Characteristics Analysis of landslides, collapses and debris flows occurred from 2010-2019 in China

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Abstract. Based on the national geological disasters database in China, this paper presents the temporal and spatial distribution characteristics, triggering factors and losses caused by landslides, collapses and debris flows in China from 2010 to 2019: (1) landslides, collapses and debris flows are usually developed extensively in the transitional areas between the three terraces and the areas between mountains and plains; landslides, collapses and debris flows of large scale are more developed in regions near active faults, and the majority of these disasters still remain active; (2) the temporal development of landslides, collapses and debris flows follows a general trend of normal distribution, and the high-incidence season is from May to August. The high-intense period slightly shift from the south to the north in China; (3) precipitation and earthquakes are important triggering factors of landslides, collapses and debris flows. The magnitude of the earthquake and properties of seismogenic faults affects the distribution and the scale of landslide, collapse and debris flow; (4) in the past decade, landslides, collapses and debris flows have caused 5,968 people dead or missing, and caused direct economic losses of over 40.98 billion yuan. According to the above research, this paper puts forward the key periods and areas for prevention of sudden geological disasters in the future in China.

Keywords: landslides, collapses, debris flows, temporal and spatial distribution characteristics, triggering factors.

1. Introduction
Six types of geological disasters are most frequently occurred in China: landslide, collapse, debris flow, ground collapse, ground fissure and ground subsidence. In recent years, many scholars have studied the development and distribution of geological disasters in China. Li et al (2013) conducted the vulnerability mapping on national scale; Qu et al. (2016), Li (2019) and Xue et al. (2016) conducted statistical analysis on the spatial and temporal distribution characteristics of geological disasters in China, and Fang et al. (2018) conducted research on geological disasters occurring from 2010 to 2015. The above analysis indicated that the development mechanism of landslide, collapse and debris flow is different from that of ground collapse, ground fissure and ground subsidence. There is few study specialized on landslide, collapse and debris flow in China. In this paper, based on China national geological disasters database, the landslide, collapse and debris flow occurred from 2010 to 2019, the geolog-
ical environment background conditions and triggering factors are studied, the spatial and temporal distribution characteristics are summarized, the death toll and direct economic losses are counted.

2. Data analysis

2.1 Distribution characteristics of landslide, collapse and debris flow in China from 2010 to 2019

According to statistics, there were 70,174 landslides, collapses and debris flows in China from 2010 to 2019, including 50,493 landslides, 13,637 collapses and 6,044 debris flows. The year and month of occurrence are shown in Figure 1 and Figure 2. The number of occurrences from May to August accounted for 81.2% of the total.

Figure 1. Numbers of landslide, collapse and debris flow occurred from 2010 to 2019

Figure 2. Monthly distribution of landslides, collapse and debris flows occurred from 2010 to 2019

From 2010 to 2019, the spatial distribution of landslides, collapses and debris flows in China is shown in figure 3. Landslides and collapses mainly occurred in the central and southeast of China, while debris flows mainly occurred in the west. At the same time, there is also a certain relationship between the spatial distribution of landslide, collapse and debris flow and time. The starting time of the frequent occurrence period is characterized by a gradual transition from the southeast coast to the northwest inland: it starts in May, June, and July in the southeast, southwest and north-central region, respectively. Due to snow melting, the frequent occurrence period in northwest regions begins in May. The landslide, collapse and debris flow entered the low occurrence period when the flood season basically ended in September.
2.2 Disaster distribution characteristics

From 2010 to 2019, a total of 5,968 people were killed or missing by landslides, collapses and debris flows, resulting in a direct economic loss of 40.98 billion yuan. The locations of landslides, collapses and debris flows that cause death are shown in Figure 4. According to the statistics, 2010 was the year with the largest number of deaths in the past 10 years, accounting for 47.2% of the total. And August was the month with the highest number of deaths throughout the year, accounting for 40.4% of the total. Overall, the death toll was concentrated between May and August, accounting for 80.3% of the total, which coincides with the frequent occurrence period of landslides, collapses and debris flows. Disasters that caused deaths are concentrated in the central and western regions, a single disaster caused more than 30 deaths mainly in western China. Because of the high mountains and steep slopes in these areas, the scale of geological disasters is large and the scope of impact is large. For example, the Zhouqu debris flow affected the entire county town, which killed 1447 people and 318 people were missing.
3. Discussion

