https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Hydrology and Earth System Sciences
Discussions
Open Access

Water erosion research in China: A review

Fang Haiyan[a,b]

a Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

b University of Chinese Academy of Sciences, Beijing 100049, China

Abstract. China, among other countries, suffers severe soil loss. Water erosion studies in China have been conducted since 1922, and great achievements have since been obtained. Promoting water erosion research in China and globally requires a systematic review of water erosion studies in China. This paper reviews the history, major achievements of water erosion research in China as well as its influencing factors, water erosion processes, changing mechanisms, sediment source identification, global changes, and water erosion impacts on water pollution and crop yield, and research needs in future water erosion study. Threshold slope lengths and water erosion gradients must be considered in hydrologic/erosion models to accurately estimate water erosion. Sedimentation information has been well-mined using chronological tracers and rainfall characteristics in China, which help offset the lack of monitored data in understudied regions. Physical water erosion models that have been well developed in China however should be programmed, promoted, and continuously updated to promote global accessibility. Tracers are used to estimate water erosion, and the efficiency of elemental selection and result confirmation is significant when fingerprinting methods are used to identify sediment sources. Climate change and land use models should be coupled with water erosion models to predict global change impacts on water erosion. In future water erosion research, extreme rainstorm impact on water erosion, water erosion impact on crop yield, smart soil and water conservation, and ecological service-oriented water erosion in China should be evaluated in depth. This review is intended to present water erosion research over approximately 100 years in China to provide future directions and highlight the need for ongoing water erosion research in China and other countries.

Keywords: China, water erosion history, achievement, research need

1 Introduction

Water erosion is an expansive environmental problem with significant ecological implications (Wuepper et al., 2020). It is associated with on-site land degradation, off-site sediment siltation in rivers, reservoirs, and lakes, and water pollution (Fang et al., 2018a; Wei et al., 2019). Thus, it directly and indirectly influences water, soil, and organism health as well as other earth surface processes (Borrelli et al., 2017).

China experiences severe water erosion (Yang, 2011; Li et al., 2020), mainly distributed in northeastern, eastern, and southern China (Fig. 1). According to the fourth national soil erosion survey in 2011, the total are of soil loss in China exceeded 1,293,200 km^2 (Liu et al., 2020).

Fig. 1. is about here

Water erosion research in China has spanned approximately 100 years, some research progress has been reviewed. For example, the causes of water erosion and the main soil control measures implemented in the black soil region of northeastern China were reviewed by Xu et al. (2010) and Liu et al. (2011). Achievements of soil erosion research in the Karst area were summarized by Lv et al. (2007). Soil control

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

measures on the Loess Plateau and their ecological functions were presented by Wen and Zhen (2020). Application conditions of 137-Casium (^{137}Cs) in China were reported by Wang and Pu (2002). The major water erosion models applied on the Loess Plateau and in China were also reviewed (Wang et al., 2004; Li et al., 2017; Zhang et al., 2009). In the red soil erosion region of southern China, water erosion characteristics, types, and vegetation restoration approaches were discussed by Lv et al. (2003). Impacts of terraces on soil loss in China were also reviewed by Chen et al. (2017). These reviews predominately focused on specific regions, methods, or notable findings. Some reviews on a national scale have also been conducted. For example, Chen and Jiang (1983) reviewed soil loss situations and denoted several issues that should be resolved. Zheng et al. (2008a) reviewed Chinese water erosion history and presented implications. Li et al. (2009) introduced notable achievements on coarse sediment source areas of the Yellow River basin, wind erosion, desertification control, and soil erosion environmental changes. Shi et al. (2020) reviewed some research hotspots of water erosion over the past ten years. These reviews improve our understanding of the progress achieved in Chinese water erosion research; however, there have not been any comprehensive reviews of national-scale water erosion research. To clarify the progress of water erosion research in China and improve future research, a systematic review of the past 100 years of water erosion research in China is urgently required.

The aims of this review article are to (i) present the developing stages of water erosion research over the study period; (ii) examine the main achievements of water

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

erosion research in China; and (iii) identify future research needs and directions.

2 Water erosion research stages

Based on study approaches, study content, and the number changes in publications, water erosion study in China can be divided into three stages (Fig. 2).

Fig. 2. is about here

2.1 Initial stage (1922–1980)

Water erosion research was first undertaken in 1877 in Germany and 1912 in the United States (Xie et al., 2003). The first water erosion study result in China was published in 1922, focusing on building runoff plots in Shanxi Province and Shandong Province (Xie et al., 2003; Zheng et al., 2008a). In 1941, Longnan and Guanzhong Soil and Water Conservation Experimental Stations were built in Gansu Province and Shaanxi Province, respectively. The Xifeng experimental station in Gansu Province and Suide experimental station in Shaanxi Province were built in 1951. Subsequently, an increasing number of experimental sites were built (Zuo and Guo, 2016), among which Soil and Water Conservation Experimental Station in Ansi County, Shaanxi Province is the most representative site that is still in use today.

This stage was characterized by the establishment of experimental sites at which large-scale investigation could be performed and basic data on water erosion could be collected. During 1952–1958, the first scientific investigation of soil loss on the Loss Plateau was conducted, and the national water erosion statistical survey was completed in 1955 (Fig. 2). Several pioneering studies were conducted, including the characterization of water erosion types and regional divisions of water erosion for the

© Author(s) 2020. CC BY 4.0 License.

Loess Plateau and China as a whole (Chen and Jing, 1983). For example, Huang (1955) initiated research on zoning soil erosion for the Loess Plateau, followed by Zhu (1958) and Luo and Zhu (1965). For China, water erosion sub-regions were described in several studies (Xin and Jiang, 1982; Chen and Zhu, 1989; Tang, 2004; the Ministry of Water Resources of the People's Republic of China, 1997). The regional divisions greatly facilitated further water erosion research and soil loss control in China.

In this period, studies primarily focused on the impacts of factors such as slope gradient, slope length, vegetation coverage, and soil conservation measures on soil loss. Some empirical models were established to estimate water erosion and sediment yield (Zhao et al., 2019). At this stage, the number of published articles is relatively low. Using the phrase "soil erosion" as a key word in the China National Knowledge Infrastructure (CNKI) database, no papers were found before 1948, and 36 papers were published during 1948–1980 (Fig. 3a).

Fig. 3. is about here

2.2 Rapid development stage (1981-2000)

After 1980, water erosion research in China developed rapidly. In 1982, the "Law on Soil and Water Conservation" was promulgated (Fig. 2), which stipulated the guidelines, departments, and study scope of soil and water conservation. In 1985, the first national soil erosion survey was initiated (Fig. 2), and water erosion type, intensity, and spatial distribution were characterized (Hu et al., 2002). During this stage, researchers began to evaluate the historical process of water erosion and its

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

influencing factors. Cai and Chen (1986; 1989) pioneered the research on raindrop erosion in China, making important progress on slope water erosion and its related influencing factors such as slope length, slope gradient, rainfall characteristics, soil properties, and soil crust (Chen, 1989). In addition, the concept of "small watershed comprehensive management" was formally proposed in 1980, and notable achievements have since been obtained for small watershed management (Cui, 2007).

The disciplined development of soil and water conservation also began to garner attention. Before 1983, Beijing Forestry University was the only provider of an undergraduate degree in soil and water conservation. By 1998, ten universities in China offered this program, and Beijing Forestry University established a college for this research field (Wu and Wang, 2006). Following the increase in students pursuing these programs, publications in the field sharply increased. The number of published Chinese papers in the CNKI database increased from 12 to over 250 from 1980 to 2000 (Fig. 3a). However, searching the Web of Science database with the key words “soil erosion” or “sediment yield” resulted in fewer than 10 papers, and only 4 papers were found when “Loess Plateau” was added to the search (Fig. 3b).

During this period, large areas of soil loss control strategies were implemented. Since 1983, the Ministry of Water Resources had successively carried out the "Eight Large Regions" soil loss control project, covering the Sanchuan River basin, Huangfuchuan River basin, Wuding River basin, Dingxi County in the Yellow River basin, Yongding River upper reaches in the Haihe River basin, Liuhe River basin upstream of the Liaohe River, Gezhouba reservoir area, and Xingguo County in the

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.
Hydrology and Earth System Sciences
Open Access
Discussions

Yangtze River basin (Department of Rural Water Conservancy and Soil Conservation, Ministry of Water Resources, 1992), the "Changzhi Project" upstream of the Yangtze River, and the large-scale "Grain to Green" program in 1999 (Lin et al., 2020). At this stage, the scope of water erosion research expanded, new approaches were employed, water erosion models were constructed (Tables 1 and 2), and more soil erosion investigations were conducted (Fig. 2).

Table 1 is about here

Table 2 is about here

2.3 Stable development stage (2001–present)

Since 2001, water erosion research in China has steadily developed. In 2005－2007, a large-scale comprehensive scientific investigation of soil erosion was conducted by the Ministry of Water Resources of the Peoples' Republic of China, Chinese Academy of Sciences, and Chinese Academy of Engineering, involving 86 institutes and schools and 251 professors and encompassing 27 provinces. A sound monitoring system for soil erosion has been established that involves a four-grade monitoring network of soil and water conservation, including one national soil and water conservation monitoring center, six large-river (i.e., Songhua-Liao R., Haihe R., Huaihe R., Yellow R., Yangtz R., Zhujiang R.) and one lake (Tai lake) controlled catchment monitoring centers, thirty provincial soil and water conservation monitoring stations, and their substations (Fig. 4). The numbers of universities with soil and water conservation programs also increased to twenty-two, and more papers on water erosion have been published. For example, 740 papers were found when

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

"soil erosion" or "sediment yield" were searched in CNKI (Fig. 3a). The number of published SCI papers searched with the key words of "soil erosion or sediment yield" and "China" increased significantly during this period (Fig. 3b).

Fig. 4. is about here

In this stage, new approaches were employed to study water erosion. In addition to traditional methods such as runoff plots, rainfall simulation, and small catchment monitoring, high-resolution remote sensing images (Wang et al., 2012; Duan et al., 2020), unmanned air vehicles UAV (Yang et al., 2019a), three-dimensional laser scanning (Fang et al., 2015), high-accuracy photogrammetry (Yao et al., 2019; Jiang et al., 2020), and compound fingerprinting technology (Chen et al., 2019) were introduced. International cooperation became more frequent as well. For example, published SCI papers in 2001–2019 in Web of Science with "soil erosion" or "sediment yield" as key words and "Loess Plateau" included research from 22 countries (Fig. 3b). Furthermore, more studies focused on large-scale land use and climate change impact on soil erosion and sediment yield (i.e., regional or national scales). In recent years, over 200 papers are published in relation to climate change impact on water erosion per year (Li and Fang, 2016).

3 Achievements

The achievements of water erosion research in China during the nearly past 100 years mainly include five aspects, which are described below.

