Spatial Distribution and its Control Factors of Landslides in Longxi County, Gansu Province, China

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Abstract. In this study, landslides in the entire Longxi County, Gansu, located in the western part of China's Loess Plateau, were interpreted using high-resolution optical remote sensing images from the Google Earth platform. A comprehensive and detailed landslide distribution map was prepared, which includes 3,741 landslides. Six factors, including elevation, slope, aspect, slope position, distance to fault, and lithology, were selected to examine their controls to the landslides in the study area. The findings show that the area between 1800 and 1900 m above sea level has a high incidence of landslides. The largest number of landslides was observed within the range of slope 15°–20°. Slopes facing south are more prone to sliding. The lower and middle belts of the slopes show higher landslide susceptibility. The number and area of landslides initially increased, then decrease as the distance to the fault increases. The Cenozoic strata, especially the regions covered by Quaternary sandy loess and the Tertiary sandy mudstone, are the main areas where landslides occur. The results would be helpful in the prevention and mitigation of landslide hazards and disaster relief.

Keywords: Longxi County, Loess Plateau, Google Earth, GIS, Spatial distribution of landslides.

1. Introduction

Landslides are a common geological hazard, which can cause severe casualties and economic losses [1-6]. China is one of the countries with frequent landslides globally, especially in the west, where loess is widely distributed, prone to land sliding. The area covered by loess in China is about 6.31×10⁶km², of which the area of Loess Plateau is about 3.17×10⁶km²[7, 8]. As a result, loess landslides have become a major concern in geotechnical engineering, engineering geology, and geography, with numerous studies [9-12], including the mechanism and spatial distribution of landslides in the Loess Plateau. Research suggests that the distribution of loess landslides is typically featured by clusters with obvious north-south zoning, dense in the south and gradually sparse to the north[13, 14]. Researchers have analyzed the relationship between landslides and some influencing factors to further address this issue and found that topography affects landslide distribution. They additionally obtained the landslide high incidence intervals of some influencing factors[15, 16].
on these results, some scholars have deeply studied the sensitivity of regional landslides to different influencing factors\cite{17,18}, suggesting that height, length, and angle of slopes significantly impact the size distribution of landslides in the loess areas\cite{19,20}.

Despite many research results on landslides in the Loess Plateau, no complete landslide database has been prepared for Longxi County in the west of this vast region (Figure 1). Therefore, to fill this gap, we used the high-resolution remote sensing images from the Google Earth platform to carry out artificial visual interpretation of landslides in this area. In addition, we used the ArcGIS platform to make statistics on the number and area of landslides, produced a comprehensive and detailed map of the landslide distribution (Figure 2), and analyze the relationship between landslides and control factors, including elevation, slope, aspect, slope position, distance to faults, and lithology. The results can provide a basis for understanding the development degree and distribution patterns of landslides in Longxi County and scientific and technological support for the prevention, mitigation, and relief of landslide hazards.

![Figure 1. Shaded map showing the location of the study area (encircled by the black line).](image1)

![Figure 2. Landslide distribution of the study area.](image2)

2. Study area
Longxi County (34°50′–35°23′N,104°18′–104°53′E) is located in the southeast of the Gansu Province, middle of Dingxi City, the upper reaches of the Wei River, bordering Tongwei County in the east, Wushan and Zhang County in the south, Weiyuan County in the west, and Anding District of Dingxi City in the north. It stretches 52 km from east to west and 60 km from north to south, with a 2,404.865 km² area. The county's terrain is higher in the northwest and lower in the southeast, with elevations 1552–2707 m. Longxi County belongs to the Longxi spiral structural system, sandwiched between Neiguan-Nanshan uplift belt and Wushan fault uplift\cite{21}. The Wei River is the main drainage in the study area. The lithology of strata in the study area includes eight types of rocks according to stratigraphic ages: pre-Sinian hornblende gneiss, Quartzite of Niutouhe Group\cite{22} of Lower Paleozoic, gray shale of Devonian-Carboniferous, Permian brown-gray limestone, Triassic gray-green thick-layered hard sandstone, Cretaceous purple shale, Tertiary red mudstone, sandy mudstone mixed with fine sandstone and coarse red sandstone mixed with medium-thick glutenite, gravel, secondary alluvial loess, sandy loess, and loam layers of Quaternary. Longxi is located in the mid-latitude inland, with temperate continental monsoon climate, mainly in temperate and semi-arid areas. The annual average precipitation is 445.8 mm, and the evaporation is 1,440 mm.
3. Data and methods

3.1. Remote sensing images and geological data
This study used two sources of remote sensing images: (a) Google Earth platform; (b) The Earth Observation System Data and Information System (EOSDIS) of NASA (https://search.asf.alaska.edu/#/). The remote sensing images of the Google Earth platform have high resolution and high coverage, which provide an excellent convenience for landslide interpretation. However, the ALOS satellite images with 12.5 m resolution obtained from NASA’s EOSDIS are slightly affected by clouds, day and night, and weather.

