Spatial distribution of landslides triggered by the Wenchuan Ms 8.0 earthquake near the epicenter

S H Cui 1, *, Q W Yang 1, 2, X J Pei 1
1 State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu, 610059, China
2 Department of Civil and Environmental Engineering, the University of Texas at San Antonio, San Antonio, USA
* Corresponding author:
E-mail addresses: cuishenghua18@cdut.edu.cn.
ORCID: http://orcid.org/0000-0002-6638-230X

Abstract. The 2008 Wenchuan earthquake (Ms = 8.0) occurred in Sichuan, China, and triggered many landslides that were more concentrated near the epicenter. A watershed of Min River of length 80 km and an area of approximately 2100 km² was chosen in this study to assess the spatial distribution of the co-seismic landslides. Both the widely used indexes, including co-seismic landslides number (LN) and landslide concentration (LC), and two new indexes, slope pixel percentages (SPP) and landslide pixel percentages (LPP), are used to make correlation analysis with topographical factors. The SPP is defined as the pixel percentage of topographic factors related to the entire study area on pre-earthquake digital elevation model. The difference between the SPP and LPP is that the latter is only considered in the area where co-seismic landslides occur. The main results of this study are: (1) The distance from surface rupture (r_f) leads to a better correlation with LC; (2) greater than one twice of the landslides that occur on the west side of the Min River line; (3) the distribution of the landslides in our study area shows a larger average distance to fault rupture comparing to the average value in the total Wenchuan earthquake; (4) the most remarkable correlation found is with the topographic aspects and the fault thrusting direction.

Keywords: Co-seismic landslide, landslide inventory, Wenchuan earthquake, causative fault, topography

1. Introduction
The Wenchuan earthquake, featuring a hypocenter depth of 19 km, is one of the most disastrous events in China (Burchfiel et al. 2008), leading to a death toll of more than 20000 (Yin et al. 2009) and extensive damage around 170 billion dollars. Meanwhile, it has been assumed that its long-term losses will be much more severe (Huang and Fan. 2013; Fan et al., 2018).
The earthquake occurred on the southern part of the Longmenshan thrust belt, in which the Maoxian-Wenchuan (MX-WC), Yingxiu-Beichuan (YX-BC), and Pengzhou-Guanxian (PZ-GX) faults are composed. The Wenchuan earthquake ruptured the YX-BC and the PZ-GX faults, which are subparallel and 15–20 km apart (Xu et al. 2009a), resulting in a surface rupture extending approximately 270 km along the northeast-trending YX-BC fault from Yingxiu to Qingchuan. The epicenter is close to the town of Yingxiu, about 80 km northwest of Chengdu, the capital of the Sichuan Province. Approximately 120 seconds of shaking resulted in many geohazards within an area of 40000 km² (Xu et al. 2013a). The earthquake-induced landslide is one of the most catastrophic geohazards (Huang and Fan 2013).

Some researchers immediately conducted field investigations of the co-seismic landslides. Wang et al. (2009) and Yin et al. (2009) did a preliminary study on the effects of seismic, topographic, geologic, and hydrogeologic conditions on the generation of landslides. Chigira et al., 2010; Huang et al. 2012; Xu et al. 2011; Cui et al. 2016; Cui et al. 2018 focused on large-scale landslides’ geologic, hydrology and tectonic effects. Due to inaccessibility in some earthquake areas, field investigations were impossible to carry out in the entire Wenchuan earthquake area; thus, the GIS method was used. By interpreting multiresolution satellite images, such as SPOT images, IRS-P6 images, and China-Brazil Earth Resources Satellite images, 13000–60000 co-seismic landslides have been mapped in the earthquake area ranging from 31000 to 41000 km². The correlation analyses of the co-seismic landslide distribution were conducted under these landslide maps. It has been revealed that most of the landslides occurred along the surface rupture and were concentrated on the hanging wall of the causative fault. Therefore, their distribution patterns were not only controlled by the original topographic factors (slope aspect, slope angle, and elevation) but were affected by the physical and kinematic characteristics of the causative fault, such as the fault geometry, motion direction, and surface rupture length. (Lin et al. 2009; Sato and Harp 2009; Chigira et al. 2010; Ouimet 2010; Qi et al. 2010; Dai et al. 2011; Gorum et al. 2011; Tang et al. 2011; Chen et al. 2012; Li et al. 2013; Guo and Hamada, 2013; Xu et al. 2013b; Xu et al. 2016; Fan et al. 2019; Liu et al. 2020).

