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Distribution Characteristics of Geohazards Induced by the Lushan Earthquake and Their Comparisons with the Wenchuan Earthquake

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ABSTRACT: The Lushan Earthquake induced a large number of geohazards. They are widely distributed and caused serious damages. The basic characteristics, formation mechanisms and typical cases of geohazards induced by Lushan Earthquake are described, and compares to the relationships of Lushan and Wenchuan earthquakes between geohazards and earthquake magnitude, geomorphology, slope angle, elevation and seismic intensity in the most affected areas in the article. (1) The numbers and volumes of landslides and rockslides differ significantly between the two earthquakes due to their differing magnitudes. The Lushan Earthquake is associated with fewer and smaller-magnitude geohazards, within the immediate area, which mainly consist of small-and medium-sized shallow landslides and rockslides, and occur on steep slopes and mountain valleys. The largest landslide induced by Lushan Earthquake is the Gangoutou Landslide debris flow with a residual volume of about 2.48×10^6 m^3. The most dangerous debris flow is at Lengmugou gulley in Baoxing County, which has similar geomorphological features and disaster modes as a previous disaster in Zhouqu County, Gansu Province. (2) Geohazards induced by the Lushan Earthquake show four mechanisms: cracking-rockslides-collision-scraping and then debris flows, cracking-rockslides, vibration-rainfall-rockslides-landslide and then debris flow, vibration-throwing or scrolling. (3) There are significant similarities and differences between the geohazards induced by these two earthquakes. The types of geohazards are the same but the volume, quantity and other factors differ: geohazards are concentrated on slope angles of 10°–40° in the Lushan Earthquake area, especially within 10°–20°, and at absolute elevation of 500–2 000 m above sea level (a.s.l.). Geohazards within the Wenchuan Earthquake area are concentrated on steeper slope angles of 30°–40° at higher absolute elevations of 1 500–2 000 m.s.l..
KEY WORDS: Lushan Earthquake, Wenchuan Earthquake, geohazards, basic characteristics, comparison.

0 INTRODUCTION

At 8:02 (Beijing time) on 20 April 2013, a catastrophic earthquake of surface wave magnitude M_S 7.0 occurred beneath the steep eastern margin of the Tibetan Plateau, adjacent to the Sichuan Basin, China. This earthquake was named Lushan Earthquake after its epicenter (30.3°N, 103.0°E), located at the town of Longmen, Lushan County, in Sichuan Province. The area lies on the Longmenshan fault and is characterized by elevations of up to 4 984 m of Jiudingshan above sea level (a.s.l.). The focal depth was 13 km with epicentral intensity degrees was IX, and the fault rupture caused by the earthquake was about 35–40 km long (China Earthquake Administration, 2013). The Wenchuan Earthquake of 12 May 2008 was centered on Yingxiu Town (China Cartographic Publishing House, 2008) and epicenters distance of the two events is approximately 85 km. Following the 2013 earthquake, as of 6 June 2013, the China Seismic Information Center (CSI, 2013) recorded 8 791 aftershocks, mainly spread along the Shuangshi-Dachuan fault zone, of which 134 were of magnitude ≥3.0. The earthquake's shallow epicenter, large magnitude and high intensity resulted in a large number of casualties and induced many secondary disasters such as landslides, rock avalanches, debris flows, unstable slopes, etc.. By 12 May 2013 the earthquake had claimed 196 people (21 people remain missing) and injured 13 484 people in Yucheng District, Lushan County and Baoxing County. At the same time, the Land Resources Bureau of Ya'an (2013) reported 2 515 landslides, mudslides and other geological disasters and 466 unstable slopes. In comparison, the Wenchuan Earthquake that occurred five years previously (12 May 2008) caused a surface rupture zone 275 km long by 50–70 km wide (China Seismic Information Center, 2013; Sun et al., 2010; Hao et al., 2009; Jin et al., 2009; Xu et al., 2009; Burchfiel et al., 2008; Fu et al., 2008; Li et al., 2008)

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and induced more than 190 000 secondary geohazards (Xu et al., 2013a, b, c).

The Lushan and Wenchuan earthquakes occurred on the Y-shaped Longmenshan fault located on the eastern edge of the Tibetan Plateau. The fault zone is also located in the binding position between the Songpan-Ganzi orogenic belt and the Yangtze block (Lin et al., 2009; Xu et al., 1992) of about 500 km length and 70 km in width, which comprises three major faults: the Longmenshan behind fault, central fault and front boundary fault. The region therefore has one of the highest incidences of earthquakes and seismic activity (Deng, 1996). The Longmen Mountain area is characterized by intensive deep valleies, high rainfall and steep slope and is one of the most geo-disaster-prone areas of China (Fig. 1). The present study analyzes the characteristics and formation mechanisms of geohazards induced by the Lushan Earthquake. Then, based on the topographic elevation, slope angle and seismic intensity, a comparison is made between the numbers and volumes of geohazards induced by the Wenchuan Earthquake.

1 CHARACTERISTICS OF GEOHAZARDS OF LUSHAN EARTHQUAKE

1.1 General Characteristics

Before the Lushan Earthquake, there were 256 geohazards and unstable slopes in Lushan County, Baoxing County, Tianquan County and the Yucheng District of Ya'an. A survey of these geological disasters showed that rainfall was the main trigger. After the Lushan Earthquake, 2 515 landslides, collapses and debris flows and 466 unstable slopes (total 2 981 geological disasters) were recorded in the same region (Fig. 2a), of which most were landslides (48% of the total), followed by collapses (24%). Based on the residual volume of geological disasters, almost all (97.6% of the total) were small- and medium-sized (Fig. 2b). Comparing geohazards before and after the earthquake, the number of landslides, rockfalls, debris flows and unstable slopes are 6, 24, 13 and 17 times greater than in the pre-earthquake period, respectively. Furthermore, rockfalls showed the greatest relative increase in frequency following the earthquake. Overall, the earthquake induced an

