Research Paper

Research on Geo-Ecological Restoration of Mountain Towns Upon the Influence of Earthquake Disasters

—A Case Study of 4.20 Lushan Earthquake

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Abstract

Earthquakes have a great destructive effect on the geo-ecological environment of mountain towns, and the restoration of the geo-ecological environment after the disaster is of great significance to the sustainable development of mountain towns. This paper applies the improved ecological footprint method to build a geo-ecological restoration footprint evaluation model from the aspects of factors affecting the geological ecology. Moreover, Comprehensive evaluation of geo-ecology were selected to analyse the dynamic change process of geological ecology before and after the Lushan earthquake in 2010-2017. The results show that earthquake disasters have a long-term and dual impact on the geo-ecological environment of mountainous towns. Earthquake disasters can change the geo-ecological footprint by reducing the output of ecological products, changing the population composition, diet structure and even the fuel ratio, thereby affecting the geo-ecological restoration process for a long time. On the one hand, the effect of sustainable restoration of the ecology after the disaster in Lushan County has achieved initial results, the geo-ecological deficit has been reduced by more than 43%. But on the other hand, the comprehensive evaluation of ecological restoration in Lushan County is in an unsustainable state and the geo-ecological environment is facing tremendous pressure. Based on this, this article considers the degree of geo-ecological restoration in Lushan County, and proposes a countermeasure for future geological and ecological restoration in Lushan County.

Keywords

Earthquake Disasters; Mountain Towns; Geo-ecology; Ecological Restoration; Geo-ecological Footprint

The term geo-ecology originally derives from the theory of landscape ecology proposed by Troll C (1971), which studied how the geosphere exerts a dual influence on human activities and the natural environment. Zhang Renquan, Chen Mengxiong, Huang Runqiu, Zeng Wei and other scholars analyzed the connotation of geological ecology from different perspectives, and defined geo-ecology as the study of the structural composition and evolution characteristics of geological ecosystems, including lithosphere and hydrosphere, under the influence of both human and natural factors. Zeng,Yang, and Zhou (2018) suggest that geo-ecological environment is an organic whole, which is composed of geological environment, ecological environment and social environment, while interacting with each other0. It is the leading factor that affects the development of mountain towns. In the geo-ecological environment, Zhou, Sun, and Ma (2001) suggest that the geological environment, such as geological structure, landform, rock, water and other factors, is an important part of the geological ecological environment system. The study of geological environment covers the ecological environment between the earth's surface and the crustal depth reached by human engineering and technical activities. Due to the interaction between lithosphere surface and atmosphere, hydrosphere and biosphere under the influence of earthquake, regional geological ecology and human life and property damage are caused, which is called earthquake disaster (Xu et al., 1999, p. 18). Song and Zhang (1982) suggest that Earthquake disasters are characterized by multiple forms of destruction, wide disaster scope and difficult post-disaster recovery, and are the main factors that endanger the geo-ecological environment. The geological environment system is a complex system affected by many factors, the more complex an ecosystem is, the stronger its anti-interference ability will be, but correspondingly, the more difficult it will be to repair after a disaster. The geological ecology of mountain towns is complex and fragile. Once damaged, it is difficult to repair and rebuild the towns in a short time.

Among the existing studies on geo-ecological restoration, European and American studies mainly focus on basic theoretical studies such as geo-ecological survey, geo-ecological information system, and geo-ecological restoration and governance (Zeng et al., 2015, p.92). Matthews(2014) targets the geological diversity that is being destroyed by human activity. The protection model and process of ecosystem based on geo-ecological methods are proposed. Ruybnikova(2017) used geo-ecological modeling to rationally use the land which is disturbed by mining in the Ural mining area. In China, scholars mainly focus on the assessment of geological environmental benefits and the countermeasures to pollution problems, and usually adopt the geo-ecological survey method for research. Lin (1999)believed that more attention should be paid to the role of geological ecology in urban pollution control. Lu (1998) proposed a regulation strategy for the sustainable development of the Yangtze River basin with comprehensive consideration of geo-ecological factors. According to He (2010) The prediction and protection of geological disasters, rational utilization of land resources, and urban security and health have gradually become the hot topics of future geo-ecological concerns in Canada and other countries.

To sum up, the current research on ecological restoration focuses on the restoration of the ecological environment after the disaster, mainly focusing on the ecological field of the earth's surface, while paying less attention to the restoration of the geological ecological environment below the surface entity. The restoration objects mainly focus on the coal mine area and other regional levels, and seldom pay attention to the mountain towns with complex and fragile ecology. As the main carrier of the interaction between the geological ecology and the human environment, mountain towns reflect the composite composition of the urban ecosystem.

Therefore, this paper starts with the construction of geo-ecological footprint model, solves the difficulties of geo-ecological restoration after disasters, such as long repairing time, wide influence scope and so on the problem, integrates the subsurface ecological restoration into the ecological footprint evaluation model, and comprehensively evaluates the degree of post-disaster geo-ecological restoration, making the geo-ecological restoration research more systematic and comprehensive. It is of great significance to realize the geo-ecological sustainable development of post-earthquake mountain towns based on case study of Lushan County.

