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Evaluation of MODIS-based Vegetation Restoration After the 2008 Wenchuan Earthquake

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Abstract. Mountainous vegetation recovery after major earthquakes has been significant for preventing post-seismic soil erosion and geo-hazards. Magnitude 7.9 Wenchuan earthquake struck western Sichuan, China in 2008, caused salient number of geological hazards and caused major vegetation damage. This recovery process could be a very long and fluctuating. And Remote sensing has been an important method of vegetation restoration monitoring. This study aims to use remote sensing technology data to analyze the post-seismic vegetation damage and recovery situation of the 2008 Wenchuan earthquake over years to 2020, and find the relevant factors affecting the restoration of ecological vegetation. This paper examined the vegetation recovery processes following the 2008 Wenchuan earthquake using 16-day interval MODIS normalized difference vegetation index time series from 2000 to 2020. It has been found that the vegetation recovery rate generally increased by years, the entire study area has recovered 49.89% by 2020. In addition, by combining remote sensing imagery and geographic information data, we also found that the heavily affected vegetation areas are mainly located along the southern part of the earthquake surface rupture, where have a very high slope which mainly over 60 degrees. It makes this part having higher probabilities to experiences secondary natural hazards and a fluctuating vegetation recovery rate. Through this research, it can be concluded that remote sensing is an effective method for monitoring vegetation dynamics in a long series. For soil and soil retention and ecological vegetation protection of landslides after the earthquake, it should be more concerned about the areas where have steep slope that over 60 degrees.

1 Introduction

Vegetation damage is a major threat for ecology system maintaining; and earthquake is a big cause of vegetation damage. 2008 Wenchuan earthquake, triggered a large number of secondary hazards such as landslides, affecting hundreds of square kilometers, damaging a vast area of vegetation by denuding, burying, or completely removing the local vegetation. Which makes South Sichuan a regional challenge for the local ecology system recovery.

Following the Wenchuan earthquake, some studies were performed to assess the vegetation recovery. For instance, Ali and Xuanmei etc assessed the regrowth of post-seismic vegetation in the landslide damaged areas using MODIS data and concluded that landslide activity may return to the pre-earthquake level within 18 years [1]. Additionally, Jiang and Jia etc used Landsat TM images to evaluate from 2005 to 2013 to assess the natural vegetation recovery processes in Mao County and found that vegetation recovery is slow and complex [2]. The principal feature of these methods involves comparing the difference in vegetation conditions of the pre and post seismic vegetation index using a limited number of images. However, these observational transactions can be easily affected by vegetation annual growth cycles. To avoid such bias from vegetation seasonal fluctuations, Wang used multiyear MODIS time series data to study vegetation recovery and found that the vegetation in the southern parts of the Wenchuan region, especially along the Longmenshan Fault, has experienced a significantly poor recovery four years after the earthquake [3]. Because of the influence of cloud and vegetation phenological changes, it has been difficult to obtain spatially resolved vegetation recovery trends since the Wenchuan earthquake.

Existing methods to evaluate post-seismic vegetation recovery suffer from the influence of interannual vegetation phenology changes and have difficulty in assessing the dynamics of vegetation recovery. Therefore, the knowledge on the spatial and temporal patterns of post-seismic vegetation recovery is limited. To this end, the objectives of this paper are: First, we will dynamically assess the vegetation recovery process in the Wenchuan earthquake affected areas by minimizing the interannual vegetation phenology influence. Second, we will analyse the relationship between post-seismic vegetation recovery and other geological factors such as evaluation and slope.

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2 Study area

The greatest earthquake in Sichuan region happened at 14:28 Beijing time on 12 May 2008 in Wenchuan county. The Wenchuan earthquake 2008 struck western Sichuan, with a Mw=7.9 (US Geological Survey, 2009), having a killed more than 88,000 people and affected millions. Also, the earthquake caused enormous number of geological hazards such as landslide, rock falls, debris flows. Which substantially damaged buildings, infrastructure, and ecological environment [4]. Wenchuan earthquake is considered as the worst natural hazard event in China since the Tangshan earthquake in 1976 and one of the largest continental thrusting events in the world. The epicenter of the earthquake was defined at 103.4°E and 31.0°N, near the city of Dujiangyan, about 80 km west-northwest of Chengdu, the provincial capital, with a focal depth of 15-20 km.

