Empirical relationships of the landslides in the Chinese Loess Plateau and affect factors analysis

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ABSTRACT

The CLP (Chinese Loess Plateau) is one of the most densely distributed landslides areas. The empirical relationships of the landslides in the CLP remain unclear, and its influencing factors are controversial. According to regional landslide data, this paper studies the relationships and discusses the factors affecting landslides in the CLP. The results show that the area ($A$) -volume ($V$) of landslides follows a power law trend described by $V = 1.53A^{1.19}$ and the frequency distribution range of $H/L$ (height drop ($H$)/travel length ($L$)) is between 0.2 and 1.0, more specifically between 0.2 and 0.4, accounting for 26.1% of the total landslides, indicating that the landslides primarily belong to long run-out landslides. The function of $V$ and $H/L$ of the landslides is followed by $H/L = 2.39V^{-0.102}$. About 87% of the landslide is distributed within the equilibrium or mature stages of the watershed. The landslide’s size increases, and the slope of the landslides are steeper with an increase in $H_i$ (hypometric integral). Meanwhile, the loess thickness, human activities, and slope effects on landslides induce landslide occurrence and have positive and negative effects on the landslides within the CLP. With climate change, the risk of landslides will increase in the CLP.

1. Introduction

Loess which, occupies approximately 10% of the Earth’s landmass, is a loose aeolian deposit of yellowish silt-sized dust formed during the past 2.5 Ma (Liu 1985; Li et al. 2020). It is widely distributed in arid and semi-arid regions in Eurasia, North America, Latin America, and Central Asia (Péczi 1990; Li et al. 2020). In China, loess is primarily distributed on the Chinese Loess Plateau (CLP), which has an area of approximately 640,000 km$^2$ and is located in the center of the Yellow River (Liu 1985, Figure 1(a)). The thickness of the loess deposits in this area varies from a few meters
to more than 300 meters and has the largest and thickest loess deposits in the world (Liu 1985). Loess is naturally deposited by accumulating wind-blown fine sand and clay components. The fine sand and clay components of loess contain various salt substances, such as KCl and NaCl, which are the primary substances that contribute to the solubility of loess in water (Zhang et al. 2013; Li et al. 2020; Zhang et al. 2020; Feng et al. 2020, 2021; Zhuang et al. 2021). This characteristic makes the loess very sensitive to water and environmental change and increases the loess’s susceptibility to erosion and loess-related geohazards (Derbyshire et al. 2000; Zhang and Liu 2010; Xu et al. 2014; Zhuang et al. 2018a). The slope failures are the most frequent form of loess-related geohazards with more than 50 landslides occurring every year in the CLP, resulting in human life loss, destruction of roads and railways, as well as decreasing useable farmland (Zhuang et al. 2018a; Juang et al. 2019).

The occurrence of landslides in the CLP are directly related to the prone failure of loess. However, they are primarily induced by human activities or precipitation (Zhuang and Peng 2014; Peng et al. 2015; Peng et al. 2019b). In the past decade, due to the severity and frequency of the landslides in the CLP as well as the increasing severity of problems caused by landslides in the CLP, the landslides have attracted the attention of many researchers. Their research interest is as follows: (1) The distribution and mobility characteristics of the landslides in the CLP. The unique characteristics of the long travel distances and the liquefaction prone landslides in the CLP were proposed (Zhuang et al. 2018a; Peng et al. 2019b; Qiu et al. 2020); (2) The soil properties of the landslides in the CLP. The clay content and mineral composition effects on the formation of the landslides in the CLP were studied. It was proposed that the salt content, such as NaCl and KCl in the loess has significant effects on its physical properties (Zhang et al. 2013; Fan et al. 2017; Zhuang et al. 2021); (3) The mechanism of landslides in the CLP. Researchers carried out numerous tests in order to study the landslide processes induced by water and human activities revealing that water is a key factor in decreasing the strength of loess and the landslides within the CLP. Human activities change the loess (loading and unloading) characteristics and induce landslides in the CLP (Zhuang et al. 2017; Zhuang et al. 2018a; Peng et al. 2018; Wang et al. 2019; 2020); (4) Prediction and risk assessment of the landslides in the CLP. The forecasted study based on the water content and displacement curves was carried out for landslides caused by rainfall and irrigation. It is believed that the advanced forecasts using SAR (Synthetic Aperture Radar) or UAV (Unmanned Air Vehicle) can prevent water infiltration into the loess and is an effective method to mitigate the landslides in the CLP due to the occurrence of the landslides having sudden adverse characteristics (Zhuang et al. 2017; Qi et al. 2018a, 2018b; Xu et al. 2019, 2020).

