Seismic Indirect Economic Loss Assessment and Recovery Evaluation Using Night-time Light Images—Application for Wenchuan Earthquake

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Abstract. Seismic indirect economic loss not only has a major impact on regional economic recovery policies, but also related to the economic assistance at the national level. Due to the Cross-regional economic activities and the difficulty of obtaining data, it's difficult that the indirect economic loss survey covers all economic activities. However, night-time light in an area can reflect the economic activity of the region. This paper focuses on the indirect economic losses caused by the Wenchuan earthquake in 2008 and evaluated the progress of restoration and reconstruction based on night-time light Images. First, the functional relationship between GDP and night-time light parameters was established based on the pre-earthquake data. Next, the indirect loss of the earthquake was evaluated by the night-time light attenuation in the disaster area after the earthquake. Then, the capacity recovery, which is characterized by the brightness recovery process of the light area, was evaluated. Lastly, the process of light expansion in the disaster area was analyzed to evaluate the economic expansion speed and efficiency.

1 Introduction

Following the accelerated pace of global economic integration and the rapid growth of population and social wealth, the damage caused by earthquake disasters is characterized by large amounts, far-reaching effects, and long recovery periods (Pielke et al., 2008). Economic recovery and reconstruction are important targets for post-earthquake economic policies (Lyles et al., 2014). However, due to the lack of detailed post-disaster economic recovery tracking data, economic policy planning is often subjectively divided based on the amount of direct economic losses resulting in insufficient policy sustainability (Song et al., 2017). In planning the allocation of post-disaster aid funds and medium- and long-term economic policies, decision makers mainly rely on the current market value of production data in the disaster area and the reconstruction cost of the production environment. Insufficient estimates of indirect losses are likely to result in gaps between aid funds and actual demand, even overlooking relatively remote disaster areas (Ge et al., 2010). Therefore, it is important in post-disaster macroeconomic policies and earthquake insurance that indirect economic losses and economic recovery in the affected areas be accurately assessed.

The 2008 Wenchuan earthquake(Mw8.0) is the biggest earthquake event in China since 1970s. This earthquake struck Sichuan Province, China on May 12, 2008. It killed nearly 70,000 people, 18,000 people were missing, and more than 370,000 people were injured. Millions of people were made homeless by the quake, the cost of which was estimated at $86 billion (Kenneth et al.,2013). In the three years after the disaster, Chinese government spent 865.8 billion yuan to complete 29,692 aid projects, which has brought Chinese Power to the attention of the world(Gu, 2018).

There are many research results related to the recovery of the disaster area after the Wenchuan earthquake, and these can be generally classed into three categories. The first is assessment of vegetation and environmental carrying capacity in the disaster area. Zhao et al. (2009) evaluated the soil loss after the Wenchuan earthquake and converted the losses into monetary values based on the environmental economics principles. Zhao et al. (2014) and Yang et al. (2018) assessed the restoration of vegetation in the affected areas of the Wenchuan earthquake by comparing remote sensing data with GVA agricultural sampling data. The second is evaluating the macroeconomic losses of the disaster areas. Such as Zhu et al. (2018) assessed the seismic economic losses based on the GDP growth model, Wu et al. (2012) considered the impact of activities within the economic activity system after the earthquake disaster and then assessed the indirect economic losses of the Wenchuan earthquake by the adaptive regional input-output model (ARIO). The third is the assessment of post-disaster community and social resilience. Liu et al. (2018) assessed the restoration of buildings and infrastructure in the Wenchuan disaster area by remote sensing and actual interview data, and Le et al. (2017) assessed the perception of recovery (PoR) of the Wenchuan earthquake-affected area from house recovery condition (HRC), family recovery power (FRP) and reconstruction investment (RI) based on a structural equation model. In a word, the current post-disaster economic monitoring is mainly based on manual surveys and regional statistical data, which are inefficient and have a large spatial scale, while remote sensing (RS) and geographic information systems (GIS) have significant advantages in the fineness of measurements and spatial distribution of post-disaster loss and recovery assessments.

Because of the obvious advantages of periodic economic monitoring(Zhou et al.,2015; Li et al.，2017； Tan，2017), night-time light has been widely recognized in the field of regional economic monitoring(Li and Li,2015; Fu et al.,2017). The application of night-time light in earthquake disasters is mainly divided into two parts. In the first part, night-time light can be used to identify earthquake-affected areas and to assess disaster losses. The first application of night-time light in the earthquake-affected area identification was the Marmara earthquake in 1999. Hashitera et al. (1999) evaluated the impact of earthquakes in the disaster area based on series of DMSP-OLS data, which contain pre-earthquake and post-earthquake night-time light images. Fan et al. (2018) determined the disaster level and area of the disaster based on the brightness changes of VIIR night-time light images from 3 months before the earthquake to 3 months after the earthquake in the earthquake-affected area. Kohiyama et al. (2004) developed the EDES disaster-stricken area determination system, which is based on the DMSP-OLS night-time light images, to delineate the earthquake-affected areas quickly within 24 hours after the disaster. In the second part, night-time light can be used for post-disaster economic recovery monitoring. Zhang (2018) focused on the relationship between night-time light and the number of deaths, missing persons, and building collapse rates in the earthquake-affected areas of the Wenchuan earthquake in 2003-2013. Gillespie et al. (2014) tracked the changes of night-time light from 2004 to

2008 and then studied the relationship between the brightness changes and some indicators such as per capita consumption, energy consumption and economic recovery capacity at the community level, thus evaluating the recovery after earthquake in Indonesia. Andersson et al. (2015) evaluated the recovery of post-disaster economic activity in southern Thailand by monitoring the recovery of night-time light in South-East Asia from 2005 to 2006. The School of Economics and Finance (2018) also assessed the long-term economic impact of the New Zealand earthquake based on the changes of night-time light intensity. It has been widely proven that there is a close relationship between night-time light and economic activity in the disaster area. So we believe that the changes of night-time light after earthquake can reflect the earthquake production capacity of the disaster area and can therefore be used for seismic indirect economic loss assessment.

2 Data and Processing

It is very important for recovery and reconstruction to understand the indirect economic loss assessment and recovery assessment of the Wenchuan 8.0 Ms earthquake, which is a significant earthquake in recent years. This study chose Sichuan Province as the research area. In order to avoid the impact of the Lushan earthquake in 2013, this paper focuses on the indirect economic impact of the Wenchuan earthquake on Sichuan Province from 2008 to 2012.

2.1 Data sources

The GDP data were obtained from Sichuan Provincial Bureau of Statistics (http://www.sc.stats.gov.cn/), which publishes the *Sichuan Statistical Yearbook* every year. The night-time light obtained from the National Oceanic and Atmospheric Administration (NOAA, http://www.noaa.gov) and the night-time light images (Figure 1) obtained by Operational Linescan System (OLS) of Defense Meteorological Satellite Program (DMSP) from 2000 to 2012 were used in this study. The satellite altitude of DMSP is approximately 830 km, its swath is 3000 km, and revisit cycle is approximately 101 minutes, and the satellite can orbit the earth 14 times a day and obtain 4 global coverage maps. DMSP/OLS can be used to detect human activities such as town lighting, aurora, lightning, fishing, fire, etc. The NOAA provides three night-time light data types: ‘cf_cvg’ is the total amount of brightness observation under cloud-free conditions, ‘avg_vis’ is the average observed brightness under cloud-free conditions, and ‘stable_lights.avg_vis’ is the brightness average of the stable light source under cloud-free conditions. This paper selected the brightness average of the stable light source under cloud-free conditions.

1.2 Radiation correction

The DMSP/OLS night-time light images during 2000-2012 came from the F15, F16 and F18 satellite. Due to the differences in satellite and other imaging conditions, radiation correction is required before quantification of night-time light image for different times.

This paper used the invariant region method proposed by Cao (2015) who gives the logistic radiation correction model of the Chinese region's night-time light image. All images were calculated following Eq. (1):

$$DN_{cal} = \mathrm{a} \times DN^b, \quad (1)$$

where DN_{cal} is the corrected image value, DN is the original image value to be corrected, and a and b represent two different constants. The correction effect is shown in Figure 2.

The radiation correction greatly increases the smoothness from the F15 to F16 and from the F16 to F18 satellite image; it indicates that the radiation correction is very effective.