Longmenshan fault is considered as the main cause of the 2008 earthquake. This study area (Figure 2) is located along the Longmenshan fault with perceived shaking level greater than strong. This region has been chosen because it covered the area of the epicenter and the area with highest earthquake magnitude. And it suffered the most extensive damage and almost all coseismal landslides during the earthquake. The study area is (1800) square meters, and having elevation range from 978 to 4960 m. The climate of this area is perennially warm and moist. The average temperature is 16℃-18℃, and the annual precipitation 1000mm-1200mm. The precipitation is mainly occurring in summer, which is the time that Wenchuan earthquake happening, which extends the vegetation damage of the earthquake caused landslides because the rainfall water reduces the surface friction. The southwestern region of this study area has relatively higher elevations and a steeper slope, whereas the northeastern region of the study area is lower in elevation and has a smaller relief difference than the other studied regions. This makes southwestern region more possible to be affected to the natural hazards.

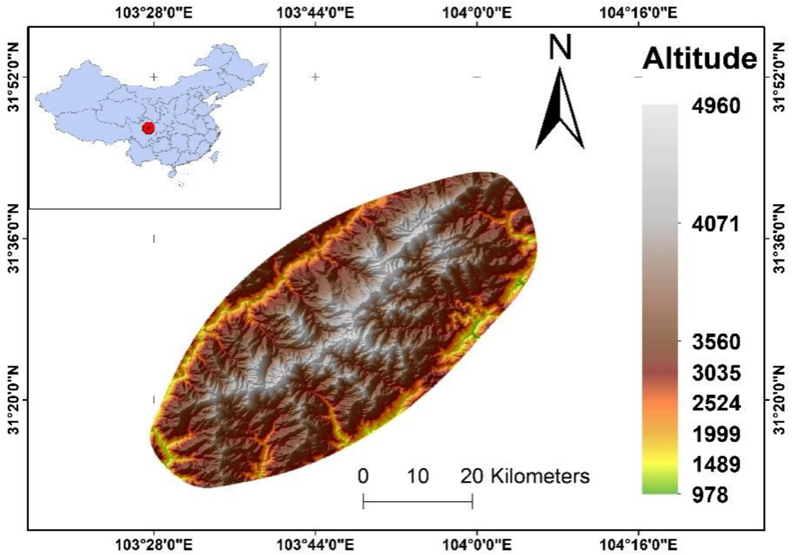

Figure 1. Study area

3 Data and Methods

3.1 Data processing

The data used in this paper include NDVI, VRR, altitude and slope. The NDVI images used in this paper were taken by the MODIS sensor on the Terra satellite, which also provides NDVI images every 16 days at 250-m spatial resolution (MOD13Q1). These data can be used to monitor global vegetation conditions, display land cover and track changes [5]. There are 12 bands for MOD13Q1, and NDVI was used in this study. The NDVI bands were preprocessed, extracted, resampled, projected and re-aligned using HEG (HDF-EOS TO GEOTIFF CONVERSION TOOL) software.

NDVI is an index used to analyze the fractional vegetation coverage. The average of the images from 113 to 209 Julian days, collected between May and August each year from 2000 to 2020 to represent optimal vegetation growth for each year. The reasons for selecting this period of time are: (1) it concludes with the period immediately following the data of the Wenchuan earthquake and was therefore suitable for comparing the vegetation for the years before and the years after the earthquake on 12 May 2008; (2) it was the period of the most luxuriant vegetation growth each year in the North Hemisphere, thereby providing the best opportunity to observe the recovery of the vegetation. NDVI variation can be used to express the level of vegetation recovery in damaged areas. Identified by the field investigation and aerial photographs, pixels with positive NDVI values were considered as areas covered by vegetation and were then included in binary vegetation maps. This research picked the images that having lowest affect by cloud, so the cloud affect is ignored in this study.

