Analysis on the Development Situation of Geo-Hazards Based on Statistical Methods in Mainland China in Recent Years

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Abstract. In recent years, many geo-hazards were triggered by the frequent occurrences of sudden and regional extreme heavy rainfall, earthquake events, and human society and economic activities during urbanization, for example, the development of underground space. The authoritative data on geo-hazards that occurred in recent years in mainland China were collected. We analyzed the correlation of the conditions of triggering geo-hazards and the spatial and temporal characteristics based on the statistical data. From the findings, geo-hazards in China were controlled by numerous factors including topography, formation lithology, slope structure, fault, and geomorphic evolution. The geo-hazards depict the concentration and zonation distribution characteristics. The most occurred geo-hazards in China are landslides, collapses, and debris flow, and most are small to medium in scale. Heavy rainfall is the major triggering factor, and geo-hazards' spatial distribution strongly correlates with spatial and temporal rainfall distribution. Finally, due to ongoing mitigation efforts, the development trend of casualties and economic losses caused by geo-hazards has shown a decreasing trend.

Keywords: characteristics of geo-hazards, spatial distributions, triggering factors

1 Introduction

Geo-hazards can be triggered by geological environments and human factors and have caused tremendous personnel and economic loss in China (Fang H et al. 2019; State Council of the PRC 2003). Geo-hazards can generally be divided into collapse, landslide, debris flow,
ground subsidence, geo-fracture, rock/soil shrinkage and swelling, sand liquefaction, land freezing and thawing, soil desertification, swamping, and soil salinization. Among these, collapse, landslide, and debris flow caused the most severe damages in China. China's topographical and geological conditions are complicated, with mountains and hills accounting for 2/3 of the national territorial region. Rainstorms and earthquakes were common in the various climates across the country. Geological hazards frequently occur due to the intense impacts of dense populations and human engineering activities. Statistics show that collapse, landslide, and debris flow hazards have caused more than 20,000 deaths over the past 50 years. The frequent collapses, landslides, and debris flows have caused a tremendous loss in people's lives and economic properties.

Since 1999, the Chinese government has carried out 1:100,000 and 1:50,000 geo-hazards investigations nationwide in disaster-prone mountainous and hilly areas and obtained a comprehensive understanding of the essential characteristics of geo-hazards. According to the multi-round investigation results of geo-hazards, the development situation, distribution characteristics, influences caused by the geological environment, and main inducing factors showed significant differences in various periods.

To support the national geo-hazards prevention and management efforts, this study summarized the occurrence situation of geo-hazards in China since 2012 based on the analysis of triggering conditions and inducing factors of the most frequently occurred geo-hazards collapse, landslide, and debris flow, respectively. The results of this study could provide suggestions for the prevention and reduction of sudden geo-hazards in the future.

2 Study area

China is located in the southeast of Eurasia, bordering on the West Pacific Ocean in the southeast, penetrating the hinterland of Asia in the northwest, and bordering on the South Asian subcontinent in the southwest. The whole terrain of China gradually declines from west to east. There are mainly mountains, plateaus, and large inland basins in the west, and in the east, there are lower mountains, hills, and plains. Thus, the geomorphic pattern of China consists of three geomorphic zones.

The highest zone is the Qinghai Tibet Plateau, with an average altitude of more than 4500 m. It is composed of mountains and extreme mountains with an altitude of more than 5,000-6,000 m and a surface plateau comprising undulating and gentle high-altitude hills,
platforms, and plains. The zone's boundary is the area with the greatest topographic relief, usually up to 3000 m, and the highest up to 5,000 m. The second zone is on the outskirts of China's largest zone, the Qinghai Tibet Plateau. Tarim Basin and Jungar Basin are located in the northwest, surrounded by mountains. The Loess Plateau and Inner Mongolia Plateau are to the east. The Sichuan Basin and Yungui Plateau are located in the south. Tianshan Mountains, Yinshan Mountains, Qinling Mountains, Daba Mountains, Dalou Mountains, and other mountains can be found in the middle. Among them, the elevation of some large basins is 1,000-2,000 m, some are 500-1,000 m, and the elevation of mountain areas are all above 1,000 m. The third zone is located east of Daxingan Mountain Taihang Mountain Funiu Mountain Wushan Xuefeng mountain line, which is the lowest zone. From north to south, there are northeast plain, Huanghuaihai Plain, and the lower reaches of the Yangtze River Plain. The east and south of the plain are mainly mountainous areas, including Changbai mountain, Shandong low mountain, and Jiangnan mountain. Most of the mountainous areas are not more than 1000m above the water level of huanghai sea, and a small part of them are mountainous areas at 1,000-2,000 m.