The geological data (faults and lithology) come from 1: 200,000 national geological maps, including the Dingxi sheet (I~48~ (03)) and Longxi sheet (I~48~ (09)). These maps are provided by China Geological Survey(https://www.cgs.gov.cn/). According to the strata and lithology of the landslides in the study area, the lithology is subdivided into six categories (Figure 3). The descriptions of lithology and stratum are shown in Table 1.

![Figure 3. Stratum distribution map of the study area. Codes are shown in Table 1.](image)

| No. | Strata     | Lithology                          |
|-----|------------|------------------------------------|
| 1   | Sinian(Z)  | Horn flash medium-long gneiss       |
| 2   | Triassic(T)| Gray-green thick-layered hard sandstone |
| 3   | Cretaceous(K)| Purple shale                      |
| 4   | Tertiary(N/E)| Mudstone, sandy mudstone, and glutenite |
| 5   | Quaternary(Q)| Gravel, sandy loess, and loam layer |
| 6   | other      | Quartzite, gray shale, granite     |

Table 1. Lithology division of the study area.

3.2. Methods

3.2.1. Landslide identification
Automatic and manual visual interpretations of optical remote sensing images are used to recognize landslides. A comparison of the interpretation results of the two methods was conducted by Xu et al.[23]. The Google Earth images are continuous and cover the entire study area, with resolutions that meet landslide interpretation requirements. We used the Google Earth platform to perform manual visual interpretation of high-resolution remote sensing images, an objective and accurate method in previous studies[24, 25]. Figure 4 depicts landslide interpretation in four areas of Longxi County.
3.2.2. GIS spatial analysis of landslides

We used the surface analysis function of the ArcGIS software to process the DEM and obtained the slope and aspect of each landslide. The slope positions came from the geospatial data cloud website in some previous studies [26, 27], while the relative position index (RPI) was introduced to define the slope position in this study [28]. The RPI of a point on the slope is defined as the ratio of the shortest Euclidean distance from the point to the valley and the sum of the shortest Euclidean distances from the point to the ridge and valley, respectively (as in Equation (1), Table 2). After processing a 1:200,000 national geological map, we established the relationship between landslides, faults, and lithology distribution in the study area.

\[
RPI = \frac{\text{the shortest Euclidean distance from the point to the valley}}{\text{the sum of the shortest Euclidean distance from the point to the ridge and valley}}
\]  

(1)

| Slope position   | RPI                  |
|------------------|----------------------|
| Valley           | \( RPI < 0.1 \)      |
| Lower mid-slope  | \( 0.1 \leq RPI < 0.4 \) |
| Mid-slope        | \( 0.4 \leq RPI < 0.6 \) |
| Upper mid-slope  | \( 0.6 \leq RPI < 0.8 \) |
| Ridge            | \( 0.8 \leq RPI \)   |

Table 2. Definition of slope positions.

4. Results and analysis

4.1. Landslides inventory

We found 3,741 landslides in Longxi County using high-resolution remote sensing images from the Google Earth platform. The total area of the landslides is 222.74 km², with the largest landslide area of 2.01 km² and the smallest 501.68 m². There are 702 places with a size greater than 100,000 m², 1,901 places with a size 10,000–100,000 m² and 1,138 places less than 10,000 m².

4.2. Spatial distribution of landslides
In this study, the spatial distribution of 3,741 landslides was analyzed. The main aspects affecting landslides generally include topography, earthquakes, and geology; hence we considered six influencing factors: elevation, slope, aspect, slope position, distance to faults, and lithology. Referring to a previous study [29], we chose landslide number density (LND) and landslide area percentage (LAP) as two indicators of landslide abundance to measure the spatial distribution of landslides in Longxi County under each influencing factor. As a result, the LND and LAP of the whole study area are 1.556/km² and 9.3%, respectively.

The elevation of the whole study area ranges from 1552 m to 2707 m. According to the elevation, the study area was divided into eight intervals: 1552–1800 m, 1800–1900 m, 1900–2000 m, 2000–2100 m, 2100–2200 m, 2200–2300 m, 2300–2400 m, and 2400–2707 m (Figure 5). The landslide area is larger in the middle and smaller on both sides of this sequence. The interval with elevations 2000–2100 m has the largest landslide area, accounting for 27.1% of the landslide area in the entire study area. The density of landslides was also higher in the middle and lower elsewhere, with the largest landslide value of 879, and density of 2.286/km² in the interval of elevation 1800–1900 m. The relationship between the landslides and elevations is shown in Figure 5.