The elevation data was directly derived from DEM (digital elevation model). The slope distribution is derived by using the slope analysis tool in ArcGIS. They are used to research the relationship between vegetation change and elevation and slope.

3.2 Method

3.2.1 Calculation of Fractional Vegetation Coverage. The index model from NDVI was widely adopted in the calculation of FVC (Fractional Vegetation Coverage) since it provided the necessary information for sample calculation. The FVC in summer (May to August) from 2000 to 2007 was steady; accordingly, the average figure was used to reflect the situation in the pre-earthquake period. A significant variation could be observed after the strike of earthquake, and each FVC between 2008 and 2020 was represented by the figure from May to August.

3.2.2 Evaluation of Vegetation Recovery in the Damage Area. Based on the difference of vegetated area between the vegetation coverage derived from the pre-earthquake image and the post-earthquake images, a vegetation recovery rate (VRR) can be calculated at any specific time point, as follows:

$$VRR = \frac{FVC1 - FVC2}{FVC1 - FVC0} \times 100\% \qquad (1)$$

In the paper, the average value of the NDVI between May to August of 2000 to 2007 was applied as FVC0, and May to August of 2008 to be FVC1. To evaluate the recovery in a specific period the FVC in that period was needed to calculate the VRR figure.

According to previous studies in the literatures and for the convenience of discussion, VRR can be divided into four types, as shown in Table 1.

Table 1. Vegetation Recovery Rate (VRR) types, value, and VRR category used to classify the vegetation growth area and how well the vegetation recovered.

VRR Type	VRR value
Type I	(–∞ to 0)
Type II	(0 to 25)
Type III	(25 to 50)
Type IV	(50 to 75)
Type V	(75 to 100)
Type VI	(100 to +∞)

For this, the six VRR types have been grouped into two categories based on the visual interpretation: well recovered and poor recovered. It has been noticed that Type I to Type IV represents poorly to partial vegetation recovery in the image interpretation, while Type V to Type VI represents good to excellent vegetation recovery.

4 Results

4.1 Dynamics of the Vegetation Coverage in the Damaged Areas

NDVI was determined for the periods of vegetation coverage and, the NVDI variation by years is presented by Figure 2. NDVI change is also used to show the vegetation damage area change.

During the average annual NDVI value is 0.5727, and this study uses NDVI0 to represent the value. It has been found that NDVI rapidly decrease after the time 2008 Wenchuan earthquake occur. However, 2009 is the peak of vegetation damage, with NDVI 0.4055 which is the lowest among 2008 to 2020. The vegetation damage area is 74% of the study area. Generally, the trend of NDVI changes is increasing by years, which demonstrating that the damaged areas generally recovered to the pre-earthquake level. But the changes are also founded as fluctuating. The fluctuating is caused by aftershock earthquake and secondary hazards like landslide.

Similar pattern could be found in the chi-chi earthquake in 1999, where the geographical structure accords with Wenchuan, and its elevation difference was as high as 2000m [6]. Post-earthquake recover situation in chi-chi also share similarities with this study, and after the slump caused by the earthquake (0.53 to 0.49) its NDVI value gradually climbed to 0.52 (2016). Moreover, the similar fluctuation can be observed here as well. Another study about the Wenchuan earthquake also used NDVI to comprehensively describe the post-earthquake damage, and its tendency was highly consistent with ours.