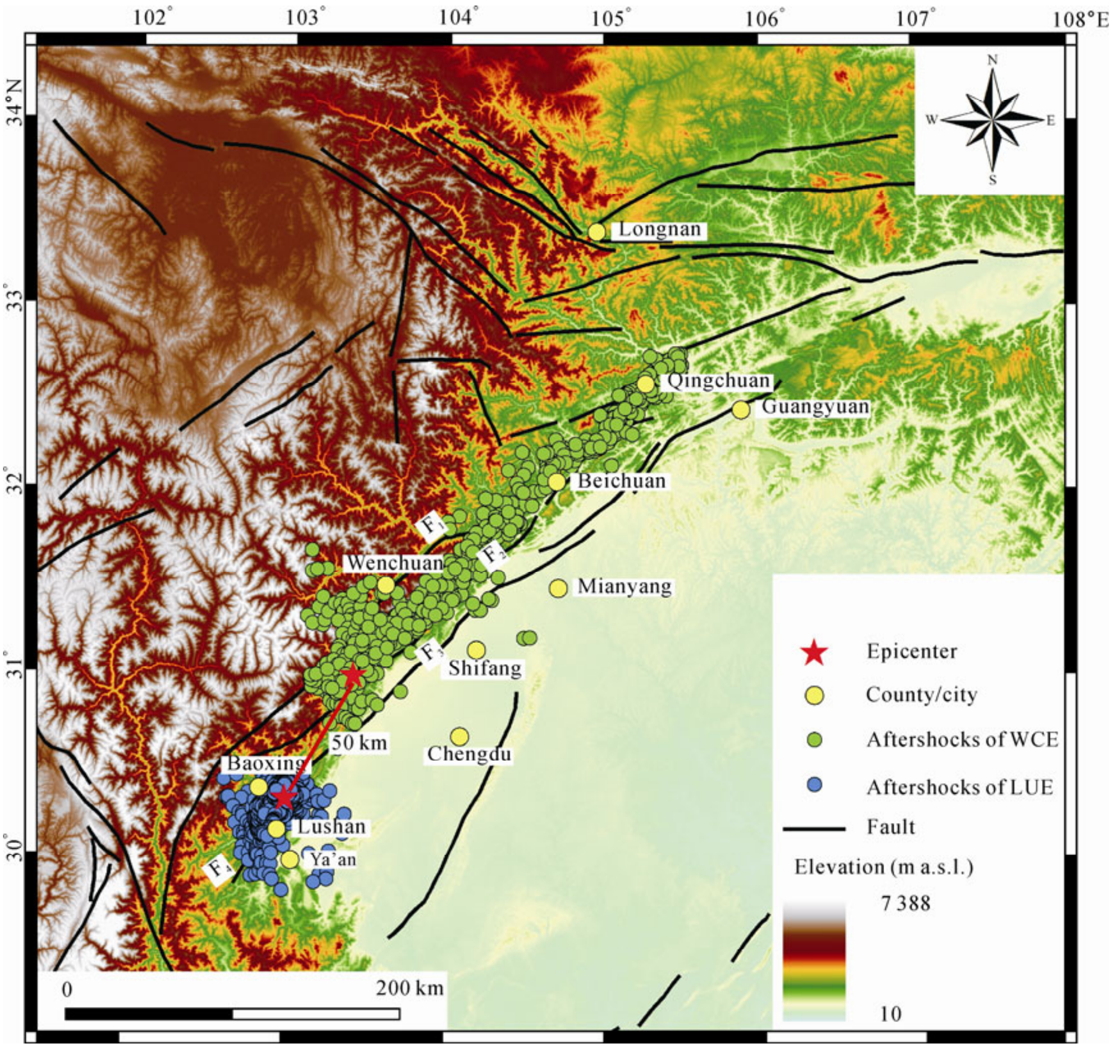

Figure 1. Regional tectonic maps of Longmenshan fault and aftershocks of the Lushan and Wenchuan earthquakes. F1. Wenchuan-Maoxian fault; F2. Beichuan-Yingxiu fault; F3. Anxian-Guanxian fault; F4. Dachuan-Shuangshi fault.

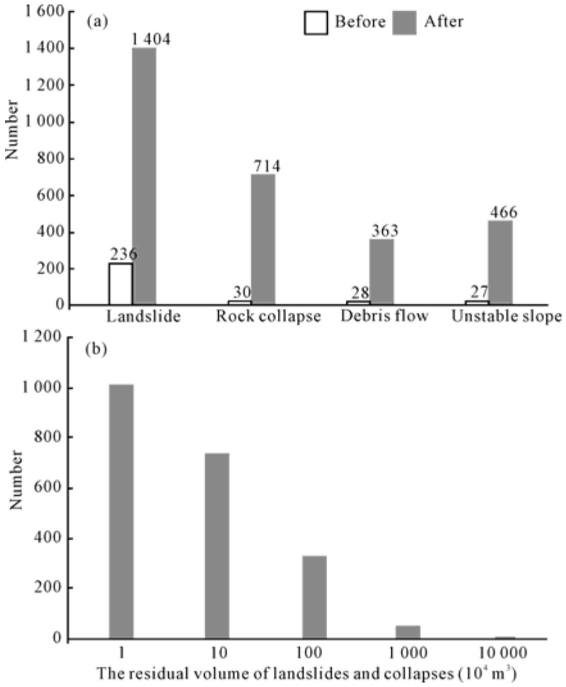

Figure 2. Characteristics of geological disasters induced by the Lushan Earthquake. (a) Types before/after earthquake; (b) residual volumes after earthquake.

11.6-fold increase in secondary geohazards compared with the number of pre-earthquake events triggered by rainfall. Therefore, the earthquake has a significant priming effect on landslides, avalanches and other geohazards.

Field investigation of geohazards and interpretation of high-resolution remote sensing images and photographs (Sato and Harp, 2009) revealed remarkable differences between the pre- and post-earthquake situations. For example, most of the geohazards induced by the Lushan earthquake are shallow landslides, followed by rockslides, then debris flow and rolling boulders. The spatial distribution flat patterns are expressed NW by banded. For example, geohazards are focused north of the Yuxi River and Taiping River, and from there extended to the town of Taiping. The remote sensing images show that 86 landslides and rockfalls occurred near the Taiping and Yuxi rivers around the town of Baosheng. The silting materials of landslides are mainly Quaternary alluvial materials and weathered rock fall, which depth are about 0.5–2 m and expressed to 'hill peeling', the accumulations provide source material for debris flows. Another notable feature is the large number of rockslides and disasters caused by dislodged stones of approximately 3 m diameter. Such stones were reported to have rolled down slopes of 70 m height and to have damaged the oils storage facility at S210 Baoxing County.

Meanwhile, images of 0.16 m resolution obtained from an unmanned aerial vehicle (UAV) indicated that some landslides and rock avalanches had blocked roads to Baosheng, seriously damaged much vegetation and many trees, an earthquake-induced landslide had formed landslide dams and inhibited drainage in the Jinxi Gorge, and so on.

Another area seriously affected by geohazards is on the right bank of the Lingguan River in Baoxing County. Image interpretation indicated at least 70 landslides and collapses throughout Southeast Baoxing County, which blocked roads and rivers, and posed risks to residents. For example, Fig. 3 shows two clusters of landslides near the village of Xueshan in Baoxing County. The area marked 'A' (Fig. 3) indicates the largest landslide mass induced by the Lushan Earthquake, located on the right bank of the Lingguan River and north of Xueshan (102°48′E, 30°22′N). The landslide is composed mainly of Quaternary sedimentary soil and the depth is very shallow. As seen in Fig. 3a, the landslide moved rapidly from an elevation of about 1 310 m a.s.l. for a distance of 190 m to the mouth of the valley, which is at an elevation of 1 195 m a.s.l.. The relative elevation is therefore 115 m, the slope angle of the landslide mass is 31°, the landslide mass covers an area of 14 500 m^2 and the residual mass volume is approximately 60 000 m^3. Figure 3b shows that many types of vegetation were destroyed by collapses along the valley.