3 Methodology

3.1 General situation of geo-hazards based on statistics

According to statistics, a total of 287,916 geo-hazards and potential disasters were identified and recorded in China by the end of 2017, including 68,419 collapses, 142,377 landslides, 33,524 debris flows, and 43,596 land collapses and land fissures, threatening the lives and property of 15.87 million people and causing losses of 512.3 billion Yuan (Ministry of Land and Resources of PRC 2012-2017). By 2017, nearly all the provinces in mainland China developed and distributed potential geo-hazards except Shanghai because it is located in the coastal plain area, and collapses, landslides, debris flows were rarely found. Among the provinces, there were 12 provinces. The number of potential geo-hazards was over 10,000, and they were respectively Sichuan, Yunnan, Gansu, Hunan, Guizhou, Shaanxi, Hubei, Xinjiang, Chongqing, Xizang, Jiangxi, and Fujian. In addition, geo-hazards threatened over 500 people in 5 provinces: Hunan, Sichuan, Guizhou, Yunnan, and Gansu, respectively. In addition, there were more than 10 billion Yuan losses caused by geo-hazards in 10 provinces, which were Fujian, Hubei, Hunan, Guangxi, Chongqing, Sichuan, Yunnan, Xizang, Shaanxi,
and Gansu, respectively (Ministry of Land and Resources of PRC, from 2012 to 2017). A comprehensive data summarization of geo-hazards was provided in Table 1.

### Table 1 Statistics of the number and threatens of geo-hazards in mainland China (as of 2017)

| Provinces       | No. of hazards | Threatens |
|-----------------|---------------|-----------|
|                 | Total No.     | Collapse | Landslide | Debris flow | Others | No. of people (Million) | Properties (Million Yuan) |
| Beijing         | 4 877         | 2 499    | 50        | 889         | 1 439  | 5.92                  | 11 000                   |
| Tianjin         | 232           | 112      | 108       | 12          | 0      | 0.12                  | 15 283                   |
| Heibei          | 4 221         | 1 267    | 726       | 1 495       | 733    | 15.40                 | 545 911                  |
| Shanxi          | 9 961         | 3 285    | 1 224     | 537         | 4 915  | 57.49                 | 594 528                  |
| Inner Mongolia  | 2 626         | 1 340    | 105       | 782         | 399    | 13.98                 | 683 071                  |
| Liaoning        | 2 946         | 1 244    | 357       | 998         | 347    | 23.40                 | 688 107                  |
| Jilin           | 8 400         | 3 130    | 313       | 1 800       | 3 157  | 2.86                  | 2 857 773                |
| Heilongjiang    | 2 189         | -        | 537       | 196         | 1 425  | 4.84                  | 298 531                  |
| Shanghai        | -             | -        | -         | -           | -      | -                     | -                        |
| Jiangsu         | 1 032         | 401      | 450       | 0           | 181    | 4.16                  | 202 100                  |
| Zhejiang        | 5 749         | 1 647    | 2 924     | 1 112       | 66     | 18.96                 | 609 963                  |
| Anhui           | 4 850         | 1 875    | 1 561     | 155         | 1 259  | 7.00                  | 269 822                  |
| Fujian          | 11 172        | 2 900    | 7 986     | 151         | 135    | 65.80                 | 1 260 000                |
| Jiangxi         | 25 894        | 5 329    | 17 416    | 189         | 2 960  | 36.77                 | 560 415                  |
| Shandong        | 3 043         | 1 870    | 257       | 264         | 652    | 8.92                  | 244 118                  |
| Henan           | 3 446         | 1 213    | 1 482     | 251         | 500     | 32.93                 | 743 632                  |
| Hubei           | 12 731        | 1 116    | 8 061     | 168         | 3 386  | 54.40                 | 2 209 558                |
| Hunan           | 20 529        | 1 803    | 12 019    | 640         | 6 067  | 125.00                | 2 312 377                |
| Guangdong       | 7 062         | 3 992    | 2 619     | 76          | 375    | 29.60                 | 954 378                  |
| Guangxi         | 8 806         | 4 820    | 3 675     | 85          | 226    | 66.96                 | 1 065 892                |
| Hainan          | 265           | 192      | 39        | 6           | 28     | 10.34                 | 34 656                   |
| Chongqing       | 16 412        | 2 132    | 13 746    | 94          | 440    | 98.96                 | 4 139 621                |
| Sichuan         | 41 366        | 8 696    | 21 914    | 6 384       | 4 372  | 161.50                | 7 907 328                |
| Guizhou         | 10 345        | 2 439    | 5 827     | 150         | 1 929  | 120.00                | 411                       |
| Yunnan          | 27 484        | 2 554    | 20 383    | 3 305       | 1 242  | 268.53                | 6 668 793                |
| Xizang          | 11 100        | 2 045    | 1 628     | 6 160       | 1 267  | 31.73                 | 3 212 600                |
| Shaanxi         | 11 736        | 2 340    | 8 250     | 519         | 627    | 50.82                 | 1 487 243                |
Provinces | No. of hazards | Threatens | No. of people (Million) | Properties (Million Yuan)
--- | --- | --- | --- | ---
Gansu | 11 687 | 4 101 | 3 204 | 2 917 | 230.54 | 10 233 457
Ningxia | 3 604 | 445 | 1 646 | 812 | 18.73 | 762 307
Qinghai | 2 498 | 524 | 659 | 961 | 7.70 | 74 194
Xinjiang | 11 653 | 5 271 | 3 701 | 1 902 | 14.12 | 585 974
Total | 287 916 | 68 419 | 142 377 | 33 524 | 43 596 | 1 587.49 | 51 233 043

