Distribution and characteristics of landslides in the 2018 Palu earthquake, Indonesia
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Abstract. The September 28, 2018 Mw7.5 earthquake of Palu earthquake, Sulawesi Island, Indonesia, has triggered a lot of landslides. We attempted to establish a detailed landslide inventory of this area, which is very important to understand the landslide distribution, geomorphic evolution and risk assessment of the earthquake. The purpose of this paper is to make a statistical analysis of the spatial distribution and influencing factors of landslides in the study area based on the landslide inventory of Palu earthquake. Combined with earthquake, topography, geology and other landslide influence factors, taking the percentage of landslide area (LAP) and landslide number density (LND) as indicators, the change trend of landslides in different factor intervals is analysed. The results show that the areas with elevation of 400-500 and 500 – 600m are prone to landslides. With the increase of elevation, LAP and landslide area showed a downward trend. LND first increased and then decreased, and reached the peak at the elevation of 1500-1600m. Large scale landslides are prone to occur in low altitude areas, while small scale landslides tend to occur in high altitude areas. LAP and LND increased with the increase of slope. The LAP decreases with the increase of the distance from the river, which is opposite to the LND, indicating that the small landslides often occur in the area far from the river. The results of this study are helpful to understand the causes of coseismic landslides. And provide a scientific reference for disaster prevention and mitigation of earthquake landslides in the seismic landslide hazard zoning.

1. Introduction
The Mw7.5 Palu earthquake struck Sulawesi island, Indonesia at 18:02 local time (UTC10:02) on September 28, 2018. This event was preceded by a sequence of foreshocks. At least 4,340 people are reported to have died as a result of this event and more than 10,000 injured, of which 4,612 were seriously injured.

There is no coseismic landslide inventory of 2018 Palu earthquake. So, the purpose of this paper is to establish a comprehensive landslide inventory of the 2018 Palu earthquake. Otherwise, we analyzed the spatial distribution, landslide size and their relationship with the geology, topography, ground shaking, and other factors. This work will help us in understanding the cause of the landslides induced by this event and providing new data support for disaster prevention in this area.

2. Study area
The U.S. Geological Survey determined the epicenter position of the Mw7.5 Palu earthquake (0.178°S, 119.840°E) is located in the northern part of Palu city in the middle of Sulawesi island, Indonesia (Fig. 1). The focal depth of the earthquake is 10 km and the strike of the main rupture surface is 358°, the dip angle is 86° N. The earthquake is located in the eastern part of Indonesia, where the geological tectonic environment is complex [1]. There are many micro plate movements between the Australian, Sunda, Pacific and Philippine plates [2]. Through the analysis of focal mechanism, it is found that the Sulawesi earthquake is caused by the shallow strike slip fault in .the Moluga sea micro plate [3-5].
Fig.1 Geological setting of the study area;

2.1 Data and method

The resolution of the DEM data selected in this study is SRTM DEM (resolution 30m). The slope and aspect information are extracted based on this DEM. River information is the main rivers and tributaries. PGA are down load from USGA. Using GIS software, all of the influencing factor maps were transformed into raster format with a grid cell size of 30 × 30m.

3. Results and analysis

3.1 Landslide inventory

Based on visual interpretation and the principles [6], using high-resolution optical satellite images (planet) before and after earthquake, a total of 15700 landslides were identified in this area by visual interpretation and were delineated as polygons. The total area of landslide is about 42.995 km². Fig.2 shows the development of shallow landslides triggered by Palu earthquake; the site is located in 1°12′45″S, 119°59′00″E. The results of this interpretation are consistent with the inverse gamma distribution proposed by Malamud et al. (2004a). The trend of probability density distribution corresponding to the landslide in the Palu earthquake shows that the area corresponding to the maximum value of the landslide (roller point) is the same, and the average value is between 100 and 200m², which indicates that the landslide with an area of 100 – 200m² is the most in this landslide inventory (Fig 2, Fig 3).
Fig. 2 Development of shallow landslides triggered by Palu earthquake; the site is located in 1°12′45″S, 119°59′00″E. The dates of the images are 06 August 2018 and 08 July 2010.

Fig. 3 probability of landslide area in Palu
Fig. 4 Probability density (A) of earthquake-induced landslides in Palu earthquake. Dotted line is a double Pareto function.

3.2 Correlation between landslides and Terrain factor

Four landslide influencing factors, elevation, slope, distance to river, PGA and aspect, are selected to study the spatial distribution of landslides in the study area. Table 1 is the classifications of control factors.

| Influencing factor | Classification |
|--------------------|----------------|
| Elevation          | (1) <100; (2) 100–200; (3) 200–300; (4) 300–400; (5) 400–500; (6) 500–600; (7) 600–700; (8) 700–800; (9) 800–900; (10) 900–1000; (11) 1000–1100; (12) 1100–1200; (13) 1200–1300; (5) 1300–1400; (6) 1400–1500; (7) 1500–1600; (8) 1600–1700; (9) 1700–1800; (10) 1800–1900; (11) 1900–2000; (12) 2100–2200; (13) >2200 |
| Slope              | (1) <5°; (2) 5°–10°; (3) 5°–10°; (4) 10°–15°; (5) 15°–20°; (6) 20°–25°; (7) 25°–30°; (8) 30°–35°; (9) 35°–40°; (10) 45°–50°; (11) 50°–55°; (12) 55°–60°; (13) 60°–75°; (14) >75° |
| PGA                | (1) 0.1–0.2 g; (2) 0.2–0.3 g; (3) 0.3–0.4 g; (4) 0.4–0.5 g; (5) 0.5–0.6 g; (6) 0.6–0.7 g; (7) 0.7–0.8 g; (8) 0.8–0.9 g |
| Distance to river  | (1) <100; (2) 100–200; (3) 200–300; (4) 300–400; (5) 400–500; (6) 500–600; (7) 600–700; (8) 700–800; (9) 800–900; (10) 900–1000; (11) 1000–1100; (12) 1100–1200; (13) 1200–1300; (5) 1300–1400; (6) 1400–1500; (7) 1500–1600; (8) 1600–1700; (9) 1700–1800; (10) 1800–1900; (11) 1900–2000; (12) 2100–2200; (13) >2200 |
It can be seen from the analysis results that with the increase of elevation, the results show that the areas with elevation of 400-500 and 500 – 600m are prone to landslides. With the increase of elevation, LAD (defined as the percentage of the landslide area in each factor category) and landslide area showed a downward trend. LND (a number in each category) first increased and then decreased, and reached the peak at the elevation of 1500-1600m (Fig4 a). The slope is between 50 ° and 60 ° and the density of landslide points reaches the maximum (Fig4 b). The larger the absolute value of river is, the lower the density of landslide is (Fig4 c). When PGA is 0.6-0.7g, the landslide area is large, accounting for 27.1% of the total landslide area, and the density of landslide points and area density reached the peak, which were 3.5 / km² and 1.4% respectively (Fig 4d). In the southeast and south direction, landslides are prone to occur (Fig 5).

Fig5 Classifications of possible controlling factors for the coseismic landslides and their relations with LND and LAD (right). LND: landslide number density; LAD: landslide area density (see text for their definitions).
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