Research progress and prospect of gravity erosion in loess region

Jiaguo Gong[1,*], *Qianqian* Zhang[2], *Hao* Wang[1], *Yunzhong* Jiang[1], *Zheng* Ren[2], and *Liangjun* Ma[3]

[1] State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China
[2] School of Water Conservancy and Hydroelectric Power, Hebei University of Engineering, Handan 056038 China
[3] College of Energy and Power Engineering, Lanzhou University of Technology, Lanzhou 730050, China

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Abstract. Gravity erosion is one of the most important types of soil erosion in the loess region, and it is the focus and difficulty of the current erosion research in the loess region. This paper systematically reviews the research progress of gravity erosion experimental observation methods, gravity erosion occurrence critical conditions, the relationship between gravity erosion and watershed water sediment, and gravity erosion process simulation and so on, It points out that the lack of monitoring capacity of gravity erosion process caused by the random, sudden and rapid characteristics of gravity erosion is the bottleneck of gravity erosion mechanism research, It is proposed that new techniques such as photogrammetry with strong anti-interference ability and high spatial-temporal resolution should be introduced to strengthen experimental observation; Integrating the long-term and short-term influencing factors of gravity erosion process, revealing the control mechanism of infiltration on the occurrence of gravity erosion, and clarifying the critical law of gravity erosion; Strengthen the study of critical conditions and redistribution mechanism based on process, and reveal the mechanism of gravity erosion material stabilization and sediment yield differentiation; The combination law of influencing factors in the process of gravity erosion and sediment yield is explored, the uncertainty mechanism of the process of erosion and sediment yield is analyzed, and the zoning method of gravity erosion prone areas is explored; A watershed water sediment coupling simulation model with the physical mechanism of gravity erosion is developed to deeply reveal the coupling relationship between gravity erosion and watershed water

*Corresponding author: gongjg185@163.com

sediment process, and to provide reference for related research.

*Corresponding author:: gongjg185@163.com

1 Introduction

Gravity erosion is an important form of soil erosion in loess Plateau. Gravity erosion refers to the process in which the rock mass or soil mass loses its balance and displaces under the action of gravity [1]. According to the mechanical mechanism, material composition characteristics and scale of gravity erosion in loess area, gravity erosion can be divided into landslide, collapse, mud flow and other types. The main inducing factors can be divided into rainfall infiltration, vegetation root splitting, water erosion and so on. Gravity erosion is the main sediment yield mechanism in the Loess Plateau. Previous studies have shown that the contribution of gravity erosion to basin sediment is more than 20% [2-5]. If the contribution of hydraulic gravity erosion process is considered, the contribution of gravity erosion to basin sediment is more than 50% [4].

Gravity erosion is characterized by randomness, abruptness and rapidity, and its occurrence and development process is affected by many factors. The coupling response relationship is complex, resulting in the complex and changeable control mechanism of the occurrence, development and sediment yield process of gravity erosion [6-7]. Compared with hydraulic erosion research, the above reasons result in the lack of basic observation data for gravity erosion research, the lack of in-depth mechanism of erosion and sediment yield, and the slow progress of simulation research [8]. Therefore, it is urgent to systematically sort out the research results of the observation method of gravity erosion test, the critical mechanism of gravity erosion, the restabilization mechanism of gravity erosion material and the differentiation mechanism of erosion sediment production, and the simulation of gravity erosion sand production process, so as to explore to break the bottleneck of experimental research and to reveal the gravity erosion in depth. Erosion mechanism, as well as the research direction of research and development of gravity erosion simulation model, in order to achieve breakthroughs, provide scientific and technological support for scientific understanding of soil erosion in the Loess Plateau, construction of the Yellow River digital twin watershed and watershed/regional soil erosion control measures, control systems, governance decisions, et al.

2 Research progress

2.1 Observation method of gravity erosion test

2.1.1 Application of early monitoring technology in gravity erosion

My country's gravity erosion monitoring technology first started in the 1980s and was developed and applied in the Loess Plateau. Early monitoring techniques are widely used in field surveys, including filling methods, volumetric methods, stylus methods and pocket soil methods. Zheng [9] used the soil filling method and the volume method to monitor the erosion amount of the rill, and analyzed the monitoring accuracy of the two methods in terms of the erosion amount. It was found that the accuracy of the soil filling method was higher than that of the volume method, but the operation steps were less. The volumetric method is cumbersome and only suitable for indoor experiments. Yang et al. [10] used the stylus method to observe the occurrence types of small-scale gravitational erosion on the Qiaogou gully slope, and successfully observed three types of gravitational erosion: gully slip, small-scale collapse, and small-scale slump. Gao et al. [11] used the stylus method and the pocket soil method to observe the influencing factors and the amount of small-scale gravity erosion in the Xindiangou watershed. The observation frequency of additional measurements after heavy rain has successfully observed gravitational erosion types such as slop, small caving, and small slumps.