3.1 Water erosion divisions

Under the background of water erosion research in the world, soil erosion regional

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

divisions were done because it facilitates the study of soil erosion characteristics and implementation of soil conservation measures. Based on the major external force leading to soil erosion, China was divided into water, wind, and freeze-thaw erosion regions. Six water erosion sub-regions were further categorized according to soil erosion characteristics, topography, and soil colors (Xin and Jiang, 1982; Fig. 1). Similar classifications were also presented by Tang (2004). Chen and Zhu (1989) divided the water erosion region into eight sub-regions. In contrast, five water sub-regions were outlined by the Ministry of Water Resources (1997). Although these classification systems were not exactly the same, the dividing boundaries between water erosion region and other two soil erosion types agree with each other in general. The water erosion classification method by Xin and Jiang (1982) has been used in several studies in China (Li et al., 2009; Cai et al., 2012). Soil erosion zoning was further conducted in the northwestern Loess Plateau that has been introduced in Section 2.1.

3. 2 Erosion process and variation mechanism

Water erosion and sediment yield vary with time and space, and their influencing factors, erosion and transport processes, and variation mechanisms have been obtained on slope and catchment scales.

3.2.1 Water erosion on slopes

Water erosion characteristics on slopes and its influencing factors, including slope gradient, slope length, soil properties, rainfall characteristics, vegetation cover, and soil conservation measures (Liu, 1953; Cai, 1989; Yu et al., 2006; Yu et al., 2009;

Chen et al., 2017; Yang et al., 2019c; Zhu et al., 2020; Sang et al., 2020) as well as changes of soil surface (Zhang, 2017; Wang et al., 2018; Shi et al., 2020.) were studied, and meaningful results have been obtained. The most significant contributions to the scientific community with regard to water erosion are the impacts of slope length and slope gradient on runoff and water erosion (Shi et al., 2020). The impact of slope length on water erosion was focused on in 1936 (Cook, 1936), and more studies were conducted later. In the 1950s, different conclusions had been obtained through analyzing recorded runoff and sediment data from runoff plots in the world, and it was found that water erosion can positively or negatively correlate with slope length (Kong et al., 2001), or do not change apparently with increasing slope length (Luo, 1958; Zheng et al., 1989). Based on experimental studies, a nonlinear relation in Fig. 5a between runoff amount and slope length was identified by Cai (1998). This conceptual model clearly shows changing threshold values of runoff amount with different rainfall intensities. Under the same rainfall characteristics, the threshold values of water erosion intensity occurred earlier on longer slopes (Fig. 5b), due to the interactions between soil crust and rill development (Fang et al., 2008b; Fang et al., 2015). Based on the interaction of crusted soil and rill development which dominate at different time period, a conceptual model that shows the mechanism of threshold value was built (Fig. 5c). The time and magnitude of rill occurrence determined the threshold value of water erosion rate, depending on slope length, slope gradient, soil properties, vegetation cover, and rainfall characteristics (Cai, 1998).

Fig. 5. is about here

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Research on the impact of slope gradient on water erosion began in 1936, when Renner (1936) first studied the changes of runoff with slope gradient and identified a threshold value of water erosion rate with increasing slope gradient. In China, systematic studies on threshold gradient were first conducted in the 1950s. Guo (1958) found that the threshold slope gradients ranged from 35 to 50 degree. On the loess slopes in Lishi and Suide, the range of threshold slope gradient from 25 to 28 degree was identified by Chen et al. (1983). Jin (1995) reported the same range. The critical values of 41.4 or 45 degree were also obtained by Cao (1993). The threshold values were determined once more to be from 41.5 to 50 degree (Liu et al., 2001). According to published studies, a conceptual model of critical slope gradient was developed and presented by Qian (1989). The existence of threshold values of slope gradient results from the interaction of runoff generation and its carrying capacity (Chen et al., 2010; Zheng et al., 2015) and can also be explained by the dynamic changes of topsoil crusting formation, destruction, and rill development during water erosion process (Fang et al., 2008b; 2015). Incorporating these dynamic development processes of soil crust and rill along slopes can improve the estimation accuracy of water erosion models such as WEPP.

3. 2.2 Water erosion in catchments

A small catchment is regarded as the basic unit for implementing soil conservation measures in China. Since the 1980s, a large number of small catchments have been monitored to study water erosion and their responses to the implemented soil conservation measures (Chen, 1983; Zheng et al., 2008a). Using the recorded runoff

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

and sediment data from small catchments, the changes of runoff, sediment, runoff-sediment relationship, and their relations to topography, land use, rainfall were studied (e.g., Zhao et al., 1980; Zheng et al., 2008b; Li et al., 2017). Based on water erosion characteristics in catchments, a "Three Defense Lines" tridimensional protection system for each water erosion sub-region was established to effectively control catchment soil loss in China (Cai et al., 2012; Sun et al., 2012).

In recent years, sediment deposited in dams was used as important data source to determine sediment yield history and response to land use and climate change based on tracer technology (Hou et al., 2007; Fang, 2015; Zhao et al., 2017). The derived data have been used as input data for water erosion models (e.g., Fang and Sun, 2017). This makes up for the lack of data over longer time spans or in understudied regions. Runoff and sediment data monitored at hydrological stations in China have also been used to analyze sediment yield changes, identify sediment source, and study their responses to anthropogenic activities and climate change (Ran et al., 2013; Wang et al., 2015). For example, through analyzing sediment concentration and water discharge at hydrological stations in the Yellow River basin, the major sediment source areas (i.e., coarse sediment area CSA with particle size > 0.05 mm in diameter and fine sediment area FSA) of the Loess Plateau were identified (Fig. 6a). This finding greatly helped for implementing soil conservation measures on the Loess Plateau and greatly reduced sediment yield of the Yellow River (Fig. 6b; Wang et al., 2015). The monitored data were also be used to disclose sediment transport dynamics at different time scales (e.g., Fang et al., 2008a; Hu et al., 2019). Changes of sediment

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

yield with spatial scales—for example, from slopes to catchments—were also studied, and factors affecting their changes were identified (Fang et al., 2007; 2011). The work greatly improves our understanding of soil erosion processes and mechanisms of change.

Fig. 6. is about here

3. 3 Water erosion modeling

Water erosion modeling in China was first implemented in the 1950s, and many models have been established to study soil erosion processes, identify sediment sources, and analyze influencing factors. Since 2000, due to intense human activities and climate change, an increasing number of studies were conducted using models to clarify their contributions to water erosion and sediment yield in combination with land use and climate change modeling (Fig. 7). Except for some empirical and physically-based based models established in China (Table 2), many models from abroad, including the soil and water assessment tool (SWAT; Yu et al., 2009; Lin et al., 2020), Water and Tillage Erosion Model/Sediment Deposition Model (WaTEM/SEDEM; Feng et al., 2010; Yu et al., 2009; Shi et al., 2012; Fang and Sun, 2017; Fang, 2020), Water Erosion Prediction Project (WEPP; Yu et al., 2009; Zhang et al., 2014; Zheng et al., 2020), and RUSLE (Teng et al., 2018; Guo et al., 2019) are used in China to study water erosion and sediment yield. Among these models, SWAT and RUSLE are the mostly widely used in China. The SWAT is also used in Chinese inland regions but not the six water erosion sub-regions (e.g., Chen, 2006). Based on the classifications of soil conservation measures in China (the established CSLE) by

Liu (2001) has been used in some regions (Liu et al., 2020; Liu and Liu, 2020). This is the most widely used empirical water erosion model in China. However, RUSLE is still widely used owing to the ease with which C and P factors can be calculated using this model. RUSLE is a slope based model, however, it is widely used at catchment and/or regional and global scale. A combination of RUSLE with gully-estimated models should be done in China and in the world.

Fig. 7. is about here

Monitored data at gauging stations is commonly used to calibrate and validate models. In recent years, sediment yield derived from deposits in dams and water erosion intensity from ^{137}Cs methods have been used to calibrate and validate water erosion models. For example, the mean annual sediment yields from the 25 reservoir catchments in Baiquan County were used to run WaTEM/SEDEM in the black soil region of northeastern China (Fang and Sun, 2017; Fang, 2017). Water erosion intensities on the slopes from ^{137}Cs technique were also used as input data to WaTEM/SEDEM (Li and Fang, 2015). The data derived from sediment deposits greatly makes up for the lack of monitored data in ungauged regions.

Although models are widely used in China to study water erosion, these studies have focused on different regions. In comparison to detailed studies in Europe (https://esdac.jrc.ec.europa.eu), more systematic work is required in China, including detailed model factor study such as RUSLE-C and -P, spatiotemporal characteristic analysis, and future conditions estimation with different global change scenarios.

3.4 Sediment source identification

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Research on sediment sources began in the early 20th century. The major methods to identify sediment sources include hydrological data analysis, fingerprinting tracers, and modeling methods (Table 1).

Whether the sediment on the Loess Plateau mainly came from slopes or gullies was the focus of debate in the 1980s (Chen and Wang, 1990). The debate stimulated the sediment source study. Hydrological data from runoff plots and gauged catchment are often used to identify sediment sources (e.g., Jiang et al.; 1966; Zhang et al., 1990; Chen, 1999). For example, the contribution of gully erosion to catchment sediment yield was obtained through monitored data from runoff plots and gauged catchments (Chen, 1999; Wei, 2002). The main sediment source areas of the Loess Plateau were also obtained through comparing runoff and discharge data at the hydrological stations in the Yellow River basin (e.g., Shi and Wang, 2003; Fig. 6a). A lot of work has also been done on the Loess Plateau and in other places using fingerprinting method (Fang, 2015). For example, based on magnetic characteristics of debris flow sediments and source soils, Jia and Wei (2009) quantified the contributions of different land use types to catchment sediment yield. Yang et al. (1999) pointed out that the gullies on the Loess Plateau were the main sediment source in the Yellow River. Zhang et al. (1992) presented the source area of fine-grained material in debris flow in northeastern Yunnan using ^{137}Cs. Based on ^{137}Cs and ^{210}Pb tracers, Zhang et al. (2004) reported that agricultural slopes accounted for 46% of the catchment sediment yield. Some studies (i.e., Chen et al., 2019; Huang et al., 2019) also use compound fingerprint tracers to identify multiple sediment sources. Selecting multiple tracers is

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

the key to employing fingerprinting technology. Models, including the multivariate mixed model, Monte Carlo model, Bayesian model, and Generalized Likelihood Uncertainty Estimation (GLUE), are required to ascertain the contributions of different sediment sources (Walling, 2013; Chen et al., 2019). Different results arise when different fingerprints and models are used. In the current study, the obtained results usually lack efficient verification, leading to great uncertainty (Chen et al., 2016ab; 2019). As methods that discriminate sediment sources are multiple, mutual confirmation is required in future studies when the fingerprinting method is used.

Identification of sediment source can be judged through field survey by manual or remote sensing technology (Li and Fang, 2016). For example, a large-scale survey started in the 1950s on the Loess Plateau, and the national soil erosion surveys in 1999 and 2001 were conducted through remote sensing investigations (Liu et al., 2020).

As mentioned above, methods used to identify sediment source and soil erosion are multiple, different methods yield different results. These methods should be coupled together when one work is done which can yield a more accurate result.

