Study on sedimentary characteristics of warping dam under different silting states in Chabagou watershed

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Abstract. It is the premise and foundation of the study on the laws of sediment transport and deposition to deeply analyze the sedimentary characteristics of warping dams in different siltation states under rainstorm conditions. Taking Chabagou basin as the research area, based on the sediment deposition information of different types of warping dams in the basin, linear regression and correlation analysis were used to analyze the characteristics of dam deposition under different silting conditions in Chabagou basin. The results show that: (1) The maximum sediment depth and average sediment depth of warping dams under different sediment conditions are as follows: blocking dam > waterlogging dam > intact dam > full dam; (2) The sediment depth of warping dams under different sediment conditions has an exponential negative correlation with the ratio of dam field to dam-controlled watershed area, and the correlation coefficient of blocking dam is best(0.7267); (3) Warping dams average modulus of intercepting sediment with different siltation types is as follows: blocking dam 14274 t/km², intact dam 12480 t/km², waterlogging dam 11725 t/km², full dam 3350 t/km².

1. Introduction
At present, the comprehensive management of the watershed in the Loess Plateau has been greatly improved, and the effect of soil and water conservation is obvious. However, when encountering a heavy rainstorm, it will still form a high sediment concentration flood, causing a major disaster, seriously threatening the life and production safety of the downstream people [1]. Warping dam has the functions of high-efficiency water and soil conservation, water storage and sediment retention, and has been widely used in the Loess Plateau [2]. In the process of rainstorm and flood, warping dam has obvious function of peak clipping and flood detention. Warping dams store a large amount of information about erosion and sediment yield while retaining sediment. Understanding the sediment deposition characteristics of warping dams is the basis and premise of the research on the process and law of sediment transport in dams [3-5]. Many scholars use the sediment information of warping dams to study the related storm flood erosion, watershed erosion and sediment yield rate, sediment source and so on, and have made many achievements. However, most scholars only focus on the same type dam of sedimentation, while there were few researches on the sediment deposition law of different types of
warping dams. The sediment deposited by warping dams under different deposition conditions can reflect the sediment transport law of the basin from multiple perspectives, and contain a lot of erosion information of the basin.

Therefore, this study takes Chabagou small watershed, the center of the "7.26" rainstorm in 2017, as the research object, through the measurement and analysis of the sand deposition layer at different spatial positions in the warping dam under different siltation states, the siltation characteristics of the sand deposition layer in the dam field are studied, which provides data support for the research on the sediment deposition and transport process of the warping dam.

2. Materials and Methods

2.1. Study area

Chabagou is the primary tributary of Dalihe basin and the secondary tributary of Wudinghe basin, with an area of 205km², the Caoping control basin area is 187km² (hydrological station). From 20:00 on July 25 to 8:00 on July 26, 2017, a torrential rain flood occurred in Wudinghe basin in Yulin area of Northern Shaanxi, with the rainfall in the rainstorm center reaching 252.3mm.

In this study, 148 warping dams (including 31 key dams, 65 medium-sized dams and 52 small-sized dams) were investigated in Chabagou basin (Figure 1). 38 warping dams with obvious siltation were selected. And the warping dams were divided into four categories: (1) Full dam (optional part): the silt filled dam (exceeding the silt storage capacity) before the rainstorm flood. (2) Waterlogging dam: a warping dam that is eroded in rainstorm and flood and collapses or forms a water hole. (3) Dam with good drainage facilities (intact dam): the warping dam project is in good condition, with drainage facilities and not blocked. (4) Dam without drainage facilities or poor drainage (blocking dam): without drainage facilities, or with drainage facilities blocked before flood.