2.1.2 Application of new technology in gravity erosion

In recent years, with the development of measurement technology, 3D laser scanning technology, geomorphometer method, unmanned aerial vehicle (UAV) aerial measurement technology and photogrammetry technology have also received more and more attention in the field of gravity erosion research.

Zhang et al. [12] used high-precision GPS, 3D laser scanner and pinprick method to monitor and analyze rill erosion amount and rill erosion evolution process, and compared the observation accuracy of the three methods, and found that the calculation accuracy and DEM image generated by 3D laser scanner were superior to the other two methods. Zhang et al. [13] and Qin [14] used the method of combining 3D laser scanning technology and Cylone6.0 to monitor the terrain changes in the indoor simulated rainfall test process, and generated a terrain DEM accuracy of 2mm×2mm under gully erosion condition, and the calculation accuracy of erosion amount reached 96.85%. Huo et al. [15], Zhao et al. [16] using 3 d laser scanner to monitor the interior more than the same slope rill erosion under the condition of rainfall simulation, the dynamic process of using the generate DEM has realized the rill plane density, maximum average long groove depth, groove, groove more than average density and erosion intensity erosion topographic index calculation.

At the same time, the monitoring technology of regional topographic change with professional camera carried by UAV has also been gradually applied to the investigation and research of soil erosion. Gao et al. [17] used UAV aerial remote sensing technology to extract characteristic data of gravity erosion caused by heavy rain on July 26, 2017 in Xindiagou Basin, with an accuracy of 89.53%. Liao et al. [18] used UAV technology to obtain spatial distribution patterns and rill characteristics of rill with different slope and slope length in the field exposed plot under natural rainfall conditions as the research object. Compared with early detection technology, 3Dlaser scanner and UAV photogrammetry of high precision, high efficiency, no monitoring can take the initiative to contact, by repeating the same area to implement the dynamic monitoring of erosion process, but as a result of monitoring efficiency, and rainfall influence on the laser echo signal and the safety of (UAV), the technology is difficult to realize real-time dynamic monitoring of erosion process, Thus limiting the application of gravity erosion in observation. In view of the above shortcomings, Xu et al. [19] independently studied a set of MX-2010-G geomorphometer and gradually improved it, realizing the near-real-time monitoring and recording of gravity erosion process and using this system to achieve accurate monitoring of erosion amount, sliding volume, soil loss caused by slope flow erosion and other indicators in the process of gully slope gravity erosion.

In addition, the close-range photogrammetry technology is gradually maturing. Due to its advantages of large-scale synchronous observation, high timeliness, strong raindrop interference resistance and high measurement accuracy, some researchers have introduced it into the dynamic monitoring test of soil erosion. Guo et al. [20] and Jiang et al. [21] integrated UAV aerial survey and handheld photogrammetry to build a photogrammetry observation system, and realized near-real-time dynamic monitoring of rill erosion process under rainfall conditions. By using this system, the terrain change monitoring with time interval of 2min and spatial resolution of 1.5mm is realized, indicating that the close-range photogrammetry system has a good application prospect in the dynamic monitoring of erosional terrain. Due to the gravity erosion process has the characteristics of sudden, random, fast, and is often accompanied by interference factors such as rainfall, early gravity erosion monitoring is limited by technical means, mainly adopts artificial stationing, timely monitoring of the observed or encryption method of gravity erosion monitoring, difficult to capture the critical state of gravity erosion occurs, The timeliness and accuracy of measurement are relatively low (Table 1), and the gravity erosion data obtained by monitoring is difficult to match with influencing factors such as rainfall process and soil moisture content process to conduct accurate correlation analysis. With the development and application of new technologies, 3D laser scanning technology, UAV aerial survey technology, geomorphic method and photogrammetry technology have been continuously improving the accuracy, timeliness and anti-interference ability of gravity erosion observation tests (Table 2). Among them, 3D laser scanning and UAV aerial measurement technology have greatly improved the efficiency and accuracy of single and large area measurement. Combining the advantages of high speed photography, the geomorphic method can record and analyze the gravity erosion process at high speed by using laser to mark feature points and manual processing. Photogrammetry technology has been in an indoor slope rill erosion successful application in the measurement test, as the technology matures, the precision of matching, time response, and the other factors, measure performance in the rain, so on real-time with high advantage, it to achieve the real time dynamic measurement of the gravity erosion process laid a solid foundation.

Table 1. Comparative analysis of early observation methods.

The serial number	The name of the methods	The main measurement The principle of	precision	Time response	And other observational factors fit	Real-time measurement performance in rain	Real-time measurement performance in rain
1	Fill in the mill	Volume method	Centimeter level	time	Poor	generally	Poor
2	Volumetric method	Volume method	Centimeter level	time	Poor	generally	Poor
3	Measuring the stitch	Volume method	Centimeter level	time	Poor	generally	Poor
4	Bag making	Volume method	Centimeter level	time	Poor	generally	Poor

Table 2. Comparative analysis of new technology observation methods.