3. 5 Global change and water erosion

Global change includes both land use and climate change (Zhang et al., 2005; Luetzenburg et al., 2020). The impacts of climate change on water erosion have been reported since the 1940s (Bryan and Albritton, 1943). They can directly or indirectly affect water erosion through altered rainfall characteristics, temperature, vegetation cover, land use, crop management, and anthropogenic and socio-economic factors as well as their interactions (Li and Fang, 2016; Peng and Li, 2018). The complex relationships between these factors and water erosion should be carefully studied. The number of publications associated with the keywords "soil erosion," "sediment yield," "climate change," and "China" has increased yearly (Fig. 3c). Similar results were also found for land use change impact on water erosion (Fig. 3d). This changing trend also was also reported in other countries by Batista et al. (2019). However, these studies mainly focus on the impact of past climate and/or land use changes on water erosion. Furthermore, these works were mainly conducted on the Loess Plateau (e.g., Zhang and Liu, 2005; Zhang et al., 2009; Hu et al., 2020) and less studies in other regions (e.g., Li and Fang, 2017; Teng et al., 2018). With increasing climate change and intense anthropogenic activities, more work should be done in relation to future global change impact on water erosion in China.

3. 6 Impacts of water erosion

In China, soil erosion is both an environmental and ecological problem. Studies on the impact of water erosion mainly include local crop yield and water pollution.

3. 6.1 Impact on crop yield

Water erosion can cause soil loss, destroy soil structure, and reduce soil nutrition (Li et al., 2007; Fang et al., 2012; Sun et al., 2015), resulting in degraded land and reduced crop yield. Wu (1982) pointed out the research prospects of the effects of soil erosion on soil productivity. In recent years, an increasing number of studies have been conducted on crop yield impact in China (Table 3). Studies have employed experimentation (Zhang et al., 2007; Wang et al., 2009; Liu and Wei, 2014; Gao et al.,

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

2015), modeling (Duan et al., 2011; Li et al., 2011; Gu et al., 2018; Lin et al., 2019), and field sampling (Sun et al., 2010; Yang et al., 2016; 2019) to evaluate water erosion impact on crop yield. However, most research has focused on the black soil region in northeastern China, likely because it is the most important grain base in the country (Fang et al., 2013). However, most studies were conducted on a small scale (i.e., local experiments or runoff plots) with field experiments or empirical models. These methods are often used in other countries as well (den Biggelaar et al., 2003). Water erosion–derived crop yield loss depends on topography, soil, precipitation, crop type, and other factors. A combination of physically-based water erosion models and crop yield models can better estimate water erosion impact on crop yield (Loo et al., 2017), as performed by Li et al. (2011). Further research could also couple with land use and climate change models to predict future water erosion impact on crop yield at a larger spatial scale (Fig. 7).

Table 3 is about here

3. 6.2 Impact on water pollution

Pollutants can be carried by both water and sediment. The fine sediments represent an important diffuse source pollutant because they can absorb nutrients, heavy metals, pesticides, and other organic contaminants due to high specific surface areas and charge densities (Walling and Collins, 2008). Furthermore, sediment is also regarded as a priority pollutant because a large amount of sediment in water systems can change water turbidity, light penetration, water temperature, and biologically available oxygen (Watts et al., 2003; Bilotta et al., 2010). These pollutants run downstream with

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

runoff and sediments, causing eutrophication and water pollution. With socioeconomic development, soil loss–induced environmental problems become increasingly prominent. Although sediment in surface water is an important pollutant (Walling and Collins, 2008; Rickson, 2014), most studies on water pollution only considered dissolved pollutants in runoff (Ouyang et al., 2020; Hua et al., 2019), with a few exceptions (e.g., Tang et al., 2011; Zhang et al, 2020). More and detailed research of soil loss related water pollution should be conducted in China.

4. Research needs

As mentioned above, although notable achievements of water erosion research in China have been obtained, there is scope for future research to enhance existing models and promote further understanding, including the following four aspects.

4.1 Extreme rainstorm impact

Large-scale soil conservation measures have been implemented in China, greatly reducing soil loss (Fig. 6b). However, their control efficiency can decrease sharply or even be completely destroyed when extreme rainfall occurs. For example, the "7-26" extreme rainstorm in 2017 destroyed many check dams and caused serious soil erosion on the Loess Plateau (Bai et al., 2020). Similarly, severe damage to soil conservation measures under the extreme rainstorm on August 10, 2019 also occurred in Shandong Province (Han et al., 2020). The magnitude and frequency of extreme rainfall events have begun to increase in relation to continuing global climate change (Li and Fang, 2016). Research on water erosion characteristics under extreme rainstorms and corresponding countermeasures is critical in China.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

4.2 Water erosion, soil quality, and crop yield

China is a large agricultural country, and crop yield is crucial to the national economy and residents' livelihoods (Liu, 2020). Although some studies in relation to water erosion and crop yield have been conducted (Table 3), most work was conducted in the black soil region in northeastern China, and large-scale spatial variations of soil quality and crop yield derived by water erosion are few. Specifically, future human activities could be more intense, and rainfall amount, extreme rainfall event frequency, and rainfall pattern will change in future (Li and Fang, 2016). These changes will greatly influence soil loss, soil nutrients, and crop yield. The impact of future water erosion on soil quality and crop yield should be fully considered to facilitate the development of management and mitigation strategies.

4.3 Smart soil and water conservation

In recent years, new methods and technologies such as UAV-based monitoring technology, artificial intelligence, and information clouds, have been used to study water erosion. These technologies can automatically measure and/or monitor water flow velocity, water depth, sediment concentration, and related parameters. They can thus smartly recognize and mirror water erosion processes and characteristic variation, guiding the implementation of soil and water conservation measures. Similar to smart agriculture (Tsige, et al., 2020) and smart forestry (Bowditch, et al., 2020), smart soil and water conservation should be focused on in future water erosion research in China and globally.

4.4 Ecological service-oriented soil conservation

© Author(s) 2020. CC BY 4.0 License.

With ongoing socioeconomic development, ecological security has attracted more attention. Soil erosion can result in many environmental problems (Liu et al., 2020) and pose a severe risk to ecological security. Therefore, the final aim of soil loss control in China is to improve the catchment and/or regional ecological service function and environmental health (Hu et al., 2019). The concept "Green Water and Green Mountains are Golden and Silver Mountains," as strengthened by President Xi in September 2019, is closely related to ecological service-oriented water erosion. In July 2020, the special projects for "Ecological Protection and Sustainable Development Mechanism in the Yellow River," released by the National Natural Science Foundation of China, also indicates the need to conduct ecological service–oriented water erosion research.

5. Conclusions

Water erosion research in China has been undertaken for approximately 100 years and can be divided into three stages from 1922 onward. The initial stage spans 1922 to 1980, the rapid development stage spans 1981 to 2000, and the steady progress stage spans 2001 to the present day, and great achievements have been obtained. On slopes, threshold values of soil loss occurred with increasing slope length or gradient, and a conceptual model was established to explain the formation mechanism of the threshold values. Regional and national water erosion zones were established through large-scale field surveys in the past decades. Deposited sediments were used to restore the soil erosion history and used as validated data for water erosion models, which offset the lack of data in understudies or unmonitored areas in Chinese water erosion

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

study. Consideration of gravitational erosion in water erosion models improved modeling accuracy of water erosion on the Loess Plateau. Ongoing validation and modification are required to increase the applicability of these models. Multiple methods have been used to identify sediment sources, and results from compound fingerprinting method should be confirmed by other methods to guarantee accuracy.

To adapt to socioeconomic development and global change, impacts of water erosion on crop yield and environmental pollution should be strengthened, and physically-based water erosion and crop yield models and climate change models should be coupled to predict water erosion impact on soil quality and crop yield. To address the issues expected to emerge with global climate and social changes, new methods and technologies should be employed to cope with extreme rainfall events impact on water erosion, promote smart soil control, and guarantee regional ecological service function.

Data availability. All the dataset can be obtained from internet, “CNKI” database and the “Web of Science”.

Author contributions. Haiyan Fang collected data, designed the study, and wrote the manuscript.

Competing interests. The authors declare that they have no conflict of interest.

Acknowledgment. This work was financially supported by the project of the National Natural Science Foundation of China (grant number 41977066).

© Author(s) 2020. CC BY 4.0 License.

References

Bai, L.C., Wang, N., Jiao, J.Y., Chen, Y.X., Tang, B.Z., Wang, H.L., Chen, Y.L., Yan, X.Q., Wang, Z.J.: Soil erosion and sediment interception by check dams in a watershed for an extreme rainstorm on the Loess Plateau, China, Int. J. Sediment Res., 35, 408-416, 2020.

Batis, P.V.G., Davies, J., Silva, M.L.N., Quinton, J.N.: On the evaluation of soil erosion models: Are we doing enough? Earth-Sci. Rev., 197, 102898, 2019.

Bilotta, .GS., Krueger, T., Brazier, R.E., Butler, P., Freer, J., Hawkins, J.M.B., Haygarth, P.M., Macleod, C.J.A., Quinton, J.N.: Assessing catchment-scale erosion and yields of suspended solids from improved temperate grassland. J. Environ. Monit., 12(3), 731-739, 2010.

Borrelli, P., R4obinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C. Alewell, C., Meusburger, K., Modugno, S., Schutt, B., Ferro, V., Bagarello, V., van Oost, K., Montanarella, L., Panagos, P.: An assessment of the global impact of 21st century land use change on soil erosion, Nat. Commun., 8, 1-13, 2017.

Bowditch, E., Santopuoli, G., Binder, F., del R ó, M., Porta, N.L., Kluvankova, T., Lesinski, J., Motta, R., Pach, M., Panzacchi, P., Pretzsch, H., Temperli, C., Tonon, G.., Smith, M., Velikova, V., Weatherall, A., Tognetti, R.: What is Climate-Smart Forestry? A definition from a multinational collaborative process focused on mountain regions of Europe, Ecosyst. Serv., 43, 101113, 2020.

Bryan, K., Albritton, C.C.: Soil phenomena as evidence of climatic changes, Am. J. Sci., 241 (8), 469-490, 1943.

Cai, J.Y., Zhou, Z.H., Liu,J.J., Wang, H., Jia, Y.W.: A distributed soil erosion model based on the three-process of runoff and sediment transport, J. Hydrau. Eng., 51(2), 139-151, 2020.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Cai, Q.G.: The role of slope length in the process of slope erosion and sediment production, J. Sediment Res., 4, 84-91, 1989.

Cai, Q.G., Chen, H.: Primary experimental study on the influence of rainfall characteristics on splash erosion, Soil Water Conserv. China, 6, 30-34, 1986.

Cai, Q.G., Chen, H.: Using the multiple regression orthogonal test to study the impact of rainfall on splash erosion, Geogr. Res., 8(4), 28-36, 1989.

Cai, Q.G., Wang, G.P., Chen, Y.Z.: Soil erosion process and modeling in small catchments of the Loess Plateau, Beijing: Science Press, 1998.