Although the relationship of loess landslide characteristics has been studied in detail, most of the regional relationships and characteristics of the landslides have been studied in-depth. For example, scientists studied the relationship and distribution characteristics of earthquake-induced and regional landslides in the CLP. This article studies the empirical relationships between landslide size, mobility characteristics, and hypsometric integrals based on more comprehensive and detailed landslide
The factors of slope, loess thickness, human activities, and climate changes that affect the occurrence of the landslides in the CLP are discussed.

2. Setting area

Four mountains surround the CLP: the Riyue Mountains in the west; the Taihang Mountains in the east, the Qinling Mountains in the south, and the Yinshan Mountains in the north (Liu, 1985, Figure 1(a)). The CLP is an area with the most concentrated loess distribution and is primarily distributed north of the Shaanxi province, east of the Gansu province, and shows the characteristics of being thin in the north and thick in the central and southern parts of the CLP.

Due to climate change during the deposition process, the loess is sequenced into layers of brownish-yellow loess and brownish-red paleosol that have been deposited. The factors of slope, loess thickness, human activities, and climate changes that affect the occurrence of the landslides in the CLP are discussed.

Figure 1. Landslides within the study area setting (a) and landform, loess stratigraphic profile (b) in the CLP. Source: Author, base data from https://geocloud.cgs.gov.cn/#/home and Google Earth.
during the Quaternary period (Liu 1985). The complete stratigraphic of the loess and paleosol deposited in the quaternary is shown in Figure 1b: Wucheng Loess (2.50–1.20 Ma; Q1), Lishi Loess (1.20–0.128 Ma; Q2), Malan Loess (0.128–0.01 Ma; Q3), and recently deposited loess (0.01 Ma; Q4) (Liu 1985, Figure 1(b)).

The CLP has three types of characteristic geomorphologies, loess platform (Yuan in Chinese) with a protruding flat and large plain, loess ridge (Liang in Chinese) with a convex and long ridge, and loess dome (Mao in Chinese) with a conical hill (Liu 1985; Li et al. 2020). The surface altitude ranges from 330 m to 3000 m above sea level. The Yuan, Liang, and Mao slopes are steep and prone to failure during rainwater infiltration, water irrigation, and slope cutting. The loess is highly subject to erosion due to the characteristics of the loess being “liked-Kast soil” which easily erodes during rainfall. The annual average sediment of the Yellow River into the sea is $2.56 \times 10^8$ t a$^{-1}$ (1987–2015), and most of the sediments come from the CLP due to soil erosion including mass sliding (Wang et al. 2010, 2016).

3. Data collection and methods

3.1. Data collection

The CLP is one of the most densely distributed and frequently occurring landslide regions. Landslides in this area are induced by rainfall and human activities (irrigation, loading, and unloading). Over the past 10 years, inventories, and databases of the landslides in the CLP have highlighted characteristics and have given us details about the spatial distribution of the landslides. The landslide data in the CLP was obtained via field investigations and reports by the geological environment monitoring station of Shanxi, Shaanxi, Gansu, Ningxia, and Qinghai provinces. The authors have conducted many field investigations and have in recent years updated the database with current landslide data. A total of 20,699 landslides were collected from the field investigations and reports within the CLP (Figure 1(a)). The landslides have been verified by field investigations or remote sensing images by authors in recent decades revealing that the landslides are primarily induced by rainfall and human activities. Landslides caused by earthquakes are not included in the study due to having been previously studied by other researchers (Sun et al. 2017; Zhuang et al. 2018b; Xu et al. 2020).