3 Method

The seismic direct economic loss refers to the damage of existing production materials and environment by earthquake, which mainly reflects the impact of earthquake disasters on economic stock. However, the seismic indirect economic loss is a systematic manifestation of losses in the chain of economic activities, which focuses on the far-reaching impact of disasters on economic flows. On the one hand, there are so many studies show that night-time light can be used as a proxy of economic activity. Chen et al.(2011) had proven nighttime luminosity could be used to improve estimates of output at the regional level, Bruederle et al.(2018) conclude that nighttime lights are a good proxy for human development at the local level, Ma et al.(2014) had proved that nightlight data could be indicative of demographic and socioeconomic dynamics in China's cities. Therefore, this paper holds that the changes in night-time light after the earthquake can reflect changes in the regional economic system. On the other hand, in order to ensure the fairness of disaster relief assistance, government should avoid the problem that the benefits of developed regions will cover up the economic difficulties of backward regions by transfer payment system. This paper defines the light recovery and lighting expansion in the disaster area as two different processes. The *Economic recovery evaluation model* only take increasing light intensity of the disaster area with light before the earthquake. And the *Economic expansion evaluation model* only take increasing light intensity of the disaster area without light before the earthquake. The technical flowchart is shown in Figure 3:

3.1 Seismic indirect economic loss assessment model

The pre-earthquake night-time light images were clipped by the administrative divisions of Sichuan Province; then, the statistics of every administrative district's DN parameters, which include night lighting area, total brightness of light, average brightness of lighting area, and average brightness of administrative area, were collected. Through the correlation analysis of characteristic parameters and GDP, the most relevant characteristic parameter, which was defined as BF, was extracted. This established the function F(BF) as Eq. (2):

$$\mathrm{GDP} = \mathrm{F(BF)}, \quad (2)$$

where GDP is the gross domestic product of each pre-earthquake administrative region, BF is the most relevant parameter. It is assumed that the productivity conversion efficiency, which can be regarded as the integral function of F(BF), is relatively close in adjacent areas. Therefore, the integral function of F(BF) can be used to calculate the GDP changes caused by the change of the annual total lights in each administrative district. It can be expressed as Eq. (3):

$$\triangle \mathrm{GDP} = \int (\mathrm{BF}) \cdot d\mathrm{BF} \tag{3}$$

3.2 Economic recovery evaluation model

It is easy to ignore those areas with weak economic foundations causing resulting reconstruction funds to be concentrated in areas with higher economic levels. However, this approach is not in line with the principle of fairness in disaster assistance. It is assumed that the night-time light of the human activity area will not disappear under the normal conditions, and the pixel whose DN value decreases after earthquake is the area to be restored. When the brightness of the pixel reaches the level of pre-earthquake, it can be considered that the economic level of the area has returned. The earthquake disaster economic recovery assessment model is as Eq. (4) and Eq. (5):

$$YR_n = \frac{\sum_{i=1,j=1}^{i=\max(i),j=\max(j)} R_n}{\sum_{i=1,j=1}^{i=\max(i),j=\max(j)} PR_{t0}} \ , \tag{4}$$

$$AR_m = \sum_{n=1}^{n=m} YR_n \ , \tag{5}$$

where AR_m is the proportion of the cumulative recovery area in m years after the earthquake, YR_n is the proportion of recovery area in n-th year after the earthquake, R_n is the matrix of recovery area in n-th year after the earthquake, PR_{t0} is the damaged area, i is the rows of a matrix, and j is the column of the matrix. Therefore, R_n and PR_{t0} are Boolean matrices and can be calculated following Eq. (6) and Eq. (7):

$$PR_{t0(i,j)} = \begin{cases} 1, & DN_{t0(i,j)} > 0 \\ 0, & DN_{t0(i,j)} = 0 \end{cases} \ , \tag{6}$$

$$R_{n(i,j)} = \begin{cases} 1, & PR_{t0(i,j)} * DN_{t0+n(i,j)} > DN_{t0(i,j)} \\ 0, & PR_{t0(i,j)} * DN_{t0+n(i,j)} = DN_{t0(i,j)} \end{cases} \ . \tag{7}$$

$PR_{t0(i,j)}$ in equation 6 refers to the value of the i row and j column in $PR_{t0(i,j)}$. DN_{t0} is the night-time light before the earthquake. In this paper, the value of t0 is 2007, and $DN_{t0(i,j)}$ is the value of the night-time light image. $R_{n(i,j)}$ in equation 7 refers to the value of the i row and j column in R_n, DN_{t0+n} is the night-time light in n-th year after the earthquake, and the symbol * indicates that the corresponding elements in the two matrices should be multiplied.

3.3 Economic expansion evaluation model

The economic expansion of the earthquake-affected areas in post-earthquake was mainly manifested in two aspects. On the one hand, the earthquake destroyed the inefficient industrial structure and rebuilt a more advanced scientific industrial structure, which has led to the expansion of the regional economy. On the other hand, the needs of recovery and reconstruction expanded the market for many industries. This paper evaluated the economic expansion post-earthquake based on the new night-time light area. The evaluation model is as Eq. (8) and Eq. (9):

$$YE_n = |PR_{n-1} - 1| * (DN_n - DN_{n-1}) \ , \tag{8}$$

$$AE_m = \sum_{n=1}^{n=m} \sum_{i=1,j=1}^{i=\max(i),j=\max(j)} YE_n \,, \tag{9}$$

where YE_n is the night light growth matrix in n-th year after the earthquake, $|PR_{n-1} - 1|$ is the non-light area in $(n-1)$-th year after the earthquake, DN_n is the value of night-time light in n-th year after the earthquake, DN_{n-1} is the value of night-time light in $(n-1)$-th year after the earthquake, and AE_m is total light expansion in m years after the earthquake.

4 Results

4.1 Indirect economic loss of Wenchuan earthquake

The total brightness of the light pre-earthquake is the best parameter to establish a regression model with GDP. First, the correlation between the total GDP and the DN parameters, which include night lighting area, total brightness of light, average brightness of lighting area, and average brightness of administrative area, was analyzed (Figure 4). It is obvious that the correlation coefficient between the total brightness of the light and the GDP is the highest, which is basically greater than 0.95 in each year. Therefore, the total brightness is selected as the DN parameter. Second, the largest value of Chengdu was removed from the sample, and then, the scatter plots of the two sets of data samples, which are pre-earthquake data and post-earthquake data, were compared (Figure 5). It is obtained that the correlation between the two parameters is strong in pre-earthquake data and poor in post-earthquake data. Third, established a regression function of GDP and total brightness (Figure 6) and then assessed the indirect economic losses of Sichuan Province after the Wenchuan earthquake (Table 1).

4.2 Economic recovery progress in Sichuan Province

Our results indicate that the economic recovery in Sichuan Province took more than 5 years, which is far more than the time spent on reconstruction (Yang,2012). Many recovery areas disappeared completely in 2009. The brightness of the night-time light image in 2007 is used as a reference. When the brightness returns to the previous brightness, the area is considered to be the economic recovery area (Figure 7). First, the post-earthquake annual economic recovery scale was assessed based on the proportion of the brightness recovery area (Figure 8). The recovery area was less than 20% in 2008, and it could reach 60-70% in the next 5 years. The recovery area in Zhangzhou, Nanchong, Neijiang, Suining, Yibin, Zigong and Ziyang was small in 2008 but grew quickly in the next years. By contrast, the recovery area in other cities was larger in 2008 but grew slowly over the next years. Second, the capacity for recovery was evaluated by the ratio of the total brightness post-earthquake to pre-earthquake (Figure 9). The results show that except for Dazhou, Zhangzhou, Aba, Panzhihua, Suining, Ya'an and Yibin, the other cities' capacity was restored to 80% in 2012. It should be noted that the economic recovery in most regions showed a significant retreat in 2009.

4.3 Expansion of new economic zone

A new economic zone of the eastern and southern regions, which has a high economic level, was developing quickly in 2009 and 2011. The night-time light image of 2007 was defined as reference to assess the expansion of the new economic zone (Figure 10). First, the capacity utilization of Ganzi, Guangyuan, Liangshan, Mianyang and Panzhihua is relatively high. The average brightness of expansion area was used to measure the capacity utilization of new economic zone (Figure 11). It is obvious that the capacity utilization of cities in 2008 is similar. In 2009, the new economic zones of Ganzi, Guangyuan, Liangshan, Mianyang, Nanchong, Panzhihua and Ya'an have higher capacity utilization. In 2011, the capacity utilization of Ganzi, Guangyuan and Panzhihua continued to grow, while the rest of the region declined. Second, the development in cities is extremely uneven (Figure 12). The new economic area of Liangshan, Guangyuan, Ganzi and Panzhihua had a relatively high cumulative capacity, while other cities are relatively low. The cumulative capacity of all new economic zones has increased significantly in 2010 and 2011, but it has declined since 2011. It is important to point out that the decline in Guangyuan, Liangshan and Panzhihua is extremely steep.