However, due to the large earthquake area, the effects of topographic and geological factors on the co-seismic landslide are very complex. As a result, the cause of the landslide spatial distribution and concentration still have not been examined thoroughly. In this study, the watershed of the Min River with a length of 80 km and an area of approximately 2100 km² has been chosen (Fig. 1) to present the results of a mapping study of the co-seismic landslide distribution around the epicenter. Based on aerial images, topographic maps, and seismic intensity maps, correlation analyses of the landslides were conducted, aiming to provide more details about the controls of topographic and faulting factors for delving into the distribution of earthquake-induced landslides in this area.
Fig. 1: The study area is near the epicenter of the Wenchuan earthquake and includes the watershed of the Min River line with a length of 80 km. The black box is the location of the images shown in Fig. 7.

Fig. 2: Geological map of the study area. The MX-WC fault, which was not ruptured during the 2008 Wenchuan earthquake, passes through the upper part of the study area. The causative fault of the Wenchuan earthquake (YX-BC fault) passes through the bottom of the area. The black box is the location of the images shown in Fig. 7.

2. Study area

Topographic elevation in this area rises sharply northwestward, and the highest point is Jianjianshan Mountain, featuring a maximum height of 3379 m a.s.l. The Min River line declines from 1300 m above sea level (a.s.l.) in Wenchuan County to 920 m a.s.l. in Yingxiu. Subtropical and humid monsoons dominate this area, causing an average annual temperature of 16°C, as well as a yearly rainfall of 1200 mm (Tang et al., 2011).

The MX-WC fault passes through the northwestern part of the study area, which was not ruptured during the Wenchuan earthquake, while the causative fault, the YX-BC fault, crosses the southern part of the area (Fig. 2). Sandstone and slate are mainly developed on the footwall of the YX-BC fault in the area, and the hanging wall is primarily composed of granite rock. In addition, the Peng Guan Complex and Metasedimentary rocks can be found locally.

Shaking of the Wenchuan earthquake was recorded by 460 seismic stations in 17 provinces across China (Li et al., 2008b). Three of them are located in our area, i.e., NO. 051WCW near the epicenter, and NO. 051LXM and NO. 051LXT near Wenchuan County, approximately 35 km north of the epicenter. The maximum seismic acceleration in our area and the maximum value in the entire earthquake area were 957.7 Gal (EW) recorded at NO. 051WCW station (Li et al. 2008a). NO. 051LXM and NO. 051LXT stations recorded the peak accelerations at 321.5 Gal (EW) and 342.1 Gal (NS), respectively. According to the seismic intensity map from the China Earthquake Administration (Yuan, 2008), the maximum seismic
intensity was reached at XI in the study area, which was also the largest value in the entire Wenchuan earthquake area.

3. Methodology

The base data used in this study include (1) Landsat thematic mapper (TM) images on April 25, 2003 and 2009 with a 10 m resolution, (2) a digital elevation model (DEM) with a resolution of 10 m before the earthquake, (3) a 1:200000 scale geologic map developed by the Sichuan geology bureau, and (4) a seismic intensity map of the Wenchuan earthquake.

After the Landsat TM images were geometrically corrected using ground-control points selected from the topographic map, the landslides were delineated manually as polygons by visual interpretation on the post-earthquake Landsat TM image. The landslide source area and deposition area were not distinguished. In the case of landslides adjacent to each other, they would be mapped as separate polygons as much as possible. The minimum size of the recognized landslide area was determined to be 100 m², and the landslides below this value were not considered due to inadequate resolutions of the satellite images. The points in the scarp areas of landslides were also used to display the landslide locations. A total of 2191 landslides were identified in the study area. Topographic data, including slope aspect, slope angle, and slope elevation, was calculated from the DEM to show the topographic factor effects on the landslides (Figs. 3a-c).