The data describes the locations, types, and features including, area, volume, and travel lengths of the landslides. The time of occurrence is based on field surveys and consultations with local villagers to approximate the time of occurrence. The landslide area is obtained from remote sensing images and topographic maps. The volume was obtained from field surveys according to the depth of the sliding surface and the original topography. Part of the landslide volume is gathered from the drilling data to obtain the sliding surface’s depth in order to estimate the volume of the landslide combined with the landslide area; some estimates in the field are based on topographic and sliding characteristics. The slope data of the landslide is gathered through topographic maps combined with the landform features around the landslide. Due to the landslides’ volume data, it is challenging to obtain the landslide area, volume, travel distance, and landslide depth. The data used in this paper is from the field
investigation survey. Area, volume, travel distance, and landslide depth data were collected and referenced from 3981 landslides.

3.2. Analysis method

3.2.1 Frequency distribution

The frequency distribution can be used to quantify the landslide distribution characteristics of size, depth, area, and volume of the landslides in the CLP according to the landslide inventories. The frequency of the density distribution feature is analyzed via Matlab software (Xie 2010). It shows the frequency distribution of each group and the difference in frequencies between each group. We obtained the maximum distribution frequency range and distribution characteristics of the landslides.

3.2.2 Volume–area scaling

The relationship between the volume and area can be described using a log–linear scaling which proposed by Guzzetti et al. (2009):

\[ V = \alpha A^\gamma \]  

(2)

where \( V \) is landslide volume, \( A \) is landslide area, \( \alpha \) is the coefficient, and \( \gamma \) is the scaling exponent. This relationship was exploited for both the area and volume of the landslide data and was plotted and fitted in a linear model. The \( \alpha \) and \( \gamma \) from the model were substituted into Eq. (2). The equation reflects the relationship between the landslide volume and area, which can estimate the landslides volume within the entire area with a limited number of measurements. Meanwhile, the equation can assess the landslide erosion rates in a given area according to the scaling exponent.

3.2.3 Volume–mobility scaling

The relationship between the \( H/L \) (height drop (\( H \))/travel length (\( L \))) ratio and the volume for the landslides in the CLP is set as a function followed by a power law curve (Legros 2002):

\[ H/L = KV^\beta \]  

(3)

where, \( K \) and \( \beta \) are the best fitting constants, and \( V \) is expressed in m³.

3.2.4 Hypsometric integral

Strahler (1952) used the shapes of the hypsometric curves to interpret the basin evolution stage. According to the hypsometric curves, the basins can be classified as youth, mature, peneplain or distorted. The hypsometric integral (\( H_I \)) calculated from the hypsometric curves is also a geomorphological parameter and can classify the stages of watershed development (Gajbhiye et al. 2014). Pike and Wilson (1971) suggested that the elevation relief ratio method is the most efficient compared to the other techniques and can estimate the hypsometric integrals. \( H_I \) can be expressed as:

\[ H_I = (m_e-min_e)/(max_e-min_e) \]  

(3)
where $H_I$ is the hypsometric integral, $m_e$ is the mean elevation, $min_e$ is the minimum elevation, and $max_e$ is the maximum elevation (Pike and Wilson 1971).

The $H_I$ value is expressed in a range from 0 to 1 and the high value represents the youthful stage, and the low value represents the older stage (Ritter et al. 1995). According to the basin evolution stage and the $H_I$ value, the basin evolution stage can be divided into three stages according to the $H_I$ value: Old, ($H_I \leq 0.3$), in which the watershed is fully stabilized; the mature stage ($0.3 \leq H_I \leq 0.6$); and the young stage ($H_I \geq 0.6$), in which the basin is highly susceptible to erosion (Strahler 1952).

