Spatial distribution and influence factors of landslides
triggered by the 2019 Ms 6.0 Changning, Sichuan, China
Ms6.0 earthquake: A statistical analysis based on QGIS

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Abstract: Based on the QGIS platform, using high-resolution remote sensing images, this work interpreted co-seismic landslides triggered by the 2019 Changning, Sichuan Ms6.0 earthquake. In total, 496 landslides with an occupation area of 1.2km2 were mapped. Then considering three types of influence factors, seismology, topography and geology, the distribution pattern of these landslides was statistically analysed by PyQGIS console and existing analysis functions. The results show that the landslides are mostly distributed at places with elevations of 400-500m, slopes facing N and SE directions, media of mudstone, tuff and siltstone, sites 2-6km distant to the fault, and zones of PGA 0.4-0.5g. This study will contribute to further understanding of the genesis and risk assessment of co-seismic landslides, providing useful information for research of the tectonic activity in the study area.

Key words: Changning earthquake, QGIS; statistical analysis; co-seismic landslides

1. Introduction
Earthquake-triggered landslides are a common geohazard threatening socio-economic and human safety. In recent years there have been many case studies on this issue. Examples abroad include the 2005 Kashmir earthquake [1, 2], the 2015 Nepal earthquake [3, 4], the 2016 Kumamoto earthquake [5] and the 2018 Hokkaido earthquake [6]. Domestic studies cover the 2010 Yushu earthquake [7], 2013 Lushan earthquake [8,9], 2015 Ludian earthquake [10, 11] 2008 Wenchuan earthquake [12, 13], 2017 Jiuzhaigou earthquake [14, 15], and 2013 Minxian
earthquake [16]. These studies focused on interpretation and mapping [17], spatial distribution pattern, risk assessment and prediction [18, 19, 20], and mechanism of landslides [21]. Among them, detailed and complete landslide inventories (including landslide distribution and impact factors) are the most important basic data.

Now in research of landslides, GIS is widely used as a platform [22], of which ArcGIS is a representative system, but with non-free and close source nature. With the emergence of open source and free GIS systems, many researchers have started to adopt the open source GIS software such as QGIS [23].

The 2019 Changning, Sichuan Ms6.0 earthquake triggered a large number of landslides which affected 168,000 people (13 deaths) and damaged many infrastructures within 4 days after the earthquake. Researchers have studied the source mechanism and tectonic setting of this event [24, 25], while no research on its co-seismic landslides has been conducted so far.

The purpose of this study is to establish an inventory of the landslides triggered by the Changning earthquake using interpretation of high-resolution remote sensing images based on QGIS. Then considering impact factors involving topography, seismology and geology, statistics was made to characterize are spatial distribution pattern of these landslides.

2. Study area and overview of the Changning earthquake

In this work, the zones with seismic intensity VII and VIII degrees of the Changning event announced by the Sichuan Earthquake Bureau were taken as the study area, covering 520km² (Figure.1). The overall shape is an ellipse with long axis NW-SE direction. It is located in the southern edge of the Sichuan basin, southeast of the Tibetan plateau. The study area is tectonically complex, hosting many NE and EW folds and active faults. The exposed strata in the area are from Cambrian to Cretaceous.

Figure 1. Location and geology of the study area. (a) shows the enlargement of the red box in (b). DFBF, Dafenba fault. GXF, Gongxian fault. DFYF, Dafoya fault. WFTF, Wafangtou fault. DDWF, Dadiwan fault. XJF, Xinjie fault.

The epicenter of the 2019 Changning Ms6.0 shock is located at 28.34°N, 104.90°E, with a focal depth 16km (http://news.ceic.ac.cn/CC201906172225543.html). More than 200 aftershocks over Ms 2.0 were recorded within two weeks after mainshock, which show a NW-trendind distribution. Existing studies have not yet reached a unanimous conclusion on the seismogenic structure of this earthquake, but the focal mechanism solutions suggest that the
mainshock was dominated by reverse faulting with a left-slip component [28, 29].

3. Data and Methods

3.1. Data
The remote sensing data used in this study are the 3m resolution data from Planet satellite. DEM data is ASTER 12.5m resolution data (https://search.asf.alaska.edu). PGA data of the earthquake were obtained from USGS (https://earthquake.usgs.gov).