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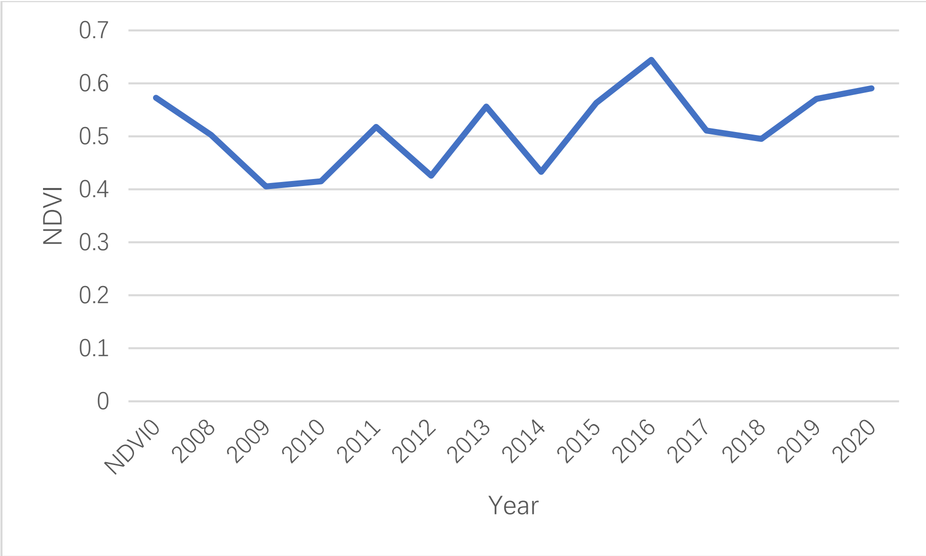
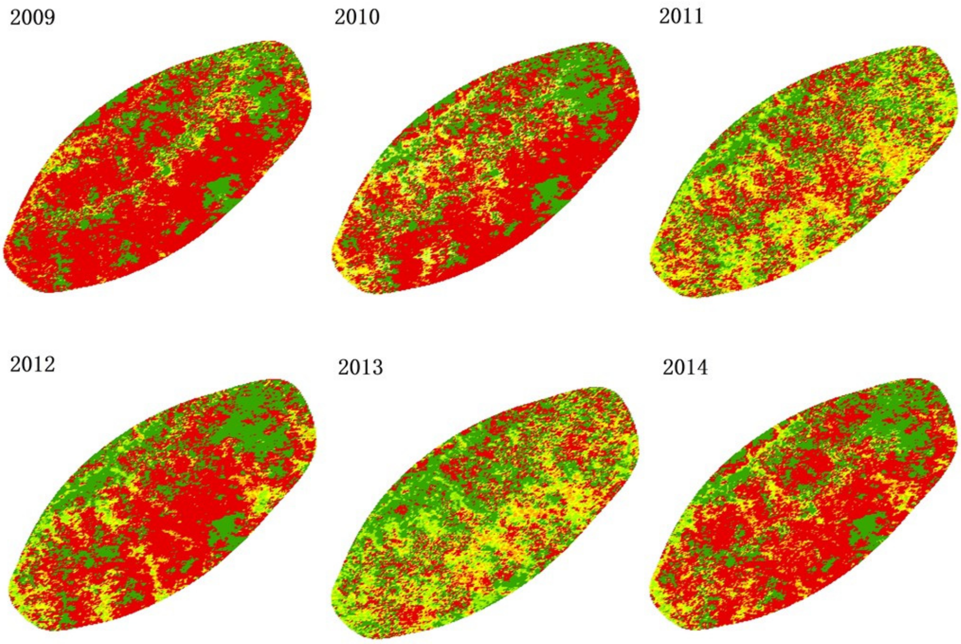


Figure 2. NVDI variation by years

4.2 Vegetation Recovery Rate Variation

It has been found that the vegetation recovery rate (VRR) generally increases by years; however, the change is fluctuated. Figure 3 illustrates the VRR from 2009 to 2020 after the Wenchuan Earthquake. The redder means more severe vegetation damage, and more green means higher vegetation recovery rate.

Another study about the Taiwan earthquake also accords with the situation in Wenchuan in this study. Fluctuation can be found in the post-earthquake area, and the gradual climb of the index indicates the recovery of the county. More specific statistics demonstrates the difference in landslide areas, where the VRR values are significantly lower than the average value regardless of the year after the earthquake [7]. Targeting at other study about Wenchuan earthquake, the similar result could be concluded.