1 Case study area and research methods

1.1. Introduction to the study area

Lushan County belongs to Ya'an City, Sichuan Province. The overall geo-ecological environment foundation is good. The terrain is complex, the water system is also very rich, and the natural resources are very abundant. The land has great potential for development. On April 20, 2013, a magnitude 7.0 earthquake occurred in Lushan County with a focal depth of 13km. The seismic zone is located in the southern section of the Longmen mountain fault zone (Su et al., 2013, p. 502) (Figure 1). It has caused great damage to the geological ecology of Lushan County, and urgently needs post-disaster geo-ecological restoration.

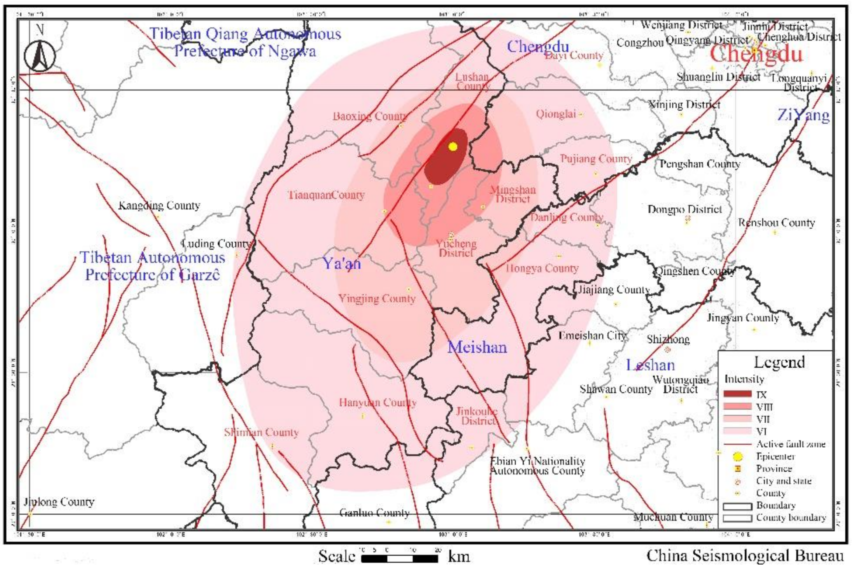

Figure 1. Lushan seismic intensity map. Source: China Seismological Bureau

1.2. Selection of research methods

In general, Zhou (1996) argues there are various forms of geo-ecological restoration methods domestic and abroad. Therefore, considering the insufficiency of dynamic analysis and complete coverage in the current geo-ecological assessment, The ecological footprint method can well quantify the degree of geo-ecological restoration. In this paper, the ecological footprint method is adopted to select three time periods such as before, during and after the Lushan earthquake, and the period from 2010 to 2017 is the continuous time series. Then, On the basis of the traditional ecological footprint model, the geo-ecological footprint model is constructed to quantitatively reflect the impact of earthquake disaster on the geo-ecological environment of Lushan County, and comprehensively evaluate the degree of geo-ecological restoration and sustainable development potential after the disaster.

2 Establishment of evaluation index system

2.1. Traditional ecological footprint calculation method

The traditional ecological footprint model was designed by Rees (1997) and Wackernagel (1998) to calculate the resource consumption and biological production area required to maintain a given population and economic scale based on the consumption of certain ecological products and resources. In the context of mutually exclusive land space, namely, single land production, each human biological consumption is reflected on productive land area. The calculation formula of ecological footprint is as follows:

$$EF = \sum_{i=1}^{n} Ci \cdot EQi/EPi$$

Where:

EF stands for ecological footprint (Ha),

Ci stands for net resource consumption,

EQi stands for the equilibrium factor,

EPi stands for the global average, (including arable land, woodland, grassland, construction land, fossil fuel land and water area).

Ecological carrying capacity refers to the maximum population that can be fed in a specific area without interfering with the normal development of regional ecological environment. According to a study by WCED (World Committee on Environment and Development), 12% of the biological production area must be reserved for biodiversity. The calculation formula is as follows.

$$EC = \sum_{i=1}^{n} (A_i EQF_i \, YF_i) \cdot (1 - 12\%) \qquad i = (1,2,3,4 \ldots 6)$$

Where:

EC stands for ecological carrying capacity (hm^2),

Ai represents the area of the class I ecosystem,

EQFi represents the equilibrium factor;

YFi represents the yield factor.

The difference between the supply of natural ecosystem and the consumption of human economic system can reflect the sustainability of ecological environment. This difference represents the ecological deficit or surplus, and the formula is as follows:

$$ED / ER = EC - EF$$

Where:

ED stands for ecological deficit,

ER stands for ecological surplus.

EC stands for the ecological footprint,

EF stands for ecological carrying capacity.

If ED > 0 indicates ecological surplus; When ED < 0, ecological deficit occurs.