Geological data source obtained from 1:200,000 national geological map. The lithologies were numbered after clipping and correcting with the study area (Table 1).

| No. | Stratum | Lithology description |
|-----|---------|-----------------------|
| 1   | Q       | Mixed colored fine sand, clay, gravel, Flood deposits |
| 2   | Kj      | Quartz fine sandstone sandwiching mudstone, shale thin layer, |
| 3   | J3p     | Mudstone, siltstone |
| 4   | J2      | Sandy mudstone, fine sandstone, calcareous siltstone, |
| 5   | T2+3    | Sandstone, chert, shale, claystone |
| 6   | T1      | Sandstone, chert, shale, mudstone |
| 7   | P2      | Siltstone, chert, shale, basalt |
| 8   | P1m     | Bioclastic tuff |
| 9   | S2l     | Marl, siltstone marl, calcareous shale |
| 10  | S1l     | Sandy chert, carbonaceous shale |
| 11  | O       | Sandy shale, dolomitic tuff |
| 12  | Є       | Dolomitic chert, marl chert, calcareous siltstone, marl |

3.2. Methods
The Planet plugin of QGIS can be used to quickly switch between pre- and post-earthquake images. By comparing the two kinds of images aforementioned, the areas where no distinctive features appeared before the earthquake but bright tones, flowing textures, and no plant cover appeared after the earthquake were identified as co-seismic landslides, and then delineated them with polygons along the boundary. For areas of uncertainty or heavy cloud cover, images from adjacent months were used appropriately for inspection to ensure comprehensive and accurate results.

Based on QGIS, the slope and direction data of the study area were obtained by using DEM data and raster terrain analysis function. Distance analysis of faults in the study area was made to get the corresponding raster data.

Then influence factors were divided into intervals by reclassification function, and the interval area (CA), landslide number and landslide area of each interval were determined statistically. The number and area of landslides were divided by the area of the corresponding interval to obtain the landslide number density (LND) and landslide area share (LAP), which were used as parameter indicators of the spatial distribution pattern of landslides in subsequent mapping and analysis.
4. Results

4.1. Landslides distribution
From remote sensing images, 496 landslides were interpreted in this study, with a total area of 1.2 km². The largest landslide area is 43945.8 m². Most of the landslides are of areas 1000-2000 m² (Figure 2).

![Figure 2. Landslide scale box plot and scatter plot.](image)

According to density analysis of landslides (Figure 3), we concluded that high-density areas of landslides distribution were mainly located in the southeast and central part of the study area.

![Figure 3. Landslides distribution map and point density map.](image)

4.2. Influence factors
In this study, elevation, slope and aspect in topography, lithology and distance from the fault in geology, and PGA in seismology were selected as influence factors for statistics.

The elevation range of the study area is 226-1354 m. The results indicate that LND and LAP are generally increasing and then decreasing, reaching the highest value in the range of 400-500 m. LND is 1.41 km² and LAP is 0.38%. The highest slope in the study area is 80.8°, and the landslides showed a rising trend on the slope interval, with the highest LND and LAP reaching 9.2 km² and 3.19%. For the slope aspect, the landslides have clear dominance in the N and SE aspects, which is consistent with the aftershock distribution sequence (Figure 4).
Figure 4. Relationship between topography and landslides. (a) Shaded map showing elevations in the study area. (b) LND versus elevations. (c) Slope angle distribution. (d) LND versus slope angles. (e) Slope aspect distribution. (f) LND versus slope aspects.

The stratigraphy in the study area is complex with oldest exposed strata of Cambrian time. The area of J3 lithology is small, but where LAP and LND are the maximum (0.4% and 1.43km$^{-2}$). LAP and LND are much higher in T1 and O lithologies than in other intervals. All three lithologies have a large amount of mudstone, chert and siltstone. Both parameters are higher in the interval of 2-6km from the fault, which is related to CA, because there are many faults in the study area, so the area of the partition closer to the fault is larger (Figure 5).

LND and LAP reach the highest values (1.4km$^{-2}$ and 0.32%) in interval of PGA 0.3-0.4g (Figure 6). Although the larger PGA reflects the higher seismic shaking, other influence factors also affect the landslide triggering.
5. Discussion and conclusions

In this work, 496 co-seismic landslides with an occupation area of 1.2km² were identified by interpretation of remote sensing images in the study district. Overall, they are of small scales, mostly concentrating in the southeast and central part of the study area. The high-density area is consistent with the elliptical long axis of aftershocks and seismic intensity zones.

Statistics show that these co-seismic landslides are mostly distributed in the areas with elevations 400-500m, slope angles above 50°, slopes facing N and SE, the places of mudstone, tuff and siltstone, within 2-6km from the fault, and zones of PGA 0.4-0.5g. It provides help for...
subsequent risk assessment and disaster prevention measures.

The extraction of influence factors in previous studies on seismic landslides mostly used the spatial connection, extraction of values at points and regional analysis functions of ArcGIS. However, the process of converting surfaces to points may cause errors, while the area analysis function requires high resolution of raster data which are usually unavailable. This study maintained the polygon form and did not have no-data values through QGIS’s connect-by-location attribute function. Compared with conventional ArcGIS, the result by this approach is not so feature-rich, but for spatial analysis and landslide database construction, it is completely achievable.

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