5 Discussion

Compared with statistical data, night-time light can not only reflect the spatial difference of economic expansion and recovery but also guarantee the accuracy of assessment. In terms of short-term economic loss, the economic loss of this model in 2008 is 95.7 billion yuan, which is closer to Sun’s results (100.8 billion yuan), but lower than Lu's results (168 billion yuan). The reason for this difference is that although these models taken into account the capacity reduction caused by earthquake, Lu's model (2008) assumed that the affected department was completely shut down during a period of time, while this paper’s model and Sun's model (2011) assumed that the production capacity was gradually restored. In terms of mid-long term economic loss, the economic loss of this model from 2008 to 2011 is 596.8 billion yuan, which is more than Wu’s results (463.4 billion yuan), and the economic loss of this model from 2008 to 2012 is 709.6 billion yuan, which is closer to Sun’s results (645.4 billion yuan).The reason for this difference is that although both models measured the impact of input changes on output after earthquake, Wu’s ARIO model (2012) and Sun’s Harrod-Domar model (2011) predicted the output based on government public expenditure, while this paper’s model measured the output based on the total investment in society which could be reflected by night lights. Generally, the indirect economic losses assessment results in this paper are close to most of the evaluation results in other papers (Figure 13).

The quantitative relationship between night-time light and economic statistics in the post-earthquake years is abnormal. It’s the result of the joint action of economic suppression, which caused by the earthquake damage, and economic promotion, which caused by the reconstruction of the disaster area. The reasons for the economic shocks in earthquake-stricken areas may come from two parts. On the one hand, due to the bullwhip effect of disasters, the main impact of direct losses on the industrial chain will take longer to show up. Due to the suppression caused by the earthquake, the purchasing power of the victims was reduced. In order to reduce losses, suppliers need to reduce inventory as much as possible. Further, suppliers were also affected by earthquake, they tended to conservative strategies, and the reduction was magnified. It takes 1 year for the changing information of supply and demand to be transmitted to the economic system. Then, the gap between them was magnified and caused a turbulent change in the indirect economic loss in the next years. It explains why the economic recovery showed a significant decline in 2009. On the other hand, relief and reconstruction will stimulate the market in the disaster area. With the end of the relief activities, the market development of the disaster area will fall to a certain extent. Most of the new economic zones had developed significantly in 2010. The areas with rapid economic expansion are mainly distributed in the western Sichuan eco-economic zone, the northeast economic zone, and the Panxi economic zone. The pillar industries in these regions are mainly tourism, building materials and energy. The policy of reconstruction in 2008-2010 developed these industries in a short term. Then, the faster regions had gradually declined in 2012, which may be the result of the post-disaster recovery policy. China's reconstruction policy was basically finished (Gu, 2018) in 2010, and the demand for construction, energy and other industries was reduced. Therefore, the production capacity of the new economic zone in Guangyuan, Liangshan and Panzhihua began to fall off after 2011.

The path of economic change in the disaster area after the earthquake gradually spread from the northeast to the southeast (Figure 14). The economy level for 5 years after the earthquake in disaster area (2008-2012) were compared to the level of 2007. We found that in the first year (Fig. 14-a), the economic decline is mainly concentrated in the disaster area, and the city's economic decline is most significant. In the second year (Figure 14-b), the economic slowdown area began to spread to some major cities in the southeast of the disaster area. It was not until the third year (Fig. 14-c) that the disaster area began to recover, and the first one was not the area where the economy was reduced seriously after the disaster, but some cities located near these areas in the northeast. The force gradually spread from north to south during 2010-2012 (Fig. 14-c, Fig. 14-d, Fig. 14-e). Eventually, some cities were developed farther outside the disaster area (Figure 14-e). This explains the path of the Chinese government's aid funds from the north to the southwest and its radiation effects on the surrounding areas.

The areas where the economy first turned around were along the road or around the city in the disaster area (Figure 15). Previous analysis have proved that the economic recovery in disaster area began around 2010. Therefore, the process of economic recovery can be studied by comparing the economic level of the disaster area from 2009 to 2012 with the level of 2008. In 2009 (Figure 15-a), excepted few areas along several roads close to the disaster area, there were few economic growth in the areas. However, in 2010 (Fig. 15-b), the economy where along most roads showed significant growth, and the surrounding areas of cities, which were seriously affected by earthquake, showed an increasing trend. By 2011 (Fig. 15-c), the trend of economic growth in the disaster areas has spread to neighboring cities and provinces, and the urban economy has also begun to recover from the periphery to center. As of 2012(Fig. 15-d), the economy of disaster area showed an interesting development pattern. On the one hand, there were few recovery in the urban economy with severe recession; on the other, a series of significant growth were shown in the surrounding areas. This may help us to distinguish the industrial layout of the disaster-stricken areas after the disaster. The economically active areas after earthquake are mainly the secondary industries such as construction and manufacturing, while those areas with slow recovery are mainly the tertiary industry such as service and entertainment industry.

6 Conclusion

Due to the uneven distribution of aid funds and the adjustment of regional development strategies, the model of economic recovery and expansion differed from those before earthquake in the areas of study. Using the night-time light data of DMSP/OLS, the indirect economic losses within 5 years after the Wenchuan earthquake were evaluated. Then the economic recovery progress of Sichuan Province was evaluated. The results show the following:

(1) The GDP has a quadratic function relationship with the total night-time lights under normal conditions, and the indirect economic loss obtained by the function is consistent with the results obtained by economic statistical methods.

(2) The path of economic change in the disaster area after the earthquake gradually spread from the northeast to the southeast, the main impact of the earthquake on the economic system generally takes 1-2 years to appear; thus, the economy of the disaster area after the earthquake showed unstable and turbulent development. Tourism, building materials, and the energy industry will experience a short-lived expansion after the earthquake, after which a significant decline will be seen in the 3-4 years following the disaster.

(3) The areas where the economy first turned around were along the road or around the city in the disaster area, the economic recovery time is longer than the planned 5 years. Compared with the new economic zone, the capacity recovery of the earthquake site is slower. The recovery area is only approximately 60% of affected areas, and the production capacity can be restored to approximately 80% in 5 years.

To summarise, night-time light has significant advantages in long-term economic development monitoring in earthquake-stricken areas. It can observe the geographical differences in economic development and growth mode in earthquake-stricken areas. It can provide basis for macro-control of earthquake recovery and reconstruction.

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Table 1: Indirect economic loss of Wenchuan earthquake

ID	City	2008	2009	2010	2011	2012	ID	City	2008	2009	2010	2011	2012
	Total	-956.57	-2493.50	-1612.87	-904.57	-1128.68	11	Meishan	-11.93	-59.72	-23.56	0.00	-20.93
1	Bazhong	-6.12	-29.75	-19.04	-0.65	0.00	12	Mianyang	0.00	-93.61	-4.01	0.00	-21.05
2	Chengdu	-484.56	-1119.13	-929.03	-611.61	-635.52	13	Nanchong	-69.90	-135.59	-73.50	0.00	-15.41
3	Dazhou	-46.06	-136.62	-92.39	-60.86	-64.03	14	Neijiang	-27.12	-39.42	-34.20	0.00	-2.32
4	Deyang	-27.08	-91.93	-49.97	0.00	-31.58	15	Aba	-35.59	-69.22	-9.44	-11.35	-31.48
5	Ganzi	0.00	-19.77	-0.29	0.00	0.00	16	Panzhihua	-48.68	-166.44	-93.28	-106.08	-127.58
6	Guangan	-13.51	-58.77	-26.71	-3.96	-7.18	17	Suining	-48.63	-87.25	-79.76	-39.36	-41.05
7	Guangyuan	0.00	-0.90	0.00	0.00	0.00	18	Yaan	-3.50	-47.21	-25.79	-32.20	-46.01
8	Leshan	-24.40	-59.05	-21.93	-5.03	-19.41	19	Yibin	-33.17	-56.64	-44.42	-22.88	-42.50
9	Liangshan	0.00	-122.30	-23.40	0.00	0.00	20	Zigong	-14.49	-16.84	-1.02	0.00	-2.02
10	Luzhou	-27.10	-38.27	-27.23	-10.59	-20.62	21	Ziyang	-34.74	-45.05	-33.90	0.00	0.00