2.2. Improved geo-ecological footprint model

Ecological footprint can intuitively calculate the degree of ecological sustainable development, but the traditional ecological footprint model lacks the multi-consideration of land function, variability of calculation factors and continuity of repair time sequence. Therefore, an improved geological-ecological footprint model is proposed in this paper to construct the geological-ecological footprint model (Figure.2) by modifying the original data, localized factor processing, expanded land function and the addition of space-time continuity. To measure the geo-ecological footprints over the years makes the evaluation scope more popular, the evaluation subjects more accurate and the allocation of resources more reasonable.

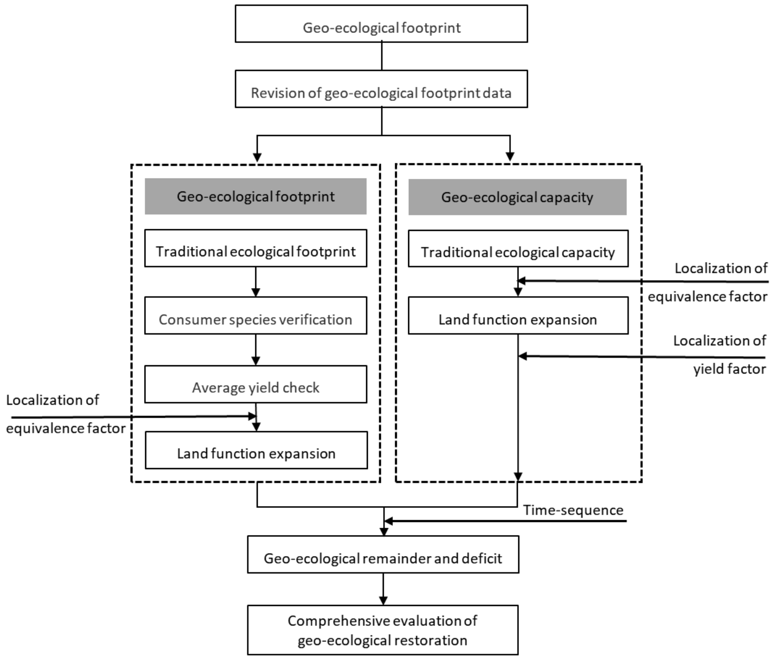

Figure 2. Calculation model of geo-ecological footprint of mountain towns.

2.2.1. Data correction of geo-ecological footprint

Corrections to the geologically ecological footprint data include two categories, the verification of consumption species and the verification of average yield, the former being based on the Wackernagel ecological footprint table (Table 1). Combined with the statistical yearbook of Sichuan and the actual situation of Lushan County, the species of coffee, cheese and butter produced less in Lushan County were deleted, and the species of rabbit meat consumed more were added. According to the breeding species in Sichuan, pork, poultry meat, poultry eggs, honey and fruit are classified as cultivated land. The improved consumption species are as follows:

Table 1. Verified consumption species.

Consumption types	Consumption items
Agricultural products	Rice, wheat, corn, peanuts, rapeseed, cotton, sugar cane, sesame, oil, beans, tobacco, vegetables and edible fungi, pork, poultry and eggs, honey, corn, potato
Livestock products	pork, beef, mutton, rabbit meat, dairy, wool tea, fruit
Forestry products	timber, bamboo, walnut, Chinese chestnut
Water products	freshwater fish , etc.
Fossil energy	fuel oil, natural gas,
Built-up land	electricity

In the average yield, the average yield of China was used to replace the global average yield data, so as to more accurately reflect the utilization and evolution of geo-ecological resources in Lushan County after the disaster (the missing data were supplemented by the global average data of WWF)(Table. 2) .

Table 2. China's average yield

Biological resource category	National average yield /(kg·hm-2)	Biological resource category	National average yield /(kg·hm-2)
rice	6840.8936 59	pear	15490.2839 6
wheat	5313.9995 09	Other fruits	13336.9740 5
corn	3821.4	pork	3033.9499 19
beans	5959.0206 14	Poultry meat	3851.4411 05
potato	1782.1277 49	honey	4893（WWF）
peanut	3761.6386 53	beef	35.5858 7181
rapeseed	3664.7122 34	mutton	21.2483 9208
cotton	1954.6408 02	Rabbit meat	4.1490 79618
Sugar cane	1604.5157 43	eggs	3535.4616 52
Raw hemp	72597.4766 6	dairy	119.4756 93
tobacco	3127.5679 62	wool	15（WWF）
vegetables	2098.1689 5	wood	385.6343 589
cocoon	39990.6183 2	bamboo	395870.5491
The tea	836.688122 7	Chinese chestnut	3714.6
apple	17635.4867 7	walnut	5709.72
citrus	14409.9753 9	fish	7705.2148 37