Cai, Q.G., Zhu, A.X., Sun, L.Y.: Paradigm of comprehensive regulation and control of soil erosion in China's main water erosion areas, Beijing: China Water Power Press, 2012.

Cao, W.H., Slope thresholds of soil erosion, Bull. Soil Water Conserv., 13(4): 1-5, 1993.

Chen, D., Wei, W., Chen, L.D.: Effects of terracing practices on water erosion control in China: A meta-analysis, Earth-Sci. Rev., 173, 109-121, 2017.

Chen, D.Z., Zhu, X.M.: Soil erosion types and division map in China, Beijing: Science Press, 1989.

Chen, F.X., Fang, N.F., Shi, Z.H.: Using biomarkers as fingerprint properties to identify sediment sources in a small catchment, Sci. Tot. Environ., 557-558, 123-133, 2016b.

Chen, F.X., Wang, X.Y., Li, X.X., Wang, J.L., Xie, D.T., Ni, J.P., Liu, Y.J.: Using the sediment fingerprinting method to identify the sediment sources in small catchments with similar geological conditions, Agr.Ecosyst. Environ., 286, 106655, 2019.

Chen, F.X., Zhang, H.Y., Fang, N.F., Shi, Z.H.: Using two kinds of fingerprint factors to identify sediment sources in a small catchment, Adv. Water Sci., 27(6), 867-875, 2016a.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Chen, H.: Sediment source on small basin in middle reaches of Yellow River, J. Soil Water Conserv., 5(1), 19-26, 1999.

Chen, H., Wang, K.Z.: A study on the slope-gully erosion relationship on small basins in the loess areas at the middle reaches of the Yellow River, Geogr. Res., 18(4), 363-372, 1999.

Chen, L.J.: Simulation of runoff and sediment discharge respond to land use and land cover changes based on SWAT model, Zhejiang Normal University, Master Dissertation, 2006.

Chen, X.A., Cai, Q.G., Zhang, L.C., Qi, J.Y., Zheng, M.G., Nie, B.B.: Research on critical slope of soil erosion in a hilly loess region on the Loess Plateau, J. Mountain Sci., 28(4), 415-421, 2010.

Chen, Y.Z.: A preliminary analysis of the processes of sediment yield in small catchment of the Loess Plateau, Geogr. Res., 2(1), 35-47, 1983.

Chen, Y.Z.: Current water erosion and control for the Loess Plateau, Beijing: Science Press, 1988.

Chen, Y.Z.: New developments of soil erosion research work in China, Soil Water Conserv. China, 9, 7-11, 1989.

Chen, Y.Z., Jing, K.: Current situation of soil loss and some problems urgently required to be solved, Bull. Soil Water Conserv., 4, 1-6, 1983.

Cook, H.L.: The nature and controlling variables of the water erosion process, Soil Sci. Soc. Am. Proc., 39, 66-64, 1936.

Cui, M., Cai, Q.G., Zhu, A.X., Fan, H.M.: Soil erosion along a long slope in the gentle hilly areas of black soil region in Northeast China, J. Geogr. Sci., 17(3), 375-383, 2007.

den Biggelaar, C., Lal, R., Wiebe, K., Breneman, V.: The global impact of soil erosion on productivity: I: absolute and relative erosion-induced yield losses, Adv. Agron., 81, 1-48, 2003.

Department of Rural Water Conservancy and Soil Donservation, Ministry of Water Resources: Remarkable management effectiveness achieved in the eight national regions, Soil Water Conserv. China, 7, 55-57, 1992.

Duan X, Xie Y, Ou T.H., Lu, H.M.: Effects of soil erosion on long-term soil productivity in the black soil region of northeastern China, Catena, 87, 268-275, 2011.

Duan, X.W., Bai, Z.W., Rong, L., Li, Y.B., Ding, J.H., Tao, Y.Q., Li, J.X., Li, J.S., Wang, W.: Investigation method for regional soil erosion based on the Chinese Soil Loss Equation and high-resolution spatial data: Case study on the mountainous Yunnan Province, China, Catena, 184, 104237, 2020.

E, L.L.: Effects of soil erosion intensities on Mollisols physical and chemical properties and filed productivity, Northeast Agricultural University, Master Dissertation, 2018.

Fang, H.Y.: Temporal variations of sediment source from a reservoir catchment in the black soil region, Northeast China, Soil Till. Res., 153, 59-65, 2015.

Fang, H.Y.: Impact of land use change and dam construction on soil erosion and sediment yield in the black soil region, northeastern China, Land Degrad. Dev., 28, 1482-1492, 2017.

Fang, H.Y.: Impact of land use changes on catchment soil erosion and sediment yield in the northeastern China: A panel data model application, Int. J. Sediment Res., 35, 540-549, 2020.

Fang, H.Y., Cai, Q.G., Chen, H., Li, Q.Y.: Temporal changes in suspended sediment transport in a gullied loess basin: the lower Chabagou Creek on the Loess Plateau in China, Earth Surf. Process. Landf., 33, 1977-1992, 2008a.

Fang, H.Y., Chen, H., Cai, Q.G., Li, Q.Y.: Effect of rainfall regime and slope on runoff in a gullied

© Author(s) 2020. CC BY 4.0 License.

loess region on the Loess Plateau in China, Environ. Manage., 42, 402-411, 2008b.

Fang, H.Y., Chen, H., Cai, Q.G., Li, Q.Y.: Scale effect on sediment yield from sloping surfaces to basins in hilly loess region on the Loess Plateau in China, Environ. Geol., 52, 753-760, 2007.

Fang, H.Y., Li, Q.Y., Cai, Q.G., Liao, Y.S.: Spatial scale dependence of sediment dynamics in a gullied rolling loess region on the Loess Plateau in China, Environ. Earth Sci., 64, 693-705, 2011.

Fang, H.Y., Li, Q.Y., Sun, L.Y., Cai, Q.G.: Using ^{137}Cs to study spatial patterns of soil erosion and soil organic carbon (SOC) in an agricultural catchment of the typical black soil region, Northeast China, J. Environ. Radioactiv., 112, 125-132, 2012.

Fang, H.Y., Sheng, M.L., Tang, Z.H., Cai, Q.G.: Assessment of soil redistribution and spatial patterns for a small catchment in the black soil region, Northeastern China: using fallout $^{210}Pb_{ex}$, Soil Till. Res., 133, 85-92, 2013.

Fang, H.Y., Sun, L.Y.: Modelling soil erosion and its response to the soil conservation measures in the black soil catchment, Northeastern China, Soil Till. Res., 165, 23-33, 2017.

Fang, H.Y., Sun, L.Y., Tang, Z.H.: Effects of rainfall and slope on runoff, soil erosion and rill development: an experimental study using two loess soils, Hydrol. Process., 29, 2649-2658, 2015.

Feng, X.M., Wang, Y.F., Chen, L.D., Fu, B.J., Bai, G.H.: Modeling soil erosion and its response to land-use change in hilly catchments of the Chinese Loess Plateau, Geomorphology, 118(3-4), 239-248, 2010.

Gao, X.F., Xie, Y., Liu, G., Liu, B.Y., Duan, X.W.: Effects of soil erosion on soybean yield as estimated by simulating gradually eroded soil profiles, Soil Till. Res., 145, 126-134, 2015.

Gu, Z.J., Xie, Y., Gao, Y., Ren, X.Y., Cheng, C.C., Wang, S.C.: Quantitative assessment of soil productivity and predicted impacts of water erosion in the black soil region of northeastern China, Sci. Tot. Environ., 637-638, 706-716, 2018.

Guo, J.Z.: Discussion on the issue of the relations of slope gradient and runoff amount and sediment production, Yellow River, 3, 47-49, 1958.

Guo, Y.R., Peng, C.H., Zhu, Q.A., Wang,M., Wang, H., Peng, S.S., He, H.L.: Modelling the impacts of climate and land use changes on soil water erosion: Model applications, limitations and future challenges, J. Environ. Manage., 250, 109403, 2019.

Han, J.Q., Ge, W.Y., Hei, Z., Cong, C.Y., Ma, C.L., Xie, M.X., Liu, B.Y., Feng, W., Jiao, J.Y.: Agricultural land use and management weaken the soil erosion induced by extreme rainstorms, Agr. Ecosyst. Environ., 301, 107407, 2020.

Hou, J.C., Li, Z.B., Li, M.: Research on the sediment source and sediment yield intensity in a small watershed based on the alluvium information of soil saving dam, J. Xi'an Univ. Technol, 23(2), 118-122, 2007.

Hu, J.F., Gao, P., Mu, X.M., Zhao, G.J., Sun, W.Y., Li, P.F., Zhang, L.M.: Runoff-sediment dynamics under different flood patterns in a Loess Plateau catchment, China, Catena, 173, 234-245, 2019.

Hu, Y.F., Gao, M.: Evaluations of water yield and soil erosion in the Shaanxi-Gansu Loess Plateau under different land use and climate change, Environ. Dev., 34, 100488, 2020.

Hu, Y.W., Chen, H.L., Xu, K.B.: The using of digital remote sensing image method in soil erosion survey, J. Lanzhou Uni. (Nat. Sci.), 38(2), 157-162, 2002.

Hua, L.L., Li, W.C., Zhai, L.M., Yen, H., Lei, Q.L., Liu, H.B., Ren, T.Z., Xia, Y., Zhang, F.L., Fan, X.P. An innovative approach to identifying agricultural pollution sources and loads by using nutrient export coefficients in watershed modeling, J. Hydrol., 571, 322-331, 2019.

Huang, B.W.: Experiences and lessons of drawing up soil erosion zoning in the middle reaches of the Yellow River, Sci. Bull., 12, 14-21, 1955.

Huang, D.H., Du, P.F., Wang, J., Wei, X., Liu, B., Xu, J.J.: Using reservoir deposits to quantify the source contributions to the sediment yield in the Black Soil Region, Northeast China, based on the fingerprinting technique, Geomorphology, 339, 1-18, 2019.

Jia, S.W., Wei, F.Q.: Tracing sediment sources using magnetic measurements- a case study of Jiangjiagou valley, Yunnan Province, J. Sediment Res., 1, 54-59, 2009.

Jia, Y.Y., Zheng, F.L., Yang, Q.K., Wang, Z.L.: Construction of water erosion prediction model at small watershed in the loess hilly and gully region, Bull.Soil Water Conserv., 24(2), 5-16, 2004.

Jiang, D,Q., Zhao, C.X., Chen, Z.L.: Analysis of sediment source of small catchments in the middle reaches of Yellow River, Acta Geogr.Sini., 32(1), 20-35, 1966.

Jiang, J.M., Shi, H.J., Wen, Z.M., Guo, M.H., Zhao, J., Cao, X.P., Fan, Y.M., Zheng, C.: The dynamic process of slope rill erosion analyzed with a digital close range photogrammetry observation system under laboratory conditions, Geomorphology, 350, 106893, 2020.

Jin, C.X.: A theoretical study on critical erosion slope gradient, Acta Geogr. Sini., 50(3), 234-239, 1995.

