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Progress of Silt Dam Research on Loess Plateau

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Abstract

The current status of silt dam research on the Loess Plateau is analyzed, aiming to reveal the key directions and main tasks of future silt dam research. The main research results of siltation dams on the Loess Plateau in the past 16 years are analyzed and summarized by using academic paper database and bibliometric analysis. The number of papers on silt dams on the Loess Plateau has been decreasing over the past 16 years. Silt dams are a major initiative in the management of small watersheds on the Loess Plateau in China, and their practice over the years has proved that they have achieved significant results in soil and water conservation. In the future, domestic scholars need to continue to expand the depth of research on silt dams, pay attention to multidisciplinary intersection and regional comparison research, and continuously improve the scientific research level of silt dams.

Keywords

Loess Plateau; Silt Dam; Research Progress.

1. Introduction

Soil erosion survey shows that the area of soil erosion in China is more than 3.5×10^6 km^2, accounting for about 1/3 of the total land area [1]. Due to the arid climate, fragmented terrain, ravines and sparse vegetation, the Loess Plateau has become the most serious soil erosion and the most fragile ecological environment in China. Severe soil erosion will cause the reduction of arable land area, intensify drought and flooding disasters, bring serious challenges to the ecological environment and food security, and restrict the healthy and sustainable development of economy and society. As a key measure to control soil erosion in small watersheds on the Loess Plateau, silt dams can effectively block sediment transport downstream, effectively control channel erosion, promote small watershed water use, and improve flood control capacity. In the 1970s, the successful testing and application of the water fall method of dam construction made the construction of silt dams exponentially more efficient, and the total number of dams built in the Loess Plateau has exceeded 1.07×10^5 by now [2]. In recent years, the construction of control dams in small watershed ditches has greatly improved the standard of flood control in watershed ditches, and the comprehensive benefits of sand control, siltation and irrigation have also been significantly improved. Therefore, it is of great significance to

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carry out in-depth research on silt dams in the Loess Plateau and strengthen the overall planning of silt dam engineering facilities to further improve the management of soil erosion in the Loess Plateau with small watersheds as the unit.

Due to the lack of foreign regions with such serious soil erosion as the Loess Plateau and the difference in the purpose and standard of dam construction in China and abroad, the research work done by domestic and foreign scholars is different. Foreign scholars such as Castillo [3], Boix-Fayos [4] and Lenzi and Comit [5] focused on the effect of silt dams on channel morphology and surrounding vegetation, especially on the effect of dams on erosion rates, while domestic scholars mainly focused on soil and water conservation effectiveness. Domestic research on silt dams began in the 1950s, and government departments at all levels and relevant research institutions attached great importance to soil erosion control, and invested a lot of research funds to carry out a series of experimental studies on silt dams in the Loess Plateau area, but summaries of the research results are not common and few papers have been published. In this paper, we analyze the research progress in the field of silt dams in terms of research hotspots, technical methods and research mechanisms, and summarize the difficult problems in the research of silt dams, expecting to provide references to strengthen the scientific research of silt dams in the future.

2. Research Data and Methods

There have been mature applications for analyzing the research progress of a frontier issue in geography using journal network academic paper database and bibliometric analysis methods [6-7]. In this paper, we used the China Knowledge Infrastructure (CNKI) as the platform for accessing literature information and the full-text data of Chinese journals as the data source [8], and adopted the advanced search type with "topic (including: title, abstract, keywords)" as the search item and "siltation dam "Silt dam" was used as the search term, and 1492 relevant articles were retrieved from 2000 to November 2015. After content analysis of the retrieved papers according to the titles, keywords and abstracts of the articles, 890 papers were removed from the conference announcements, newsletters, and papers with little relevance to siltation dams. In addition, 388 papers were selected based on the content of the papers, papers closely related to siltation dams on the Loess Plateau, such as "Criteria for judging the failure of sand retention function of siltation dams in the middle reaches of the Yellow River in Shaanxi Province", "Journal of Geography", "Journal of Water Resources", "Study on flood and sand reduction and erosion reduction of silt dams in the middle reaches of the Yellow River", a total of 388 papers to analyze the progress of silt dams in the Loess Plateau.