The serial number	The name of the methods	The main measurement The principle of	precision	Time response	And other observational factors fit	Real-time measurement performance in rain	Real-time measurement performance in rain
1	3D laser scanning	Principle of laser positioning	millimeter level	time	Good	Poor	Poor
2	Aerial photogrammetry by UVA	Principle of aerial triangulation	Centimeter level	time	Good	general	Poor
3	Method of sonar	Laser positioning, human eye recognition	Centimeter level	time	Good	Good	general
4	Close range photogrammetry	Principle of aerial triangulation	millimeter level	Second level	Good	better	Good

2.2 Study on the mechanism of gravity erosion

2.2.1 Research progress on factors affecting gravity erosion and its criticality

There are many factors affecting the process of gravity erosion on the Loess Plateau, including soil type, soil weathering degree, soil structure, soil bulk density, soil moisture content, slope, slope aspect, vegetation type, vegetation root system, soil animal activity, rainfall intensity, rainfall duration, earthquake, Freezing and thawing, human activities, et al. According to the time course of influence on gravity erosion, it can be divided into short-term influencing factors and long-term influencing factors. Short-term influencing factors include rainfall, earthquake and soil infiltration characteristics, while long-term influencing factors mainly include soil types, soil structure, topography and vegetation, et al.

Rainfall is an important driving factor of gravity erosion. Yang et al. [3, 22] analyzed the factors influencing the occurrence of small-scale gravity erosion and found that the higher the rainfall, the higher the frequency of gravity erosion. Yan [23], Liu [24], Xu et al. [25] found through indoor simulation tests that when the rain intensity was small, the proportion of large-scale gravity erosion events was large, and the topography development could be deduced from the side of the current generation. The rainfall duration has an obvious effect on the gravity erosion process in the early stage of topography development, and the effect gradually decreases with the topography development. There is no simple proportional relationship between gravity erosion and rainfall, which is affected by both rainfall intensity and rainfall. Xu et al. [26] analyzed the gravity erosion process and sensitivity and found that gravity erosion on gully slope is mainly manifested in three forms: landslide, collapse and mud flow. At the same time in the process of rainfall, with the same pattern and massive destruction of similar size will often appear adjacent, gravity erosion occurred frequency, scale and rainfall and rainfall intensity has a direct relationship, but in the early relief development, the influence of rainfall the obvious, therefore, no matter from gravity erosion test total peak, Rainfall duration is the main sensitive parameter affecting landslide and mud flow.

The influence of vegetation on gravity erosion is positively and negatively correlated. Sun et al. [27] used the grey correlation degree method to analyze the correlation between shear strength and soil parameters of landslide soil in Zhonggou Watershed, and found that the correlation between dry bulk density, water content, slope, root content and shear strength decreased successively. Zhang [28] analyzed the influence of vegetation restoration on gravity erosion from two aspects of soil moisture and root soil fixation, and found that with the increase of soil moisture, roots would inhibit gravity erosion. However, the root extrusion in the process of growth will promote the occurrence of collapse and landslide. Gao et al. [29] studied the effect of vegetation on the occurrence time, intensity and erosion rate of gravity erosion on the gully slope, and found that when the rainfall conditions on the gully slope model were consistent, the effect of vegetation on the occurrence of gravity erosion showed a time lag effect, which was different from that of the gully slope model. Compared with the bare land model, vegetation increases the distribution of small gravity erosion scales, but vegetation increases the gravity erosion rate in the short term and slows down the development of gravity erosion in the long run. Zhao et al. [30-31] analyzed the influence of vegetation on the gravitational erosion of gully slope under heavy rain conditions through the rainfall test of the bare soil model of the loess gully slope and the root-soil composite model, and found that the amount of secondary rainfall gravitational erosion in the root-soil model and the bare soil model was All showed a trend of rapid growth at first and then a gradual decrease, but the increase in the amount of gravity erosion in the root-soil model was smaller than that in the bare-soil model. Jiao et al.[32] and Wang [33] analyzed the soil erosion characteristics of different vegetation types based on the vegetation pattern characteristics of typical small watersheds in the loess hilly and gully area, and found that the erosion reduction ability of artificial shrubs is better than that of artificial trees, and with vegetation The increase in coverage achieves the effect of resisting the erosion of heavy rain. The above studies show that the influence of vegetation on the gravity erosion process is mainly manifested in two aspects: one is to change the mechanical properties between soil masses through root growth and interpenetration distribution; the other is to change the soil through the redistribution of rainfall and its infiltration process. The mechanical properties between the bodies affect the frequency, location, and amount of gravity erosion.