2.2.2. Expansion of land functions

Aiming at the problem of unity of land functions in the original model, this paper incorporates the pollutant factors that have the greatest impact on the surface entities into the geo-ecological footprint model, expands the original ecological footprint, and combines the water ecological footprint model of Huang (2008)错误!未找到引用源。 , consider expanding the purification and absorption of pollutants in the water area. Considering the characteristics of pollutants and water resources in Lushan County, the calculation formula is as follows:

$$EFn = \frac{QC}{AC} EQi$$

Where:

EFn stands for the geo-ecological footprint of pollutant (hm^2),

QC refers to the respective discharge of various pollutants (t),

AC stands for the absorption capacity of all types of land (water area, cultivated land and forest land) to pollution,

EQi stands for the equilibrium factor

Among them, in order to maintain the sustainable development of regional water resources and maintain the health of geological ecosystem, the regional development and utilization of water resources should not exceed 40% of the total amount(Zhang,Y. 2000) .

2.2.3. Factor localization processing

In this paper, the provincial hectare method is adopted to improve the equalization factor, the provincial average productivity method to improve the yield factor, the carbon sink method to improve the energy ratio, etc., and the time series is introduced into the factor calculation to make up for the original model, which ignores the effect of time change and space variation on the conversion factor. In terms of the energy ground ratio of energy consumption, this paper adopts the calculation method of Liu (2010) and uses the carbon sink method to calculate the average energy ground ratio of China. Thus, it can accurately reflect the changes of geo-ecological footprint in Lushan County and construct an appropriate geo-ecological footprint model. The calculated equilibrium factor and yield factor are shown in Table 2 and Table 3.

Table 3. Equilibrium factors in Sichuan Province in 2010-2017

	Cropland	Grazing land	Forestry	Fishing ground	Fossil energy land	Built-up land
2010	3.08	0.02	1.07	0.32	3.08	1.07
2011	3.32	0.02	0.99	0.36	3.32	0.99
2012	3.00	0.02	1.09	0.33	3.00	1.09
2013	2.12	0.01	1.37	0.25	2.12	1.37
2014	1.84	0.02	1.33	0.15	1.84	1.33
2015	2.06	0.02	1.26	0.18	2.06	1.26
2016	2.05	0.02	1.26	0.18	2.05	1.26
2017	1.87	0.02	1.31	0.18	1.87	1.31

Table 4. Yield factors of Sichuan Province in 2010-2017/(s-nha /hm^2)

	Cropland	Grazing land	Forestry	Fishing ground	Fossil energy land	Built-up land
2010	1.00	0.84	0.37	0.29	1.00	1.00
2011	0.96	0.83	0.30	0.30	0.96	1.00
2012	0.93	0.82	0.35	0.33	0.93	1.00
2013	1.01	0.72	0.59	0.35	1.01	1.00
2014	0.89	0.81	0.49	0.21	0.89	1.00
2015	0.88	0.81	0.40	0.21	0.88	1.00
2016	0.90	0.82	0.36	0.19	0.90	1.00
2017	0.88	0.82	0.40	0.20	0.88	1.00

2.2.4. Improved mountain geo-ecological footprint model

The advanced geo-ecological footprint model is as follows:

$$EF_G = EF + EFn + EFw = \sum_{i=1}^{n} \frac{Ci}{EPi} EQi + \frac{QC}{AC} EQi + \frac{W}{P} \times \gamma w$$

$$EC_G = EC + ECW = \sum_{i=1}^{n} (AiEQi\,YFi) \cdot (1 - 12\%) + 0.4 \times \psi \times \gamma \times \frac{Q}{P}$$

$$ED'/ER' = EC' - EF'$$

Where：

EFG stands for improved geo-ecological footprint,

EF stands for traditional ecological footprint,

EFN represents the ecological footprint of pollutants,

EFW stands for ecological footprint of water resources,

ECG represents the improved geo-ecological carrying capacity,

EC stands for traditional ecological carrying capacity,

ECW stands for water resources ecological carrying capacity,

ED' represents the improved ecological deficit,

ER' stands for improved ecological surplus.

3. Calculation of geo-ecological footprint in Lushan County

3.1. Geo-ecological footprints of Lushan County over the years

According to the geo-ecological footprint calculation model, the per capita geo-ecological footprint of Lushan County over the years is calculated as follows (Table 5& Figure 3). The data are from the Statistical Yearbook of Ya 'an City, Lushan field survey and collection, and Lushan official government website.