Notes: ① data came from provincial departments related with geo-hazards in China.
② "Others" means other types of geo-hazards except for collapse, landslide and debris flow, and mainly includes land collapse and land fissure, excluding land subsidence.
③ "-" means un-statistical data or no data.

3.2 Losses caused by sudden geo-hazards based on statistics

Sudden geo-hazards mainly include collapse, landslide, and debris flow. Since 2012, there were 63,396 sudden geo-hazards in mainland China, including 11,873 collapses, 47,066 landslides, and 4,457 debris flows. They caused 2,488 deaths or missing people and direct economic losses of about 30 billion Yuan (Ministry of Land and Resources of PRC, from 2012 to 2017).

The statistical data indicated that the total amount of losses caused by geo-hazards is inversely proportional to the scale and grade. Small, middle, large, and super-large scale geo-hazards account for 78.4 %, 16.9%, 3.6 %, and 1.1 % of all geo-hazards. In addition, death and economic losses account for 42 % and 60 % of total losses, respectively, due to the large number of small-scale geo-hazards, while the large scale and super-large scale geo-hazards account for 32 percent and 20 percent, respectively.

### Table 2 Statistics of the number and threat of sudden geo-hazards that occurred since 2012 in mainland China

| Year | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | In total |
|------|------|------|------|------|------|------|---------|
| In total | 13 898 | 14 703 | 10 543 | 7 903 | 9 471 | 6 878 | 63 396 |
| Landslide | 10 888 | 9 849 | 8 128 | 5 616 | 7 403 | 5 182 | 47 066 |
| Collapse | 2 088 | 3 313 | 1 872 | 1 801 | 1 484 | 1 315 | 11 873 |
| Debris flow | 922 | 1 541 | 543 | 486 | 584 | 381 | 4 457 |
| Death or missing of people | 375 | 669 | 400 | 287 | 405 | 352 | 2 488 |
| Direct | 52.8 | 101.5 | 54.1 | 24.9 | 31.7 | 35.4 | 300 |
In general, the number of geo-hazards was decreased annually, and geo-hazards occurred in 2017 were just a half of that occurred in 2012. Furthermore, the number of deaths and missing people caused by sudden geo-hazards and direct economic losses decreased. The decreasing trend of geo-hazard developments also indicated the greater efficiency of prevention and mitigation.