2.2. Study method

2.2.1. Sedimentation volume and dam field. Combining field survey and satellite image observation, the distribution of warping dams in the basin was investigated and numbered (dam number). According to the topography and catchment conditions of the warping dam, several silting sections are set up for the

![Figure 1. (a) The basin area of Diaolihe.(b) distribution of warping dams in different silting states (four types) of Chabagou basin.](image-url)
main and branch ditches of the dam respectively. The length of the section is measured and recorded by laser rangefinder, and the silting area of the dam is calculated by blocks (combined into the dam field). Three test pits are excavated manually at each section, and the sediment deposition thickness of "7.26" flood is based on the sediment cycle depth of rainstorm flood. The calculation formula of sediment volume of dam field as follows.

\[ V = \sum_{i=1}^{n} S_i h_i \]  
\[ h_i = \frac{1}{3} \sum_{j=1}^{3} r_j \]

Where: \( S_i \) is the silting area between two adjacent sections of the investigated warping dam, \( m^2 \); \( h_i \) is the average silting thickness of the \( i \) section, \( m \); \( n \) is the number of sections; \( r_j \) is the silting thickness of the \( j \) test pit, \( m \).

2.2.2. Modulus of intercepting sediment. The GPS geographic coordinates of the warping dam site are transformed into a map with geodetic coordinate system, and the dam site is regarded as a dumping point by using ArcMap spatial analysis tool to obtain the dam-controlled watershed area. The sediment deposition of each warping dam is spread to the dam-controlled watershed area of the warping dam, and modulus of intercepting sediment of a single dam is obtained [6]. Calculation formula as follows.

\[ M_Y = 1.30Y/A \]

Where: \( M_Y \) is the modulus of intercepting sediment of single dam, \( t/km^2 \); \( Y \) is the sediment volume, \( m^3 \); \( A \) is the dam-controlled watershed area, \( km^2 \).

3. Results and Analysis

3.1. Siltation depth of dam field

The maximum sediment depth of single warping dam ranges from 0.15m to 2.00m, and the average sediment depth ranges from 0.11m to 1.46m. From high to low, mean of maximum sediment depth and mean of average sediment depth of different types of warping dams are: blocking dams(1.07m and 0.62m), waterlogging dams(0.72m and 0.53m), intact dams(0.70m and 0.45m), full dams(0.19m and 0.15m). The difference between the mean of maximum sediment depth and mean of average sediment depth (the mean sedimentation depth difference) of is blocking dam of 72.58%, intact dam of 55.56%, waterlogging dam of 35.85%, full dam 26.67% (figure 2).

![Figure 2. Sediment depth of warping dams in different siltation states.](image)

In the process of rainstorm and flood, the mean of average sediment depth of blocking dam is the highest, and the ability to retain water and sediment is the most significant. The mean of average sediment depth of waterlogging dam is higher than intact dam, and the ability to retain sediment is better. The sediment depth of intact dam is different according to its different drainage forms and outlet elevation; The full dam still has a certain ability to retain sediment in the process of flood, which is consistent with the relevant research results [7].

![Figure 3. Relationship between mean sediment depth and rainfall (blocking dam).](image)
Rainfall is an important factor for erosion and sediment yield of warping dams. In different types of warping dams, the average sediment depth of blocking dams is positively correlated with rainfall, and the correlation coefficient is 0.5188 (Figure 3).

3.2. Ratio of dam field to dam-controlled watershed area
Studies have shown that the ratio of dam field to dam-controlled watershed area is an important index of warping dam stability [8]. According to the data (Figure 4), the average siltation depth of warping dams under different siltation conditions and the ratio of dam field to dam-controlled watershed area show an overall opposite trend. The smaller the ratio of dam field to dam-controlled watershed area, the higher the average siltation depth in the dam.

![Figure 4. Sediment depth and the ratio of dam field to dam-controlled watershed area of warping dams in different siltation states.](image)

There is a negative exponential correlation between the sediment depth and the ratio of dam field to dam-controlled watershed area under different siltation conditions (Fig 5), and the correlation coefficient of blocking dam is 0.7267.