Kong, Y.P., Zhang, K.L., Tang, K.L.: Impacts of slope length on soil erosion process under simulated rainfall, J. Soil Water Conserv., 15(2), 17-24, 2001.

Li, G.Q., Fang, H.Y.: Modeling soil erosion and sediment yield in a small catchment of the black

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

soil region using ^{137}Cs technique and WaTEM/SEDEM, J. of Shaanxi Nor. Uni. (Nat. Sci. Edi.), 43(3), 86-92, 2015.

Li, J.L., Sun, R.H., Xiong, M.Q., Yang, G.C.: Estimation of soil erosion based on the RUSLE model in China, Acta Ecol.Sini., 40(10), 3473-3485, 2020.

Li, M., Li, P., Yang, E.: Characteristics of sediment retention and transport in small watershed after construction of check dams in Loess Hilly Area, Trans. Chin. Soc. Agr. Eng., 33(18), 80-86, 2017.

Li, P.F., Mu, X.B., Holden, J., Wu, Y.P., Irvine, B., Wang, F., Gao, P., Zhao, G.J., Sun, W.Y.: Comparison of soil erosion models used to study the Chinese Loess Plateau, Earth-Sci. Rev., 170, 17-30, 2017.

Li, R., Shangguan, Z.P., Liu, B.Y., Zheng, F.L., Yang, Q.K.: Advances of soil erosion research during the past 60 years in China, Sci. Soil Water Conserv., 7(5), 1-6, 2009.

Li, Y., Zhang, Q.W., Reicosky, D.C., Lindstrom, M.J., Bai, L.Y., Li, L.: Changes in soil organic carbon induced by tillage and water erosion on a steep cultivated hillslope in the Chinese Loess Plateau from 1898－1954 and 1954－1998, J. Geogr. Res., 112, G01021, 2007.

Li, Z., Liu, W.Z., Zhang, X.C., Zheng, F.L.: Assessing the site-specific impacts of climate change on hydrology, soil erosion and crop yields in the Loess Plateau of China, Clim. Change, 105, 223-242, 2011.

Li, Z.Y., Fang, H.Y.: Impacts of climate change on water erosion: A review, Earth-Sci. Rev., 163, 94-117, 2016.

Li, Z.Y., Fang, H.Y.: Modeling the impact of climate change on watershed discharge and sediment yield in the black soil region, northeastern China, Geomorphology, 293, 255-271, 2017.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Lin, B.Q., Chen, X.W., Yao, H.X.: Threshold of sub-watersheds for SWAT to simulate hillslope sediment generation and its spatial variations, Ecol. Indi., 111, 106040, 2020.

Lin, H.H., Xie, Y., Liu, G., Zhan, J.R., Li, S.: Soybean and maize simulation under different degrees of soil erosion, Field Crop. Res., 230, 1-10, 2019.

Lin, J.K., Guan, Q.Y., Tian, J., Wang, Q.Z., Tan, Z., Li, Z.J., Wang, N.: Assessing temporal trends of soil erosion and sediment redistribution in the Hexi Corridor region using the integrated RUSLE-TLSD model, Catena, 195, 104756, 2020.

Liu X.B., Zhang, S.L., Zhang, X.Y., Ding, G.W., Cruse, R.M.: Soil erosion control practices in Northeast China: A mini-review, Soil Till. Res., 17, 44-48, 2011.

Liu, B.Y., Xie, Y., Zhang, K.L.: Soil Loss Prediction Model, Beijing: Science Press, 2001.

Liu, B.Y., Xie., Y., Li, Z.G., Liang,Y., Zhang, W.B., Fu, S.H., Yin, S.Q., Wei, X., Zhang, K.L., Wang, Z.Q., Liu, Y.N., Zhao,Y., Guo, Q.K.: The assessment of soil loss by water erosion in China, Int. Soil Water Conserv. Res., in press,2020.

Liu, H., Wei, Y.X.: Influence of soil erosion thickness on soil productivity of black soil and its evaluation, Trans. Chin. Soci. Agr. Eng., 30(20), 288-296, 2014.

Liu, H.Q.: The strategic thinking and working initiatives for accelerating the realization of the change from large country to powerful country in agriculture. Chin, J. Agr. Resource Region. Plan., 41(3), 7-11, 2020.

Liu, J., Liu, H.H.: Soil erosion changes during the last 30 years and contributions of gully erosion to sediment yield in a small catchment, southern China, Geomorphology, 268, 107357, 2020.

Liu, Q.Q., Chen, L., Li, J.C.: Influences of slope gradient on soil erosion, Appl. Math. Mech., 22(5), 449-457, 2001.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Liu, S.J.: Soil loss measurement and analysis, Sci. Bull., 12, 59-65, 69, 1953.

Loo, M.V., Dusar, B., Verstraeten, G., Renssen, H., Notebaert, B., D'Haen, K., Bakker, J.: Human induced soil erosion and the implications on crop yield in a small mountainous Mediterranean catchment (SW-Turkey), Catena, 149, 491-504, 2017.

Luetzenburg, G., Bittner, M.J., Calsamiglia, A., Renschler, C.S., Estrany, J., Poeppl, R.: Climate and land use change effects on soil erosion in two small agricultural catchment systems Fugnitz-Austria, Can Revull-Spain, Sci. Tot. Environ., 704, 135389, 2020.

Luo, L.X.: Primary result of water erosion amount from gully slopes through field investigation in Lianshi Gou catchment in Gansu province, Geogr. Data, 2, 111-118, 1958.

Luo, L.X., Zhu, Z.D.: Explanation and Experience of Compiling the Map of Soil and Water Loss and Conservation on the Loess Plateau, Beijing: Science Press, 1965.

Lv, M.H., Wang, H.Y., Cai, Y.L.: General review of soil erosion in the Karst area of southwest China, Prog. Geogr., 26(2), 87-96, 2007.

Ministry of Water Resources of the People’s Republic of China: Classification Criteria for Soil Erosion (sl190-96), Beijing: China Water and Power Press, 1997.

Ouyang, W., Wei, P., Gao, X., Srinivasan, R., Yen, H., Xie, X.H., Liu, L.H., Liu, H.B.: Optimization of SWAT-Paddy for modeling hydrology and diffuse pollution of large rice paddy fields, Environ. Model. Soft., 130, 104736, 2020.

Peng, S.Z., Li, Z.: Potential land use adjustment for future climate change adaptation in revegetated regions, Sci. Tot. Environ., 639, 476-484, 2018.

Qi, W., Cao, W.H., Guo, Q.C., Lu, Q.: Study on a distributed model for soil erosion and sediment yield in small watersheds, Sci. Soil Water Conserv., 2(1), 16-21, 2004.

© Author(s) 2020. CC BY 4.0 License.

Qian, N.: Hyperconcentrated flow movement. Beijing: Tsinghua University Press, 1989.

Ran, L.S., Lu, X.X., Xin, Z.B., Yang, X.K.: Cumulative sediment trapping by reservoirs in large river basins; A case study of the Yellow River basin, Glob Plant. Change, 100, 308-319, 2013.

Renner, F.G.: Conditions influencing erosion of the Boise River Watershed, U.S. Dept. Agrn. Tech. Bull., 528, 1936.

Rickson, R.J.: Can control of soil erosion mitigate water pollution by sediment? Sci. Tol. Environ., 468-469, 1187-1197, 2014.

Sang, Q.M., Wang, L., Zheng, F.L.; Qing, C., Zhang, X.C., Zuo, X.F., Wang, Y.F.: Comparative study on hillslope soil erosion between sloping ridge-tillage and longitudinal rideg-ridge-tillage in Chinese Mollisol region, J. Soil Water Conserv., 34(3), 73-78, 2020.

Shi, Z.H., Ai, L., Fang, N.F., Zhu, H.D.: Modeling the impacts of integrated small catchment management on soil erosion and sediment delivery: a case study in the Three Gorges Area, China, J. Hydrol. 438, 156-167, 2012.

Shi, Z.H., Liu, Q.J., Zhang, H.Y., Wang, L., Huang, X., Fang, N.F., Yue, Z.J.: Study on soil erosion and conservation in the past 10 years: progress and prospects, Acta Pedol. Sinica, 57, 2020.

Si, W., Bao, W.M., Jiang, P., Zhao, L.P., Qu, S.M.: A semi-physical sediment yield model for estimation of suspended sediment in loess region, Int. J. Sediment Res, 32, 12-19, 2017.

Su, Z.A., Zhang, J.H., Nie, X.J.: Effect of Soil Erosion on Soil Properties and Crop Yields on Slopes in the Sichuan Basin, China, Pedosphere, 20(6), 736-746, 2010.

Sun, L.Y., Cai, Q.G., Chen, S.Y., He, J.J.: Integrated governing system on soil and water loss of small watersheds in a typical black soil region of northeast China, Res. Soil Water Conserv.,

© Author(s) 2020. CC BY 4.0 License.

19(3), 36-40, 57, 2012.

Sun, L.Y., Yang, F.T., Wang, J.Y., Fang, H.Y., Cai, Q.G.: Impacts of forest types on soil C, N and DOC loss in runoff in the laterite hilly region of southern China, Environ. Earth Sci., 74, 1391-1402, 2015.

Tang, K.L.: Soil and Water Conservation in China, Beijing: Science Press, 2004.

Tang, L.H., Yang, D.W., Hu, H.P., Gao, B.: 2011. Detecting the effect of land-use change on streamflow, sediment and nutrient losses by distributed hydrological simulation. J. Hydro. 409, 172-182.

Tang, L.Q.: Study on sediment yield model of basin, Adv. Water Sci., 7(1), 47-53, 1996.

Teng, H.F., Liang, Z.Z., Chen, S.C., Liu, Y., ViscarraRossel, R.A., Chappell, A., Yu, W., Shi, Z.: Current and future assessments of soil erosion by water on the Tibetan Plateau based on RUSLE and CMIP5 climate models, Sci. Tot. Environ., 635, 673-686, 2018.

Tian, P., Zhao, G.J., Mu, X.M., Wen, Z.M., Wang, F.: A modified RUSLE model to estimate sediment yield in the Huangfuchuan watershed, Resour. Sci., 37(4), 832-840, 2015.

Tsige, M., Synnevag, G., Aune, J.B.: Gendered constraints for adopting climate-smart agriculture amongst smallholder Ethiopian women farmers, Sci. Afri., 7, e00250, 2020.

Walling, D.E.: The evolution of sediment source fingerprinting investigations in fluvial systems, J. Soils Sediments, 13, 1658-1675, 2013.

Walling, D.E., Collins, A.L.: The catchment sediment budget as a management tool, Environ Sci. Policy, 11(2),136-43, 2008.

Wang, G.Q., Wu, B.S., Li, T.J.: Digital yellow river model, J. Hydro. Environ. Res., 1, 1-11, 2007.

Wang, L.J., Zhuang, G.H., Wang, X., Zhu, P.Z.: Soil loss: Effect of plant litter incorporation rate under simulated rainfall conditions, Land Degrad. Dev., 30, 1193-1203, 2018.