4 Analysis
4.1 Susceptible zones of geo-hazards

According to topography, formation lithology and structure, and geomorphologic evolution, and based on the susceptibility of collapse, landslide, and debris flow, mainland China can be divided into three susceptible zones: high, middle, and low susceptible regions, respectively. And the characteristics of every zones are as follows:

First, the high susceptible zones of geo-hazards cover an area of $1.31 \times 10^6$ km$^2$, accounting for 13.6% of the total territory area, and mainly include southwestern Yunnan-eastern Xizang, southwestern Sichuan-central Yunnan, Yunnan-Guizhou Plateau, Qingling-Daba Mountains, central Gansu-eastern Gansu Loess Plateau, Lüliang Mountain-Taishan Mountains, etc. Secondly, the middle susceptible zones of geo-hazards cover an area of $2.78 \times 10^6$ km$^2$, accounting for 29.0% of the total territory area, and mainly include southeastern Qinghai-Tibet Plateau, Guangdong-Guangxi-Hu'nan-Jiangxi, central Southern Hainan, eastern Hubei-eastern Hu'nan, Zhejiang-Fujian-Jiangxi, Ili River Valley Meddle-High Mountain, Yanshan Mountain-Eastern Liaoning-Western Liaoning, and Changbai Mountains, etc. Finally, beyond the high and middle susceptible zones of geo-hazards, those are low susceptible zones, mainly central-western Qinghai- Tibet Plateau, central-eastern Helan Mountains, Yanshan Mountains, Da Hinggan ling-Xiao Hinggan ling, etc. The mountainous and hilly regions in the southeast, middle south, southwest, and northwest of China are still the high prone regions of geo-hazards.
4.2 Spatial distribution characteristics of geo-hazards

The mountainous areas account for two-thirds of national territory areas, with large topography differences. Due to the influences of topography and geomorphology evolution, formation lithology, slope structure, and fault, geo-hazards show some distribution regularities.

According to the analysis of development, occurrence, and geological environment of sudden geo-hazards, it showed that geo-hazards had the characteristics of concentrated distribution along with steepening zone of the topographical stage, e.g., in the eastern margin zones of the Qinghai Tibet Plateau, Yunnan Guizhou Plateau, Qinba Mountain, Loess Plateau, Tianshan Mountain, and Qilian Mountain, etc. and in the transition from the first zone to the second one, as well as in the southern area of the middle and lower reaches of the Yangtze River, Southeast mountainous and hilly regions, etc., in the transition from the second zone to the third one.

The geo-hazards are mainly distributed in high mountainous and valley areas in southwest regions, hilly regions of Qinba regions, hilly regions of Hunan, Hubei, and Guangxi, and mountainous and hilly regions of southeast coastal areas and eastern Liaoning.
areas, with characteristics of the linear distribution of large landslide, debris flow along with active structural zone and valley.

Formation lithology and slope structure controlled the types, scales, and susceptibility in concentrated contiguous regions and zoning areas of geo-hazards. From the view of spatial distribution, the height differences between peak and valley can be over 2,000 m in transition steepening zones, mountainous areas, and each stage's edged zones. Because of the relatively large terrain slopes, many empty faces of the slope, and loose deposits in the areas, these areas are more prone to collapse, landslide, and debris flow. Collapse and landslide mainly occurred in the second landform stages and fluctuant hilly areas surrounding the stages. They developed most in middle fluctuant hilly areas, accounting for 34.2% of the total number of collapses landslides. Debris flow mainly occurred in the transition zones between the first and second stages. It developed most in large fluctuant hilly areas, accounting for 33.4% of the total number of debris flows.

### Table 3 Number percentage of collapse, landslide and debris flow in different terrains

| Types            | Terrains       |
|------------------|----------------|
|                  | >2500m | 1000-2500m | 500-1000m | 200-500m | <200m |
| Collapse & Landslide | 0.6%    | 27.1%      | 34.2%      | 23.4%    | 14.7% |
| Debris flow      | 2.4%    | 33.1%      | 30.3%      | 16.3%    | 17.9% |
The major engineering and geological formation complex susceptible to collapse and landslide include special strata such as loess in northwest areas and its underlying formation in Neogene, Xigeda in southwest regions, sandstone clastic rock, soft and hard interphase mudstone, coal and shale clastic rocks, and carbonate rock with the interstratified formation in Sichuan basin.