Table 5. Geo-ecological footprints per capita in Lushan County in 2010-2017 (hm^2/person)

Consumption types	2010	2011	2012	2013	2014	2015	2016	2017
Cropland	1.1711	1.253	1.1105	0.7304	0.6397	0.7483	0.7149	0.5356
Grazing land	0.0167	0.0177	0.0159	0.0097	0.0115	0.0137	0.0092	0.0045
Forestry	0.0263	0.0294	0.0321	0.0381	0.0369	0.0312	0.0125	0.0154
Fishing ground	0.0189	0.0236	0.0228	0.0174	0.0108	0.0124	0.0128	0.0163
Fossil energy land	0.0245	0.0366	0.0516	0.0391	0.0424	0.0643	0.054	0.0394
Built-up land	0.7295	0.6748	0.4718	0.9334	0.8658	0.6877	0.6537	0.6362
Water resources land	0.0007	0.0004	0.0003	0.0003	0.0004	0.0004	0.0004	0.0005
Geological ecological footprint	1.9878	2.0356	1.705	1.7685	1.6074	1.558	1.4575	1.2479

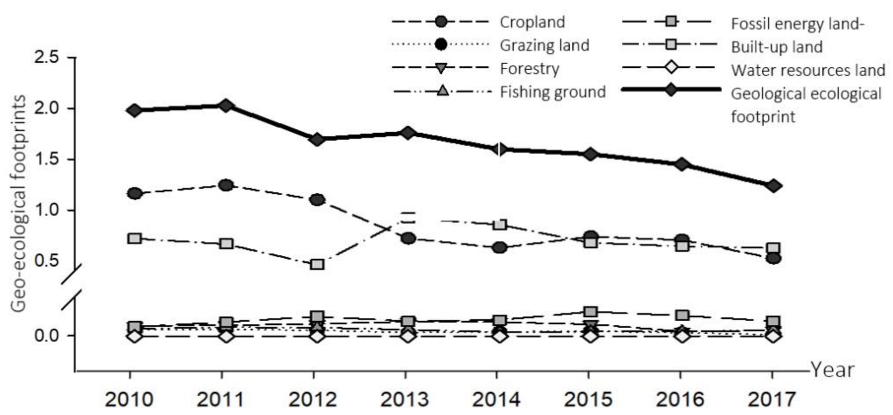

Figure 3. The per capita geo-ecological footprint of Lushan County over the years

As can be seen from the above data, the geo-ecological footprint per capita of Lushan County decreased gradually from 1.98777hm in 2010 to 1.24787 hm² in 2017, and increased slightly in 2011 and 2013. Except for building land, almost most of the geological ecological footprint showed a trend of decline, but showed a small increase in 2013. This shows that the Lushan earthquake in 2013 did have a certain impact on the local geological ecology, which slightly increased the geological ecological footprint in that year and gradually reduced it later. This shows that Lushan County pays attention to the restoration of geological ecology after the disaster and control of pollution, so as to slow down the ecological footprint consumption.

The reasons can be divided into three categories. The first is the change of population structure, the decrease of geological ecological footprint of cultivated land by nearly 54%, the loss of population caused by the earthquake, the increasing of aging population, the decline of farming ability and the decrease of dependence on cultivated land. Second, it attaches great importance to the protection of relevant resources. The per capita geological ecological footprint of forestland has decreased by nearly 41%, which indicates that Lushan County Forestry Bureau has attached great importance to the protection of forestry ecology in the county over the years and strengthened forest supervision, so as to reduce the geo-ecological footprint of forestland and promote geo-ecological restoration. The third is the change of diet structure, the per capita geo-ecological footprint of grassland decreased by nearly 70%. This shows that the diet structure of people in Lushan County has changed greatly, and the production and consumption of meat have been greatly reduced.

3.2. Calculation of geo-ecological carrying capacity of Lushan County in 2010-2017

According to the geo-ecological footprint calculation model, the per capita geo-ecological carrying capacity of Lushan County in 2010-2017 is calculated as follows (Table 6& Figure 4):

Table 6. Geological ecological carrying Capacity per capita in 2010-2017/(hm²/person)

Consumption types	2010	2011	2012	2013	2014	2015	2016	2017
Cropland	0.4334	0.4475	0.3907	0.2801	0.2095	0.2178	0.2222	0.1229
Grazing land	0.0005	0.0005	0.0005	0.0003	0.0004	0.0004	0.0004	0.0004
Forestry	0.0866	0.0647	0.0826	0.1728	0.1371	0.1055	0.0947	0.1117
Fishing ground	8.87E-06	1.08E-05	1.14E-05	9.12E-06	3.48E-06	1.25E-05	1.18E-05	1.35E-05
Fossil energy land	0.008	0.0085	0.0077	0.0059	0.0056	0.0058	0.0071	0.0065
Built-up land	0.2329	0.2155	0.2381	0.2952	0.2775	0.2655	0.2663	0.2806
Geo-ecological carrying capacity	0.7455	0.7238	0.7087	0.7393	0.63	0.5991	0.5954	0.5349

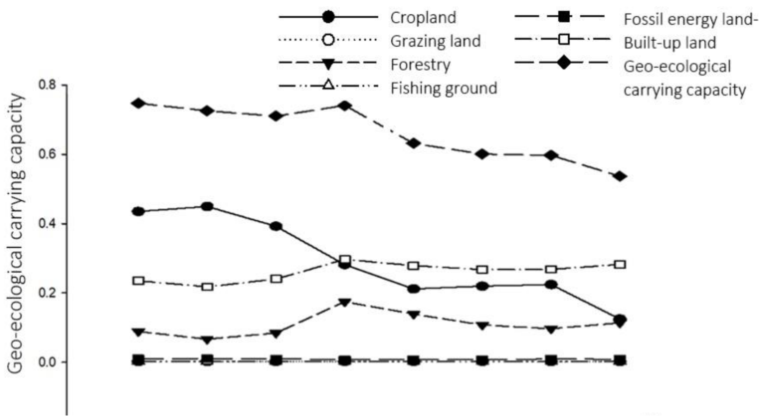

Figure 4. The per capita Geo-ecological carrying capacity of Lushan County over the years