Geomorphic development stage determines the intensity of internal and external forces, and influences the action direction, occurrence frequency and erosion intensity of gravity erosion [27]. Xue et al. [34], Xin et al. [35], Wang et al. [36] analyzed the relationship between terrain fractals, river network channel fractals and gravity erosion, and found that the fractals can reflect the comprehensive factors of the basin topography and geomorphology, which can be used for The macroscopic prediction of gravity erosion, in which slope is the most important factor affecting the frequency, type and scale of gravity erosion [3]. Zhao [37] and Wang [38] based on the simulation test of gravity erosion on loess gully slope, found that the slope determines the type and scale of gravity erosion, and the slope height is an important factor affecting the occurrence of gravity erosion. When the gully slope has the same slope, the total gravity erosion is positively correlated with the slope height, but the slump erosion is less affected by the slope height, and the water content of the underlying surface is an important triggering factor for the gully slope gravity erosion. Yu et al. [39-40], Dong [41] took Baota District, Yan'an City, Shaanxi Province as the research object, analyzed the impact of topography and landform on gravity erosion, and found that slope is an important limiting factor for gravity erosion. With the increase of slope, the development of landslide at the foot of gully slope is accelerated, but for the landslide near the gully edge line, the impact of rainfall is higher than the slope. Ma et al. [42] found through the simulated rainfall test that the gravity erosion is the main driving force of the gentle slope land loss, and the correlation coefficient between the gentle slope land loss area and the gully side gravity erosion is 0.93. Tang et al. [43] found that landform is the congenital condition for the development and distribution of landslides, and geological structure is an important influencing factor for the centralized development and distribution of landslides. Earthquakes have a dual effect on the occurrence of landslides. In a short time, the structural zone affected by the release of seismic energy is easy to directly cause landslides; Over a long period of time, critical energy balance will be formed in some slopes affected by earthquake, and landslides will be more likely to occur in the future under other triggering factors of the same conditions.

Soil structure mainly affects gravity erosion by affecting the shear strength and mechanical stability of soil. Zhou et al. [44] analyzed the influence of freeze-thaw on the physical properties of soil samples and found that the changes of density and void ratio of soil samples showed "conjugate" changes, and multiple freeze-thaw cycles could change the internal structure and hydraulic properties of loess. Yao et al. [45] studied the erosion mechanism of arsenic sandstone and found that gravity erosion is closely related to the slope gradient and lithology of arsenic sandstone. When the slope Angle is larger than the critical slope Angle, gravity erosion is easy to occur. Yang [46] believes that all kinds of landslides will be affected by formation lithology and topographic structure. Due to the high content of clay minerals in Loess and strong hydrophilicity, it is easier to cause sliding, and the volume shrinkage of loess after water loss will cause soil fracture and loosening, which is very prone to gravity erosion. He et al. [47] and Xu et al. [48] believe that due to the existence of plant root pores, biological caves, bedding and pores in the Loess Plateau, with the seepage of water and the loss of particles, the pores can also continue to expand into caves, especially along the vertical joints, it is easier to produce caves and caves, and finally cause ground collapse. Li et al. [49] analyzed the impact of loess caves on loess landslides and believed that caves can accelerate the development of gullies, form landslide perimeter and free face, and intensify soil loss, fragmentation and local collapse. At the same time, the seepage conditions of the slope are changed, resulting in the concentrated infiltration of surface water, which induces the occurrence of landslides and the revival of ancient landslides.

The critical condition of gravity erosion in loess area is that the sliding force of unstable soil exceeds the shear resistance of sliding surface. The mechanical properties of soil such as structural strength, shear strength, cohesion and internal friction angle are mainly affected by soil type, dry density and water content of soil. Dang et al. [50-51] analyzed the influence of water content on the strength of unsaturated loess, gave a method to determine the structural strength of loess, and pointed out that the structural strength of unsaturated loess can be measured by the strength lost after its natural structure is destroyed, and there is a power function relationship between the structural strength and the initial water content; There is a good linear relationship between structural strength and unstable cohesion; The concept of ultimate strength moisture content of unsaturated loess is proposed. Zhang et al. [52] took the Loess in Yangling area as the research object, and found that with the increase of water content, its structural strength and shear strength showed a decreasing trend, but the ratio of shear strength to structural strength basically remained unchanged, and the cohesion of unsaturated loess was negatively correlated with water content. Fan [53] analyzed the shear strength of shallow undisturbed soil in the Loess Plateau and found that with the increase of <0.01mm physical clay content in the soil, the cohesion of the soil increases and the internal friction angle decreases; With the increase of dry bulk density, soil cohesion increased, internal friction angle decreased, and shear strength increased; With the increase of soil moisture content, the cohesion and internal friction angle of soil decrease, and the shear strength decreases. Yang et al. [3, 22] found through direct shear test that the cohesion and internal friction angle of loess decreased significantly with the increase of water content; For Malan loess, it is easy to collapse when the average water content of the soil near the collapse surface reaches 12%~15%. At this time, the internal friction angle is 30 ° ~35 °. The cohesion at the collapse surface is below 5kpa, which is far less than the measured cohesion of the undisturbed loess of about 25kpa under the same water content. Chen et al. [54] analyzed the relationship between water content and shear strength parameters of unsaturated loess in Lanzhou, Gansu Province, and found that the cohesion of unsaturated loess is greatly affected by water content. Guo et al. [55] analyzed the rapid shear test and believed that the dry density affects the shear strength by affecting the cohesion and internal friction angle, while the water content only affects the shear strength by affecting the cohesion.