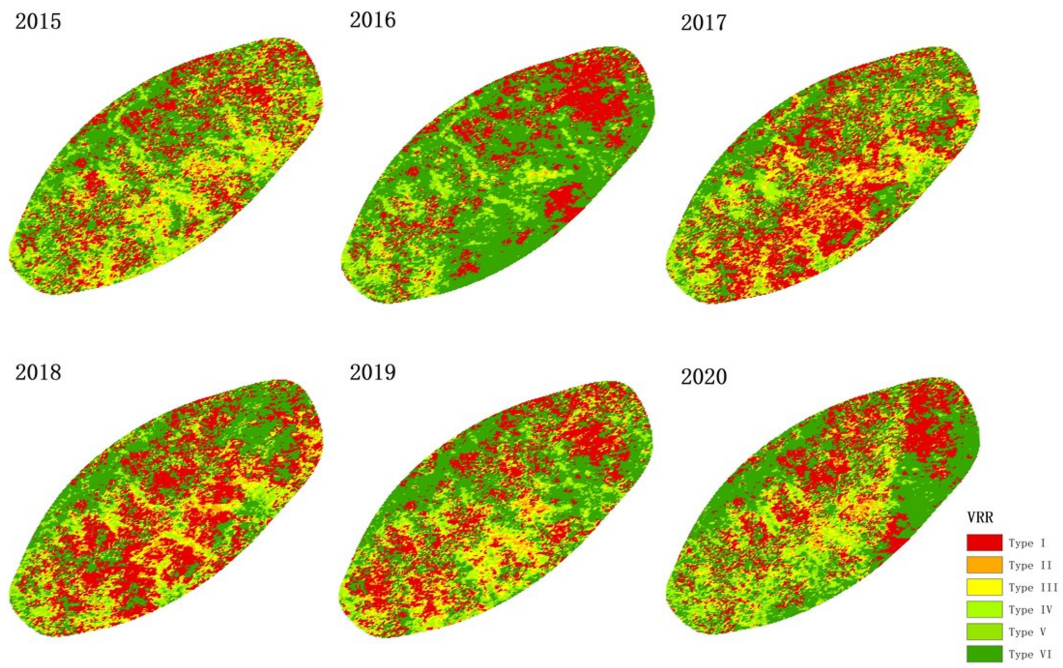


Figure 3. Vegetation recovery rate vary by years

4.3 Elevation, slope and VRR

4.3.1 Relationship Between Elevation and VRR. This paper compares the elevation value with the type of VRR to find the relationship between elevation and VRR. It has been found that the lowest and highest elevation area have lowest VRR, and the rest part of this study area has a general negative relationship between elevation and VRR. With the elevation value goes up the vegetation recovery rate is lowered. In table 2 and 3, it picked the year of the most damaged 2009 and the least year from present 2020 to keep the accurate and updated level of the analysis.

Table 2. 2009 Elevation and VRR relationship analysis

Elevation	Type I	Type II	Type III	Type IV	Type V	Type VI
978-1641	12.6%	38.4%	23.1%	10.3%	4.1%	11.5%
1641-2305	19.8%	29.5%	14.7%	9.1%	6.5%	20.4%
2305-2969	22.6%	20.9%	10.9%	6.7%	8.1%	30.8%
2969-3632	17.2%	19.5%	12.7%	11.4%	12.0%	27.1%
3632-4296	18.1%	19.8%	16.7%	13.0%	13.6%	18.8%
4296-4960	24.5%	16.1%	14.6%	13.0%	8.9%	22.9%

Table 3. 2020 Elevation and VRR relationship analysis

Elevation	Type I	Type II	Type III	Type IV	Type V	Type VI
978-1641	12.5%	5.9%	10.0%	21.4%	29.8%	20.4%
1641-2305	16.0%	7.7%	15.4%	21.0%	23.0%	16.9%
2305-2969	17.4%	12.5%	18.3%	18.2%	18.8%	14.7%
2969-3632	18.5%	17.0%	18.7%	16.2%	14.1%	15.5%
3632-4296	20.3%	15.5%	17.6%	17.0%	13.4%	16.2%
4296-4960	20.2%	10.9%	17.3%	17.3%	15.3%	19.0%

Elevation could affect the VRR value. Vegetation recovered more easily in lower altitude because the relief is much lower than other regions and soil is fertile [1]. This regulation also applies in this study, where VRR in lower altitude places shows better recovery. Moreover, area with relatively high elevation showed a faster recovery rate than the medium altitude places, due to less human activities and less destruction caused by slope.