The geohazards triggered by the Lushan earthquake are mainly distributed within the region of earthquake intensity IX, VIII and VII. Within that region, closer to the epicenter, higher earthquake intensity is associated with increased numbers of landslides, casualties and damage to property. Interpretation of remote sensing data showed that geohazards are mainly distributed in Lushan, Baoxing and Tianquan counties, and in the Yucheng district of Ya'an City and other areas. These characteristics are similar to those triggered by the Wenchuan Earthquake of 12 May 2008, reflecting the close relationship between earthquake epicenter, intensity and numbers of geohazards (Fig. 4).

1.2 Main types of Geohazards of Lushan Earthquake

Field investigation showed that geohazards induced by the Lushan Earthquake are mainly landslide, debris flow, rock collapses and rolling boulders according to their material components and behavior characteristics (Xu et al., 2013d; Yin et al., 2009). Collapses and landslides provided much source material for subsequent debris flows in gullies.

1.2.1 Landslides

In the Lushan earthquake area, landslides are relatively few and smaller in scale than in areas affected by the Wenchuan Earthquake. Typical landslides induced by the Lushan Earthquake is Gangoutou Landslide, Tianquan County, where lies in the Wenchuan earthquake-affected zone after 2008, the mountains cracking, combined on this earthquake shocks, the unstable slopes are failing under the gravity. Because of the high mountain elevation, there is an obvious effect of terrain slope in amplifying landslides. Therefore, this mechanism of landslide formation is expressed as cracking-rockslides-collision-scraping followed by debris flows (Fig. 5a), thereby termed a landslide-debris-flow.

1.2.2 Rock collapses

Rock collapses occur in various forms and are small in scale. Most occur in the high position of mountains, strongly incised valleys, steeply sloping areas and highway cuttings. They usually occur in areas where rock is strongly weathered and obviously broken, mainly in sandstone, conglomerate and

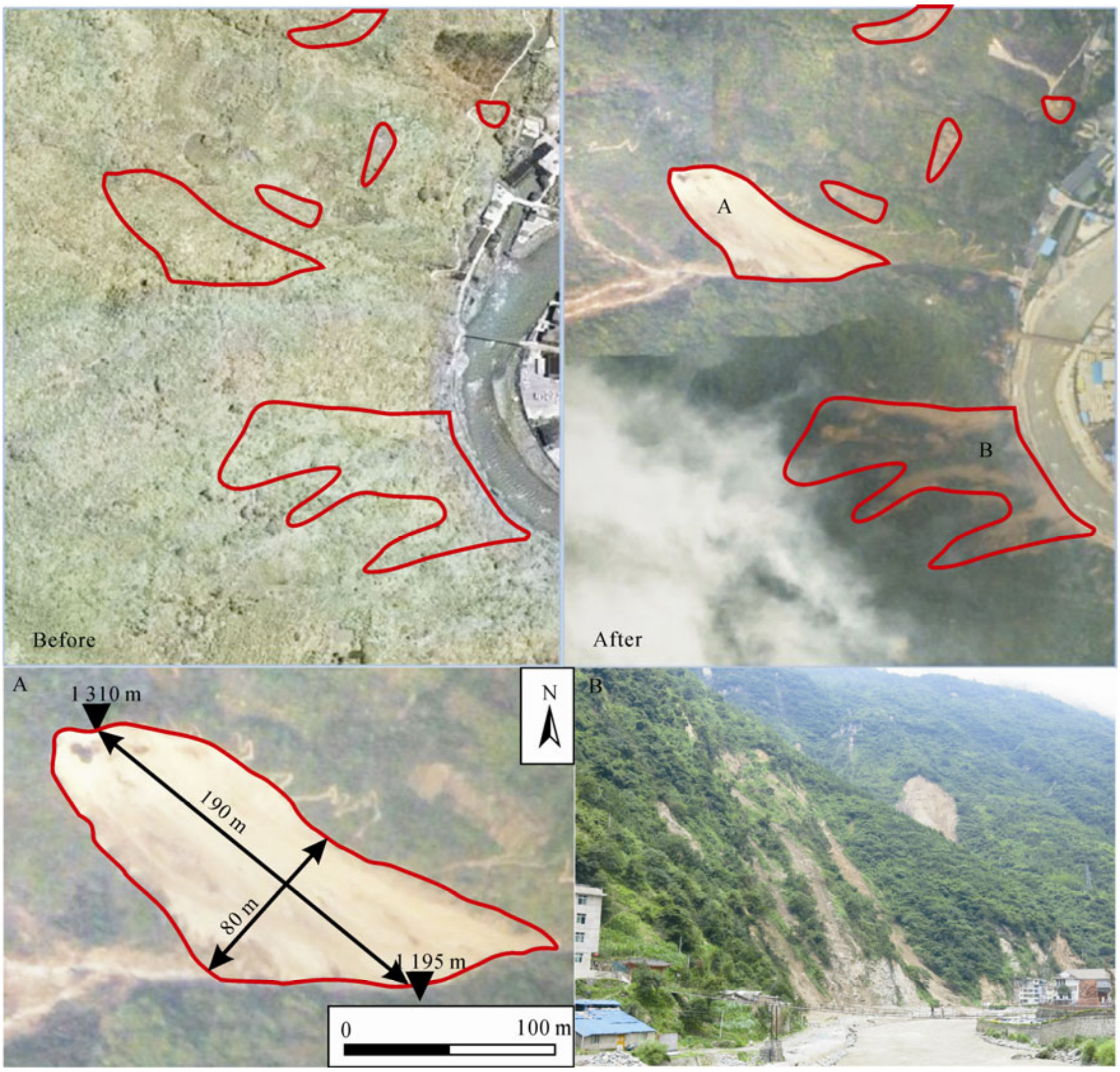

Figure 3. Remote Sensing (RS) and photographs of landslide and collapse clusters in Baoxing County. The RS images from www.scgis.net/yadb. The solid red line indicates the boundary of landslides.

limestone lithology. Under the effect of an earthquake, some loose rocks become increasingly cracked and fragmented, leading to instability. Typical earthquake-induced landslides are mainly located along the route of national highway 210 and the reaches of the Baoxing River (Fig. 5b).

1.2.3 Debris flow

After the earthquake, many loose landslides and rock masses accumulated on the circulation area of debris flow that has added new material source; the latter contributes to the formation of subsequent storm debris flows. Field investigations found that the Lengmugou gully debris flow in Baoxing County is most representative of debris flows induced by the Lushan Earthquake. On both sides of the gully, six large-scale landslides or rock collapses are found, which increase the source materials for secondary debris flows (Fig. 5c).

1.2.4 Large dislodged boulders

Some large boulders in high mountain areas were further destabilized or dislodged by the earthquake, thereby rolling to the slope toe (the rock blocks, similar to spherical, smaller seismic vertical acceleration area) or parabolic throwing motion (rock blocks irregular, larger seismic vertical acceleration area). Some large rocks have greater impact, often further fracturing the slope beneath buildings, roads and pavements. Take, for example, a large boulder of poorly-cemented calcareous conglomerate with approximate diameter 5–20 cm and volume 6 m^3. The rock originated at 911 masl on the mountain ridge, rolled 98 m vertically downslope, smashed through the roof of the oil station depot and hit the ground (Fig. 5d).