Slope angle is the steep degree of surface units, which determines the exposed surface and, to some extent, landslide occurrence. The study area's slope angles range from 0 to 61.6°, divided into eight intervals (Figure 6). Gentle slope terrain dominates the study area, and the partition area is larger in the middle and smaller on both sides. LND increases with the growth of slope angle, indicating that the higher the slope is, the more prone to land sliding. For example, LND reaches 5.022/km² in the interval of 35°–61.6°. There are 1,135 landslides in the slope interval of 15°–20°, accounting for 30.3% of the total landslides. The relationship between landslides and slope angles is shown in Figure 6.

The slope aspect (facing direction) significantly affects mountain ecology, thus affecting the occurrence of landslides. The area of eight aspect divisions in the study area is approximately equal, and LND in the southeast, south, south-west, and west directions is slightly higher than that of the other four aspect divisions. Among them, landslides in the south direction have the largest number of 587, and a total area of 37.4 km², accounting for 16.8% of the landslide area in the study area. The relationship between landslides and aspects is shown in Figure 7.

Slope position affects the landslides occurrence and reflects the landform type where the slope is located. The research region's landslide area is positively connected with the slope position's partition area, with a general trend of smaller on both sides and greater in the middle (abscissa in Figure 8). Landslides on the lower-mid-slope have the most of them, with 1,595 total and a density of 2.480/km². Figure 8 depicts the link between landslide and slope position.
Active faults are closely related to the occurrence of earthquakes, thus affecting their occurrence. The statistical results show that the number and area of landslides in the study area increase with the distance to the faults but later decrease. Landslides in distances 15–20 km from the faults have the largest number of 885. LND in the interval of 20–25 km to the fault is the highest, 2.503/km². The relationship between landslides and the distances to the fault is shown in Figure 9.

The influence of stratum lithology on landslides is remarkable because it is the material basis for slope failure. The strata in the study area include Sinian (Z) to Quaternary (Q). The area of (Q) strata is 1,648.2km², accounting for 68.5% of the total area of the study area, where 2,468 landslides are present, with LND1.497/km². The Tertiary (N, E) strata have an area of 684.8km², accounting for 28.5% of the total area of the study region, with 1,222 landslides and LND 1.784/km². This finding suggests that landslides mostly occur in the Cenozoic strata, particularly in locations covered by Quaternary sandy loess and Tertiary sandy mudstone. The relationship between landslides and lithology is shown in Figure 10.

**5. Conclusions**

The study area of this work is the entire Longxi County, Gansu Province, located in the western part of the Loess Plateau of China, with a total area of 2,404.865km². Interpreting the remote sensing images, we identified 3,741 landslides with a total area of 222.74km². This study used LND and LAP as evaluation indexes for statistics. Results show that the LND and LAP of the study area are 1.556/km² and 9.3%, respectively. We examined the relationship between landslides and six influencing factors of topography and geology. The results show that the places with elevations of 1800–1900 m have a high incidence of landslides. The largest number of landslides appears in the range of slope angles 15°–20°, and the higher the slope is, the more easily landslides occur. The slopes facing south are more prone to slide. The landslide area in the study area is positively correlated with the partition area.
of slope positions; lower-mid slopes show higher sliding susceptibility. As the distance to the fault increases, the number and area of landslides in the study area show a trend of first increasing and then decreasing. The Cenozoic strata, especially the areas covered by the Quaternary sandy loess and the Tertiary sandy mudstone, are the main areas where landslides occur. The results can provide a basis for understanding the distribution pattern and mechanism of landslides in Longxi County and offer scientific and technological support for preventing, mitigating, and relieving landslide hazards.