4.3.2 Relationship Between Slope and VRR. This research picked three special years to do the analysis between slope and VRR, which are 2012, 2014 and 2017. Because it has been found that the NDVI surprisingly decrease in those years from their previous year after the main 2008 Wenchuan earthquake. With the data set of 2012, 2014 and 2017, which are shown on Table 4 to Table 6, it has been found that the VRR value from type IV-VI which represent good recovery rate are generally decreasing with the slope increasing.

Slope may have a negative effect on the vegetation to the post-earthquake recovery. Slope could worsen the damage caused by the earthquake when looking into topographic analysis of vegetation [8]. This study finds out another regulation that the steep slopes in the area may cause a second hazard to the post-earthquake region and negatively impact on the NDVI and VRR values. Another study indicates that ridgelines could cause more damage, thus have a negative impact on vegetation recovery condition [9]. That situation could also be explained by the gradient of the slope.

Table 4. 2012 Elevation and VRR relationship analysis

Slope	Type I	Type II	Type III	Type IV	Type V	Type VI
1-12(°)	43.7%	7.5%	7.6%	6.9%	4.7%	29.6%
12-24(°)	44.7%	9.1%	8.5%	7.1%	5.1%	25.5%
24-36(°)	42.6%	12.6%	11.0%	8.6%	5.7%	19.5%
36-48(°)	42.2%	13.1%	10.9%	8.0%	5.2%	20.6%
48-60(°)	54.4%	13.6%	10.1%	5.7%	2.9%	13.3%
60-72(°)	59.5%	17.5%	7.1%	3.2%	1.2%	11.5%

Table 5. 2014 Elevation and VRR relationship analysis

Slope	Type I	Type II	Type III	Type IV	Type V	Type VI
1-12(°)	46.5%	9.7%	7.8%	5.4%	4.2%	28.1%
12-24(°)	46.8%	11.6%	8.2%	6.1%	4.3%	23.0%
24-36(°)	43.7%	15.8%	10.6%	7.1%	5.0%	17.8%
36-48(°)	43.0%	17.1%	10.8%	6.3%	4.1%	18.8%
48-60(°)	54.8%	17.3%	9.5%	4.2%	2.2%	12.0%
60-72(°)	53.5%	19.2%	9.6%	2.2%	3.0%	12.5%

Table 6. 2017 Elevation and VRR relationship analysis

Slope	Type I	Type II	Type III	Type IV	Type V	Type VI
1-12(°)	27.5%	9.9%	12.0%	11.0%	10.1%	29.6%
12-24(°)	27.7%	11.9%	12.7%	12.1%	10.2%	25.3%
24-36(°)	26.1%	15.4%	15.7%	13.4%	10.8%	18.6%
36-48(°)	25.8%	16.2%	15.9%	12.8%	9.6%	19.6%
48-60(°)	30.1%	20.3%	17.7%	11.8%	6.4%	13.6%
60-72(°)	32.0%	22.0%	19.2%	11.0%	4.3%	11.6%

4.3.3 Southwest area finding

This research found the southwest area of this study area suffered the most and recovered the slowest. This may highly possible due to the extreme high slope of this area which makes there are easily affected by aftershock caused landslide.

Comparing the Figure 4 which is the slope distribution of this study area and Figure 3. Li etc's study on the same region also confirms the finding that there is a negative relationship between slope and vegetation recovery rate. [10] The high slope makes the place harder to recover from vegetation damage.