1.3 Typical Cases

During July 2013, the authors surveyed the area and found that the largest landslide debris flow induced by the Lushan Earthquake was located in Damiao Village, Tianquan County. The largest debris flow gulley is the Lengmugou gulley, along a branch of the Baoxing River; these two geohazards present great risks to settlements located on the alluvial fans. The characteristics of the Gangoutou Landslide debris flow and the Lengmugou gulley are shown in Table 1.

Table 1 Basic characteristics of typical geohazards triggered by Lushan Earthquake

No.	Name of geo-disaster	Type	Location	Coordinates	Volume ($\times10^4$ m^3)
LS-01	Gangoutou Landslide	Landslide debris flow	Laochang Town	30°10′17″N, 102°45′58″E	248
LS-02	Lengmugou gulley debris flow	Debris flow	Muping Town	30°22′19″N, 102°49′31″E	280

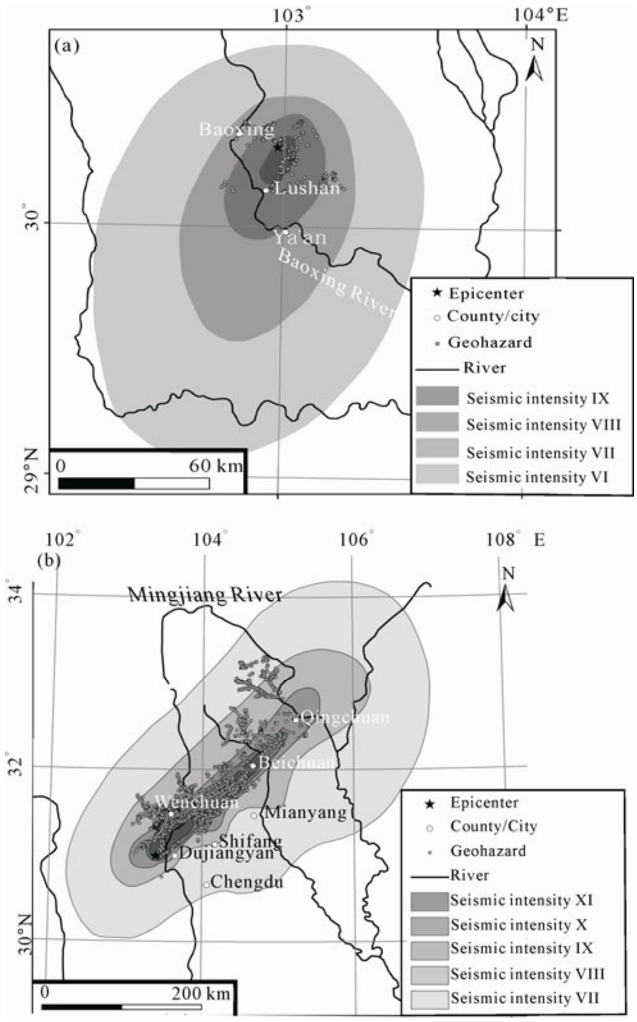

Figure 4. Relationship between earthquake intensity and landslides. (a) Lushan Earthquake area, F1. Dachuan-Shuangshi fault; (b) Wenchuan Earthquake area, F1. Wenchuan-Maoxian fault; F2. Beichuan-Yingxiu fault; F3. Anxian-Guanxian fault.

1.3.1 Gangoutou landslide-debris-flow

Gangoutou landslide-debris-flow is located at Tangjia gully in Laochang, Tianquan County at the north end of the Dachuan-Shuangshi fault. During the sliding process, the landslide-debris-flow branched into two parts according to the terrain: the back-trailing elevation of the highest point is 2 105 m and the landslide-trailing slope is 60°. In the process of sliding, the landslide mass was subject to collisions and scraping against materials on the mountains, then divided into two parts along the Tangjiagou gully and Chunjianwo gully and converged into a landslide-debris-flow that accumulated at the mouth of the main Tangjiagou gully (Fig. 6). The elevation at this point is 1 161 m, and therefore the height difference between the front edge and back trailing is 944 m. From pre-earthquake remote sensing images (source: Google), two deep ravines are clearly visible. During the Lushan Earthquake, the landslide-debris-flow presented as a "^-shaped" formation on planar maps. These two gullies have different length and width: Tangjiagou gully on the north is about 1 500 m long with average width about 110 m, and the main sliding direction is 310°; Chunjianwo gully on the south is about 780 m long with average width about 64 m. Overall, the average thickness of accumulate material is 8 m, the landslide debris flow area is approximately 0.31 km^2 and has a total volume of 2.48×10^6 m^3.

Field investigation revealed significant destruction of forests along the valley. The areas adjacent to the landslide consist of Permian mudstone intercalated with limestone, with a Quaternary alluvial surface layer. The landslide-debris-flow mass contains many rock blocks of various sizes, mainly within the range 10 cm to 5 m, which present a great risk to local settlements downstream in the event that the landslide debris re-flows as a result of heavy rainfall.

1.3.2 Lengmugou gulley debris flow

In east Baoxing County there are two debris flows in Lengmugou gully and Jiaochang gully. The Lengmugou gully debris flow is located in the town of Muping, and was the site of previous debris flows in 1918, 1936, 1966, 1998 and 2012. After the Lushan Earthquake, it is described as an area of category VI seismic intensity. Because the Lengmugou debris flow is largest, it was selected as an example of the influence of the Lushan Earthquake. The Lengmugou gully runs east to west and consists of six tributaries and the main gully; the latter is about 5.35 km long with an average slope of 19°, but the slope of the forming region reaches 50°. On both sides of the mountain slope about 40°–60°, locally up to 70°; the top elevation of the back trailing edge is 2 850 m while the elevation of the front edge of the alluvial fan is 1 020 m (relative elevation of 1 830 m) and the entire watershed covers an area of about 12.4 km^2. Prior to the earthquake, the total amount of source material was about 2.8×10^6 m^3; after the earthquake, there were large increases in the number of high-elevation landslides, fractured mountainous areas, high rock-collapses and rolling boulders—the residual mass of which afforded much loose material for subsequent debris flows. There are many buildings located in front of the debris flow fan, which are therefore at direct risk of further debris flows as a result of heavy rainfall. A notable example was the Zhouqu debris flow of 8 August 2010, which destroyed the village of Yueyuan in Gansu Province, killing nearly 1 800 people. The Zhouqu debris flow was located in the area affected by the Wenchuan Earthquake of 12 May 2008, and large quantities of loose materials generated by the earthquake flowed to front residential areas by the heavy rainfall interval of 2 years. If comparing the topographic characteristics of these two sites, pregnancy disaster types, there are many similarities between the Lengmugou and Sanyanyu gullies (Fig. 7); both have two potentially dangerous debris flow