![Fig. 3. Co-seismic landslides and seismic intensity lines showed on topographic maps built from the DEM models with a resolution of 10 m. (a) Slope aspect map, (b) slope angle map, (c) slope elevation map, and (d) seismic intensity map.](image-url)
The landslide concentration \( LC \), defined as landslide number per square kilometer of surface area by Keefer (2000), is calculated using Eq. (1).

\[
LC(i,j) = \frac{LN^i_j}{A}
\]

(1)

Where \( i \) is the index of topographic factors, including slope angle category \((i = s)\), elevation category \((i = e)\), or slope aspect category \((i = a)\). \( j \) is from 1 to \( n \), the index in topographic category \( s, e, \) or \( a \). \( n \) is the maximum index. \( LN^i_j \) is the landslide number in category \( j \), and \( i \). \( A \) is the total area. Considering the DEM resolution and previous literature (Qi et al. 2010; Dai et al. 2011; Gorum et al. 2011), the slope aspects \((i.e., i = a)\) were divided into eight categories with 45° interval \((i.e., n = 8)\). Slope angles were classified at an interval of 10° \((i.e., i = s \) and \( n = 9)\), and slope elevations were divided into 18 categories at an interval of 300 m \((i.e., i = e \) and \( n = 18)\). For example, \( LC(a,2) = \frac{LN^2_a}{A} \), means that the landslide concentration in 10°–20° slope angle range is the ratio of the landslide number that occurred on the slopes with a slope angle range of 10°–20° to the total area.

LC can describe the distribution of landslide points, but it cannot show the topographic information in the landslide area because it uses points to represent landslides. This study defined two new parameters: landslide pixel percentage \( LPP \) and slope pixel percentage \( SPP \). The boundaries of co-seismic landslides were firstly projected on the pre-earthquake DEM. And then, the pixel number and topographic properties of the pixels in the landslide area were extracted from the DEM to show the original topographic features. The \( LPP \) is calculated by using Eq. (2).

\[
LPP(i,j) = \frac{N^i_p}{N_p}
\]

(2)

Where \( i \) is the index of topographic factors, including slope angle category \((i = s)\), elevation category \((i = e)\), or slope aspect category \((i = a)\). \( j \) is from 1 to \( n \), which is the index in topographic category \( s, e \) or \( a \). \( N^i_p \) is the pixel number in categories \( i \) and \( j \). \( N_p \) is the total pixel number involving landslides. The category number and interval are the same as that of \( LC \). For example, \( LPP(a,2) = \frac{N^2_p}{N_p} \), means the pixel
percentage in a slope angle range of 10°–20°, which is the ratio of the number of the pixels with a slope angle range of 10°–20° to the total pixel number. In addition, the SPP, which referred to the entire area, can be calculated with Eq. (3).

$$SPP(l,f) = \frac{N_{St}^{f}}{N_{S}} \quad (3)$$

Where $N_{St}^{f}$ and $N_{S}$ have the same definitions as LPP. The difference is that the data for SPP is extracted from not just the potential landslide area but the total study area. The detailed calculation process of LC, LPP, and SPP is shown in Fig. 4.

![Fig. 4: Calculation process for LN, LC, SPP, and LPP.](image)

The geological map was used to give the positions of the causative fault surface rupture. Distances of the isoseismals lines to the surface ruptures were calculated (Fig. 3d), which were referred to as faulting factors to conduct landslide correlation analysis. Two distance definitions were clarified: the distance to the epicenter ($r_e$) and the distance to the surface rupture ($r_f$). Horizontal acceleration and displacement data from NO. 051WCW station were plotted to show the motion direction of the causative fault. Since many researchers have studied the faulting behavior (e.g., Shen et al. 2009; Lin et al. 2009; Xu et al. 2009b), no further investigations on the causative fault were conducted in this study. Instead, the results regarding surface rupture, geometry, offset displacement, and fault motion direction in the previous studies were used to interpret our data to show the contribution of fault kinematic on the co-seismic landslide.
4. Results

4.1 Topographic factors

4.1.1 Slope aspect. The calculation results of LN and LC are shown in Fig. 5. It was found that the LN and LC both increase as the slope aspects change from N to SE (Fig. 5), and they decrease after reaching the peak values (488 landslides and 2.81 landslides/km²) in SE. As shown in Fig. 6, the SPP curve features an ellipse with low eccentricity. Its long axis has only 2% beyond the short axis, indicating that the pixel number in different aspect categories does not differ significantly. However, the results of LPP show that the pixel number in the aspect range from 40° to 160° accounts for 46% of the total pixel number, especially the pixel number with aspects ranging from 100° to 160° reaches 27% (Fig. 6).