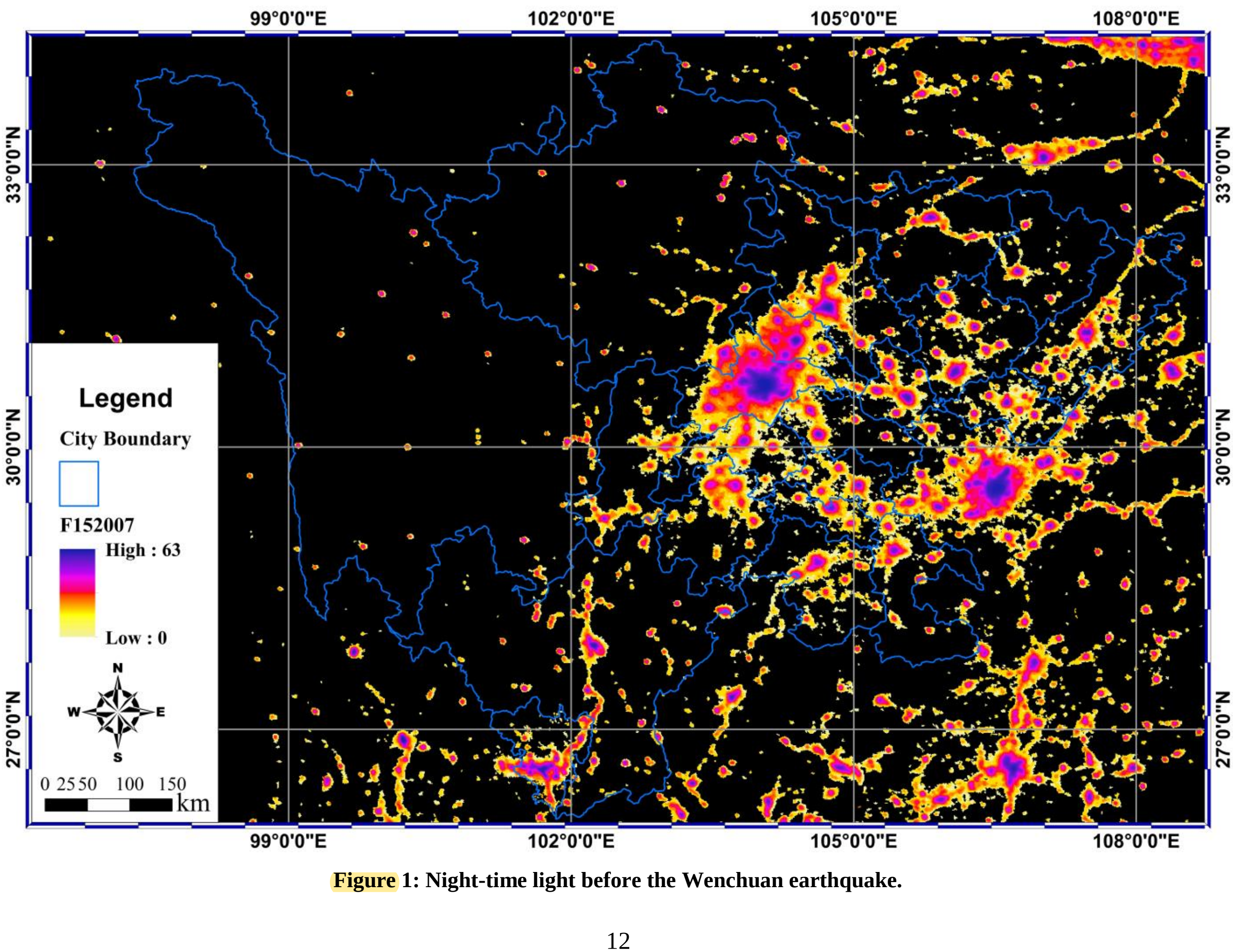

Figure 1: Night-time light before the Wenchuan earthquake.

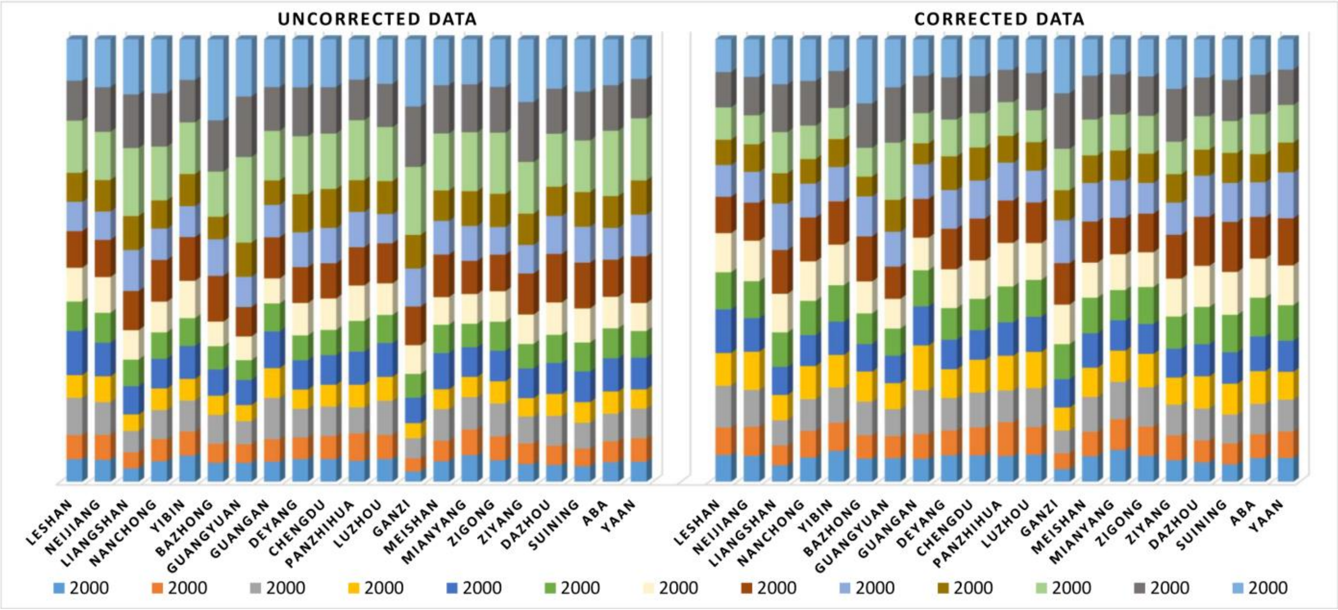

Figure 2 Normalized total lightness of uncorrected and corrected data.

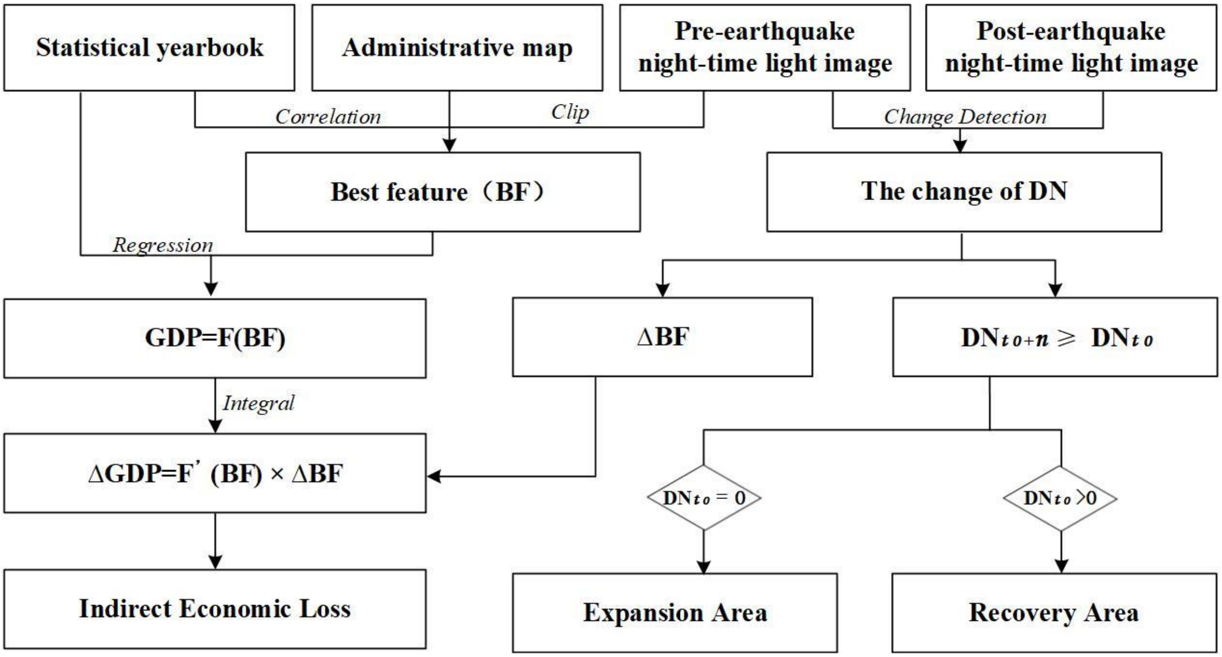

Figure 3: Technical flowchart.