2.2.2 Research progress on redistribution of gravity eroded materials

The redistribution process of gravity eroded material generally includes two forms: the first form is the process of rapid sliding and redistribution of gravity eroded soil under the action of gravity; The second form is the process of secondary erosion of gravity eroded soil under the action of rainfall and surface runoff. For the first redistribution process, there is no relevant research. For the second redistribution process, Guo et al. [56] found that gravity erosion has a significant impact on the particle size distribution of suspended sediment through field observation and analysis. With the occurrence of large-scale erosion, the proportion of sand particles in runoff sediment decreased from 71% to 51%, while the proportion of clay particles and silt particles increased from 1% to 7% and 28% to 42% respectively. According to this, when gravity erosion occurs, the suspended sediment load becomes smaller, and the sediment is easier to be transported to the gully flow. Gravity erosion makes the particle size distribution of suspended sediment more uneven and irregular.

2.2.3 Study on control mechanism of gravity erosion reduction

Water and soil conservation is an important basic national policy and an important starting point for the construction of ecological civilization in China. In the 1950s, various water and soil conservation projects, such as the construction of terraces, check dams, planting trees and grass, were implemented in the Yanhe River Basin; Since the 1990s, ecological restoration projects focusing on vegetation restoration, such as beautiful mountains and rivers and returning farmland to forest (grass), have been implemented successively [57]. Many scholars have explored and studied the regulation effect of soil and water conservation measures on gravity erosion. Yu et al. [58] considered that the erosion reduction effect of silt dam is stronger than that of vegetation in small watershed scale, while that of vegetation is better than that of silt dam in large scale. Chai et al. [59] taking Tianjiagou small watershed as the research object, the research shows that five control measures, namely, three-dimensional protection, landscape shelter, gully slope treatment, gully locking and foot fixing, have better control effect on erosion of red soil diarrhea sliding surface. Zhao et al. [60] proposed a method for selecting and optimizing combination of water and soil conservation plants on the Zhuanyaogou watershed of Hequ County, Shanxi Province, in the hilly and gully area of the Loess Plateau, by identifying four representative herbal plant roots to enhance soil shear strength. Hu [61] Research holds that artificial planting of seabuckthorn in arsenic sandstone Valley can gradually reduce or eliminate the influence of dry, wet, cold and heat changes, prevent the generation of new clastics layer, at the same time, the root system and litter have good protection to the existing clastics layer, so as to effectively block the diarrhea and reduce the occurrence of gravity erosion. Based on the above studies, gravity erosion in the loess area is characterized by soil destabilization under the combined action of soil and its structure, topography, vegetation, rainfall and other factors. The critical mechanism is that the sliding force of unstable soil exceeds the shear resistance of sliding surface. In the process, long time history influence factors including soil and its structure, topography, vegetation, etc., short-term factors mainly include rainfall characteristic parameters and the redistribution process, and the adjustment of the soil mechanics parameters, including rainfall, rainfall duration, rainfall intensity, soil moisture, soil infiltration rate and so on. The complex coupling effect of the above factors makes the sliding force and shear resistance of the sliding surface of soil in a complex dynamic adjustment, which makes the occurrence of gravity erosion sudden, random and rapid, and causes great difficulties to the observation and research. At the same time, the influence of gravity erosion on watershed water and sediment processes is coupled with the redistribution of erosion materials and the complex interaction with hydraulic processes after the occurrence of gravity erosion, which further aggravates the complexity of watershed water and sediment processes. At the same time, it is relatively weak to identify the mechanism of gravity erosion control from the perspective of soil and water conservation practice.