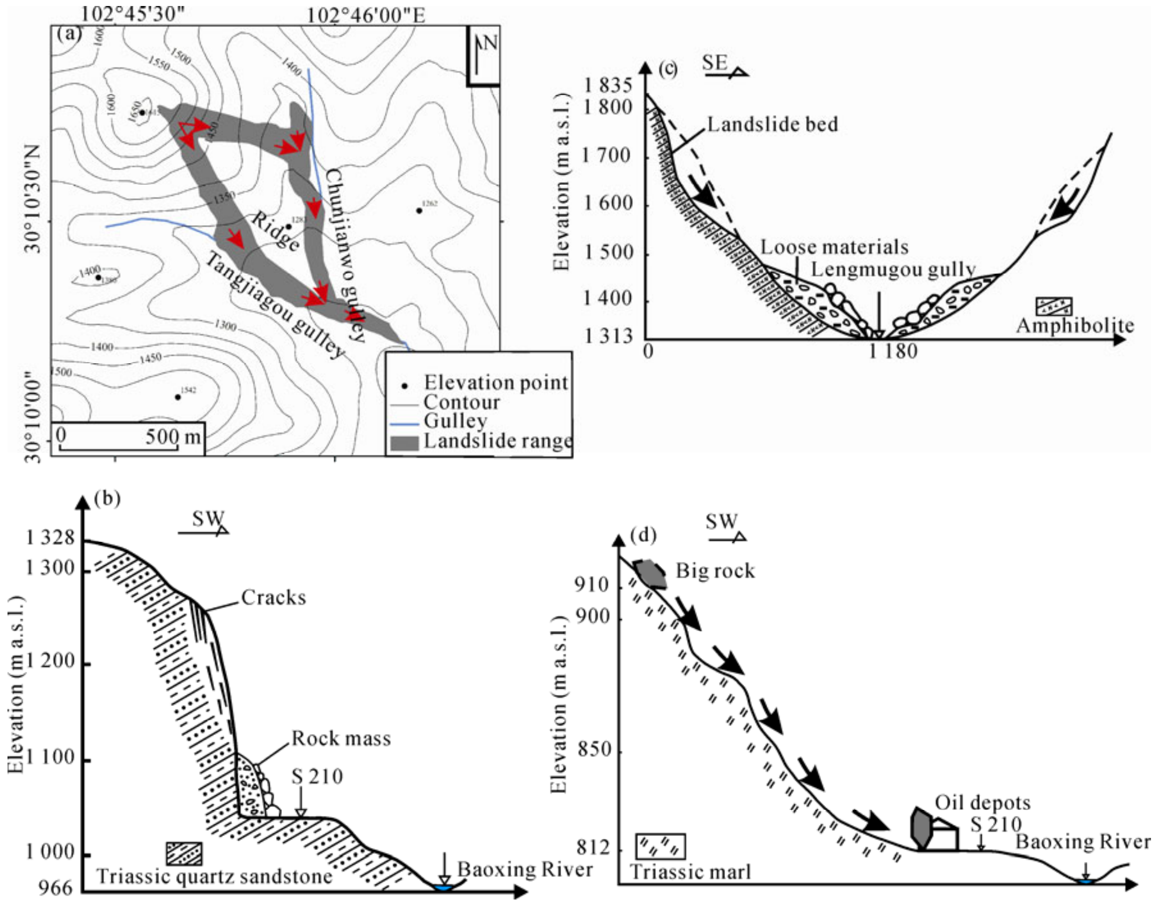

Figure 5. Formation mechanisms of geohazards induced by Lushan Earthquake.

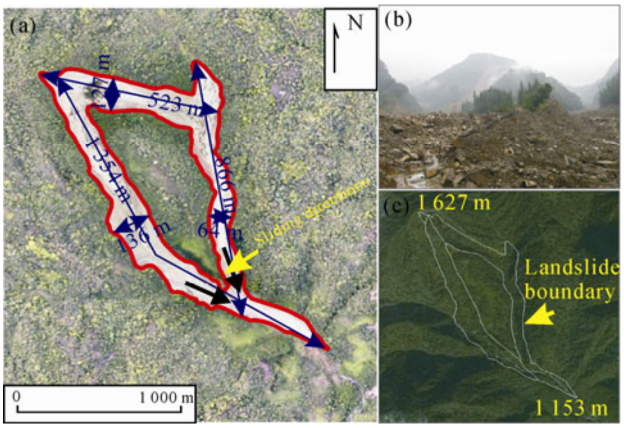

Figure 6. Remote sensing images and photographs of Gangoutou Landslide debris flows. (a) Post-earthquake; (b) trailing edge and deposit zone; (c) pre-earthquake, Google image.

gullies that present great risks to local neighborhoods. Therefore, lessons should be learned from the Zhouqu debris flow to prevent the reoccurrence of similar disasters.

2 COMPARISON OF CHARACTERISTICS OF LUSHAN AND WENCHUAN EARTHQUAKES

The M_S 7.0 Lushan and M_S 8.0 Wenchuan earthquakes both occurred on the Longmenshan central fault. The epicenter of the M_S 8.0 Wenchuan Earthquake was the town of Yingxiu located in the northern part of the belt and controlled by the Beichuan-Yingxiu fault (Li Q et al., 2009; Li H B et al., 2008). The distribution characteristics of aftershocks and thrust-fault rupture surfaces are NE-trending (Gorum et al., 2011), but the epicenter of the M_S 7.0 Lushan Earthquake was in the southern Longmenshan belt and was controlled by the Dachuan-Shuangshi belt. The distribution of Lushan aftershocks is indicated by circles. The distance between the two epicenters is approximately 80 km. The basic characteristics of the Wenchuan and Lushan earthquakes are listed in Table 2.

Geohazards triggered by the Lushan Earthquake were mainly concentrated within Lushan County, Baoxing County and other two counties (districts), whereas those associated with the Wenchuan Earthquake are mainly concentrated within 12 counties (cities) of Sichuan Province.