3.1 Topography

Topography is one of the basic conditions to form the hazards of collapse, landslide, and debris flow. In general, the topography and elevation of China declines from the west to the east, and there are three major terraces in terms of landforms. The highest terrace is the Qinghai-Tibet Plateau, called “The Roof of the World”, whose average elevation is over 4500 meters; the second terrace lies between the rim of Qinghai-Tibet Plateau and the line along the Dahinganling Mountains, the Taihang Mountains, the Funiu Mountains, the Wushan Mountains and the Xuefeng Mountains, with an average elevation from 1000 to 2000 meters; and the third terrace lies on the east of the line along the Dahinganling Mountains, the Taihang Mountains, the Funiu Mountains and the Wushan Mountains, with an average elevation below 500 meters. These geological hazards are usually developed extensively in the transitional areas between the three terraces and the areas between mountains and plains, because of the huge altitude differences between them. Statistics shows that approximately 90.4% of extremely large and 84.4% of large landslides, collapses and debris flows are distributed along the edge of Qinghai-Tibet Plateau, Losses Plateau as well as in the mountainous areas in southwestern China. In addition, over 80% of landslides, collapses, and debris flows are distributed in the mountainous terrain, and the rest are found within hilly areas and river valleys. See Table 1.

Table 1. Table of statistics of the amount of landslides, collapses and debris in different terrains

| Elevation difference (m) | Landslides and Collapses | Debris Flows |
|-------------------------|--------------------------|--------------|
| Extremely large (>2500) | 0.50%                    | 2.60%        |
| Large (1000~2500)       | 28.00%                   | 33.40%       |
| Medium (500~1000)       | 34.20%                   | 29.90%       |
| Small (200~500)         | 22.80%                   | 16.60%       |
| Hilly areas, river valleys | 14.50%               | 17.50%       |
3.2 Active Faults

Active faults mainly control the spatial distributions, scales and overall stability of landslides, collapses and debris flows in macroscopic and regional scales. Three-period tectonic movements since two hundred and fifty five million years, including Indosinian Movement, Yanshan Movement, and Himalayas Movement, have formed three tectonic systems in China. Active faults mainly concentrate in orogenic belts and the edge of each orogenic belt, which affect development of landslides, collapses and debris flows from three ways: firstly, deep valleys and steep mountains are formed due to the active faults, which provide the topography conditions; secondly, long term movements of active faults gradually break rock mass and structural surface, which not only produce the weak material sources for collapses, landslides and debris flows, but also provide the geological condition as an important triggering factor (Guo et al. (2009)); finally, new geological hazards could be formed due to the long-term and continuous movements of active faults. Therefore, landslides, collapses and debris flows which concentrate in or near active faults have characteristics of larger density, huge scale and more frequent appearance.

3.3 Precipitation

Precipitation is an important triggering factor of landslides, collapses and debris flows. Controlled by natural geographical environment, the precipitation in China gradually decreases from the southeast to northwest. The annual precipitation, usually in the form of rainstorm, mostly concentrates in summer with humility and high temperatures. Rainfall from June to September could take up 60% to 80% of the total precipitation. The number of torrential rain days (rainfall within 24 hour is greater than 50 mm) shows gradually decreasing trend from southeast to northwest in China mainland. The number of torrential rain day could be 8 to 10 days in coastal areas in the southeast of China, whereas this could be less than 1 day in the northwest of China. Over 60% of collapses and landslides can be formed in the region where the average annual rainfall is between 1000 and 1600 mm, and average annual torrential day within 2 to 6 days (Figures 5 and 6). These areas are in mountainous regions: the Yunnan-Guizhou Plateau, upper and middle Yangtze River, and the front and back edges of second steps and ladders. Debris flows normally occur in the areas where the average annual rainfall reaches to 400 to 1200 mm or the number of torrential rain days is between 0.1 and 4 days. (Figures 5 and 6). However, in the middle west of China, debris flows could even occur within the torrential rain days less than 0.1 day. In these regions the surficial soil is dry and weak, which can easily trigger debris flows when the heavy rainfall storms appear in a short period.