4.3 Time distribution characteristics of geo-hazards

The occurrence time of geo-hazards in China is seasonal under natural conditions. Firstly, from the interannual aspect of the geo-hazards statistics, more than 13300 new geo-hazards were triggered annually, more than 12,800 geo-hazards were cured, and the net increase in geo-hazards was about 5000 each year (Ministry of Land and Resources of PRC 2012-2017). Therefore, the numbers of geo-hazards in China were maintained at a high level from 2012 to 2017. Secondly, during the rainy season of 2012-2017 (May to September), more than 54,000 geo-hazards occurred, accounting for about 85% of the total disasters. After the rainy season (October to April of the following year) from 2012 to 2017, there were about 9000 geo-hazards, accounting for about 15% of the total disasters. Non-flood geo-hazards mainly
occurred in Chongqing, Guangxi, Guangdong, Fujian, Yunnan, Jiangxi, Hubei, and Hunan in the south and Shaanxi, Gansu, Shanxi, and Xinjiang in the north. In addition, several geo-hazards were triggered by human reasons that resulted in more than 5 deaths and disappearances in the non-rain season. For example, in 2017, “1.20” small landslide disaster in group 3: Benhe village, Chengguan Town, Nanzhang County, Xiangyang City, Hubei Province, with a volume of 200 m$^3$, resulted in 12 deaths and disappearances. Likewise, “10.21” small landslide disaster in group 19: Yecha village, Hongtu Township, Wanzhou District, Chongqing City, with a volume of 240 m$^3$. In 2016, the “2.8” small-scale collapse disaster in Du’an County, Hechi city, Guangxi province, with a volume of 2,250 m$^3$, caused the death and disappearance of 6 people.

According to the general situation of geo-hazards triggered in recent 20 years, the high-incidence period of collapse, landslide and debris flow disasters in China is closely related to the rainy season. Geo-hazards were triggered mainly in May to August every year, and the number of disasters was over 80% of the total. It peaked in July. In China, the high-incidence period of geo-hazards triggered in the southeast is earlier than that in the northwest; furthermore, the high-incidence period of geo-hazards triggered by rainfall in the rainy season is characterized by gradual delay from the southeast to the northwest.

Fig. 3: The provincial high-incidence period of geo-hazards
5 Discussion

5.1 Influence of rainfall on geo-hazard

Among geological and environmental factors, heavy rainfall is the major and most important one to reduce geo-hazards from 2012 to 2017. According to China’s geo-hazards database, the high-incidence time of the collapse, landslide, and debris are closely related to rainfall. As affected by the physico-geographical environment, rainfall in China generally tends to decrease from SE to NW gradually, and local rainstorm concentrates in western mountains. According to China’s rainfall contour, the annual average rainfall at the south of the Qinling mountains-Huaihe River Line is above 800 mm, showing abundant rainfall and a humid region. Rainfall is rare towards the north line, and the region is semi-arid and arid. Taiwan, the hilly area of the coastal region of south China, and some boundary areas of northwestern Yunnan Province and southeastern Xizang(Tibet) Autonomous Region have an average annual rainfall above 2,000 mm. In the west, such as in Toksun in Xinjiang Uygur Autonomous Region, the average yearly rainfall is merely 7.1 mm. Rainfall in China varies greatly with the season.

| Amount of precipitation/mm | Hazard types | Amount of precipitation/mm | Hazard types |
|-----------------------------|--------------|----------------------------|--------------|
|                            | Collapse/landslide | Debris flow | Collapse/landslide | Debris flow |
| <75                         | 0.20%         | 0.80%         | 500–600        | 3.20%        |
| 75~100                      | 0.70%         | 1.50%         | 600–800        | 6.30%        |
| 100–150                     | 1.40%         | 2.90%         | 800–1000       | 16.90%       |
| 150–200                     | 2.20%         | 3.30%         | 1000–1200      | 14.80%       |
| 200–300                     | 0.30%         | 2.50%         | 1200–1400      | 17.00%       |
| 300–400                     | 1.60%         | 8.00%         | 1400–1600      | 19.20%       |
| 400–500                     | 3.40%         | 17.50%        | ≥1600          | 12.70%       |

The development period of major geo-hazard is generally from May to August. During this period, the number of hazards accounts for over 80% of that. On the other hand, July is the peak period of geo-hazards developments (Fig.4). In general, the peak period when the most geo-hazard occur per month in southeast areas is earlier than that in northwest regions. Thus, the peak period of geo-hazards with rainfall features in the wet season has gradually developed characteristics from southeast to northwest.
Fig. 4: Percentage number of collapse, landslide, and debris flow in each month in mainland China