3. Results and Analysis

3.1. The Engineering and Construction Achievements of the Silt Dam

Since 2003, China has made remarkable progress in the Loess Plateau area with silt dams as one of the 3 highlight projects of water conservancy. At the same time, the Yellow River Water Conservancy Commission in the completed "planning" pointed out that from 2003 to 2020, the Loess Plateau area will build 1.63×10^5 silt dams, including 30,000 backbone dams. After the completion of the project, it can add 4.00×10^{11} t of mud stopping capacity, 1.7×10^{11} km^3 of water storage capacity, 7.00×10^8 t of annual reduction of sediment into the Yellow River, and the economic benefits amount to more than 180 billion yuan in 30 years of calculation period. According to the Ministry of water resources organized in 2009, the safety inspection statistics of silt dams [9], by the end of 2008, the Loess Plateau area built 9.10×10^4 silt dams, silt into dam land about 3.00×10^8 hm, the total reservoir capacity reached $1.03\times10^{11}km^3$, mud stopping reservoir capacity reached $7.00\times10^4km^3$, control area of $3.26\times10^4km^3$. According to the Ministry of Water Resources, by 2015, the Loess Plateau has built 1.07×10^5 silt dams, and the

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future should strengthen the construction of silt dams in the Loess Plateau area and remove dangerous dams, and complete the comprehensive management of soil erosion with an area of 5.00×10^4 km^2. In addition, on the basis of 33 tributaries (pieces) in the sandy area, we should continue to strengthen the construction of silt dams in the whole Loess Plateau area.

3.2. Analysis of Silt Dam Research Literature

From the analysis of the literature data, it is clear that the number of papers on silt dams in the Loess Plateau from 2000 to 2015 has been decreasing in fluctuation, with the highest number in 2003 (68) and the second highest in 2005 (40). The 388 papers retrieved were published in 40 journals, and there were three journals with more than 20 papers: China Soil and Water Conservation (55 papers), China Water Resources (30 papers), and Shanxi Soil and Water Conservation Science and Technology (22 papers). Domestic geography authoritative journals Agricultural Engineering Journal and Chinese Journal of Science and Water Resources published 12 articles, accounting for about 4% of the total, and core journals published 172 articles, accounting for about 46%. The fact that the research papers on silt dams in Loess Plateau were published in these key journals indicates that the research on silt dams is a frontier topic in geography and hydrology, and also indicates that there is a need to continuously expand the depth of research on silt dams, improve the level of theoretical research in this field and promote methodological innovation. Research teams and research groups are the basis of high level research output. According to the research institutions to which the authors belong, the Upper and Middle Yellow River Administration of the Yellow River Conservancy Commission and the Xi'an University of Technology have published the most papers, among which the Upper and Middle Yellow River Administration of the Yellow River Conservancy Commission focuses on the overall construction scale and management of siltation dams on the Loess Plateau, while the Xi'an University of Technology focuses on the analysis of siltation volume of siltation dams. According to the research themes of silt dams on the Loess Plateau, combined with the characteristics of the total number of journal papers, it shows that the research on silt dams on the Loess Plateau presents more obvious stage characteristics. It can be divided into 2 phases, with the year 2007 as the boundary. In the first stage (2000-2007), the total number of papers was 223, with an annual average of 27, and the research area was mainly concentrated in the sandy and coarse sand area of the Loess Plateau, and the research method was mainly hydrological and water conservation method, with the representative authors being Xu Jiongxin and Li Zhanbin, which accounted for 10% of the total number of papers in this stage. In the second stage (2008-2015), the total number of papers is 165, with an annual average of 20. Compared with the previous stage, the research area is more extensive, and the research method focuses on hydrological modeling method, especially the application of GIS and RS technology method is more common, represented by RUSLE model simulation, and the professional module about the sand transport capacity of the watershed and the sand retention efficiency of the silt dam is increased, with the representative author being Tian Peng [10]. Through an in-depth analysis of the above-mentioned literature, it is found that the domestic silt dam research is characterized by the relative concentration of hot spots and hot areas, continuous improvement of technical methods and deepening of mechanistic research.