Wang, Q.H., Hu, G.Q., Dong, Y.J., Liu, C.S., Zhang, X.W., Qiu, X.K., Wang, Y.H.: Runoff and sediment yield and spatial variation of soil erosion slope under magnetic tracing condition, J. Soil Water Conserv., 26(2), 21-28, 2012.

Wang, S., Fu, B.J., Piao, S.L., Lv, Y.H., Ciais, P., Feng, X.M., Wang, Y.F.: Reduced sediment transport in the Yellow River due to anthropogenic changes, Nat. Geosci., 9, 38-41, 2016.

Wang, Z.L., Huang, X.H., Niu, Z.H.: Review of Models of Soil Erosion and Sediment Yield in Catchment in China, Res. Soil Water Conserv., 11(4), 28-33, 2004.

Wang, Z.Q., Liu, B.Y., Wang, X.Y., Gao, X.F., Liu, G.: Erosion effect on the productivity of black soil in Northeast China, Sci. China Ser. D: Earth Sci., 52(7), 1005-1021, 2009.

Watts, C.D., Naden, P.S., Cooper, D.M., Gannon, B.: Application of a regional procedure to assess the risk to fish from high sediment concentration, Sci. Tot. Environ., 314-316, 551-565, 2003.

Wei, T.X.: Sediment source4s and effects of vegetation on erosion control in the gully-hilly loess area in north China, J. Beijing Forestry Uni., 24(5-6), 19-24, 2002.

Wei, Y.J., Wu, X.L., Cai, C.F., Wang, J., Xia, J.W., Wang, J.G., Guo, Z.L., Yuan, Z.J.: Impact erosion-induced land degradation on rainfall infiltration in different types of soils under field simulation, Land Degrad. Dev., 30(14), 1751-1764, 2019.

Wen, X., Zhen, L.: Soil erosion control practices in the Chinese Loess Plateau: A systematic review, Environ. Dev., 34, 100493, 2020.

Wu, F.Q., Wang, J.: Establishment of new course framework for soil and water conservation and desertification control, Bull. Soil Water Conserv., 26(4), 56-59, 2006.

Wu, Z.M.: Prospects of research on the effects of soil erosion on soil productivity, Bull. Soil Water

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Conserv., 82, (04): 61-65, 1982.

Wuepper, D., Borrelli, P., Finger, R.: Countries and the global rate of soil erosion, Nat. Sustain., 3, 51-55, 2020.

Xie, Y., Lin, Y., Zhang, Y.: Application and advancement of universal soil loss equation, Prog. Geogr., 22(3), 279-287, 2003.

Xin, S.Z., Jiang, D.Q.: Introduction to Soil and Water Conservation in China. Beijing: China Agricultural Press, 1982.

Xu, J.X., Cheng, D.S.: Relation between the erosion and sedimentation zones in the Yellow River, China, Geomorphology, 48, 365-382, 2002.

Xu, X.Z., Xu, Y., Chen, S.C., Zhang, H.W.: Soil loss and conservation in the black soil region of Northeast China: a retrospective study, Environ. Sci. Pol., 13, 793-800, 2010.

Yang, M.Y., Tian, J.L., Liu, P.L.: Studying sediment sources in small watershed using ^{137}Cs tracing, J. Soil Water Conserv., 5(3), 49-53, 1999.

Yang, S.T., Guan, Y.B., Zhao, C.S., Zhang, C.B., Bai, J., Chen, K.: Determining the influence of catchment area on intensity of gully erosion using high-resolution aerial imagery: A 40-year case study from the Loess Plateau, northern China, Geoderma, 347, 90-102, 2019a.

Yang, T., Xu, C.Y., Zhang, Q., Yu, Z., Baron, A., Wang, X., Singh, V.P.: DEM-based numerical modelling of runoff and soil erosion processes in the hilly–gully loess regions, Stoch Environ. Res. Risk Assess., 26, 581–597, 2012.

Yang, W.G., Han, Y., Zheng, F.L.: Investigating spatial distribution of soil quality index and its impacts on crop yield in a cultivated catchment of the Chinese Mollisol region, Soil Sci. Soc. Am. J., 80(2), 317-327, 2016.

Yang, W.G., Zhang, X.C., Gong, W., Ye, Y.Y., Yang, Y.S.: Soil erosion and corn yield in a cultivated catchment of the Chinese Mollisol region, Plos One, 14(10), 1-18, 2019b.

Yang, X.: Study of soil erosion regionalization and soil loss survey in China, J. Nat. Dis., 20(4), 131-136, 2011.

Yang, Y., Wei, W., Chen, L.D., Feng, T.J., Daryanto, S.: Quantifying the effects of precipitation, vegetation, and land preparation techniques on runoff and soil erosion in a Loess watershed of China, Sci. Tot. Environ., 652, 755-764, 2019c.

Yao, Y.X., Li, J., Duan, P., Chen, F.: Research on three-dimensional model reconstruction of slope erosion based on sequence images, Opt. Laser Technol., 110, 209-218, 2019.

Yu, X.X., Zhang, X.M., Li, J.F.: 2009. Processes and Mechanism of Soil Erosion. Beijing: Science Press.

Yu, X.X., Zhang, X.M.M Wu, S.H., Wei, T.X., Zhang, X.P.: The effect of vegetation and precipitation upon runoff and sediment production in sloping lands of loess area, J. Mt. Sci., 24(1), 19-26, 2006.

Zhang, G.H.: Potential effects of changes in near soil surface characteristics driven by farmland abandonment on soil erosion, Sci. Soil Water Conserv., 15(4), 143-154, 2017.

Zhang, G.M., Li, Z.J., Shi, J.W.: Progress of study on water erosion model in China, Soil water conserv. China, 2, 12-15, 2004.

Zhang, J.S., Wang, P.Y., Liu, Y.H.: Mathematical model on sediment yield of middle small watershed at the area of the Three Gorges Reservoir, J. Chongqing Jiaotong Uni., 23(4), 117-120, 2004.

Zhang, P.C., Tang, K.L., Zheng, F.L., Jiao, J.Y.: The source and quantitative analysis of sediment

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

of the Huangfu river watershed, J. Soil Water Conserv., 4(4) , 29-36, 1990.

Zhang, X.B., He, X.B., Wen, A.B., Walling, D.E., Feng, M.Y., Zhou, X.: Study on the sediment sources of small watersheds in the central Sichuan province using dual isotopes ^{137}Cs and ^{210}Pb, Chin. Sci. Bull., 49(15), 1537-1541, 2004.

Zhang, X.B., Walling, D.E., He, X.B., Wen, A.B., Wen, Z.M., Feng, M.Y., Yang, Q.K., Qi, Y.Q.: A test of t he pollen tracing technique for studies of vegetation changes erosion and sedimentation in a small catchment in the Loess Plateau of China, Q. Sci., 25(6), 722-728, 2005.

Zhang, X.B., Wang, Y.C., Li, S.L., Zhang, Y.L., Zhao, Q.C., Jiang, J.J., Bai, L.X., Yan, M.Q., Wu, L.P.: A preliminary study on the sources of fine materials of the sediment and debris flow, Soil Water Conserv., China, 2, 28-31, 1992.

Zhang, X.C., Liu, W.Z.: Simulating potential response of hydrology, soil erosion, and crop productivity to climate change in Changwu tableland region on the Loess Plateau of China, Agr. Forest Meteorol., 131, 127-142, 2005.

Zhang, X.C., Liu, W.Z., Li, Z., Zheng, F.L.: Simulating site-specific impacts of climate change on soil erosion and surface hydrology in southern Loess Plateau of China, Catena, 79, 237-242, 2009.

Zhang, X.Y., Meng, L.Q., Liu,X.B., Sui, Y.Y., Zhang, S.L., Herbert, S.J.: Effect of soil loss in the black soil region on dry material and corn yield, Soil Water Conserv., 22, 47-49, 2007.

Zhang, Z.Q., Wang, S.P., Sun, G., Zhang, M.L., Li, J.L.: Response of sediment production to land use change in Luorgou watershed of Loess Plateau, Chin. J. Appl. Ecol., 16(9), 1607-1612, 2005.

© Author(s) 2020. CC BY 4.0 License.

Zhang., Q.W., Dong, Y.Q., Li, F., Zhang, A.P., Lei, T.W.: Quantifying detachment rate of eroding rill or ephemeral gully for WEPP with flume experiments, J. Hydrol., 519, 2012-2019, 2014.

Zhao, G.J., Mu, X.M., Han, M.W., An, Z.B., Gao, P., Sun, W.Y., Xu, W.L.: Sediment yield and sources in dam-controlled watersheds on the northern Loess Plateau, Catena, 149, 110-119, 2017.

Zhao, J.L., Yang, Z.Q., Govers, G.: Soil and water conservation measures reduce soil and water losses in China but not down to background levels: Evidence from erosion plot data, Geoderma, 337, 729-741, 2019.

Zhao, R.J., Wang, P.L.: Analysis of runoff discharge and sediment yield at the Zizhou experimental station, Yellow River, 2, 15-19, 1980.

Zheng, F.L., Tang, K.L., Zhou, P.H.: Study on factors affecting rill erosion on cultivated slope land, Acta Pedol. Sina., 26(2), 109-116, 1989.

Zheng, F.L., Wang, Z.L., Yang, Q.K.: The retrospection and prospect on soil erosion research in China, Chin. J. Nat., 30(1), 12-16, 2008a.

Zheng, F.L., Zhang, X.C., Wang, J.X., Flanagan, D.C.: Assessing applicability of the WEPP hillslope model to steep landscapes in the northern Loess Plateau of China, Soil Till. Res., 197, 104492, 2020.

Zheng, M.G., Cai, Q.G., Cheng, Q.J.: Modelling the runoff-sediment yield relationship using a proportional function in hilly areas of the Loess Plateau, North China. Geomorphology, 93(3-4), 288-301, 2008b.

Zheng, Z.C., Qin, F., Li, T.X.: Changes in soil surface microrelief of purple soil under different slope gradients and its effects on soil erosion, Trans. Chin. Soc. Agr. Eng., 31(8), 168-175,

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

2015.

Zhou, Z.H., Du, S.Q., Liu, G.C.: Research on effect of soil erosion on cultivated land soil productivity, J. Anhui Agr. Sci., 37(16), 7601-7603, 2009.

Zhu, P.Z., Zhuang, G.H., Wang, H.X., Zhang, B.J., Wang, X.: Land surface roughness affected by vegetation restoration age and types on the Loess Plateau of China, Geoderma, 366, 114240, 2020.

Zhu, X.M.: Issues on soil erosion zoning in the middle reaches of the Yellow River, Chinese J. Soil Sci., 2(1), 1-6, 1958.

Zuo, D.P., Xu, Z.X., Yao, W.Y., Jin, S.Y., Xiao, P.Q., Ran, D.C.: Assessing the effects of changes in land use and climate on runoff and sediment yields from a watershed in the Loess Plateau of China, Sci. Tot. Environ., 544, 238-250, 2016.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.
Hydrology and Earth System Sciences
Open Access
EGU
Discussions

Table 1. Main methods used to study water erosion in China.