Based on the investigation of China Geological Survey and the precipitation record of China Meteorological Administration: Prior to the Wenchuan Earthquake there were approximately 1 061 geohazards in the 12 counties/cities most at risk of earthquake (such as Wenchuan and Beichuan counties) along the Longmenshan belt in Sichuan Province; after the earthquake, the numbers rapidly increased to 5 335, most which were in Wenchuan County (up to 1 357 events), followed by Mianzhu and Beichuan counties (961 and 726 events respectively) (Wang Y F et al., 2012; Wang F W et al., 2009). Therefore, the number of geohazards sites in the Wenchuan area

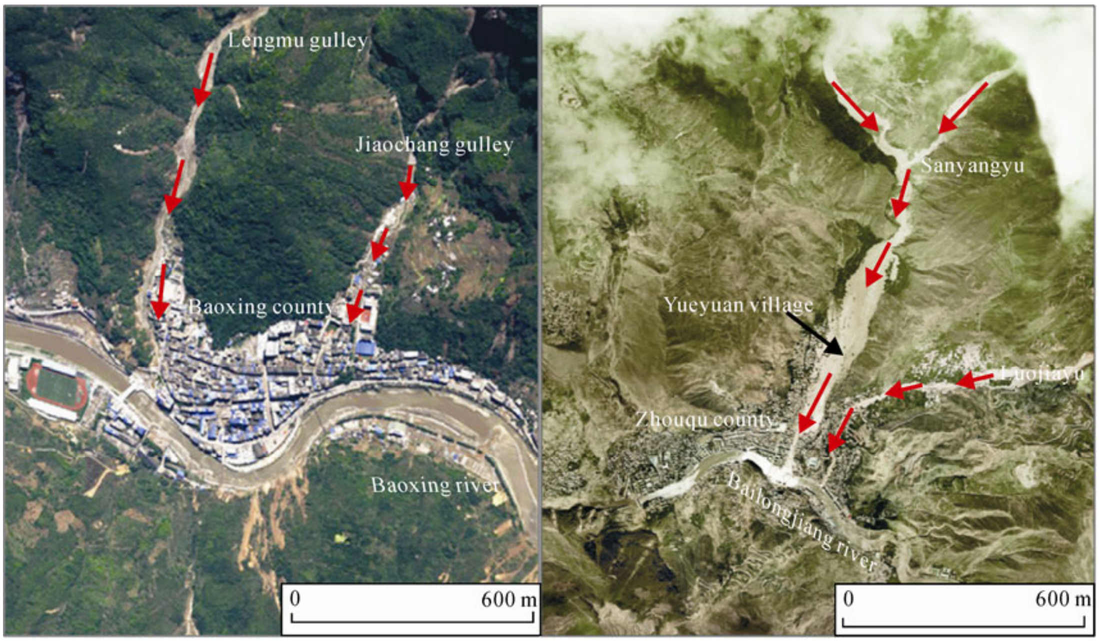

Figure 7. Remote sensing image of Lengmugou gully and Jiaochanggou gully (a) after earthquake and Zhouqu City (b) after debris flows (the red arrows indicate flow direction).

Table 2 Some basic characteristics of Lushan and Wenchuan earthquakes

Name	M_S	Focal depth (km)	Epicenter intensity	Epicenter	Fatalities	Controlling fault
Lushan	7.0	13	IX	Longmen town	196	Beichuan-Yinxiu
Wenchuan	8.0	14	XI	Yinxiu town	69 227	Dachuan-Shuangshi

induced by earthquake is five times higher than those triggered by rainfall, and up to 18 times higher in the Lushan Earthquake zone. This demonstrates that these two earthquakes had significantly different effects on the characteristics of earthquake-triggered geohazards, while aftershocks are amplified at peaks and ridges in mountainous areas, resulting in numerous rock falls (Yin et al., 2011; Huang and Li, 2009).

There are obvious similarities and differences in the geohazards induced by the Lushan and Wenchuan earthquakes. The similarities include the types of geohazards: collapses, landslides, debris flow, unstable slopes, rolling boulders, landslide lakes, etc.. The differences include residual volume, quantity, movement characteristics because of magnitude, patterns of seismogenic fault activity, surface rupture and terrain slope.

Lushan Earthquake: shallow M_S 7.0 earthquake with a focal depth of 13 km; maximum intensity at the epicenter of IX degree (Table 2); and aftershocks are concentrated in a circle around the epicenter. There are many earthquake-induced geological disasters that present potential risks to life and damage to property.

Wenchuan Earthquake: a shallow earthquake located at 31.03°N and 103.29°E with a focal depth of 14 km; maximum intensity at the epicenter of XI degree; and unipolar NE-trending surface rupture zone and aftershocks (Tang C et al., 2011; Tang H M et al., 2010; Xu et al., 2009; CEA, 2008). More than 197 000 geohazards were triggered by the earthquake (Xu et al., 2013a), including high-speed remote giant landslides and debris-flow-landslides (Wang et al., 2012; Xu, 2012; Yin et al., 2012, 2011, 2009; Wu and Zhang, 2008) and 33 dammed lakes (Cui et al., 2009) some of which buried large sections of towns including locations within Beichuan County. Compared to the Lushan Earthquake, the Wenchuan Earthquake caused more serious secondary geohazards, casualties and property losses. In terms of the distribution characteristics of aftershocks, there is an area free of aftershocks between the two epicenters, which distance is 50 km. The brief comparison of geohazards induced by Lushan and Wenchuan earthquakes see Table 3.

The influences of differing geomorphologic elevation and slope angle on geohazards were compared via the concentrations of post-earthquake landslides and collapses around the two epicenters (Fig. 8).

2.1 Differences in Earthquake Magnitude

The Lushan and Wenchuan earthquakes were both shallow earthquakes. According to the earthquake magnitude and energy formula: LgE=11.8+1.5M (E=energy, M=magnitude), the Wenchuan Earthquake (M_s 8.0) released approximately 31.6 times more energy than the Lushan Earthquake (M_s 7.0), thereby resulting in higher risks than in the Lushan area.

2.2 Differences in Type of Fault Activity

The activities of the seismogenic fault of the Wenchuan Earthquake was to the main thrust, which caused a number of co-seismic thrust surface rupture zones after the earthquake (Li, et al., 2008) and the seismic energy along faults through time-variable rupture (Kusky et al., 2010; Liu and Kusky, 2008). Geohazards had significant upper/below fault effects induced by the Wenchuan Earthquake (Huang and Li, 2009) and mainly spread along the fault zone. However, there is no significant surface rupture zone in the Lushan earthquake area (Zhang et al., 2013). This is a typical blind thrust earthquake, and its causative fault does not reach the surface (Xu et al., 2013a). Therefore, the two events show significantly different seismogenic fault activity and nature of the exposed surface rupture zone of geological disasters.

2.3 Differences in Topographical Amplification Effect

The epicenter of the Wenchuan Earthquake was located in a canyon. Due to the plateau uplift and profound impacts on the Minjiang River, greater differences in terrain elevation, slope inclination and free space in the mountainous front, it is very easy to form elevated landslides, rock collapses and debris flows, and therefore the effects of terrain amplification are obvious. In comparison, the epicenter of the Lushan Earthquake was located in an area of small basins with small valley sides slope elevation. The resulting terrain amplification effect is not obvious, so the risk from elevated landslides is relatively small (Fig. 9).

2.4 Differences in Terrain Slope Angle

In the area most affected by the Lushan Earthquake, geohazards mainly occurred on slope angles of 10°–40° with the highest concentration on slopes of 10°–20°, and the maximum area is approximately 40–60 km^2 (see Fig. 10a). In the area of the Wenchuan earthquake, geohazards are mainly concentrated on slopes of 20°–40° (maximum 30°) and the maximum area is approximately 240 km^2, while the slope angle of geohazards also concentrated in the 20°–50°, especially the highest concentration zone is 30°–40° (Fig. 10b). The geohazards associated with the Wenchuan Earthquake therefore occur on significantly steeper slopes than those attributed to the Lushan Earthquake.