3.3. Modulus of intercepting sediment

![Figure 6. Relationship between modulus of intercepting sediment and the rainfall of warping dams in different siltation states.](image)

The average rainfall in the basin is 178.16mm. And the modulus of intercepting sediment of warping dam varies greatly in Chabagou basin under different siltation conditions (Fig 6). The maximum modulus being more than 30000 t/km² and the minimum being only 986 t/km². The average modulus of intercepting sediment of different types with warping dams from large to small is: blocking dam 14274 t/km², intact dam 12480 t/km², waterlogging dam 11725 t/km², full dam 3350 t/km². Due to the spatial distribution of warping dams in the watershed is limited, and the correlation between warping dams and rainfall is not obvious.
4. Discussion
The mean sedimentation depth difference can be understood as the fluctuation of sediment layer and the state of sediment movement and distribution in the dam. For blocking dam, the mean value of sediment depth is the highest and the mean sedimentation depth difference is the largest, which indicates that the fluctuation of final siltation depth is the most obvious, while that of full dam is the least. Studies have shown that the thickness and difference of siltation layer are large under the condition of large water and sediment, and the thickness and difference of siltation layer decrease when the water and sediment are small [5].

The average deposition depth of dam field increases with the increase of rainfall intensity, which indicates that rainfall is still an important key factor of erosion and sediment yield. The impact of rainfall intensity on watershed erosion can be well reflected by the deposition depth of dam field blocking dam.

5. Conclusion
In this study, the silt retention effect and siltation law of warping dam under different siltation conditions were analysed. Under the rainstorm, the sediment depth of warping dams from high to low show: blocking dam > waterlogging dam > intact dam > full dam. The mean sedimentation depth difference show: blockding dam (72.58%) > intact dam (55.56%) > waterlogging dam (35.85%) > full dam (26.67%). And the results show that there is an exponential negative correlation between the sediment depth and the ratio of dam field to dam-controlled watershed area under different siltation conditions, and the correlation coefficient of blocking dam is 0.7267. The average modulus of intercepting sediment of warping dams from large to small is: blocking dam \(14274 \text{ t/km}^2\), intact dam \(12480 \text{ t/km}^2\), water damaged dam \(11725 \text{ t/km}^2\), full dam \(3350 \text{ t/km}^2\).

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References
[1] Wang, D.X., Hou, S.Z., Yang, J.X., Guo, Y., Zheng, Y.S. (2017) Analysis of the sediment source of the flood formed by July 26 rainstorm in the Wuding river basin. Yellow River, 39: 22-25.
[2] Luo, X.C. (2016) Current situation and development of warping dams in Loess Plateau. Soil and Water Conservation in China, 09: 24-25.
[3] Li, M., Yao, W.Y., Shi, X.J. (2005) Study on the effect of silt dams for conserving soil and water and its sedimentation characteristic. Research of Soil and Water Conservation, 12: 111-115.
[4] Zhang, F.B., Xue, K., Yang, M.Y., Shen, Z.Z. (2012) Variations of sediment nutrient in check dam and its implication for small catchment sediment resources. Transactions of the Chinese Society of Agricultural Engineering, 28: 143-149.
[5] Li, M., Yang, E., Li, P., Bao, H.Z., Li, L., Shen, Z.Z. (2017) Characteristics of sediment deposition in check dam in small watershed in Loess Hilly Area. Transactions of the Chinese Society of Agricultural Engineering, 33: 161-167.
[6] Shi, X.J., Wang, L.L., Yang, J.X., Li, L. (2019) Calculation of soil erosion modulus based on sedimentation investigation of check dam. Yellow River, 39: 103-106.
[7] Liu, X.Y., Gao, Y.F., Ma, S.B., Dong, G.T. (2018) Sediment reduction of warping dams and its timeliness in the Loess Plateau. Journal of Hydraulic Engineering, 49: 145-155.
[8] Fang, X.M., Zeng, M.L. (1996) Equilibrium dam system in small watersheds of the Middle Yellow River basin. Journal of Sediment Research, 03:12-20.