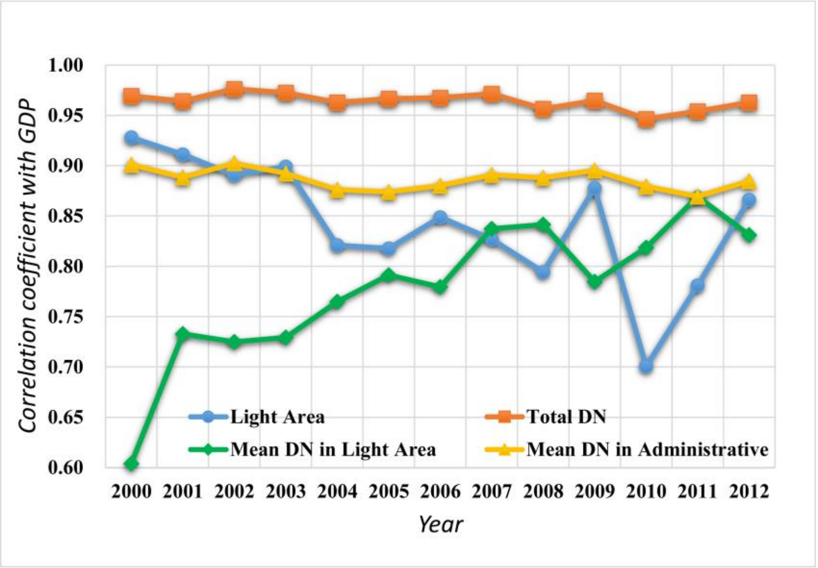

Figure 4: Correlation coefficient between GDP and DN parameters.

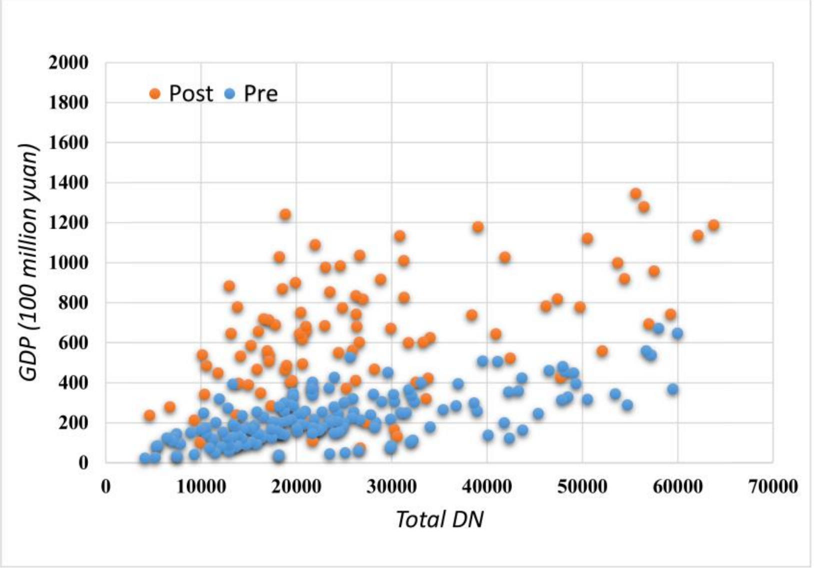

Figure 5: Scatterplot of total DN and GDP.

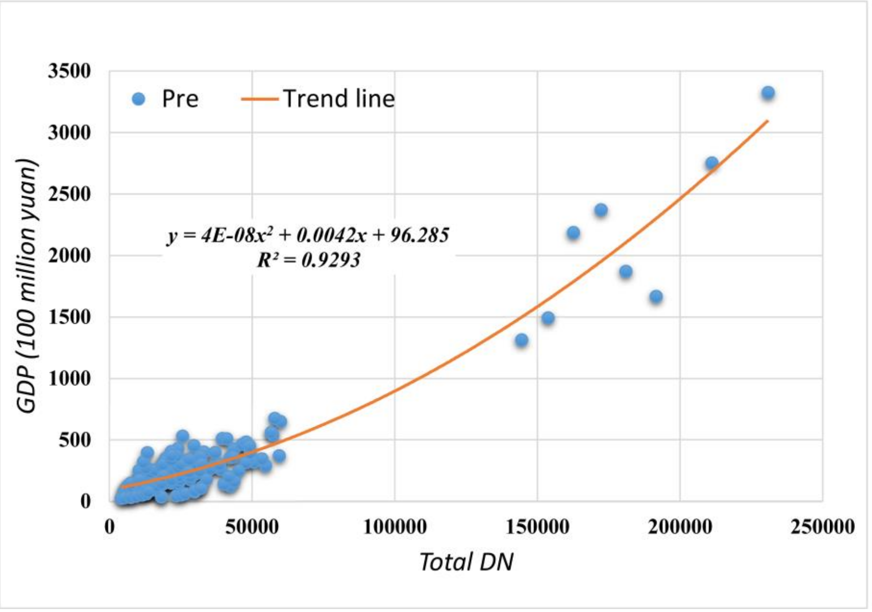

Figure 6: Regression function of total DN and GDP.