4. Relationship

4.1. Depth and area

The distribution of the landslide’s thickness reflects the depth of the sliding surface. The landslide thickness has a wide distribution range from 1 m to nearly 100 m. However, the landslide thickness is primarily distributed from 5-15 m accounting for 66.7% of the total landslides, and the landslide thickness below 10 m accounts for 40% of the total landslides (Figure 2(a)). According to the classification of landslides associated with landslide sliding depth, the landslides in the CLP are primarily shallow.

Figure 2b shows the relationship between the depth and the area of the landslides. The depth and area data dots with positive correlation indicate low scatter as well as the landslide area affecting the sliding depth. The larger the landslide area, the deeper the sliding surface and the greater the increase of more than two orders of magnitude with increasing landslide area.

4.2. Size scaling

Landslide transport of soil is difficult to quantify due to regional landslide inventories, making it impractical to get the depth of each landslide sliding depth needed to determine landslide volume. Hence, the relationship between the landslide volume and the area relies on relatively few field measurements to predict volume ($V$) based on landslide area ($A$), meaning that the relationship depends on a volume-area scaling exponent. On a log–log graph of $A$ as a function of $V$, the data for the landslides follows a power–law trend described by $V = 1.53 A^{1.19}$.

Figure 2. Frequency distribution of landslide thickness (a) and the relationship between depth and area of the landslide in the CLP (b). Source: Author.
The $V-A$ scaling power-law trend of the globe landslide in other landslide regions was compared with that of the landslides in the CLP. Nearly all the $V-A$ scaling exponents fall within the 95% probability interval of the $V-A$ power-law trend of different slopes (Figure 3). The difference in the slopes affect the landslide’s erosion material, primarily the landslide per unit area, which can be used to calculate how much soil material is eroded away. The greater the slope of the $V-A$ power-law trend, the greater the erosion capacity of the landslide (Larsen et al. 2010; Jaboyedoff et al. 2020). The erosion capacity of the landslide in the CLP is larger when the area is smaller. However, the erosion capacity of the landslide in the CLP decreases when the area is greater than 100,000 m$^2$.

4.3. Mobility

The landslide mobility uses the $H/L$ ratio to express the maximum vertical-to-horizontal landslide displacement fraction. The $H/L$ ratio can help elucidate the relationship between landslide mobility and the size of the landslide (Hungr 1995; Legros 2002; Roback et al. 2018). Travel distance was estimated using a simplified polygon enclosure of the mapped landslides from which the lengths of the long and short axes are calculated. The height drop of the landslide mass was measured as the difference in elevation between the upper-most part of the source and the lowermost part of the deposit.

The frequency distribution of $H/L$ ranges between 0.2 and 1.0, more specifically between 0.2-0.4, accounting for 26.1% of the total landslides (Figure 4). Overall, landslides in the CLP were most mobile when the median $H/L$ is 0.53 when compared with other material landslides; for example, the median $H/L$ of marine volcanoclastic landslides is 0.55, the median $H/L$ of granodiorite landslides is 0.67, the median $H/L$ of submarine basalt and chert landslides is 0.76, and the median $H/L$ of mudstone, siltstone, and sandstone landslides is 0.73 (Bessette-Kirton et al. 2020). According to the classification of travel-distance landslides, the value of $H/L$ was less than 0.6. About 56% of the landslides in the CLP with a $H/L$ below 0.6 belonged to the long-
travel-distance landslide category. Meanwhile, a landslide will fluidize when the $H/L$ is below 0.17 (Wang 2000). About 5.5% of the landslides in the CLP had a $H/L$ below 0.17, indicating that the landslides in the CLP translate to a flow motion resulting in sliding longer distances.