3.2.1. Research Hotspots are Relatively Concentrated in Hot Areas

Some of the research sites selected by domestic scholars for silt dams on the Loess Plateau are mainly focused on the sandy and coarse sand areas of the Loess Plateau, especially Huangfu River, Wuding River, and Huangtuwa. In order to systematically analyze the relationship between single dams' water retention and sand reduction benefits and their influencing factors, Jiao Juying et al [11] used five small watersheds, Huangfu River, Cuyuno River, Jia Lu River, Douwei River, and Dali River, as the study sample areas, and the results showed that the water

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retention benefits of single dams in the five sample areas were inversely proportional to rainfall and the sand reduction benefits were positively proportional to rainfall. In 2006, Xu [12] on the basis of a large number of actual measurements of silt dams in the Wuding River, concluded that the rate of increase in dam area peaked in the 1970s, decreased significantly in the 1980s, and declined further in the 1990s. Long et al [13] took the earliest silt dam in China, Zizhou County, as the object of study, and calculated the modulus of sand production per storm flood based on the changes of sediment particle size and spodumene concentration, and concluded that the soil erosion intensity in this area in Ming Dynasty was close to that of modern times.

3.2.2. Continuous Improvement of Technical Methods

With the increasing number of sites investigated on the Loess Plateau, the research methods on the water and sand reduction benefits of silt dams have gradually transitioned from hydrological and water conservation methods to hydrological models, and model tests of dam systems on the Loess Plateau have emerged. In 2004, Ran et al [14] used the "water conservation method" to study the flood and sand reduction and erosion reduction effects of silt dams in the sandy and coarse sandy area of the middle reaches of the Yellow River from Hekou town to Longmen area (HeLong area) and in the Jing, BeiLuo, and Wei rivers, i.e., to calculate the annual flood production and sand transport moduli for each basin during the year, so as to obtain a more consistent flood reduction and erosion reduction effect. In 2005, Xu [15] studied the flood and sand reduction effects of silt dams. In 2005, Xu used a model test method of the Loess Plateau trench and dam system, i.e., a half-scale model test method to compare the rainfall and sand production of the trench and dam system, in order to predict the evolution of the prototype landform. This method correlates the geomorphological evolution of the model trench with the prototype geomorphological phenomena and facilitates the use of the model test to demonstrate the prototype soil and water conservation management scheme. In 2010, Qi et al [16] established an empirical relationship between precipitation water flow and precipitation water sand, and calculated the amount of water and sand that should be generated when the precipitation data were substituted into the measured precipitation data, which resulted in a sand reduction of about 65% for the erosion control method based on engineering measures such as reservoirs and dams in the Kibagou watershed.

3.2.3. Mechanism Research is Deepening

The siltation mechanism of silt dam is that after the construction of silt dam, the erosion reference surface of the upstream channel of the dam site will be raised due to the siltation height of the dam site, thus slowing down the specific drop of the river bed in the siltation section upstream of the dam site, widening the river bed and greatly reducing the erosion capacity and sand holding capacity of the water flow. At the same time, the sand retention time in the silt dam is prolonged due to the sand retention effect of the dam, which increases the sedimentation and siltation volume.