Water is not only an essential constituent of debris flow but also a triggering condition and transportation medium. There are three basic parameters in the rainfall process: total rainfall, rainfall time, and rainfall intensity. The values of the three parameters must reach a certain degree to trigger geo-hazards in the slope with specific geological background and mechanical environment. In the beginning, the rainfall will form stagnant water in the shallow surface of the slope, which will increase the overall water content of the soil layer, increasing the self-weight of the slope body and the gradual increase of its potential energy. In contrast, the water body brought by the rainfall will continue to infiltrate and reach the groundwater position. As a result, the groundwater level of the water body rises, increasing the gap between the slope and the mountain bodies, reducing the friction angle, and increasing the permeability along the landslide direction. Because the soil is saturated, a surface runoff will form. The rainwater washes down along the slope to cause a dynamic water pressure. When the rainwater flows down the slope, it erodes the slope angle, further destroy the original balance, and then a landslide occurs right after the balance of various forces is destroyed. Contrarily, suppose the total amount of rainfall has insufficient energy to penetrate and soften the rock soil layer and cause a landslide because of too short rain duration, the rainwater will only infiltrate the shallow surface. Thus, not enough to affect the structure of the slope bottom. If the rainfall intensity is too small, the water body is discharged through the rocky soil perforations, and the water in the rocky soil does not reach saturation.
Different types of rainfall set off different geo-hazards. Geo-hazards triggered by typhoons are consistent with their paths and times. Small collapses and shallow landslides often occur in typhoons’ rainfall processes because of the ample rain, short time, and large wind force. On the other hand, due to the long duration and vast rainfall, the rock and soil are fully saturated, so large landslides and the period of continuous heavy downpours often triggers debris flows. In addition, geo-hazards often occur in the local area and on that day when the local rainstorms happen.

Under natural conditions, there are some transformation relations among collapses, landslides, and debris flows. For example, the continuous accumulation of collapse rock masses causes landslides in the process of weak rainfall. On the other hand, large solid materials brought by collapses and landslides are easy to produce debris flows under the action of relatively open terrain, high and steep surrounding mountains, broken mountain bodies, poor vegetation growth, and heavy rainfalls.

5.2 Influence of earthquake on geo-hazard

China is located in the high-prone regions, and earthquakes are also one of the major causing factors of geo-hazards. After each earthquake, many landslides, collapses, and debris flows occur in disaster and nearly influence areas, which cause heavy casualties and property losses. For example, on August 13, 2010, a super-large debris flow happened at Wenjiagou, in Mianzhu, Sichuan province, in a high-intensity area, and generated approximately 4 million m$^3$ of sand and mud, which caused a total of 14 people’s death or missing. On the same day, Hongchungou, located at the epicenter of the Wenchuan earthquake, also experienced a super-large debris flow, resulting in the submerging of new Yingxiu county and the death of 13 people, 59 missings, and over 8,000 people were forced to relocate. Nationally, secondary disasters caused by the earthquake have large scale and severe losses, and they are easy to occur in susceptible areas.

An earthquake could loosen slope soil and rock structures. Under the repeated vibration shock by the earthquake, rock and soil masses are dislocated along the original or new soft structural planes and provide abundant loose materials for debris flow. In addition, the earthquake produces fractures and faults, which favor seepage of rainfall and melted snow. Thus, after the earthquake, landslides or collapses often happen due to rainfall and snowmelt. Generally, earthquakes and simultaneous (co-developing with an earthquake) landslides occur
in the rainy season or during rainstorms or snow melting. In the dry season, slopes are dry and have high stability; simultaneous landslides rarely develop. Post-developing (follows an earthquake after a very long time) landslides are often formed.