![Figure 5](image-url). The Percentage of Landslides, Collapses and Debris Flows in Different Areas with Various Average Annual rainfall.
3.4 Earthquakes
Earthquake is an important factor triggering landslides, collapses and debris flows. Earthquake is a long-term and slowly moved activity of the earth’s crust. When concentrated stress is larger than the strength limit of the crust, ground fissures could be generated due to the failure of crust. Seismotectonics in China is characterized by apparent division. There are five divisions: northeast China division, north China division, Qinghai-Tibet Plateau division, Tianshan Mountains division and southeast China division. In recent years, there have been frequent activities in the Qinghai-Tibet earthquake tectonic area and causing a large number of landslides, collapses, and debris flows. The important characteristics of geological disasters induced by earthquakes are listed as followed: 1. geological disasters are normally distributed along active faults, and more landslides with larger scales and longer affecting distances could be caused by thrust earthquakes than those caused by strike slip earthquakes; 2. earthquakes with greater magnitude cause steeper slopes and more significant detritions, which may induce greater risks and damages by geological disasters; 3. the regions prone to earthquakes can also induce landslides, collapses and debris flows for a long period after earthquake occurs(Ying et al., 2013).

3.5 Engineering Activities
After the establishment of People’s Republic of China, especially after the Chinese reform and opening, engineering activities contribute to the occurrence of landslide, collapse and debris flow disasters. The most prominent human engineering activity is the slope excavation during road construction, and inappropriate farm irrigation, etc. Such disasters usually occur in densely populated provinces such as hunan, jiangxi and guangdong in central and southern China, shows the characteristics of small scale and large number. Although most of them are induced by rainfall, they are fundamentally caused by unreasonable human engineering activities that have changed the original stable state of the slope.

3.6 Analysis of the disaster
The study found that the number of deaths and direct economic losses caused by landslides, collapses and debris flows from 2010 to 2019 has the following characteristics:1. The average number of deaths and direct economic loss decreased with the decrease of scale;2. Due to the large number of small-scale disasters, the total number of deaths, disappearances and economic losses caused by them accounted for the most.3. The number of landslides is the largest and the direct economic loss is the largest, accounting for 72.0% and 53.2% respectively.4. Debris flow is the most disastrous, although the number is the least, but the death toll is the most, accounting for 8.6% and 43.6% of the total, respectively. A debris flow caused an average of 0.54 deaths and about 2.66 million property losses, which is 7.7-27 times the death toll and 5.4-11 times direct economic loss caused by others.

4. Conclusion
From 2010 to 2019, A total of 70,174 landslides, landslides and debris flows occurred in China, and caused 5968 death or missing and 40.98 billion direct economic losses. The year with the highest number of occurrences is 2010, and the month with the largest number is July, and the number from
May to August accounted for 81.2% of the total. The starting time of the frequent occurrence period is characterized by a gradual transition from the southeast coast to the northwest inland; it starts in May and ends in August.

Due to the deep valley, complicated terrain, and topography in the transitional areas among three ladders, mountains and plateaus, landslides, collapses and debris flows developed intensively. Large scales are more developed in regions near active faults, and the majority of these disasters still remain active. Over 60% of the landslides and collapses occurred in regions where the average annual precipitation is 1000 to 1600 mm or the numbers of annual torrential rain days are between 2 and 6. Debris flows mainly occur in regions where the average annual precipitation amount is 400 to 1200 mm or the number of annual torrential rain days is between 0.1 and 4. The magnitude and type of earthquake rupture could have a direct influence on the distribution and the scale of geological hazards. In the years following the occurrence of earthquakes, the region under the influence has a higher possibility of secondary geological hazards. Human engineering activities increase risk of geological hazards and provide the triggering conditions that allow easy occurrence of collapses, landslides and debris flows.

In summary, this paper puts forward the following prevention and control suggestions: 1. May-August is the key period of emergency work for landslides, landslides and debris flows in China, and the key emergency areas are transferred from the southeast coast to the northwest inland; 2. Major engineering construction should avoid the transitional areas between the three terraces as far as possible; 3. For central and southeastern China, human engineering activities should be restricted to avoid landslides caused by cutting slopes, etc; 4. For western China, targeted biological or engineering measures should be taken to prevent debris flow disasters.

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