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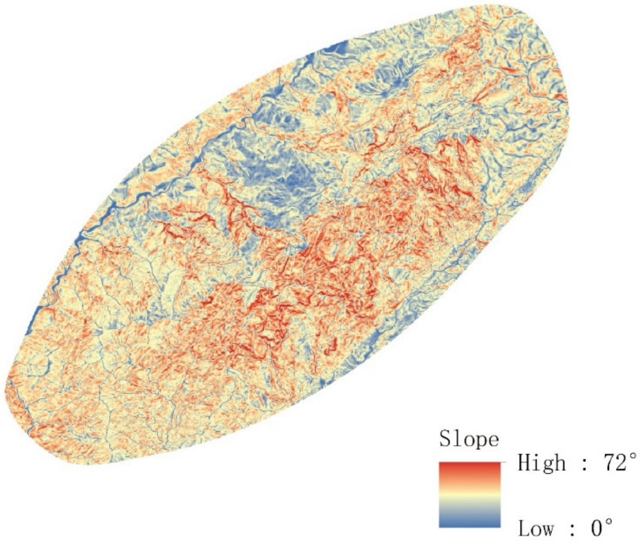

Figure 4. Slope distribution of study area, the lighter color means steeper

5 Conclusion

The earthquake happened on May 2008 triggered massive destruction of vegetation in the area, and the condition did not fully recover in the ten-year period which judged by NDVI. The mountainous terrain and the relatively steep slope in the county may cause a second deterioration to the plants. During the decades, vegetation keeps recovering at slow pace, but fluctuation reflected by NDVI and VRR index suggested such hazard.

Based on elevation and slope statistics, this research looked into a specific area which are along raptures and having extreme high slope, and the yearly VRR index in the area does validate this assumption and post-earthquake recovery can be affected by the slope.

Reference

1. Ali P. Yunusa, Xuanmei Fana , Xiaolu Tangb , Dou Jied , Qiang Xua , Runqiu Huang, Decadal vegetation succession from MODIS reveals the spatio-temporal evolution of post-seismic landsliding after the 2008 Wenchuan earthquake, Remote Sensing of Environment.
2. Wei-Guo Jiang, Kai Jia, Jian-Jun Wu, Zheng-Hong Tang, Wen-Jie Wang and Xiao-Fu Liu, Evaluating the Vegetation Recovery in the Damage Area of Wenchuan Earthquake Using MODIS Data. Remote Sens. 2015, 7, 8757-8778
3. M. Wang, W. Yang, P. Shi, C. Xu, and L. Liu, “Diagnosis of vegetation recovery in mountainous regions after the wenchuan earthquake,” IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens., vol. 7, no. 7, pp. 3029–3037, Jul. 2014.
4. Xing, H.L.; Xu, X.W. M8.0 Wenchuan Earthquake; Springer-Verlag: Berlin, Germany, 2011.
5. Vegetation indices 16-Day L3 global 250m. Available online: https://lpdaac.usgs.gov/products/modis_products_table/mod13q1 (accessed on 20 May 2014).
6. Ming-Der Yang and Hui-Ping Tsai, 2019: Post-earthquake spatio-temporal landslide analysis of Huisun Experimental Forest Station. Terr. Atmos. Ocean. Sci., Vol. 30, No. 4, pp.493-508
7. Ming-Der Yang, Su-Chin Chen and Hui Ping Tsai, 2017: A Long-Term Vegetation Recovery Estimation for Mt. Jou-Jou Using Multi-Date SPOT 1, 2, and 4 Images.remote sensing
8. Quanjun Jiao • Bing Zhang • Liangyun Liu • Zhenwang Li • Yuemin Yue • Yong Hu, Assessment of spatio-temporal variations in vegetation recovery after the Wenchuan earthquake using Landsat data.Nat Hazards (2014) 70:1309–1326
9. Wen-Tzu Lin, Wen-Chieh Chou, Chao-Yuan Lin, Pi-Hui Huang, Jing-Shyan Tsai,Vegetation recovery monitoring and assessment at landslides caused by earthquake in Central Taiwan.Forest Ecology and Management 210 (2005) 55–66.
10. LI Jing-zhong, CAO Ming-ming, QIU Hai-jun, XUE Bing, HU Sheng,CUI Peng Spatial-temporal process and characteristics of vegetation recovery after Wenchuan earthquake: A case study in Longxi River basin of Dujiangyan, China.