![Fig. 5: LN and LC vs. slope aspect.](image)

![Fig. 6: Radar map showing the calculation results of SPP and LPP (in %). SPP value is connected with the black line, and the LPP value is associated with the red line. The white arrow indicates the thrust direction of the causative fault. Star indicates the azimuth of the epicenter.](image)

The remote images before and after the earthquake show that the landslides developed on the western side of the Min River line are more than that on the eastern side (Figs. 7a and b). Thus, the belts within 1 km on both sides of the river were additionally analyzed. LN and LC provide value that the landslides on the western side of the Min River are two times greater than on the eastern side (Fig. 8a). It should be noted that these landslides on the two sides both prefer the slopes with southeastern aspects (100° to 160°), as shown by LPP (Fig. 8c), although the dominated topographic aspects of the two sides are different as shown by the results of SPP (Fig. 8b). The eastern side of the Min River line is dominated by northwest aspects, while the western is much-facing southeast.
Fig. 7: Google Earth image of a segment of Min River line in the study area before (a) and after (b) the 2008 Wenchuan earthquake. It shows more co-seismic landslides on the slopes west side of the Min River line than that on the east side.

Fig. 8: Calculation results for LN, LC, SPP, and LPP (in %) on different sides of the Min River line. (a) LN and LC vs. slope aspect. (b) SPP and LPP for the east Min River line. (c) SPP and LPP for the west Min River line. The dark line connects the SPP value, and the red line connects the LPP value. The white arrow indicates the thrust direction of the causative fault. Star indicates the azimuth of the epicenter.
4.1.2 Slope angle. As shown in Fig. 9, LN increases with growing slope angle until it reaches a peak value (1433 landslides) at 30°–50°. Then, LN decreases rapidly with a growing slope angle. LC also shows the increasing trend with growing slope angle, and then decreases after reaching the peak point (4.69 landslides/km²) at 60°–70°. There are 85% pixels with their slope angles concentrated in the range of 20°–60°, which accounts for 25% of all pixels in the range of 30° to 55° (Fig. 10). The shape of the LPP curve is the same as that of SPP, but the LPP curve moves toward the left by approximately 10°, i.e., the landslides are concentrated on the slopes with topographic angles of 20°–45° (accounting for 25% of total pixels).

Fig. 9: LN and LC vs. slope angle.

Fig. 10: Calculation results of SPP and LPP for slope angle.

4.1.3 Elevation. The variations of LN, LC, SPP, and LPP with the elevations are shown in Figs. 11 and 12. The curves of LN and LC show that the landslides concentrate on the slopes with elevations of 1200 and 2400 m (Fig. 11). They reach their peak value at the height of 2100 m. The pixels in the area are dominated by the elevations from 1900 m to 2800 m, accounting for 45% of the total pixel number as shown by the curve of SPP (Fig. 12). However, the pixels in the potential landslide area accounting for 45% of the total pixel number are distributed in the elevation range of 1500–2400 m, as shown by the curve of LPP.

Fig. 11: LN and LC vs. elevation.

Fig. 12: Calculation results of SPP and LPP for slope elevation.

4.2 Faulting factors
4.2.1 Distance to surface rupture. The surface rupture exposed in our study area features a length of 16 km,
and approximately 93% of the co-seismic landslides occurred on the hanging wall of the fault surface rupture (Fig. 13). Four hundred sixty-two landslides occurred within the distance to surface rupture of 5 km (0–5 km zone), corresponding to $LC$ of 5.1 landslides/km$^2$. $LN$ and $LC$ both decrease as the distances to surface rupture increase. They decrease by half for the distance to surface rupture of 5–10 km, and they are around 30% of the values for the 0–5 km zone when focusing on the 35–40 km zone.

The seismic intensity categories of VIII, IX, X, and XI were distributed in our study area. The maximum seismic intensity was developed on the hanging wall. These isoseismals lines are subparallel to each other, and they are parallel to the surface rupture. The XI, X, IX and VIII zone distances are 0–20 km, 20–25 km, 25–35 km, and 35–45 km, respectively (Fig. 14). Figure 3d shows that the XI zone and VIII area are the largest and smallest, accordingly in our study area. The value of $LN$ decreases with decreasing seismic intensity. The value of $LC$ for the X zone is the smallest because its area is smaller than the other zones.