A visual comparison of the relationship between landslide volume and $H/L$ in Figure 5 reveals that the $H/L$ ratio decreases as the volume increases. The result is consistent with many other studies on $H/L$ that found that the run-out distances decrease with increasing volume (Legros 2002). In our study, the $H/L$ ratio for the landslides in the CLP is set as a function of the landslide volume $V$ followed by a power law curve $H/L = 2.39 V^{-0.102}$ ($R^2 = 0.45$).

4.4. Hypsometric integrals

Hypsometric integrals have been widely used in geomorphology processes and hydrology characteristic analysis (D’Alessandro et al. 1999; Singh et al. 2008; Pérez-Pena et al. 2009). The occurrence of landslides is also related to landscape evolution and several studies have revealed that the $H_I$ corresponds to the erosion resistance rates (Lifton and Chase 1992; Hurtrez et al. 1999). This paper investigates the relationship between $H_I$ and the landslide characteristics in order to assess the influence of landscape evolution on landslide occurrence.

The $H_I$ of the CLP has a normal distribution, and the basin is in equilibrium or in the mature stage ($0.3 \leq H_I \leq 0.6$), accounting for 87.57%, and the young stage accounting for 8%. The landslide occurrence is primarily distributed in the equilibrium or mature stage ($0.3 \leq H_I \leq 0.6$), accounting for 87% of total landslides (Figure 6(a)). According to the relationship between the landslide characteristics and the $H_I$ in the CLP, the $H/L$ value decreases with an increase in $H_I$; thus, the landslides travel longer distances in the young basin (Figure 6(b)). The relationship between the $H_I$ value and the landslide volume and slope shows that the landslide size increases, and the slope becomes steeper with an increasing $H_I$ (Figure 7(c, d)).
5. Factors analysis

5.1. Does the thickness of loess affect the occurrence of landslides?

The CLP is known for its large accumulation area and high depth of loess (Liu 1985). The previous studies believed that the thickness of the loess is essential for the occurrence of landslides (Peng et al. 2019a; Shi et al. 2020). The accumulated depth of loess provides rich material for landslide occurrence. Loess is primarily distributed in eastern Gansu, north of Shaanxi, which is also the primary distribution area of the CLP landslides. Therefore, it is generally believed that landslides are prone to occur in areas where the thickness of the loess deposits is greater. Figure 7a shows the relationship between the landslide distribution and the thickness of the loess in the CLP. The number of landslides increases with a loess thickness of more than 150 m. The relationship between the number of landslides and the thickness of the loess shows a negative correlation. The landslides in the CLP are primarily distributed in the loess areas with a thickness of 100–150 m. The distribution frequency of the landslides also...
shows the same characteristics. According to the landform characteristics of the CLP, the areas with thinner loess coverage are the Gobi Desert where the landform is flat within the northern Shaanxi province. The areas with a greater loess deposit thickness are primarily distributed in the loess tableland area, for example, the Dongzhi, Xianyang tableland. The loess in these areas is deposited with a greater thickness and a flat landform resulting in areas not prone to landslide occurrences. Loess with a thickness of approximately 150 m is primarily distributed in the Liang, Mao loess plateau, where the landform process is rapid due to a steep slope and soil erosion, making the area prone to landslide occurrences. The distribution frequency of the depth of the landslides in the CLP shows that the landslides in the CLP do not positively correlate with loess thickness. Figure 7b shows that approximately 79.3% of landslides in the CLP with a depth less than 20 m and loess thickness is not a key factor affecting landslide occurrences. The thickness of the loess only provides the material to cause the landslide.

5.2. How do human activities affect landslides in the CLP?

Numerous researchers have conducted studies on the impact of human activity on landslides and analyzed the relationship between the occurrence of landslides and human activities, such as the relationship between the density of roads and landslides (Alexander 1992; Li et al. 2020), the frequency of landslide occurrence before and after the construction of reservoirs, and the impact of urbanization on the occurrence of landslides have been published (Tang et al. 2019). Human activity affects the landslide through vibrations caused by the construction of roads, engineering activities, and impermeable surfaces, for example maintaining urban areas, the need for extensive earthworks for roads and buildings, and interferences with natural drainage pathways have increased the susceptibility of landslides (Alexander 1992; Li et al. 2020).