2.5 Differences in Geomorphologic Elevation

The geohazards induced by the Lushan Earthquake mainly occur at absolute elevations of 600 m to 1 500 m and are concentrated within an area of 2 089 km^2 (peak area is approximately 40–60 km^2) comprising 3.85% of the study area. While the average elevations of geohazards are mainly concentrated within the range 500–2 000 m, especially the largest number developing zone is focused on 1 000–1 500 m. Within the Wenchuan Earthquake area, geohazards are mainly concentrated within an area of 7 503 km^2 at elevation between 1 000–2 000 m (maximum area of approximately 240 km^2 at 1 300–1 400 m a.s.l. elevation) that accounts for 13.84% of the study area. While the average elevations of geohazards are mainly concentrated within the range 1 000–3 500 m, especially the developmental largest numbers are interval of 1 000–2 000 m (Fig. 11a). Comparison of the above data shows significantly higher elevation of geomorphology and geohazards in the Wenchuan Earthquake area (Fig. 11b), which may also be the reason why there were fewer geohazards than in the Wenchuan Earthquake area.

3 CONCLUSIONS

In this paper, the influences of differing geomorphologic elevation and slope angle on geohazards were compared via the concentrations of post-earthquake landslides and collapses around the two epicenters. The main conclusions are as follows.

(1) Landslides and rockslides differ significantly in number and volume due to the effect of earthquake magnitude. The Wenchuan Earthquake results in smaller and fewer geohazards

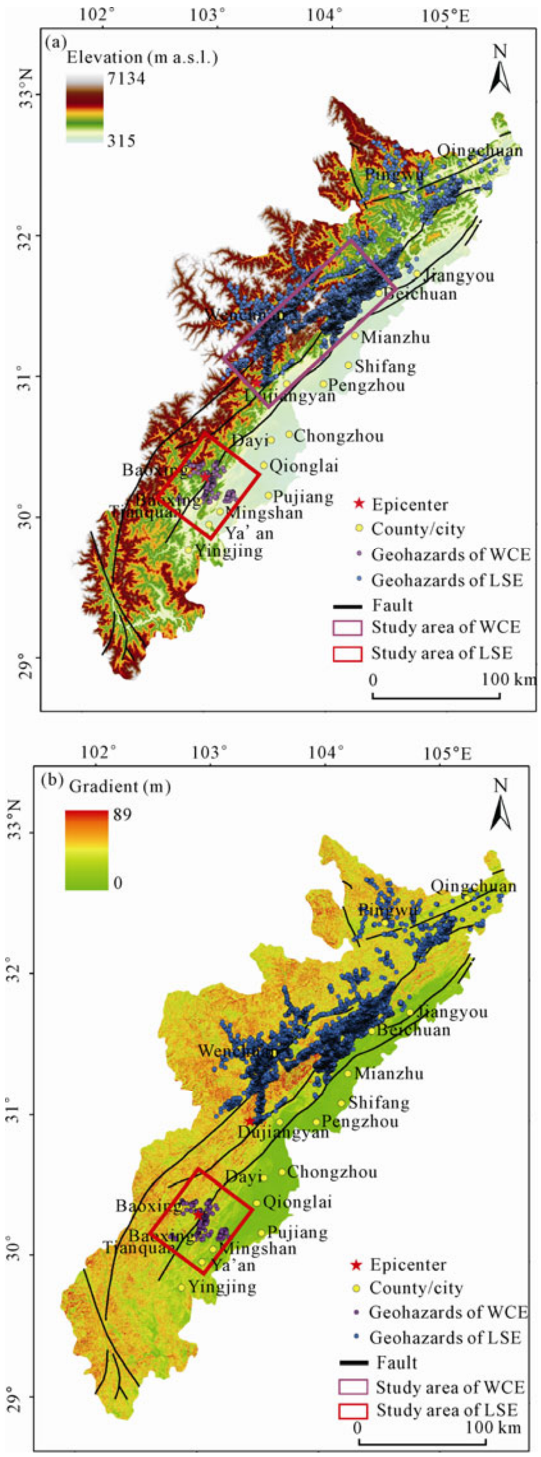

Figure 8. Topography elevation, slope angle and geological disasters in Longmenshan fault area.

(mainly small- and medium-sized shallow landslide and rock-slides) and these occur in steeply sloping areas and mountain valleys. The Gangoutou landslide debris flow (Damiao valley, Tianquan County) is the biggest geo-disaster induced by the Lushan earthquake and has an estimated residual volume of 2.48×10^6 m^3, Potentially the most dangerous debris flow is that in Lengmugou gulley (Baoxing County), which has similar geomorphological features and disaster in Zhouqu County (Gansu Province).

(2) There are four formation mechanisms of geological modes as the event disasters induced by the Lushan earthquake: cracking-rockslides-collision-scraping and then debris flows,

Table 3 The brief comparison of geohazards induced by Lushan and Wenchuan earthquakes

Earthquakes	Geohazards	Scale of geohazards	Numbers of geo-hazards	Extent of serious harm	General characteristics	Typical geohazards
Lushan Earthquake	Landslides, rock collapses, debris flows, Large dislodged boulders, and sand-soil liquefaction	Scale in small, middle and large	About 3 000	The geohazards caused no casualties	Small numbers, little scales, mainly in low slope landslides, and less dangerous to local residents	The only typical landslide debris flows induced by earthquake named Gangoutou.
Wenchuan Earthquake		Scale in small, middle, large, super large and giant	More than 190 000	The geohazards caused more than 10 000 people died	Large quantities with wide ranges, high density and more high-speed remote landslides	There are more than 10 giant, high speed remote distance landslides, e.g., Daguangbao landslides, Donghekou landslides and etc.

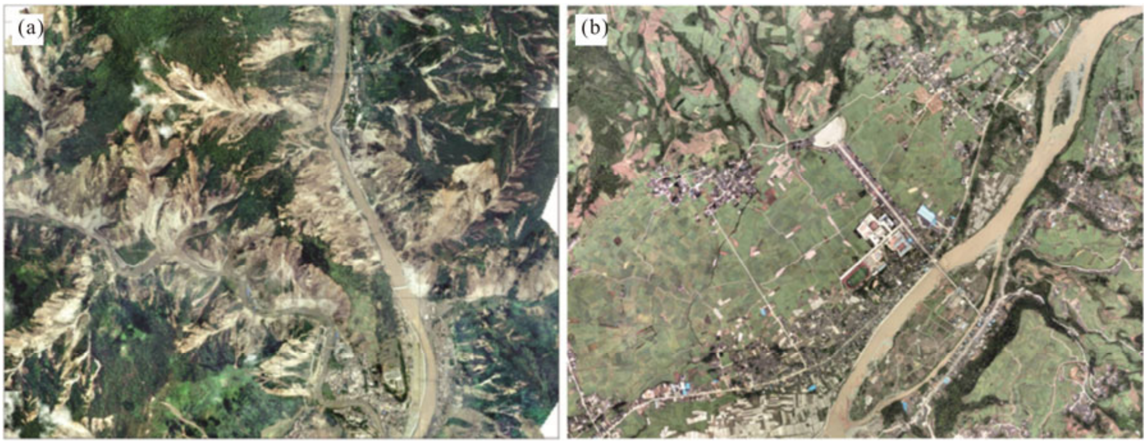

Figure 9. Comparison of remote sensing images of epicenters of Wenchuan and Lushan earthquakes. (a) Yingxiu; (b) Longmen.