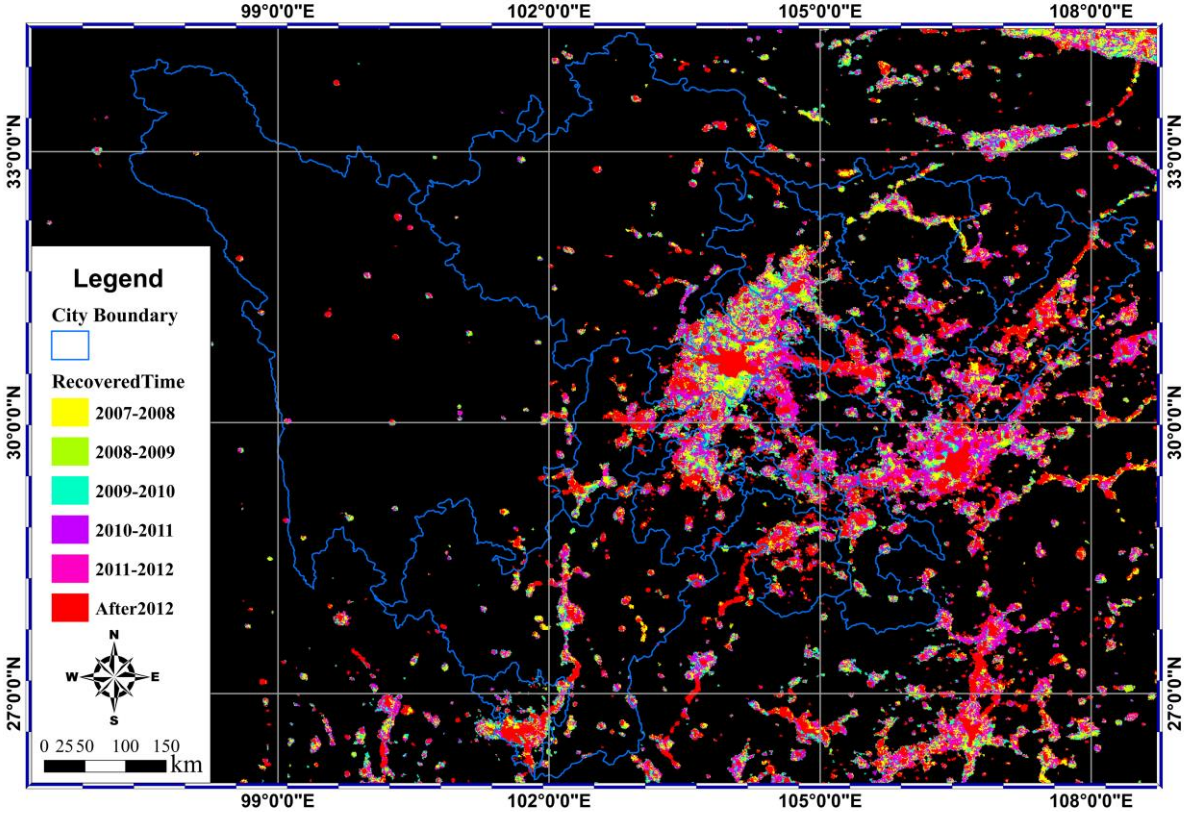

Figure 7: The time of light recovery

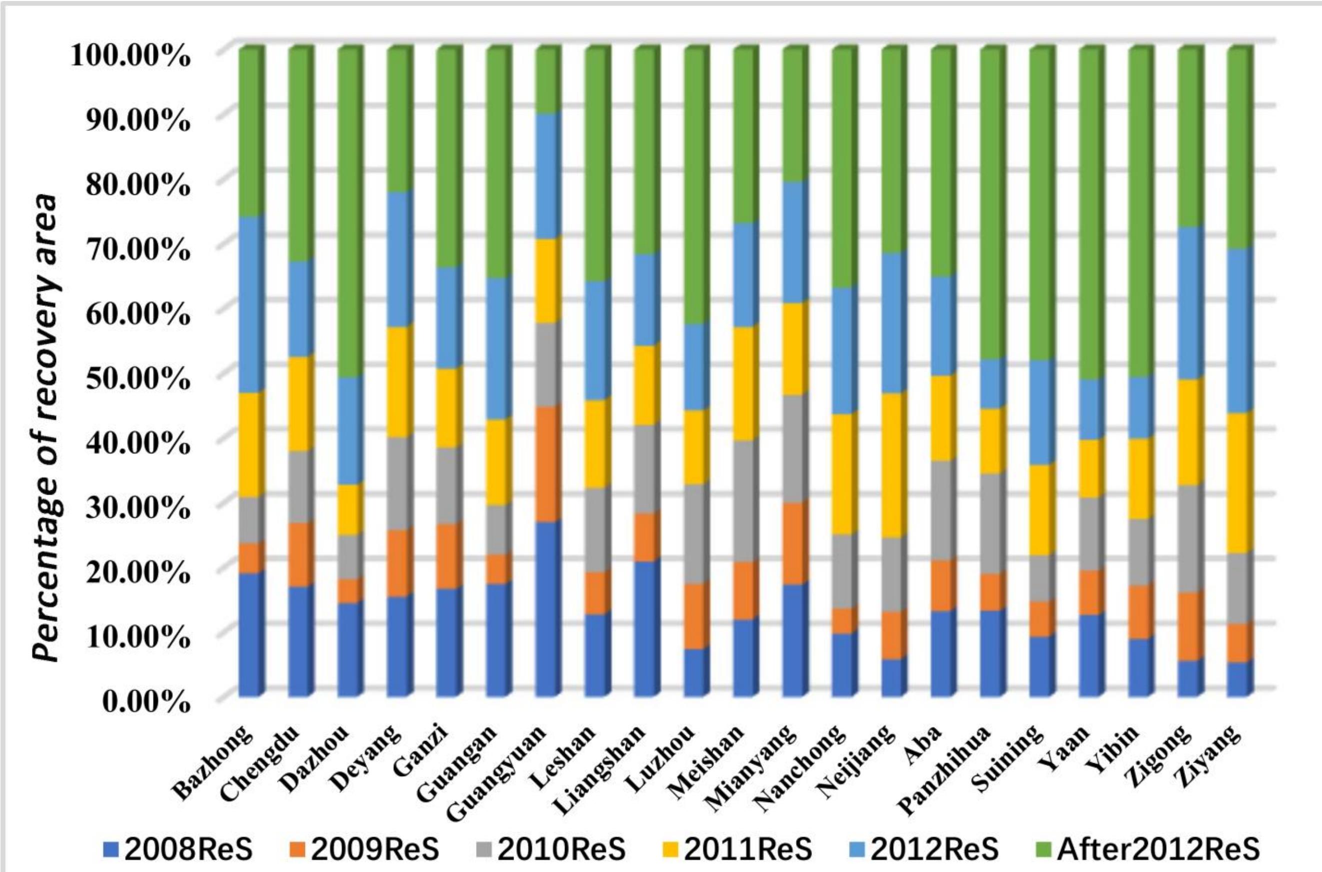

Figure 8: The percentage of light recovery area.