As can be seen from Table 3, the per capita geo-ecological carrying capacity of Lushan County gradually decreased, but it showed a small increase in the year of earthquake in 2013, and a downward trend in the two periods from 2010 to 2012 and 2014-2017. Earthquake caused geological ecology itself visible double effects, one is the earthquake caused the decrease of cultivated land, cultivated land bearing capacity of geological ecological down, the second is the earthquake reduced the human engineering activities may make woodland geo-ecological bearing capacity increases, which in a certain extent, to strengthen the total geological ecological carrying capacity. In general, the per capita geological ecological carrying capacity of Lushan County is gradually declining, indicating that the land is gradually being destroyed and the geological ecology is in an unsustainable state. In the future, Lushan County will face the problem of insufficient geological ecological carrying capacity.

3.3. Geo-ecological surplus and deficit of Lushan County in 2010-2017

According to the formula above, the ecological profit and loss of Lushan County from 2010 to 2017 is calculated (Table 7& Figure 5).

Table 7. Statistics of various types of geo-ecological budget in Lushan County in 2010-2017/ (hm^2/person)

Consumption types	2010	2011	2012	2013	2014	2015	2016	2017
Geological ecological footprint	1.9878	2.0356	1.705	1.7685	1.6074	1.558	1.4575	1.2479
Geo-ecological carrying capacity	0.7455	0.7238	0.7087	0.7393	0.63	0.5991	0.5954	0.5349
Ecological deficit	-1.2423	-1.3118	-0.9962	-1.0292	-0.9775	-0.9589	-0.8621	-0.713

Note: the positive number in the above table represents the geological ecological surplus, while the negative number represents the geological ecological deficit.

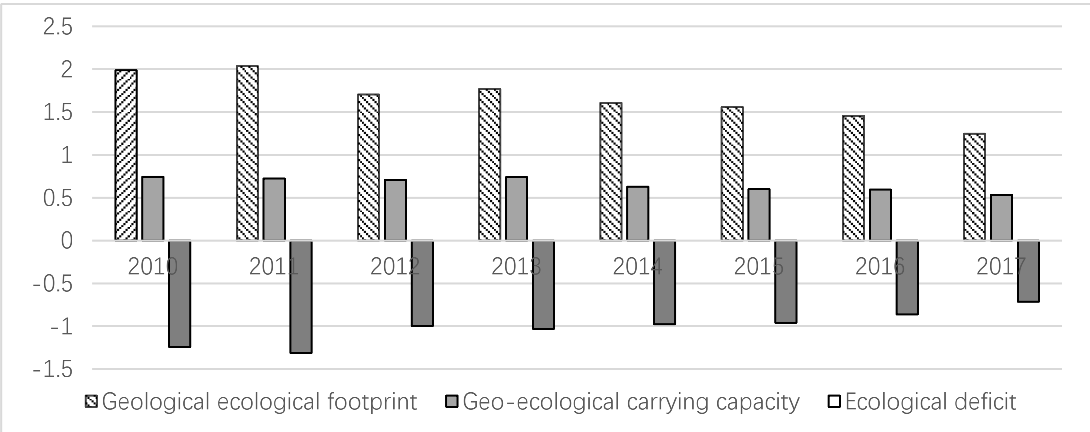

Figure 5. Statistics of geo-ecological budget in Lushan County over the year

From Table 4, the geological ecology of Lushan County showed ecological deficit from 2010 to 2017, and the pressure brought by the economic development of Lushan County far exceeded the carrying capacity of the geological ecology. In 2010, the geo-ecological deficit was -1.24227 hm^2/person, and in 2017, the geo-ecological deficit was -0.71296 hm^2/person, indicating that Lushan County has made certain measures in geo-ecological protection. Although Lushan County has achieved initial results in the ecological sustainable restoration after the disaster, the geo-ecological deficit has been reduced by more than 43%. Most of the ecological productive land in Lushan is in the state of unsustainable development, and the ecological carrying capacity has been declining continuously over the years, which reflects that Lushan is currently in the state of geo-ecological imbalance, the sustainable ability of geo-ecological development is poor. The geo-ecological security is not optimistic now.

3.4. Comprehensive evaluation of geo-ecological restoration in Lushan County

According to the calculated results of geo-ecological footprint, the degree of geo-ecological restoration was comprehensively evaluated from two aspects of ecological restoration index and economic restoration index. Among them, ecological restoration index is composed of ecological stress index (EPI) and ecological sustainability index (ESI), while economic restoration index is composed of 10,000 yuan GDP index of and ecological economy Coordination index (EECI)(Chu et al., (2017) p. 43).