In order to analyze the relationship between the siltation volume of silt dams and the influencing factors, Wang et al [17] analyzed the 137Cs content of sedimentary sediment in the dam site of Yan Gou basin and found that the nucleophile concentration in the sediment layer would vary with the thickness of the sediment layer (sub rainfall erosion). In 2011, Xue et al [18] divided the erosion history of the sub-basin into three stages during the operation period of the silt dam based on the annual sediment accumulation curve during the operation period of the dam. By comparing with the corresponding rainfall data, it was found that human activities were the main factor influencing the stage changes in soil erosion intensity. In 2012, Gao et al [19] used the modified universal soil loss equation (RUSLE) to analyze the soil erosion modulus of the watershed in different periods and quantitatively revealed the effect of increasing siltation height on the hydraulic erosion of the watershed.

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4. Conclusion and Prospect

4.1. Conclusion

By analyzing the engineering construction achievements of silt dams and literature research results, it shows that although the total number of papers published on silt dam research has shown a decreasing trend in the past 16 years, significant progress has been made in research contents and methods, mainly in terms of more research sites, deeper research mechanisms, a greater pace of technological innovation, and the computer, "3S" and other technical means are widely used. However, there are still difficult or controversial issues in the analysis, such as the objective evaluation method of sand control function effectiveness and dam heightening repair.

4.2. Prospect

(1) Study of the criteria for determining the failure of sand retention function. In the study of silt dams on the Loess Plateau, as the engineering structure of silt dams changes, it is important to guide the study of future changes in the criteria for determining the failure of sand control. In 2009, the Ministry of Water Resources carried out a safety inspection of silt dams on the Loess Plateau, from which it was found that there are more silt dams in each province (region) with a siltation capacity exceeding the mud retention capacity. Moreover, the direct mud storage capacity as the judgment criterion for the failure of the silt dam sand stopping function is deviated from the reality, which will lead to the increase of the calculation error of the silt dam flood mitigation and siltation field. Gao [20] analyzed that the change of drainage and sand discharge location is the reason for the formation of the judgment criterion from the perspective of the engineering structure of silt dams, and proposed 0.77 and 0.88 as the appropriate judgment criterion for the failure of sand control function of the current backbone dams, small and medium-sized dams. However, as the engineering structure of silt dams changes, their failure criteria will also change. Therefore, to accurately assess the sand control function of existing silt dams, it is necessary to further study the criteria for determining the failure of the sand control function of silt dams.

(2) Ecological risk study of the staged raising of silt dams. Carry out the silt dam system model test, compare the relationship between the effect of sand stopping and siltation and the order of dam construction has important practical significance for the planning and design of silt dam construction. At present, in the actual construction process of silt dams, many silt dams are planned and designed once and raised in stages to reach the designed dam height. In order to avoid duplication of construction and waste of funds due to unreasonable planning, the constructed dam system cannot play its proper role. Zhang [1] reduced the investment by establishing a mathematical model for the phased raising of the dam front sloping, i.e., using the siltation in front of the dam as part of the earthwork volume of the dam. However, due to the annual siltation of silt dams, the silt storage capacity decreases during the design siltation life, and the siltation in front of the dam will increase. Therefore, it is necessary to further study how to raise the dam in stages in a small basin, including the number of times, time interval and height of each raise, in order to make it more scientific and reasonable.

(3) Multidisciplinary cooperation research. In recent years, most researchers only focus on the sand control benefits of silt dams, but relatively little research has been done on the erosion reduction effects of silt dams that raise the erosion datum during the siltation process and inundate the steeper slopes where erosion was more severe. Wang Yan applied the principle of datum rotation in high-resolution stratigraphy and made an exhaustive analysis of the datum change, i.e., the elevation change of the datum caused the relative change of the growth rate of the accommodable space (A) and the sediment supply (S). Therefore, enhanced cooperation between geography and geology-related fields is expected to provide a reliable source of data for studying the abatement effects of silt dams on severely steep-slope areas. In addition,

research on the hydrological effect of soil moisture from silt dams on groundwater recharge can be studied in depth and coordinated between hydrohydrology and soil science where the intersection of the disciplines is involved. In particular, more cooperation between disciplines is needed to study silt dams in the Loess Plateau region from multiple perspectives, so that each discipline can learn from the other's strengths and contribute to the improvement of the research level.

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