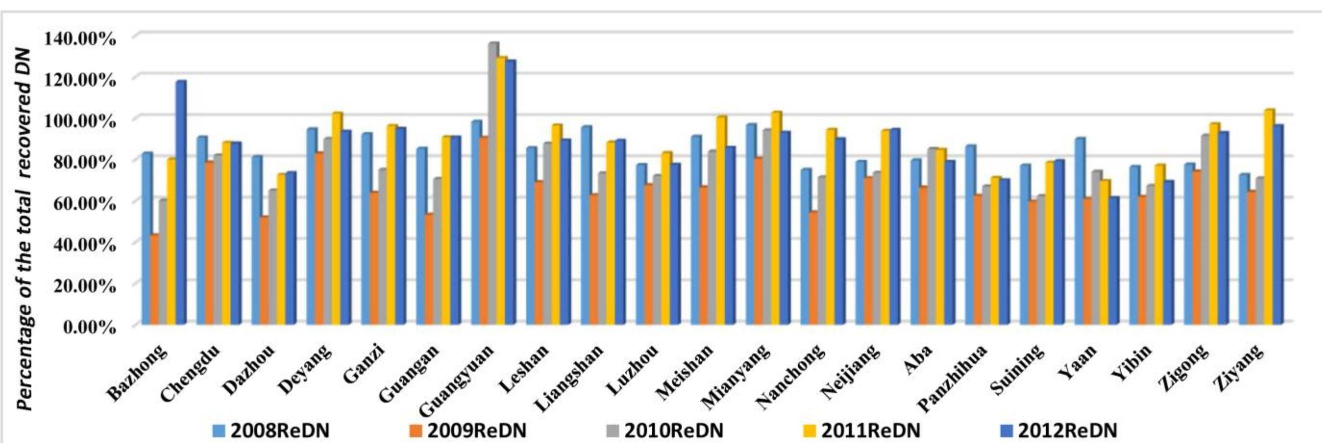

Figure 9: The percentage of total recovered DN

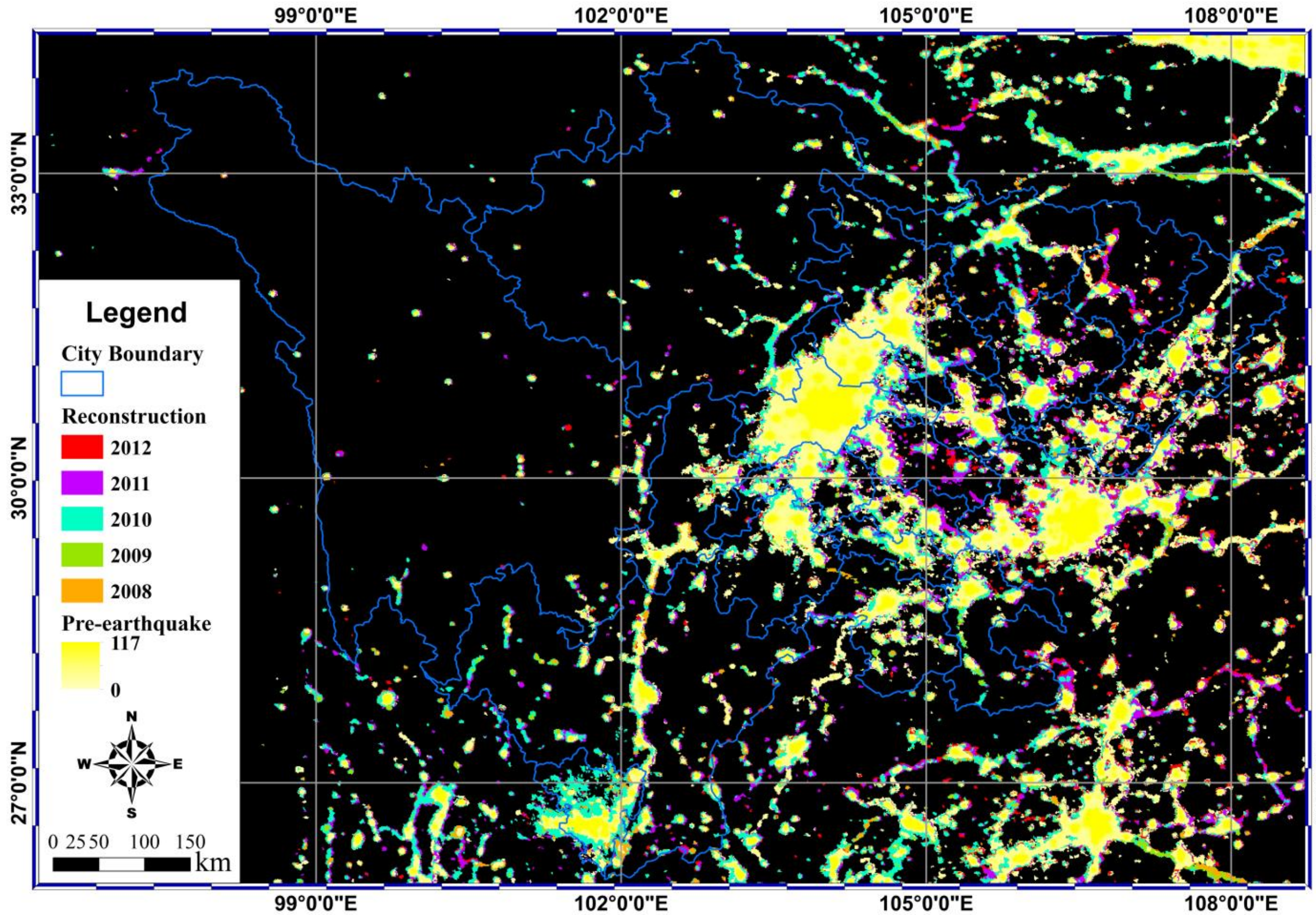

Figure 10: **Distribution of new lighting areas after earthquake**

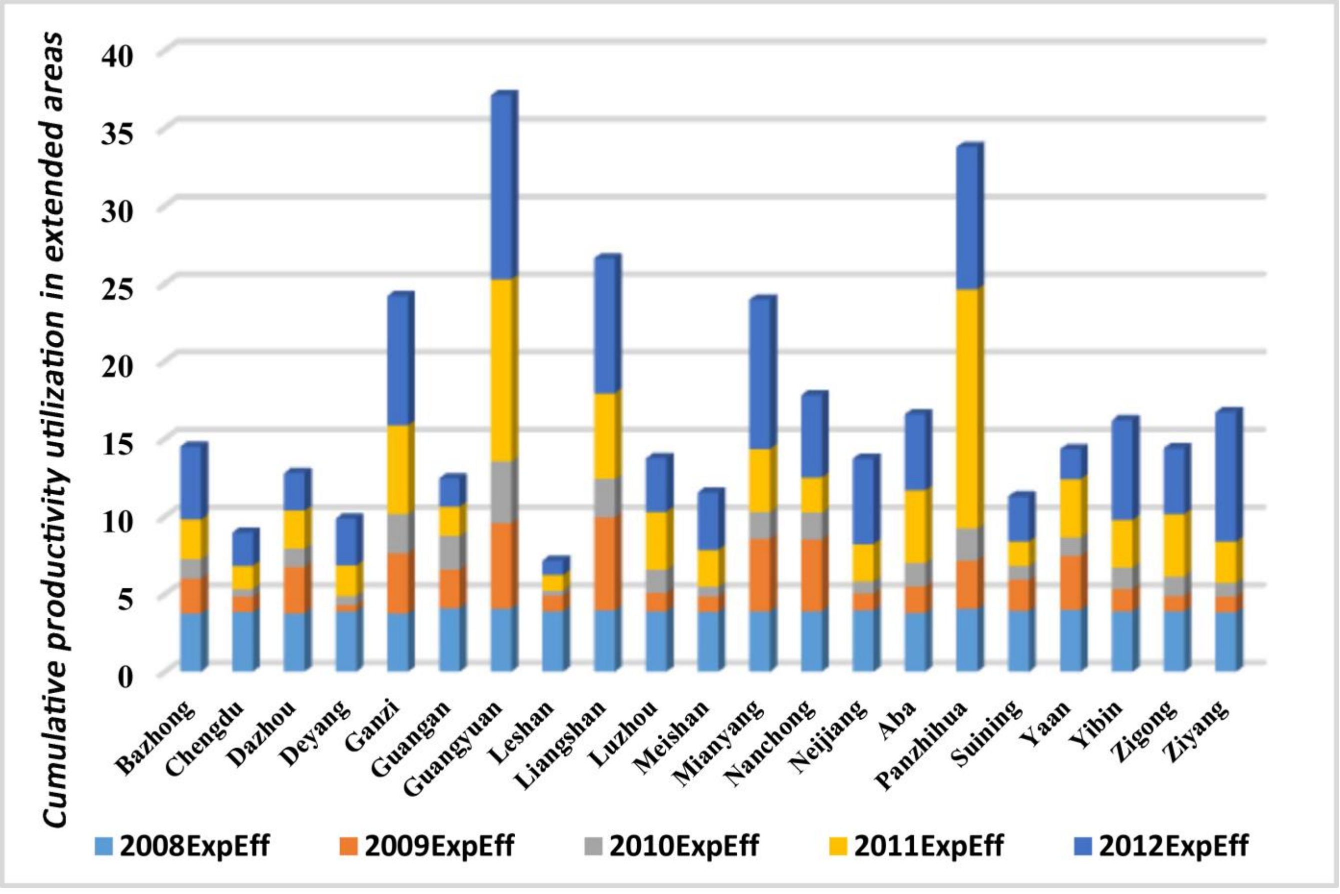

Figure 11: The cumulative productivity utilization in extended areas

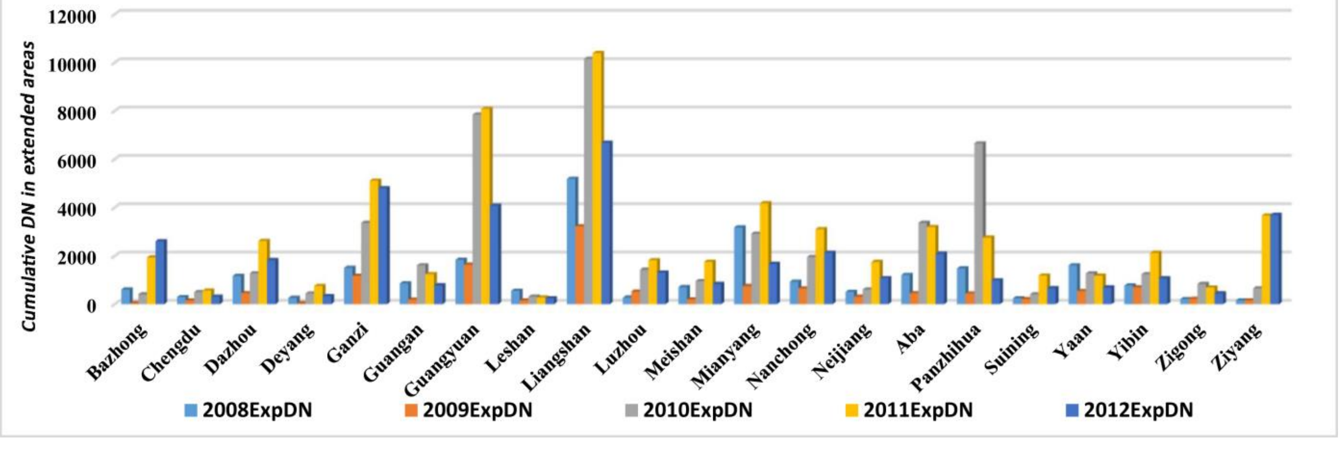

Figure 12: The cumulative DN in extended areas

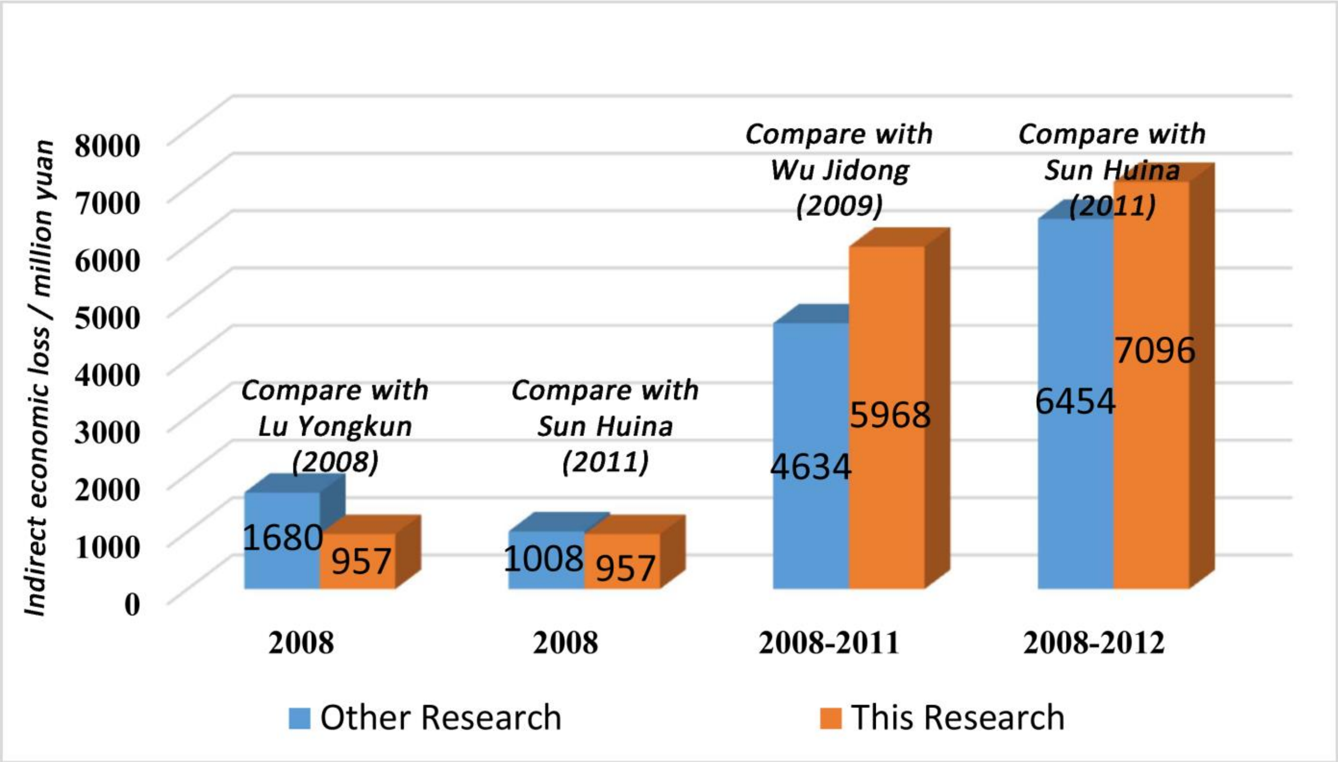

Figure 13: Comparison of indirect loss with other research