Type	Method	Simple description
Hydro-sedimental monitoring	Runoff plot	Traditional method for studying water erosion. There are over 1000 runoff plots in China
	Rainfall simulation	A common method used in laboratory and field conditions to study the impact of a specific treatment on water erosion
	Small catchment monitoring	A basic unit for implementing soil conservation measures and evaluating soil erosion control efficiency
	Hydrological station monitoring	Use record sediment concentration and runoff to study large catchment water erosion and sediment yield; a dense hydrological station network in China facilitates water erosion study
Topographical Measurement	Artificial measurement	Measure soil surface changes or sedimentation bodies with erosion pins, stylus plate, or meter ruler to estimate water erosion rate
	Remote sensing	New approaches, including photogrammetry, UAV-based sensing, and remote sensing with different spatial resolutions for water erosion estimation
Tracing method	Different types of tracers	Mainly include radionuclides, magnetic minerals, REEs, geochemical elements, biomarkers, and soil nutrients; these tracers can be absorbed onto soils and sediments and moved with them
Modeling	Water erosion modeling	Mainly include physically-based and empirical models; widely used to evaluate or predict water erosion under different scenarios

© Author(s) 2020. CC BY 4.0 License.

879 **Table 2.** Some physically-based water erosion models established in China.

No.	Developers	Input variables	Characteristics	Remarks
1	Cai et al., 1996	Climate, soil, topography, land use, vegetation cover; soil moisture, soil crust and rill conditions, runoff, and sediment record	Contains slope, gully, and channel sub-modules; Considers gull/channel, gravitational, and cave erosion	Event-based, catchment model
2	Tang, 1996	Rainfall characteristics, soil, topography, stream flow, sediment record, and sediment availability	Considers splash erosion and slope erosion	Event-based, catchment model
3	Qi et al., 2004	Rainfall characteristics, soil, topography, land use, vegetation cover, runoff, and sediment record	Considers inter-rill and rill erosion	Sub-event based, small catchment model
4	Jia et al., 2004	Rainfall characteristics, soil, topography, vegetation cover, land use, runoff, and sediment record	Considers splash, sheet, rill, gully, and channel erosion types	Event-based, catchment model
5	Zhang et al., 2004	Climate, topography, soil, land use, vegetation cover, monthly runoff and sediment record, sediment texture, and sediment grading data	Considers slope erosion and channel sediment transfer	Monthly scale, catchment model
6	Wang et al., 2007	Climate, topography, soil, land use, and vegetation cover	Considers slope, gravitational erosion, and channel sediment transport	Daily scale; catchment model
7	Yang et al., 2012	Rainfall, topography, soil, land use, vegetation cover,	Considers slope erosion, gully erosion,	Event-based, catchment model

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.
Hydrology and Earth System Sciences Discussions
Open Access
EGU

		runoff, and sediment record	and groove erosion	
8	Tian et al., 2015	Precipitation, topography, soil, land use, and vegetation cover	RULSE-based, consider slope, and ephemeral gully erosion	Multi-annual based, catchment model
9	Si et al., 2017	Rainfall, topography, soil, land use, and vegetation cover	Considers slope, gully, and river sub-modules	Sub-event based, catchment model
10	Cai et al., 2020	Rainfall, topography, soil, land use, and vegetation cove	Considers slope and gravitational erosion	Daily based, catchment model

880

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Table 3. Papers published on water erosion impact on crop yields in China.

No.	Method	Study region	Simple description	Authors
1	Experiment	NEC	Impact of different erosion levels on dry maize material and its yield	Zhang et al., 2007
2	Experiment	NEC	Water erosion impact on soil properties and bean yield	Wang et al., 2009.
3	Crop yield and ^{137}Cs sampling	Sichuang province	Field slopes; relations of soil erosion rate and crop yield	Su et al., 2010
4	Modified productivity index	NEC	Water erosion impact on crop production	Duan et al, 2011
5	Climate model and WEPP model	The Loess Plateau	Runoff plot and models; future relations of runoff, soil loss, and crop yield under different cultivation measures	Li et al., 2011
6	Experiment	NEC	Impact of different erosion levels on soil properties and bean yield	Liu and Wei, 2014
7	Experiment	NEC	Measure the impact of water erosion levels on bean yield	Gao et al, 2015
8	Crop yield and soil sampling method	NEC	Relation of crop yield and soil quality	Yang et al., 2016
9	Experiment	NEC	Water erosion impact on soil properties and crop yield	E, 2018
10	Productivity index model	NEC	Spatial variations of crop yield in relations to water erosion	Gu et al., 2018
11	Crop yield and ^{137}Cs sampling	NEC	Relation of ^{137}Cs-estimated water erosion and crop yield	Yang et al., 2019b
12	Agriculture Land Management Alternatives with Numerical Assessment Criteria model	NEC	Impact analysis of water erosion level on crop yield	Lin et al., 2019

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Figure captions:

Fig. 1. Divisions of water erosion regions in China and dynamically monitored runoff plots and small catchments (Data source: the Soil and Water Conservation Monitoring Center of the Ministry of Water Resources)

Fig. 2. Chronology of and important events in water erosion studies in China (1922–present). Note: NSES represents the National Soil Erosion Survey

Fig. 3. Number of publications by year: (a) in the "CNKI" database with the key word "soil erosion," (b) in the "Web of Science" with the key words "soil erosion or sediment yield" and the address "China," (c) in the "Web of Science" with the key words "soil erosion or sediment yield" and "climate or climate change" and with the address "China," and (d) in the "Web of Science" with the key words "soil erosion or sediment yield," "land use," and the address "China." Note: S I, S II, and S III represent three developing stages of water erosion study in China.

Fig. 4. The four-grade monitoring network for soil and water conservation in China. Note: the SWCMC and MWR represent the Soil and Water Conservation Monitoring Center of the Ministry of Water Resources (Grade I); rivers' and lake's names represent their catchment monitoring centers (Grade II), smaller circles along the second large circle represent provincial monitoring stations (Grade III), and needle signs represent their sub-station (Grade IV). The numbers of provincial monitoring stations and their sub-stations on the circles just display levels and not the actual amount.

Fig. 5. Threshold slope lengths of runoff (a), threshold values of water erosion intensity on different slopes with rainfall durations (b), conceptual model showing the formation mechanism of threshold value of water erosion intensity (c), and threshold values of slope gradients in relation to

© Author(s) 2020. CC BY 4.0 License.

water erosion intensity (d). Note: (a) was adapted from Cai (1998a), within which the figures were the maximum 30-min rainfall intensity (I_{30}); (b) was adapted from Cai (1998b), and (d) was adapted from Qian (1989).

Fig. 6. Sediment source area identification of the Loess Plateau ((a) modified from Xu, 2002) and temporal changes of sediment load monitored at three hydrological stations ((b) modified from Wang et al., 2015). Note: H, CSA, FSA, and YLQ represent low sediment concentration area in the upstream of the Yellow River, coarse sediment area, fine sediment area, and low sediment concentration areas in the Yiluohe and Qinhe River basins. The hydrological stations Lijin, Huayuankou and Toudaoguai in (b) are labeled in (a).

Fig. 7. Diagram showing the impacts of land use and/or climate change on water erosion are studied. RCM represents regional climate model.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

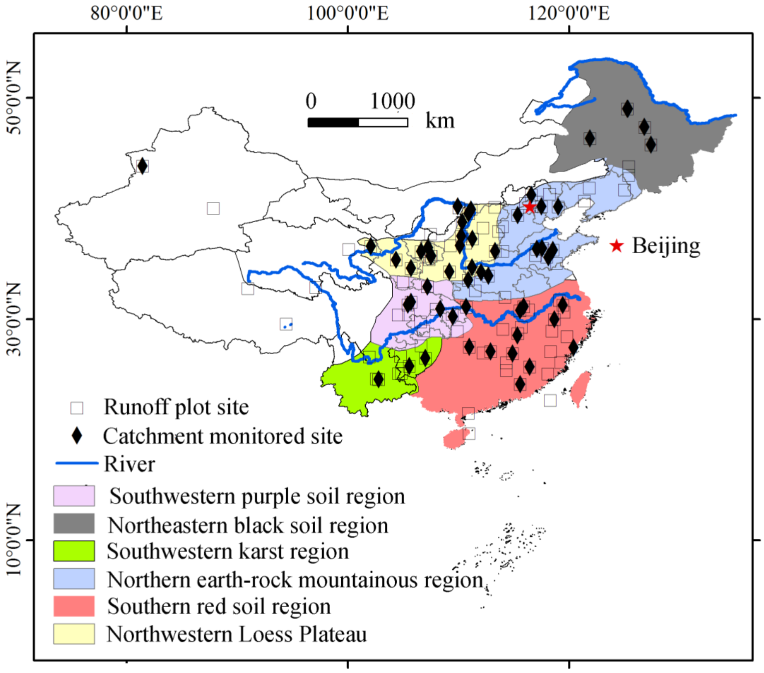


Fig. 1.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.
Hydrology and Earth System Sciences
Open Access
Discussions