Human activities that affect the occurrence of landslides are double-sided. Human activities both promote landslide occurrences and can prevent landslide occurrences; thereby, increasing the human dependency on both the environment and the impact of environmental improvement; for example, greening projects, slope prevention, and slope drainage projects. The relationship between the landslide’s spatial distribution and that of towns was analyzed to determine the relationship between human activities and the landslide occurrence in the CLP. The landslide frequency increases when
the distance increases to 20 km and decreases when the distance is greater than 20 km (Figure 8(a)). Furthermore, the landslide frequency at a distance of 5 km from any town or city is the lowest, and the landslide frequency at a distance of 20 km is the highest. The landslide frequency begins to decrease with an increase in distance. The distribution characteristics indicate that the number of landslides is minimal, although human activities are greatest in areas closest to towns and cities (<5 km). Human activities need to pay close attention to the slope’s stability in these areas and try their best to stabilize the slope during engineering and construction. This is due to landslides having a severe impact on humans in this region with a high population density. As distance increases, human activities are farther from cities and towns. The impact of human activities on slopes is not considered high due to the area being relatively far from the densely populated human settlements. Therefore, human activities in this area have a more significant impact on the geological environment resulting in greater landslide occurrences. Human activities gradually weaken as distance increases, decreasing the occurrence of landslides. Therefore, it can be divided into four areas according to the distribution characteristics: (1) The first area is densely populated and close to towns and cities (<5 km); thus, belonging to the area where human activities and the natural environment coexist in equilibrium, and human activities protect the natural environment. (2) The second area is where human activities and the natural environment influence each other (5–10 km). This area is farther away from human habitation, and human activities are within the range of protection and development. (3) The third area is even farther away from the town and is highly affected by human activities (10–40 km); engineering activities change the natural environment and induce landslides. (4) The fourth area is farthest away from cities and towns (>40 km). This area has decreased human activities and has less impact on the environment due to the distance from the cities and towns (Figure 8(b)). Therefore, human activities have both negative and positive effects on the occurrence of landslides. The key is how do engineering activities consider the natural environment and its effects on humans.

5.3. Is a steeper slope more prone to landslides in the CLP?

The slope is an essential component of the stability analysis of the slope (Zhuang et al. 2015). As the slope gradient increases, shear stress in the soil generally increases
However, loess is a unique soil, and dry loess has a high cohesive strength; however, it loses strength significantly when wetted and fails (Derbyshire et al. 1994). The steady rainfall infiltration rate decreases rapidly as the slope increases. The steeper the loess slope, the less water infiltrates into the loess per unit time. Meanwhile, rainfall can enter the loess and decrease per unit area as the slope increases. Steep natural slopes occur due to very little water entering the loess. The gentle hillslopes (20–40°) are beneficial to the collection and infiltration of rainfall. There is a certain potential energy that promotes landslide occurrence. It is noted that a slightly lower frequency of landslides occurs in high slope areas compared to gentle hillslope areas. Landslide frequencies on gentle hillslopes (20–40°) are a common field observation within the study areas (Figure 9).

5.4. Does an increase in vegetation reduce landslide occurrences in the CLP?

Several studies have investigated the effect of climate change on landslide occurrence and reactivation by applying climate model simulations combined with slope stability models (Collison et al. 2000; Dehn et al. 2000; Dixon and Brook 2007; Crozier 2010; Gariano and Guzzetti 2016). Most researchers have studied the climate and land use change of the CLP and found that the climate in the CLP has become warmer and more humid over the past ten years, with rainfall increasing in the last few decades (An et al. 2021). Increasing rainfall and temperature have caused an increase in vegetation greening greater than 25% (Feng et al. 2016). Whether these changes positively or negatively affect slope stability remains unclear (Gariano and Guzzetti 2016). An increase in rainfall will increase soil erosion and slope instability, although vegetation growth slows down the erosion, the amount of rainfall infiltration increases the water content of the soil. For example, it was found that the rainfall required for runoff generation has increased more than 40% with the restoration of vegetation via analysis of the rainfall-infiltration and runoff generation in the CLP, meaning that a large amount of rainfall infiltrates into the loess (Jin et al. 2018). In particular, the wet peak is often formed at a depth of 2 m which is the end of the vegetation’s root system and also the depth of many shallow landslides (Jin et al. 2018). Loess is characterized by macro-pores, vertical joints, loose texture, and water sensitivity, making it prone to erosion and collapse (Derbyshire et al. 2000; Zhang and Liu 2010; Xu et al.}