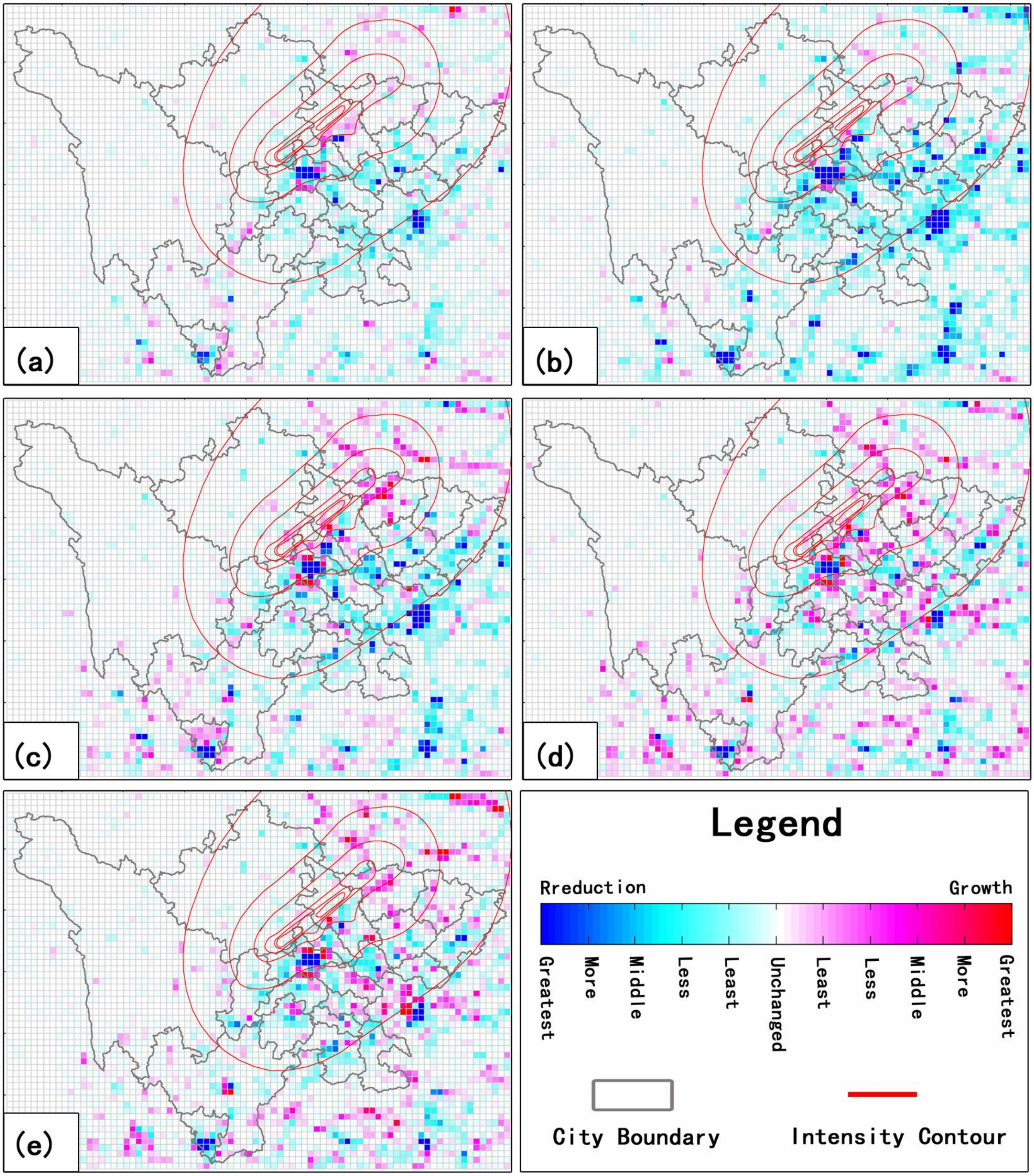

Figure 14: The economic change path in disaster area ; (a) The path of 2008; (b) The path of 2009; (c) The path of 2010; (d) The path of 2011; (e) The path of 2012;

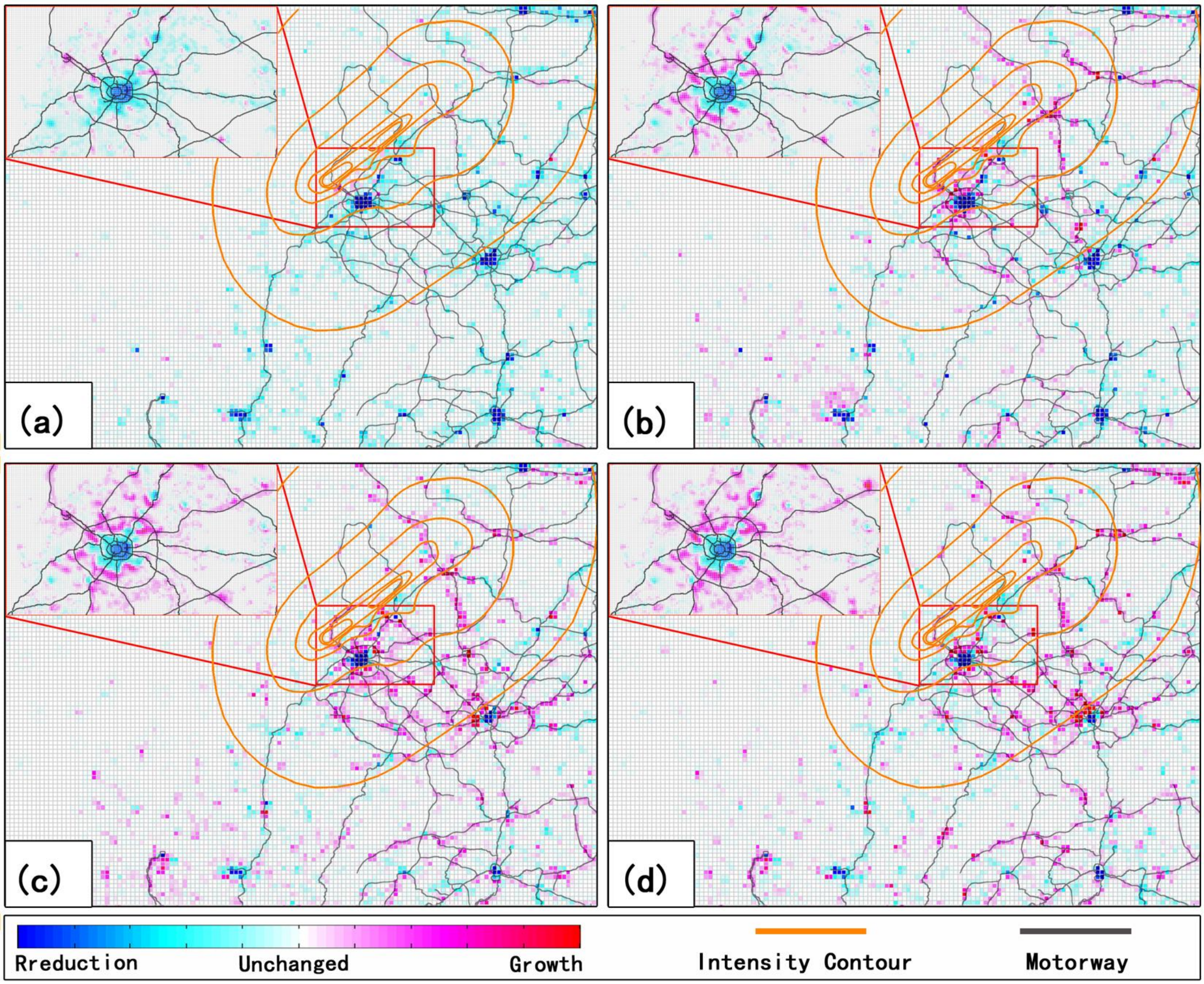

Figure 15: Economic recovery process in the disaster area ; (a) Economic recovery area in 2009; (b) Economic recovery area in 2010; (c) Economic recovery area in 2011; (d) Economic recovery area in 2012;