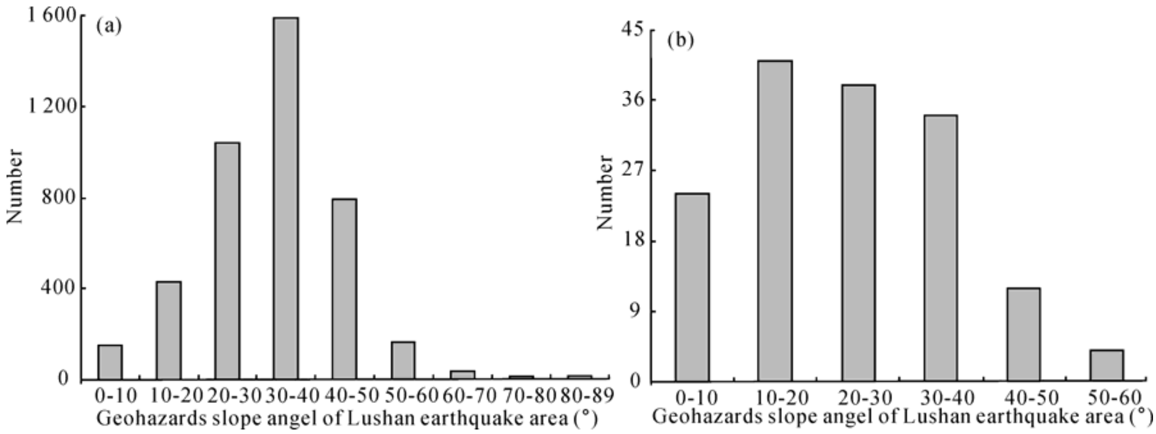

Figure 10. Frequency distribution of average slope angle of geological disasters induced by Wenchuan (a) and Lushan (b) earthquakes.

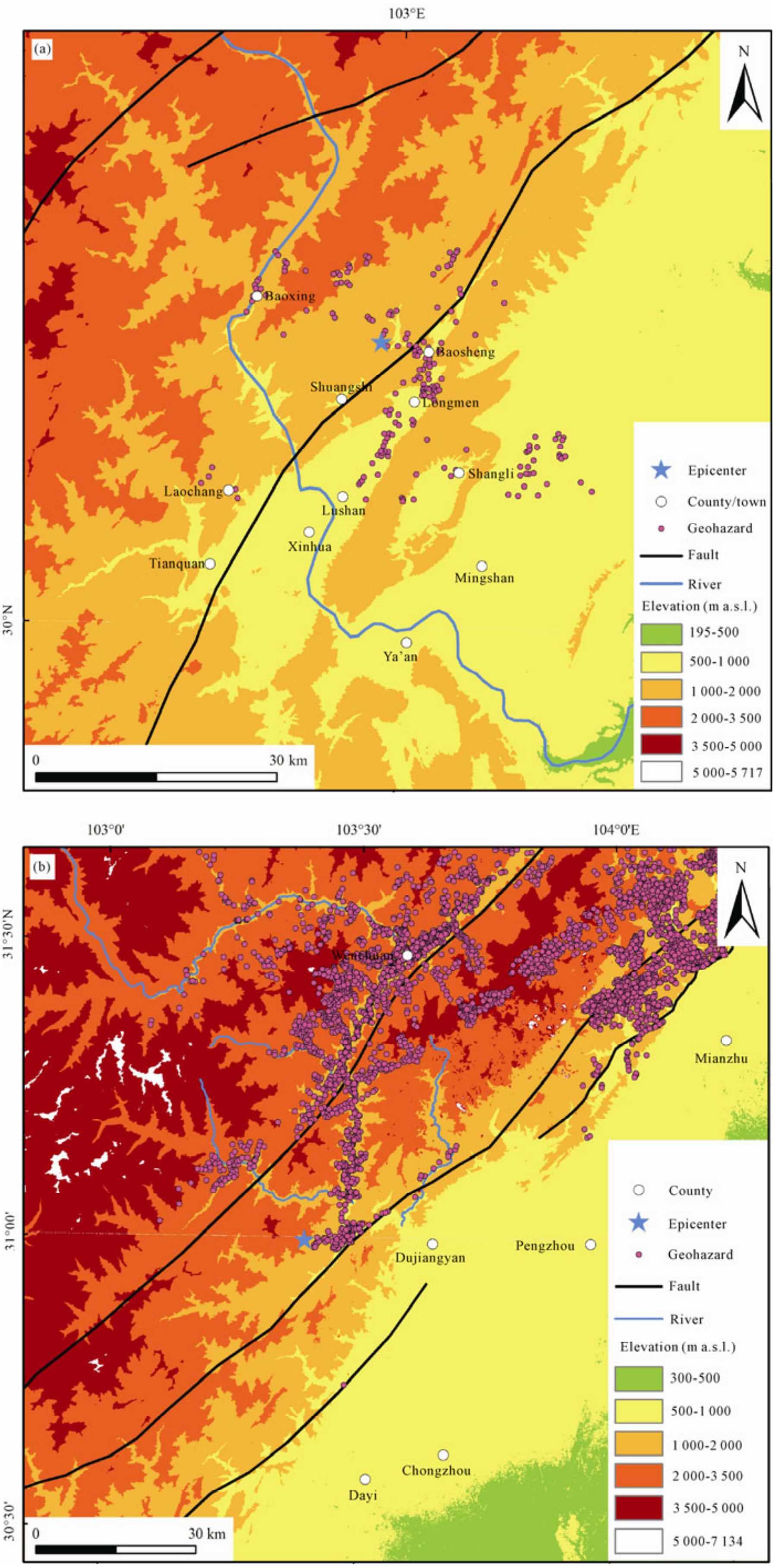

Figure 11. Elevation of geohazards associated with Lushan (a) and Wenchuan (b) earthquakes.

cracking-rockslides, vibration-rainfall-rockslides-landslide and then debris flow, vibration-throwing or scrolling.

(3) There are very significant similarities and differences between the geohazards induced by the Lushan and Wenchuan earthquakes. The types of geohazards are the same but the volume, quantity and other factors differ: those in the Lushan Earthquake area occur mainly on slopes of 10°–40° (especially in the 10°–20° range), and at absolute elevation of 500–2 000 m. In the Wenchuan earthquake area, they are concentrated on steeper slopes of 30°–40° and at higher absolute elevation of 1 500–2 000 m, which are more conducive to the occurrence of landslides.

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