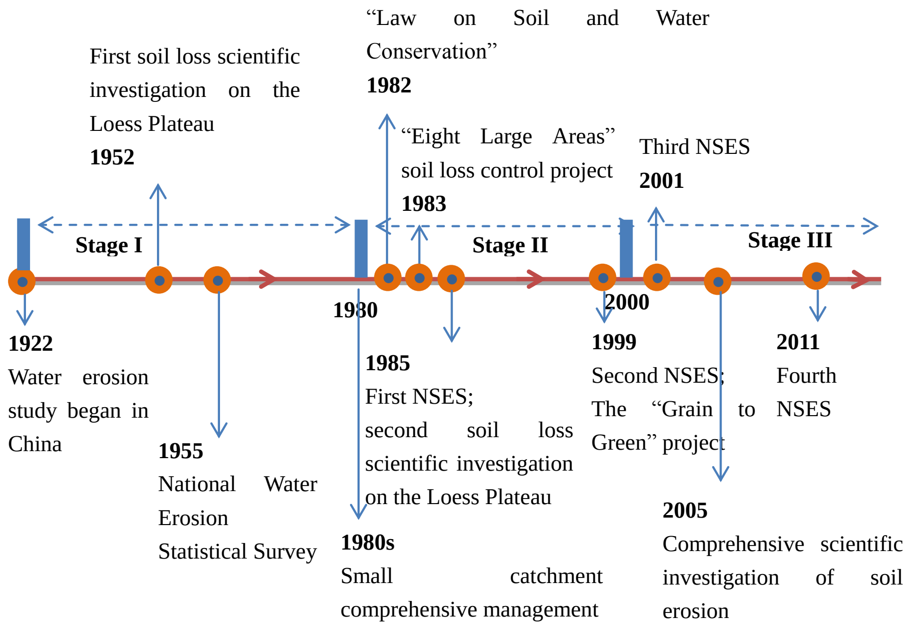


Fig. 2.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

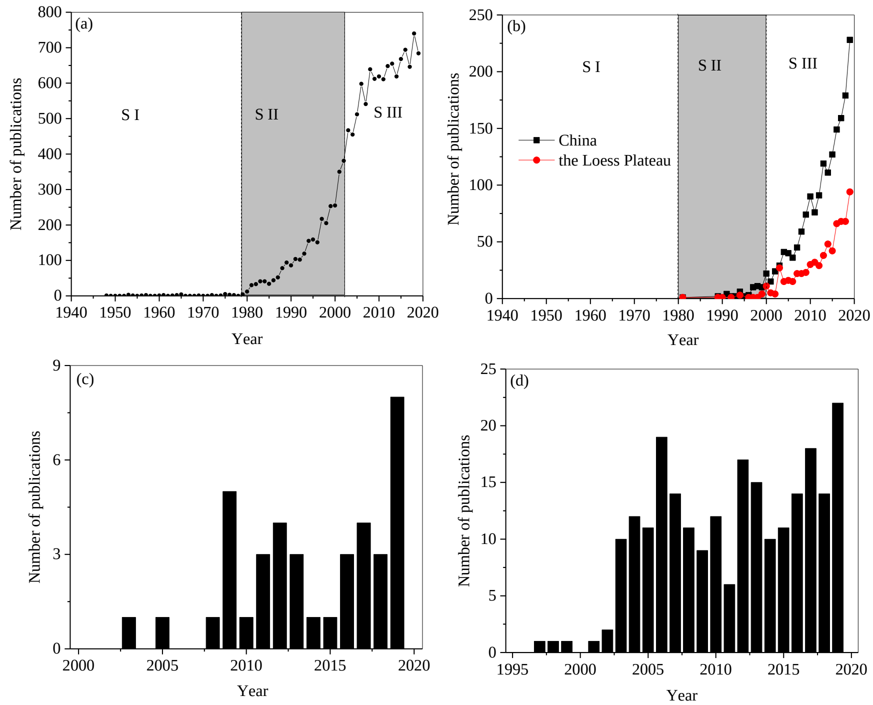


Fig. 3.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

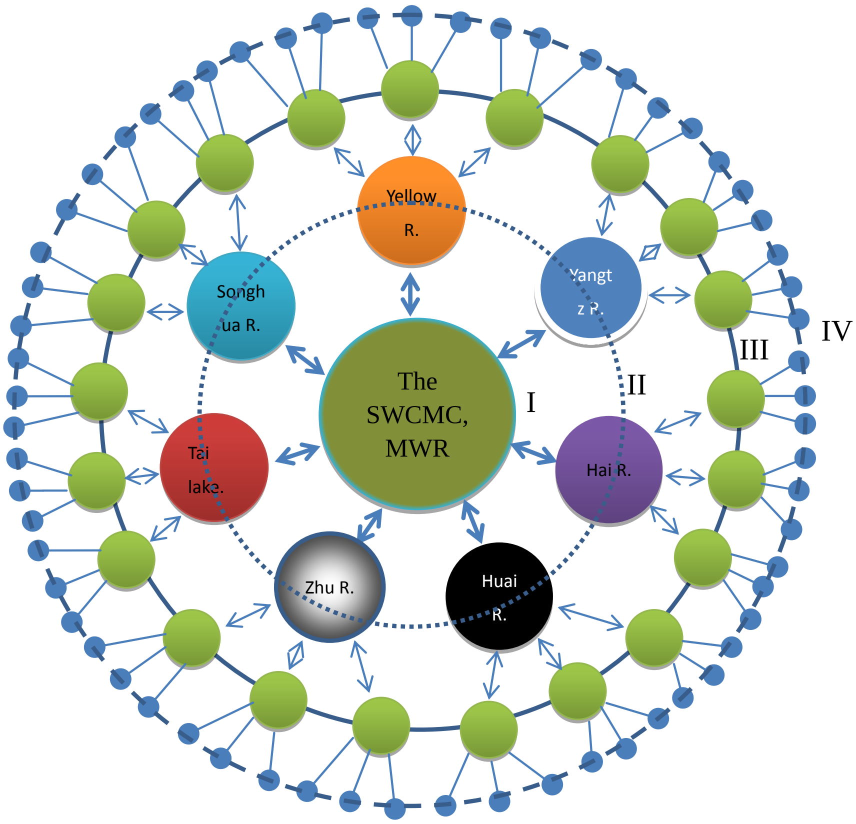


Fig. 4.

© Author(s) 2020. CC BY 4.0 License.

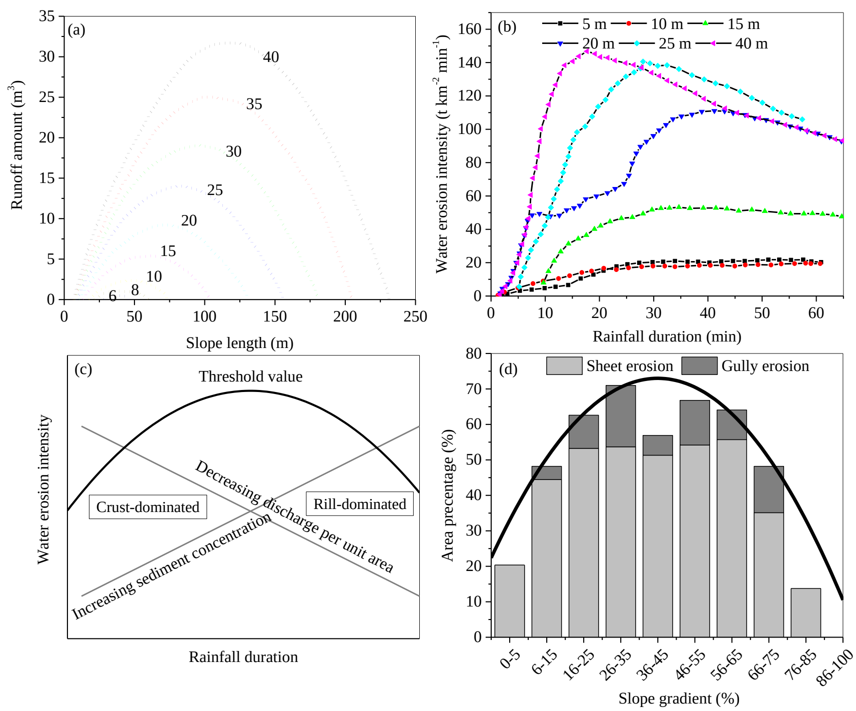


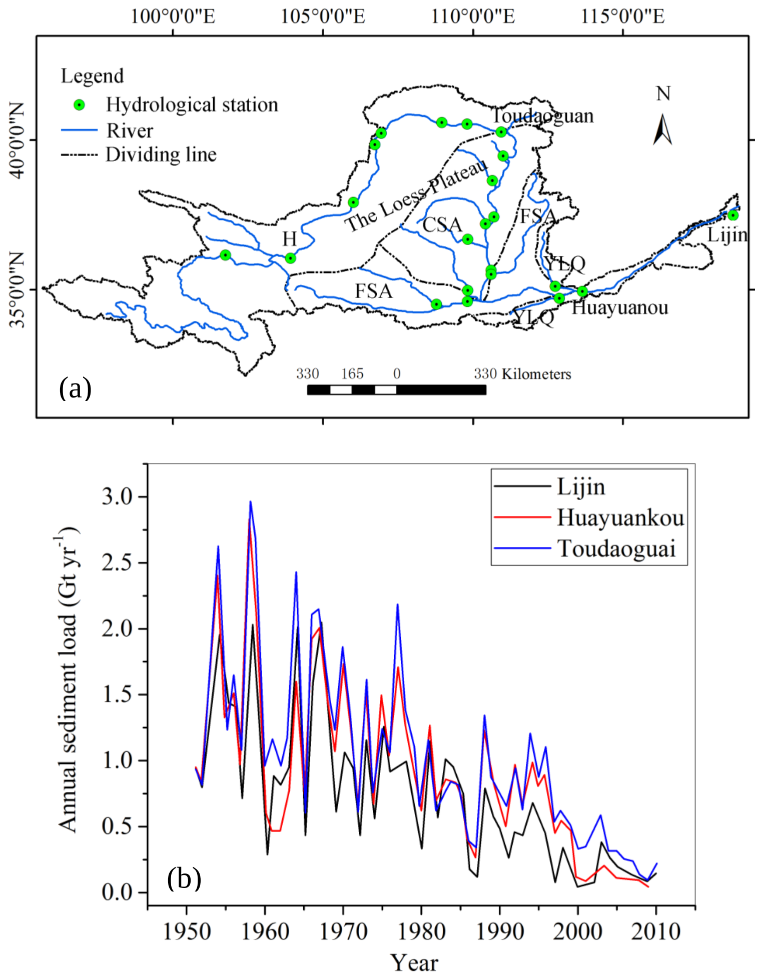
Fig. 5.

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

1009

1010

1011



1012 Fig. 6.

1013

1014

1015

https://doi.org/10.5194/hess-2020-568
Preprint. Discussion started: 26 November 2020
© Author(s) 2020. CC BY 4.0 License.

Hydrology and Earth System Sciences
Open Access
Discussions

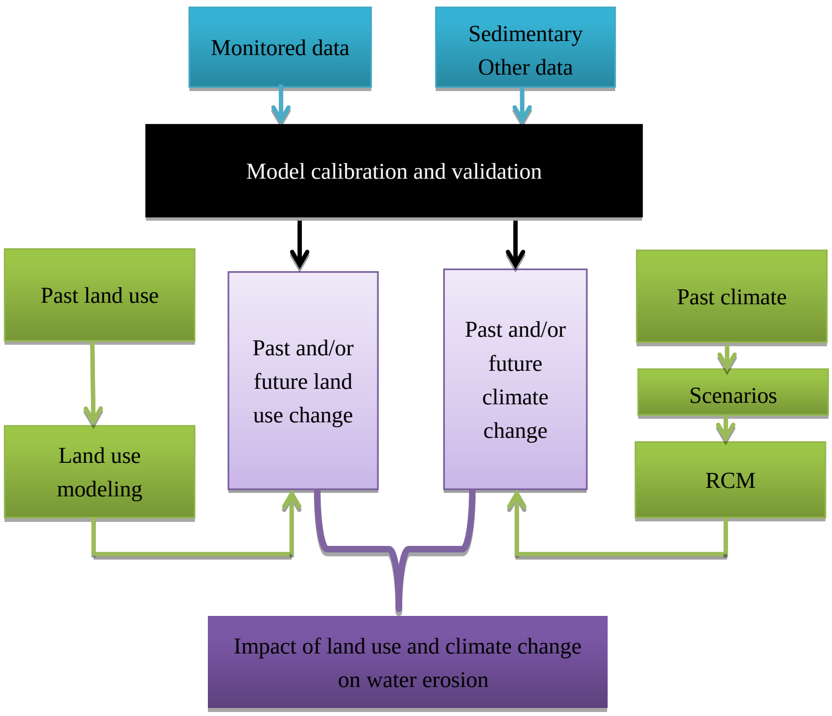


Fig. 7.