2.3 Research progress of gravity erosion simulation

2.3.1 Simulation of gravity erosion based on watershed water and sediment processes

The process of gravity erosion and sediment yield is an important part of the watershed water and sediment process. However, due to the lag of its mechanism research and the complexity of the process, most of the existing studies use indirect methods or generalized theoretical models to simulate gravity erosion and sediment yield. Cai et al. [62] based on the field observation and simulated rainfall test data of small watershed, a process model for predicting erosion and sediment yield of small watershed in Loess Hilly and gully region is established, which is composed of slope sub model, gully slope sub model and gully sub model. In the gully slope sub model, the power function relationship between gravity erosion and runoff depth is obtained by fitting. This study also provides a good reference for gravity erosion simulation in the process of watershed runoff and sediment. Li et al. [63-64] , Wang et al. [65] integrating three sub models of slope erosion, gravity erosion in gully slope area and unbalanced sediment transport in gully, a digital watershed model of the Yellow River is proposed and applied to the simulation of erosion and sediment production process in small watersheds. It is found that within the scale range of 10^5~10^6 m^2, the gravity erosion modulus increases with the increase of water flow, but at a larger watershed scale, the landform adjacent to the gully no longer exists, and gravity erosion no longer contributes to the total sediment transport. Wang [66] based on hydrological station network of gully and indoor simulated rainfall test data, an indoor general model of small watershed is established. Based on three time scales of annual, secondary flood event and secondary flood process, the water and sediment characteristics of geomorphic unit in different time and space scales of slope-gully-watershed system are obtained and applied in small watershed of Peijiamaogou and Qiaogou. Zhu et al. [67] the regional division of gravity erosion in West Shanxi is carried out by using fuzzy clustering method, and a typical small watershed is selected in each area to study the sediment yield mode, intensity and its proportion in total erosion. It is concluded that gravity erosion accounts for 35%~46% of total erosion. Zhang et al. [68] using quantitative geomorphology, the relationship between topographic factor of gravity erosion (A) and gravity erosion intensity is introduced and quantified. It is found that the gravity erosion intensity of loess sandstone, soft rock and hard rock will reach A severe degree when A value is greater than 0.8, 1.0 and 1.6 respectively. Fu et al.[69-70] based on the grey theory, a grey system prediction model based on the dynamic change law of gravity erosion is constructed to analyze the correlation between the predicted value series and the observed value series of gravity erosion. The core of the model is the correlation degree between the predicted value and the measured value. In essence, the grey system model belongs to the category of empirical regression model and does not directly involve the mechanical mechanism. Jin et al. [71] assuming that the occurrence of gravity erosion is controlled by internal and external factors, the internal and external factors are quantified by linear regression method and normalized comparison method respectively, and all channel units are queued according to the size of impact factors, so as to determine the channel unit where gravity erosion occurs. The above models are generally statistical models, which do not fully consider the mechanical mechanism and randomness of soil instability, and have poor applicability.

Wang et al. [72-74] , Li et al. [2] the gully slope gravity erosion theoretical model based on soil instability is coupled and integrated with the slope rainfall runoff and soil erosion model and the gully unbalanced sediment transport model under the framework of DYRIM model. The simulation of watershed water and sediment processes including gravity erosion and sediment production process is realized and applied in Chabagou and Wuding River basins. Gong et al. [75] based on WEP model, the mechanism of raindrop splash erosion, thin layer flow erosion, stream erosion and gravity erosion is systematically considered, and the watershed water sediment coupling simulation model is established and applied in Nanxiaohegou watershed and Jinghe Watershed. The simulation of gravity erosion process is mainly to generalize the sliding soil mass into a triangular body, judge the gravity erosion critical by comparing and analyzing the sliding force and the shear strength of the sliding surface, and calculate the sediment production process by using the sediment carrying capacity of water flow and the principle of unbalanced sediment transport, which has achieved good simulation results. Liu et al. [76-77] a grid based small-scale continuous computing distributed hydrological model for arid and semi-arid areas is proposed, and the hydraulic erosion and gravity erosion sediment yield modules are reserved to realize the coupling calculation of water and sediment in the future research work, and establish the water and sediment yield and sediment transport model for the Loess Plateau. Cai et al. [78] , Zhu et al. [79] A distributed water-sediment model (WEP-SED) was established to simulate the gravity erosion based on the collapse process, and the erosion soil was generalized as a four-prism to simulate the calculation. The results are in good agreement with the literature data.

To sum up, there are many uncertainties in the understanding of the critical mechanism of gravity erosion and the redistribution process of eroded substances, the understanding of the mechanism of gravity erosion is not unified, there are few studies on the redistribution mechanism of gravity eroded substances, and there are complex scale effects in the watershed water and sediment process, so the existing research results of gravity erosion simulation based on the perspective of watershed water and sediment process are basically: Indirect analysis of gravity erosion based on water sediment relationship; Quantitative analysis based on short-term and small-scale field observation data; Empirical model based on fuzzy clustering, regression analysis and grey system prediction model; Based on the physical mechanism model generalized in theory, the research results are speculative to some extent, and the representativeness is insufficient. Its reliability and multi-scale applicability are still in doubt. Watershed/regional scale water and sediment process analysis is the basis for large-scale water and soil loss control. It is urgent to carry out simulation research on gravity erosion water and sediment process based on physical mechanism, so as to provide basic scientific tools for watershed water and sediment coupling simulation based on physical process.