The calculation formula of ecological pressure index is as follows:

$$EPI = EF/EC$$

Where:

EPI refers to the ecological pressure index of renewable resources,

EF refers to the per capita ecological footprint of regional renewable resources,

EC refers to the ecological carrying capacity.

Note: EF and EC are derived from the modified geological-ecological footprint and geological-ecological carrying capacity in the previous section

The ecological sustainability Index (ESI) is calculated as follows:

$$ESI = \frac{EC}{EF + EC}$$

Where:

ESI refers to the ecological sustainability index,

EF refers to the per capita ecological footprint of regional renewable resources,

EC refers to the ecological carrying capacity.

The ecological footprint of 10,000 yuan of GDP is defined as the ecological footprint that a region needs to occupy for 10,000 yuan of GDP. Its calculation formula is as follows:

$$EF_{GDP} = Ef/GDP \cdot N$$

Where:

EFGDP refers to the ecological footprint of ten thousand yuan GDP,

Ef refers to the total ecological footprint per capita,

GDP refers to the total regional GDP, and N refers to the total population,

Note: Ef is derived from the modified geo-ecological footprint in Section 3.4, and N and GDP are derived from the statistical yearbook of Sichuan Province from 2010-2017.

Ecological coordination coefficient is EPI (ecological pressure) and EOI (ecological occupation) [24]. The formulas for EECI and EOI are as follows:

$$EECI = EOI/\text{EPI}$$

Where:

EECI refers to the ecological economic coordination index,

EOI refers to the ecological occupancy index,

EPI refers to the ecological stress index.

$$EOI = EF/\text{EF}'$$

Where:

in the EOI is refers to the ecological index of possession, EF is refers to the per capita ecological footprint, EF 'refers to the same period the global per capita ecological footprint,

Note: The global per capita ecological footprint used in this article are derived from the WWF's official website (http://data.footprintnetwork.org/? _ga = 2.21361330.825525641.1578277910-493873071.1578277910 #).

3.4.1. Comprehensive evaluation of geo-ecological restoration

EPI, EOI and EECI were selected to construct the geo-ecological restoration indexes, with EPI as the negative index, and EOI and EECI as the positive index. These three indexes were standardized (Zhao et al., 2006), and the calculation formula of the geo-ecological restoration indexes was as follow:

$$GRI = \left(\frac{EPI_{max} — EPI}{EPI_{max} — EPI_{min}}\right) + \left(\frac{EOI_{max} — EOI}{EOI_{max} — EOI_{min}}\right) + \left(\frac{EECI_{max} — EECI}{EECI_{max} — EECI_{min}}\right)$$

Where:

EPI max and EPI min represent the maximum and minimum values of ecological pressure index,

EOI max and EOI min represent the maximum and minimum values of ecological occupation index,

EECI max and EECI min represent the maximum and minimum values of eco-economic coordination index.

The calculated geo-ecological restoration results of Lushan County are as follows (Table7) :

Table 8. Evaluation of geo-ecological restoration grade in Lushan County

Year	EPI	Level	ESI	Level	EFGDP	EECI	Level	GRI	Level
2010	2.656	Very risky	0.2735	Moderately unsustainable	1.3204	0.2624	Very Poor	0.4905	Very Poor
2011	2.8001	Very risky	0.2632	Moderately unsustainable	1.088	0.2525	Very Poor	0.4539	Very Poor
2012	2.3907	Very risky	0.2949	Moderately unsustainable	0.813	0.2511	Very Poor	0.5325	Very Poor
2013	2.3749	Very risky	0.2963	Moderately unsustainable	0.8438	0.2592	Very Poor	0.542	Very Poor
2014	2.544	Very risky	0.2822	Moderately unsustainable	0.6678	0.2231	Very Poor	0.4791	Very Poor
2015	2.5931	Very risky	0.2783	Moderately unsustainable	0.5839	0.2157	Very Poor	0.463	Very Poor
2016	2.4422	Very risky	0.2905	Moderately unsustainable	0.4968	0.2168	Very Poor	0.4945	Very Poor
2017	2.324	Very risky	0.3008	Moderately unsustainable	0.3747	0.1947	Very Poor	0.5012	Very Poor

In general, the ecological environment of Lushan is in a medium unsustainable state, so it is urgent to repair the geological ecology. EPI decreased by 12.5%, from 2.66 to 2.32, and the ecological pressure gradually eased, but the pressure was still belong in a very unsafe area. ESI increased by 10% and the ecological sustainability increased, but the sustainability was still poor. In terms of economy, although the ecological footprint index of 10,000 yuan GDP of Lushan County has dropped significantly over the years, the utilization rate of resources has gradually increased. However, Lushan County is still in a poor state of geo-ecological restoration, so it is still necessary to pay attention to geo-ecological restoration to improve the restoration ability of geo-ecological system.