Figures 15a and b show the concentric bands extending outward from the epicenter ($r_e$) and the bands extending outward from the surface rupture ($r_f$), respectively. Figure 16a shows the variation in $LC$ with $r_e$ by using our data and the previous data in the study of Dai et al. (2011). Both data show a synthetic decrease in $LC$ as the distance to the epicenter increases. The results of $LC$ calculated from our data, and the previous data in Gorum et al.’s (2011) study both show a strong inverse correlation to $r_f$, which can be described with exponential regression equations (Fig. 16b). But it should be noted that the decreasing ratio of our data is slower than that of the data of Gorum et al. (2011), and the value is bigger than that of Gorum et al. (2011) when $r_f$ is larger than 30 km, as shown in Fig. 16b.
Fig. 15: (a) Concentric bands extending outward from the epicenter. (b) Elliptical bands extending outward from the surface rupture.

Fig. 16: (a) $LC$ vs. distance from the epicenter ($r_e$). (b) $LC$ vs. distance from surface rupture ($r_f$). The dotted line and hollow points are data from Gorum et al. (2011) and Dai et al. (2011). The solid line and solid points are the data from this study.

4.2.2 Moving direction of the causative fault. Figure 17 shows the variations of the records of NO. 051WCW in E-W direction with N-S direction. The acceleration data (Fig. 17a) and displacement data (Fig. 17b) are characterized as ellipse shapes. The long arises of the ellipses are almost parallel to each other in S 40° E-S 45° E direction, which indicates the moving direction of the causative fault. This direction is also subparallel to the dominated topographic aspect in the study area, as shown in Fig. 6.
Fig. 17: Seismic records of station No. 051WCW located in the study area: (a) E-W acceleration vs. N-S acceleration, (b) E-W displacement vs. N-S displacement.

5. Discussion

Generally, there are two types of surface rupture formed by an earthquake. One type is short or concealed rupture, such as the 1994 Northridge earthquake, where the hypocenter fracture did not extend to the ground surface (Todorovska and Trifunac 1997). This earthquake resulted in the isoseismal characterized by concentric circles with the epicenter as the center, and the co-seismic landslides were concentrated in a roughly concentric area (Budimir et al., 2015). The other type is prolonged rupture, such as the 2008 Wenchuan earthquake featuring a surface rupture of 270 km in length. The co-seismic landslides were subparallel clustering with respect to the surface rupture (Gorum et al., 2014). Due to the significant difference in co-seismic landslide distribution patterns of the two types, the definition of distance (to the surface rupture or epicenter) is critical before conducting correlation analysis. The use of $r_f$ can lead to a good correlation when the surface rupture of an earthquake is large in lengths, such as the cases studied by Khazai and Sitar (2003) and Gorum et al. (2014). In contrast, $r_e$ should be utilized when surface rupture is short or concealed, such as the case studied by Budimir et al. (2015). Although the surface rupture exposed in our study area is only a 16 km segment, the parallel distribution pattern of the co-seismic landslides is still apparent, and we get a better correlation analysis by using $r_f$ than $r_e$.

Our study area obtained larger LCs on the hanging wall than the whole earthquake area when $r_f > 30$ km. The result is assumed to be related to the fault geometry-dependent seismic energy release. As for a thrust fault with significant surface rupture in length, $L$ (L1 or L2) and $R$ (R1 or R2) are defined as the distance of a site on the hanging wall (Site 1) or the footwall (Site 2) to the surface rupture and the hypocenter, respectively. If site 1 and site 2 have the same distance to the surface rupture (i.e., $L_1 = L_2$), the distance between site 1 on the hanging wall and the hypocenter (R1) is closer than that between site 2 on the footwall (R2) (Fig. 18a). It has been proposed that this more immediate position feature results in more vigorous shaking on the hanging wall than on the footwall (Li and Xie 2007; Grimaz and Malisan 2014). Besides, one had a steep fault plane (Fig. 18b) for two thrust faults, and the other had a moderate fault plane (Fig. 18c). Site 1 locates on the hanging wall of the steep fault, while site 2 locates on the hanging wall of the moderate fault. If the two sites have the same distance to their hypocenter (i.e., $R_1 = R_2$), site 2 is farther away from its surface rupture than site 1 (i.e., $L_2 > L_1$). This farther position feature would result in a wider belt for triggering a co-seismic landslide on the hanging wall of the moderate fault than that of the steep fault. It has been concluded that the causative fault plane dip southern segment is gentler than the northeast segment of the causative fault (Shen et al., 2009). Thus, the landslides occurred in a broader belt on the hanging wall in...
our area with a moderate fault plan than the average width in the total earthquake area.