2.3.2 Gravity erosion simulation research based on Engineering Perspective

Gravity erosion is also an important form of geological disaster. Many scholars have carried out simulation research on gravity erosion based on soil mechanics, material mechanics and other principles for potential sites of gravity erosion. Cao [80] used the sliding arc method in traditional soil mechanics to analyze the force on the valley slope, and proposed the ratio of shear strength to shear stress of the soil on the sliding surface as the critical judgment condition for the occurrence of gravity erosion, and pointed out that whether the slope is balanced depends on the dynamic balance relationship between shear force and shear resistance. Yu et al. [81-82], Zhang et al. [83], Lu et al. [84], Jin et al. [85] used the finite difference FLAC3D software to study the gravity erosion mechanism of the generalized model of the small watershed on the Loess Plateau. It was found that the internal stress of the slope in the small watershed was mainly generated by the self weight of the rock and soil mass of the slope, and the yield of the internal soil mass was mainly in the "pressure shear" yield mode; At the same time, it is found that when there is vegetation coverage, the root reinforcement improves part of the stress of the shallow soil, weakens the stress of the root layer through the diffusion effect, enhances the sharing effect of the root system on the soil, effectively reduces the stress concentration of the slope soil, is conducive to controlling the deformation of the slope and improving the stability of the slope, and reduces the volume of the plastic yield zone and the tensile plastic yield zone through the shallow layer of the slope to varying degrees, The failure degree of gravity erosion is reduced, but the shear failure mode is still the main mode of gravity erosion yield. Based on the strength reduction theory, Zhang [86] used the finite element simulation software geo5 and ABAQUS numerical simulation software to study the mechanical mechanism of gravity erosion collapse process and pattern of coarse sand bank slope in desert in a small watershed, and compared it with the collapse characteristics of loess bank slope, pointing out that the sensitivity of bank slope stability to cohesion, internal friction angle and groundwater level decreased in turn, The longer the plastic deformation and complete instability of the bank slope soil take, the stronger the stability of the bank slope soil is, and the slope angle is the most dangerous part. Wei [87], Zou [88-89], Gao et al. [90-91] used the finite element software and the strength reduction coefficient method to establish the generalized model of the slope gully system in the nianzhuang gully basin and the generalized model of the Guandi gully slope gully system. By using the method of probability statistics and numerical simulation analysis, they studied the correlation between the residual slope length of the slope gully system and the siltation height of the dam site, and obtained that under the same siltation height, There is a binomial relationship between the amount of sediment deposited and the height; With the same sediment yield, the vertical siltation height on the dam site and the current siltation height on the dam site satisfy the power correlation.

The gravity erosion simulation research based on the engineering perspective, based on the mathematical and physical equations, takes the soil as a continuously changing material medium, uses a variety of mathematical methods to simulate and analyze the stress state and continuous deformation process of the soil, and establishes the continuous equation for mathematical calculation and description, which is quite different from the actual situation of loess with expansibility and joint structure development, and the scope of application is limited. In addition, this kind of model often focuses on the process of soil instability. Although it has certain advantages in the study of the critical characteristics of gravity erosion and is helpful for the in-depth understanding of the mechanism of gravity erosion, the research scale is relatively small and rarely involves the sediment production process. Therefore, it is difficult to meet the needs of the study of watershed water and sediment processes.

3 Analysis and Prospect

3.1 problem analysis

To sum up, some research achievements have been made in the aspects of experimental observation system and method, influencing factors, process mechanism, model simulation, etc. There are still some problems in gravity erosion research:

(1) The monitoring system of gravity erosion process is still the bottleneck of further mechanism research. Due to the sudden, random and rapid characteristics of gravity erosion process, the early gravity erosion monitoring technology mainly adopts the methods of manual point distribution, regular monitoring or intensive observation, which is difficult to make coupling and matching analysis with the influencing factors such as rainfall and soil moisture content process, and the timeliness and accuracy of measurement are difficult to meet the research needs for further revealing the critical characteristics of gravity erosion. The emerging three-dimensional laser scanner and UAV aerial photogrammetry have high precision, high work efficiency, no active contact, and can realize the dynamic monitoring of the erosion process by repeatedly monitoring the same area. However, due to the monitoring efficiency and the impact of rainfall on the laser echo signal and UAV safety, it is difficult to realize the real-time dynamic monitoring of the erosion process. Close range photogrammetry includes the advantages of the above technologies, as well as the advantages of large-scale synchronous observation and strong resistance to raindrop interference. However, there are still deficiencies in the application of gravity erosion, resulting in the lack of basic observation data. It has always been the bottleneck for the progress of gravity erosion mechanism and simulation research.

(2) The soil and its structure, topography, vegetation, rainfall and other factors are divided into long-term and short-term influencing factors. The complex coupling effect of long-term and short-term influencing factors makes the soil sliding force and the shear resistance of the sliding surface in complex dynamic adjustment. The complex dynamic changes make the erosion material redistributed after the occurrence of gravity erosion or coupled with the hydraulic process, further aggravating the complexity of the watershed water and sediment process. The main reason is that the existing erosion and sediment yield mechanism is not deep enough due to the numerous influencing factors of gravity erosion process, the complex coupling response relationship and the lack of basic observation data. Most of the research results focus on the qualitative relationship between gravity erosion and rainfall, topography, vegetation, soil and other factors. It is difficult to form a unified conclusion from the Angle,

depth and level of research. There are few quantitative research results, and the mechanism of gravity erosion is not clearly understood.