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**Figure 9.** Distribution of the landslide and the slope: (a) slope and landslide distribution; (b) relationship between the landslide and the slope. Source: Author.
Therefore, landform changes are rapid, and gravity erosion (gravity landslides) occurs due to the evolution of the landform.

At present, the Chinese government’s plan ‘Returning Farmland to Forest’ has been implemented in the study area. The traditional view is that soil and water conservation projects have effectively reduced surface runoff, reduced flood runoff, and flood sediment transport, thus, reducing flooding disasters. Vegetation roots strengthen the soil resulting in a reduction of soil erosion and shallow landslides (Arcemojica et al. 2019; Preti 2013). However, some researchers have noticed that there is still great uncertainty in the role of vegetation restoration effects on geohazards (Kobayashi and Mori 2017). Forest evapotranspiration will increase with increasing forest coverage leading to higher water consumption (Liu et al. 2019; Sun et al. 2020), resulting in drier land (Yan et al. 2018). When the reinforcement depth of the vegetation root system is much smaller than the depth of the sliding surface, the macroporous system formed by the roots of the vegetation will promote water infiltration increasing landslide occurrence (Wang et al. 2015; Zhuang et al. 2017; Guo et al. 2020). Therefore, the landslide’s response in the CLP to climate change should be studied, especially the impact of increased rainfall and vegetation changes on the slopes.

6. Conclusions

Using one of the most densely distributed landslide areas of the CLP as a study area, 20,699 landslides were obtained. The characteristics of scale, mobility of the landslides, area-volume relationship, and relationship analysis with watershed evolution were studied. The following conclusions were drawn:

1. The landslide thickness is primarily distributed at 5–15m accounting for 66.7% of the total number of landslides. Below 10m is the most distributed type of landslides in the CLP and accounts for 40% of the total number of landslides. According to the classification of landslides associated with landslide sliding depth, the landslides in the CLP are primarily shallow.

2. The data for the volume-area of the landslides in the CLP follow a power-law trend and can be described by $V = 1.53A^{1.19}$. The difference in slopes affects the landslide erosion material, and the erosion capacity of the landslide is larger when the area is smaller. However, the erosion capacity of the landslide decreases with an increasing area.

3. About 56% of the landslides in the CLP with a $H/L$ below 0.6 which belong to the long-travel-distance landslides, and 5.5% of the landslides in the CLP with a $H/L$ below 0.17 indicates that the landslide in the CLP can translate to a flow motion resulting in a longer sliding distance. The $H/L$ ratio for the landslides in the CLP data is set as a function of the landslide volume $V$ followed by a power law curve $H/L = 2.39V^{-0.102}$.

4. The landslides in the CLP are primarily distributed in the equilibrium or mature stage ($0.3 \leq H_I \leq 0.6$), accounting for 87% of the total landslides. The $H/L$ value
decreases with an increase in $H_I$. The landslide size increases and the slope becomes steeper as the $H_I$ increases.

5. The loess thickness does not affect landslide occurrence in the CLP, and the positive and negative effects on the occurrence of landslides in the CLP on human activity, slope, and climate change are proposed.

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No potential conflict of interest was reported by the authors.

Data availability statement

The data that support the findings of this study are available from the corresponding author, Jianqi Zhuang, upon reasonable request.

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