![Image of a sketch of geo-hazards triggered by fracture activities initiated by earthquakes](image)

**Fig. 5: A sketch of geo-hazards triggered by fracture activities initiated by earthquakes**

### 5.3 Influence of improper human engineering activities on geo-hazard

With the rapid social and economic development in mountainous areas and promotion of urbanization, improper engineering activities such as slope cutting, mining activities, and water affairs destroy the geological environment, leading to severe geo-hazards disasters and an increasing trend of their developments. There is a common phenomenon of a mountain to ditch and environmental disturbance in the construction of mountainous towns, roads, communication facilities, water conservancy and hydropower projects, and other infrastructure. In the case of insufficient understanding, prevention, and control of geo-hazards, it is possible to form major geo-hazard risks. For example, in May of 2001, a landslide took place at Gangkou town in Wulong county, leading to the collapse of a nine-story building and the death of 79 people due to improper engineering slope cutting. In June of 1980, there was a collapse at the phosphorite area in Yichang, Hubei, because of mining activities, resulting in the death of 307 people. Also, a large-scale landslide happened at Qianjiangping of Hubei in July 2003 because of water storage, leading to the death of 24 people and rendering over 1,100 people homeless. The pattern of geo-hazards induced by improper human engineering activities is complicated and needs additional investigation on the failure mechanisms of unstable slopes caused by improper engineering activities.
5.4 Chain of geo-hazards

Based on field observations, secondary disasters are often induced. This kind of disaster phenomenon usually has continuous or chain characteristics and forms the geo-hazards chain. For example, the chain of rainstorm-collapse-landslide-debris flow is very common in mountainous areas.

Generally, clastic rocks and soft, flaky metamorphic rocks mainly cause collapse and landslide. They are lithologically dominated by mudstone, shale, slate, soft rock beds containing carbonatites, argillization beds, and fractured structural beds. After water softening, these soft beds feature low shearing strength, form soft sliding surfaces, and easily cause collapse and landslide. In snow and ice melting seasons, seasonally frozen ground brings water, which impacts the stability of rock/soil slopes and triggers collapse and landslide. Loose accumulation deposits produced from collapse and landslide, slope residues on mountains slopes, and pluvial alluvial sediments within valley beds are the sources of solid materials of debris flow. Debris flows easily occur under certain rainfall conditions.

Fig. 6: High-level rock landslide and its formation mechanism
6 Suggestions for geo-hazard prevention and mitigation

According to the forecast and analysis on the development of geo-hazards in 2017, there was a noticeable increasing trend of extreme weather cases in China, which suggested that middle and high magnitudes of the earthquake will be in a frequently-occurring stage. In addition, with social and economic development, human engineering activities will still be frequent. Therefore, numerous suggestions on geo-hazard prevention and mitigation are proposed as below:

(1) Deepening the investigation and assessment of geo-hazards. Developments should be coordinated in economic and strategic regions such as Yangzi, Beijing, Tianjin, and Hebei. It is necessary to carry out geo-hazards and risk investigations as well as assessments on the scale of 1:50,000 to 1:10,000 or more accurate scales to clarify the background of geo-hazards conditions in places such as Three Gorges areas, South-to-North Water Diversion areas, and engineering areas along the high-speed railway.

(2) Promoting the capacities and techniques for supporting and serving the geo-hazards prevention and control. It is necessary to conduct professional monitoring in significant geo-hazards potential sites and promote group and individual monitoring. It is crucial to improve the technical and standard system of geo-hazards prevention and control, promote scientific knowledge regarding the mechanism, identification, and pattern recognition of geo-hazards to enhance the risk assessment research of hazards. Moreover, it is beneficial to promote the applications of new theories, technologies, and methods.

7 Conclusions

Since 2012, sudden geo-hazards such as landslides, collapse, and debris flow have become major hazards. Through the analysis of the general situation and geo-hazards characteristics in this period, these can be found in recent years:

(1) Landslide, collapse, and debris flow are still the primary geo-hazards, and the scale is mainly middle and small. Small scale geo-hazards have large numbers and cause large amounts of losses, while super-large and large scale geo-hazards cause significant events with mass deaths and casualties. The geo-hazards damage showed low deaths and high economic properties.
(2) There are substantial regional differences in the development and distribution of geo-hazards, which are distributed densely along with steepening zone of the topographical stage.

(3) It is apparent that the occurrence time of geo-hazards in China is seasonal. As a whole, the number of geo-hazards increases moderately every year, and the rainy seasons are the primary development periods of geo-hazards.

(4) Extreme weather, seismic activity, and climate warming make geo-hazards frequently accompany floods, earthquakes, avalanches, and other disasters. Rainfall is one of the major inducing factors of geo-hazards relatively strong and consistent in spatial and temporal distribution between them.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

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