(3) The engineering perspective is mainly used to analyze the process of soil instability caused by gravity erosion. It has certain advantages in studying the critical mechanism, but the research scale is small, and the sediment production process is rarely involved; From the perspective of watershed water and sediment process, the relationship between watershed water and sediment is analyzed mainly based on the empirical model and the physical mechanism model after theoretical generalization, It is only a quantitative analysis of short-term and small-scale field observation data. Its representativeness is insufficient, and its reliability and applicability are still in doubt. The main reason is that most of the existing studies are based on the response relationship of gravity erosion influencing factors, so it is difficult to quantitatively reveal the occurrence, development and sediment yield process of gravity erosion, and it is difficult to support the research and development of gravity erosion simulation model based on physical mechanism. At the same time, due to the lack of effective observation data, it is difficult to judge whether the results of the existing gravity erosion simulation model can reflect the real situation, which makes the simulation research progress slow.

3.2 Prospect

In view of the above problems, it is urgent to reveal the mechanism of gravity erosion, the mechanism of gravity erosion material re stabilization and sediment yield differentiation on the basis of breaking through the monitoring means of gravity erosion process, On the one hand, it supports the uncertainty analysis of gravity erosion sediment yield process, and forms a scientific classification and zoning method of gravity erosion prone areas to provide support for gravity erosion control; On the other hand, support the research and development of gravity erosion simulation model based on physical mechanism, and improve the scientific research "Puzzle" of soil and water loss in the loess region.

(1) Break through the bottleneck of gravity erosion process observation. In the process of gravity erosion, the soil displacement is the main body, and the soil is a good light scattering body, so the photogrammetry observation method becomes a better choice, which can realize the dynamic monitoring with high time and space resolution under the condition of rainfall; By introducing photogrammetry technology, a terrain change process monitoring test system with large scene synchronous measurement, high time resolution and high spatial resolution is constructed. Through comprehensive configuration of terrain change monitoring, soil water content monitoring, vegetation, soil and other parameter characteristics, a gravity erosion process monitoring and test system is formed. Research and develop observation technology suitable for gravity erosion test. So as to "see" the process of gravity erosion sediment production, and lay a foundation for revealing the mechanism of gravity erosion and exploring the field monitoring method of gravity erosion.

(2) The control mechanism of infiltration on gravity erosion is revealed. The physical process of gravity erosion can be regarded as the instability process of erosion body. In this process, the soil, vegetation, terrain and other factors have a long action time process on the erosion body, while rainfall rapidly changes the mechanical properties of the sliding surface of the erosion body under the action of near ground wind speed, vegetation, terrain, soil hydrological characteristics and other factors, and the action time process is relatively rapid. It is necessary to grasp this key process, integrate different long-term and short-term influencing factors, use the gravity erosion process observation and test system to clarify the characteristics of gravity erosion sliding surface, study the coupling relationship between the critical terrain, soil moisture content, sliding surface characteristics, etc. of different types of

gravity erosion such as landslide, collapse and mud flow, and deeply reveal the control mechanism of infiltration on the occurrence of gravity erosion.

(3) Reveal the mechanism of gravity erosion material re stabilization and sediment yield differentiation. Among the existing studies, the research on the redistribution process of gravity erosion is relatively weak, which is difficult to support the analysis of the impact of gravity erosion on watershed water and sediment. The current research results on the process of gravity erosion on watershed water and sediment are mostly based on the qualitative or semi quantitative relationship obtained from the analysis of mutual relationship. Using indoor and outdoor monitoring tests, the coupling relationship between the moving process of erosion body to the downstream and the influencing factors such as rainfall, vegetation and topography is analyzed, and the proportion between the material quality directly entering the gully bottom and the contribution of secondary erosion is studied; It reveals the differentiation mechanism of gravity erosion and sediment yield, which directly converges into the watershed runoff, indirectly converges into the watershed runoff through the land surface hydrological process, and restabilizes the erosion body.

(4) The uncertainty mechanism of gravity erosion sediment yield process is analyzed, and the zoning method of gravity erosion prone areas is explored. On the basis of systematically identifying the characteristics of controlling factors in the occurrence and development process of gravity erosion, Based on indoor and outdoor tests, the variation range of characteristic values of different factors is analyzed, the combination law of influencing factors of gravity erosion sediment yield process is explored, the uncertainty mechanism of erosion sediment yield process is analyzed, and on this basis, the zoning method of gravity erosion prone areas is explored to provide scientific support for gravity erosion prevention and control.

(5) Research and develop a basin water sediment coupling model for the physical mechanism of gravity erosion. The existing gravity erosion simulation, on the one hand, focuses on the small-scale finite element method and soil mechanics method simulation, on the other hand, focuses on the generalized simulation of water and sediment process simulation model, which is still far from the demand for water and sediment coupling in the basin. Based on the physical process of gravity erosion and sediment yield, integrating the long-term and short-term influencing factors, and based on the requirements of distributed model driven by rainfall and DEM digital grid, the scale conversion law of DEM topographic characteristic parameters with different resolutions can be studied; A perfect basin water sediment coupling simulation model is established to quantitatively analyze the impact of gravity erosion on the water sediment process of small watershed under the comprehensive action of basin scale precipitation, vegetation and topography.

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