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References
[1] Wen H J, Zhang Y X and Liu Y 2004 Research trends and development trends of landslide prediction at home and abroad Chinese Journal of Geological Hazard and Control 15 1-5
[2] Wang G X 2005 Key technologies and treatment methods in landslide prevention and control Chinese Journal of Rock Mechanics and Engineering 24 3818-27
[3] Brabb E E 1991 The world landslide problem Episodes 14 52-61
[4] David P 2012 Global patterns of loss of life from landslides Geology 40 927-30
[5] Trigila A, Ladanza C, Esposito C and Scarascia-Mugnozza G 2015 Comparison of logistic regression and random forests techniques for shallow landslide susceptibility assessment in Giampilieri (NE Sicily, Italy) Geomorphology 249 119-36
[6] Cui Y F, Zhou X J and Guo C X 2017 Experimental study on the moving characteristics of fine grains in wide grading unconsolidated soil under heavy rainfall Journal of Mountain Science 14 417-31
[7] Li T L, Long J H and Li X S 2007 Development types of loess landslide and its spatial prediction method Journal of Engineering Geology 15 500-5
[8] Xu Q, Peng D L, Qi X, Dong X J, Li Y J and Ju Y Z 2016 Study on basic characteristics and genetic mechanism of dangchuan 2# landslide in heifangtai, Gansu Province on April 29, 2015* Journal of Engineering Geology 24 167-80
[9] Yin Y P, Zhang Z C, Li Z H, Zhang S Q and Yu J D 2004 Study on characteristics and disaster assessment of loess landslide in gaolan mountain, Lanzhou* Quaternary Sciences 24 302-400
[10] Xu L, Dai F C, Kuang G L, Tuan G H and Tu X B 2009 Analysis of typical engineering geological problems of loess landslide Chinese Journal of Geotechnical Engineering 31 287-93
[11] Qiu H J, Regmi A D, Cui P, Cao M M, Li J Z and Zhu X H 2016 Size distribution of loess slides in relation to local slope height within different slope morphologies Catena 145 155-63
[12] Derbyshire E 2001 Geological hazards in loess terrain, with particular reference to the loess regions of China Earth-Science Reviews 54 231-60
[13] Le Z X and Han Q X 1988 Distribution characteristics and macroscopic mechanism of landslides in the Loess Plateau China soil and water conservation 21-5
[14] Xu Z J, Lin Z G and Zhang M S 2007 Loess and loess landslide in China Chinese Journal of Rock Mechanics and Engineering 26 1297-312
[15] Cao D N, Zhang B X, Yan Y Q and Gan S J 2010 Landslide development law in Danjiangkou reservoir area journal of North China Institute of Water Conservancy and Hydroelectric Power 31 127-30
[16] Li M H, Chen Y and Guo G 2012 Statistical analysis of landslide development law in Goupitan reservoir area Journal of Guizhou University(Natural Sciences) 29 27-30
[17] Qiu H J, Cao M M, Liu W, Hao J Q, Hu S, Gao Y and Liu Q 2014 Study on variable dimension fractal characteristics of spatial distribution of regional landslides Geoscience 28 443-8
[18] Ma S Y, Qiu H J, Hu S, Pei Y Q, Yang W L, Yang D D and Cao M M 2019 Quantitative assessment of landslide susceptibility on the Loess Plateau in China Physical Geography 41 489-516

[19] Qiu H J, Cui Y F, Hu S, Yang D D, Pei Y Q, Ma S Y and Liu Z J 2019 Size distribution and size of loess slides in response to slope height and slope gradient based on field survey data Geomatics, Natural Hazards and Risk 10 1443-58

[20] Qiu H J, Cui P, Regmi A D, Hu S, Wang X G and Zhang Y Z 2019 The effects of slope length and slope gradient on the size distributions of loess slides: Field observations and simulations Geomorphology 300 69-76

[21] Pan J L, Tian W S and Fan X M 2018 Study on geological disaster characteristics and vulnerable areas in Longxi County, Gansu Province Western Resources 3 100-1

[22] Song Z G, Zhang Z Y, Zhang M and Jia Q Z 1991 Decomposition of "Niutouhe Group” in Shaanxi-Gansu border and its tectonic significance* Journal of Xi'an Institute of Geology and Mineral Resources, Chinese Academy of Geological Sciences 31 1-14

[23] Xu C and Xu X W 2014 Construction of landslide basic data triggered by several major earthquake events in the early 21st century Seismology and Geology 36 90-104

[24] Xu C 2015 Preparation of earthquake-triggered landslide inventory maps using remote sensing and GIS technologies: principles and case studies Geoscience Frontiers 6 825-36

[25] Tian Y Y, Xu C, Xu X W and Chen J 2016 Detailed inventory mapping and spatial analyses to landslides induced by the 2013 Ms 6.6 Minxian earthquake of China Journal of Earth Science 27 1016-26

[26] Ma S Y, Xu C, Tian Y Y and Xu X W 2019 Risk assessment of Jiuzhaigou earthquake landslide based on logistic regression model Seismology and Geology 41 162-77

[27] Xu C, Tian Y Y, Ma S Y, Xu X W, Zhou B G, Wu X Y, Zhuang J Q, Gao Y X, Wu W Y and Huang X Q 2018 Landslide logging and distribution law in high intensity area of Haiyuan Ms 8.5 earthquake in 1920 * Journal of Engineering Geology 26 1188-95

[28] Skidmore A K 2007 Terrain position as mapped from a gridded digital elevation model International Journal of Geographical Information Systems 4 33-49

[29] Xu C, Ma S Y, Tan Z B, Xie C, Toda S and Huang X Q 2018 Landslides triggered by the 2016 Mj 7.3 Kumamoto,Japan, earthquake Landslides 15 551-64