4 Conclusions and prospects

In general, the earthquake affected the local population structure, resulting in population migration, and thus reduced the total population. The earthquake also reduced the production of ecologically productive products that year. As Lushan County promotes post-disaster reconstruction and restoration measures, The overall geo-ecological footprint of Lushan County decreased by 37%. Initial results have been achieved in the geo-ecological restoration. Due to the reduction in land area caused by the earthquake, the ecological carrying capacity of the geology decreased by 29%. Lushan County is still in a state of poor geo-ecological restoration. That means post-disaster geo-ecological restoration work in Lushan County still needs to be paid attention to.

Earthquake disasters have a long-term and dual effect on the geo-ecological environment of mountain towns. On the one hand, disasters can enhance the ecological carrying capacity of forest land. Earthquake may reduce the damage to forestland by reducing the human activities of the year, thereby enhancing the total geological ecological carrying capacity to a certain extent. On the other hand, disasters can inhibit the geo-ecological footprint and damage the ecological carrying capacity of cultivated land. The earthquake disaster reduced the cultivated area of Lushan County and reduced the total geo-ecological carrying capacity of cultivated land. The long-term nature of earthquake disaster is reflected in the fact that the impact of earthquake disaster on the geo-ecological footprint is a long-lasting process, which not only affects the geological ecology in the year of the earthquake, but even the geological ecology one to two years later.

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References

TROLL, C.(1971) ' Landscape ecology (geo-ecology)and biogeoecology — A terminological study ' , *Geoforum*,2(4), pp. 43-46.

Zeng, W. Yang, C. and Zhou,H.T.(2018) ' Associative analysis of geo-ecological environment and urbanization: a case study of Chongqing ', *Journal Of Mountain Science*, 36(05), pp. 21-34.

Zhou,A.G. Shun,Z.Y. and Ma, R. (2001)*Geo-ecology in arid regions an introduction*. Beijing: China Environmental Science Press.

Xu, J.X. Kang,F.X. (1999) ' Discussion on the contents and methods of geo-ecological survey ', *Shandong Land and Resources*, 000 (001), pp. 18-23.

Song,C.Q . Zhang,Z.C.(1982) *Basic geology (second edition)*. Beijing: Higher Education Press.

Zeng, W. Chen,X.Y, (2015) ' Analysis of the decline of mountainous cities under the change of geological ecology ', Journal of Human Settlements in West China, 30(01), pp. 92-99.

Matthews, T.J. (2014) ' Integrating Geoconservation and Biodiversity Conservation: Theoretical Foundations and Conservation Recommendations in a European Union Context ' , *Geoheritage*, 6(1), pp. 57-70.s

RYBNIKOVA, L. S. RYBNIKOV,P. A. and TARASOVA I. V. (2017) ' Geoecological challenges of mined-put open pit area use in the ural ', *Journal of Mining Science*, 53(1).

Lin, J.X. et al. (1999) ' An outline on the ecological environmental geology ', *Environmental Protection*, 1999 (09), pp. 37-39.

Lu,Y.R. (1998) ' Sustainable development and comprehensive harness on territory geo-ecological environment-the ways for promoting benefits and taking precautions against natural hazards in the valley of Yellow river and Yangtze river ' , Chinese Journal of Geological Hazards and Prevention, 1998 (S1), pp. 95-103.

He,K.Q.(2010) *Research on coordinated development of geo-ecological environment and economy and its spatial database*. Beijing: Science Press.

Su, F.H. et al. (2013) ' Rockfall and landside susceptibility assessment in Lushan earthquake region ' , *Journal of Mountain Science*, 31 (04), pp. 502-509.

Zhou,P.Q.(1996) ' Research methods for environmental geology from the view-point of general system ' , *Earth Science Frontiers*, 1996 (1), pp. 35-42.

Wackernagel, M. REES, W.(1997) 'Our ecological footprint: reducing human impact on the earth' ,*Electronic Green Journal*, 1(7).

Wackernagel, M. Yount, J. D. (1998) 'The ecological footprint: an indicator of progress toward regional sustainability ', *Environmental Monitoring and Assessment*, 51(1-2).

Liu,M.C.(2010) ' Temporal dynamics and spatial patterns of China 's ecological footprints ' , Graduate School of Chinese Academy of Sciences, 2010(1), pp. 49-53.

Huang, L.N. et al. (2008) ' Calculation method of ecological footprint of water resources ' , *Journal of Ecology*, 31 (04) , pp. 502-509.

Zhang, Y. (2000) China's water resources and sustainable development. Nanning: Guangxi Science and Technology Publishing House.

Chu, X. et al.(2017) ' Ecological security assessment based on ecological footprint approach in Beijing-Tianjin-Hebei region, China' , Physics & Chemistry of the Earth Parts A/b/c, 10 (101) , pp. 43-51.

Zhao, X.G. et al.(2006) ' Design of sustainability indicators system based on ecological footprint ' , Scientia Agricultura Sinica, 39(6) , pp. 1202-1207.