![Diagram of thrust fault and hanging wall effect](image)

**Fig. 18:** Hanging wall effects of thrust fault (Li and Xie, 2007). L1 or L2 is the distance to the surface rupture, and R1 or R2 is the distance to the hypocenter. (a) For a thrust fault, site 1 and site 2 are located on the hanging wall and footwall, respectively. R1 will be shorter than R2 when L1 is equal to L2. (b) Site 1 is located on the hanging wall of thrust fault 1, which has a steep angle fault plane. (b) Site 2 is located on the hanging wall of thrust fault 2 with a moderate angle fault plane. L1 will be smaller than L2 when R1 is equal to R2.

![Diagram of point rupture and directivity effects](image)

**Fig. 19:** (a) Point rupture without directivity effects. (b) Forward directivity effect occurred when rupture speed \(v_r\) is lower than S-wave speed \(c_s\) (modified from Chioccarelli (2010)). Black arrows indicate the direction of fault rupture propagation.

The rupture of an earthquake begins at the hypocenter with a spreading shear wave (S-wave) (Fig. 19a). The rupture spreads at a velocity \(v_r\) that is approximately equal to the S-wave velocity \(c_s\). If \(v_r\) is close to but lower than \(c_s\), the shear wavefronts are concentrated in the forward direction and separated in the backward direction (Fig. 19b). This phenomenon is called the forward direction effect in the study of Somerville et al. (1997). It has been shown that the forward direction effect can lead to larger amplitudes and higher frequencies in the forward direction (Bolt and Abrahamson 2003; Dunham and Bhat 2008; Grimaz and Malisan 2014). Meanwhile, it leads the seismic energy release to be more significant in the direction vertical to fault strike (Somerville et al., 2002). In addition, thrusting generates permanent ground displacement in the direction normal to surface rupture. This permanent ground motion can result in enlarged seismic movement in subparallel direction and sub perpendicular to the fault plane (FP and FN) (Fig. 20). The enlarged seismic motion in subparallel direction was called the fliing step effect in the study of Somerville et al. (1997). Therefore, it can be reasonably inferred that FP and FN can enhance the seismic ground motion and slope failure on the hanging (Fig. 21).

![Sketch of ground motion in fault normal (FP) and subparallel (FN) directions](image)

**Fig. 20:** Sketch in vertical cross-section showing ground motion in fault normal (FP) and subparallel (FN) directions in the case of dip-slip faults (modified from Somerville (2002) and Chioccarelli (2010)).
Fig. 21: Sketch showing the seismic motion on the hanging wall of the causative fault. The enhanced seismic shaking causes slopes to fail in the direction sub perpendicular and subparallel to the FP.

For the Wenchuan earthquake, provided fault length of 270 km and fault rupture duration of 120 s (Xu et al. 2009a), the calculated $v_r$ is about 2.3 km/s. The value is smaller than $c_s$, which is 3.75 km/s on average in the Wenchuan earthquake area assumed by Xu et al. (2009c). And the thrust component of the causative fault in our study area is reported as large as 4.5 m (Xu et al. 2009b). These suggest that the above-mentioned front direction effect and fling step effect could be generated in our study area to vastly enhance the probability of co-seismic landslides on the slopes with topographical aspects being the same as the thrust direction (Fig. 6). If the topography of an area is dominated by the slopes with aspects being subparallel to fault thrust direction, there will be a much greater possibility for the domination slopes to fail during an earthquake. The dominated topographic aspects on the two sides of a river are generally different. If the river line is subparallel to the surface rupture of the thrust fault, such as the Min River, this means that the topographic aspects of one rive side are close to the fault thrust direction. As a result, co-seismic landslides will be more concentrated on this side during the earthquake.

6. Conclusions
The 2008 Wenchuan earthquake triggered a huge number of landslides. In this study, 2191 landslides were interpreted in the watershed of Min River near the epicenter with a length of 80 km and an area of approximately 2100 km². These landslides were concentrated more on the hanging wall than that focused on the footwall, and they were distributed in a wider belt in our study area than in the total earthquake area. Meanwhile, they are enormously concentrated on the slopes, with topographical elements subparallel to the thrusting direction, which is more significant on the western side of the Min River. The enlarged belt for co-seismic landslides was caused by the moderate dip angle of the FP. The topographic factors and thrusting direction have concentrated the distribution of the landslide failure directions. The study confirmed the contribution of topographic aspects and dipped angle of the FP on the distribution of co-seismic landslides.

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