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Soil erosion assessment and prediction play critical roles in addressing problems associated with erosion control and environmental rehabilitation. The past dynamics of soil erosion can provide information valuable for understanding the relation of soil erosion to environmental change and anthropogenic activity. The Chinese Loess Plateau was once a high, flat plain in northwestern China, but now more than 70% of the area is gully-hill dominated, owing to massive soil erosion during the later Quaternary and human-induced accelerated soil erosion in recent centuries. The present article investigates the dynamics of erosion during the Holocene and the driving forces of human activities and bio-climatic changes. Modern soil erosion on the Loess Plateau is a combination of intensive natural erosion and human-induced erosion, the latter being 4 times as intense as the former.

Keywords: *Anthropogenic activity; climate change; erosion dynamics; Loess Plateau; China.*

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Introduction

Erosion has been an important driving force in processes affecting land throughout the history of the Earth. Modern soil erosion causes major on-site and off-site environmental effects. Furthermore, floods, drought, and famine related to soil erosion can be considered not merely natural disasters but also a human catastrophe, threatening global food and environmental security, especially in developing countries (Morgan 1995; Cai et al 1999). Assessment and prediction of soil erosion play a critical role in addressing problems associated with erosion control and conservation (Liu et al 1993). In evaluating and predicting modern soil erosion under conditions of global change and population growth, we face a number of questions that can only be answered based on better knowledge of the past.

The Chinese Loess Plateau in northwestern China, the most widely distributed region of loess on Earth, was once a high, flat plain covered by thick loess. Now more than 70% of the area is a gully-hill dominated region owing to mass soil erosion during the later Quaternary and intense human activities over the past 3000 years. The Plateau has an altitude range of 1000–1600 m. Most of the area has a gully density of 3–5 km/km^2, the maximum being 10 km/km^2. Gullies occupy 30–50% of the total area in hilly regions (Figure 1). The loess sequence, typically characterized by an alternation of

FIGURE 1 The landscape at Yanan on the Loess Plateau of China. Deep gullies developed during the Quaternary, with typical loess geomorphological units in between: *yuan* (tableland), *liang* (ridges) and *mao* (mounds). Large-scale soil erosion control measures such as construction of terraces on slopes have been carried out during the past decades. The crops are mainly soybeans and potatoes. (Photo by Keli Tang)

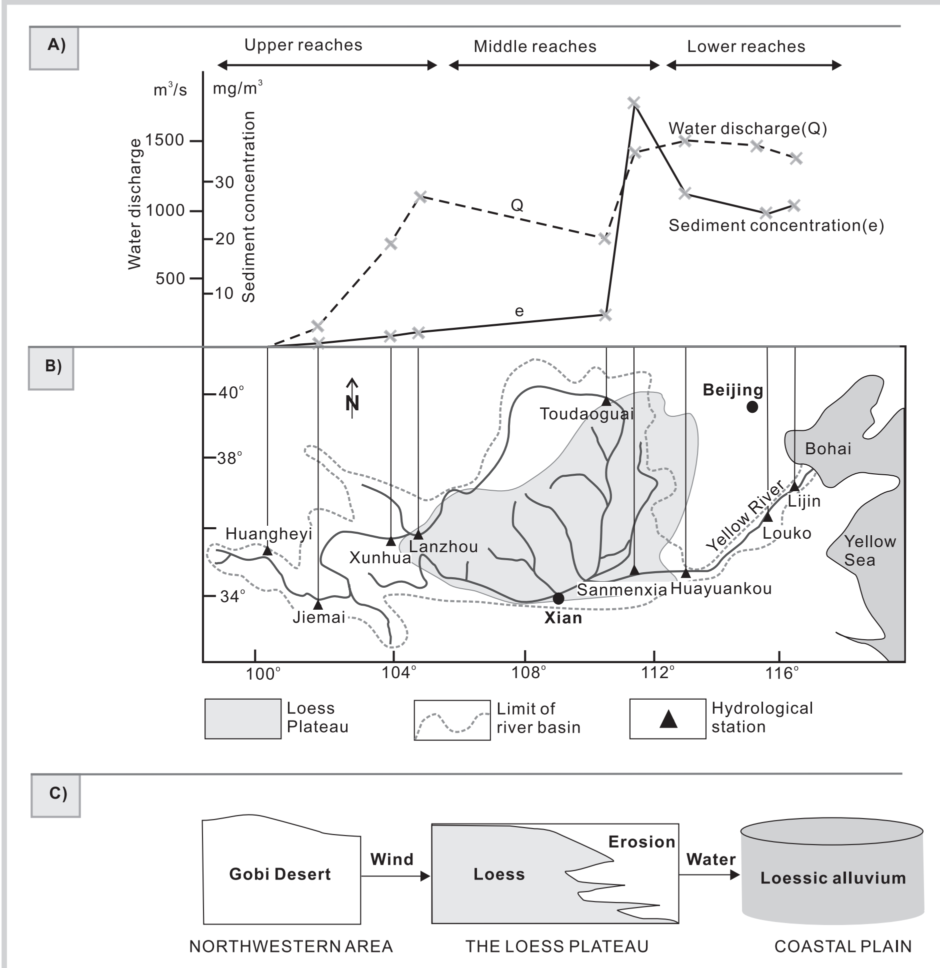


FIGURE 2 Natural scenario of the Loess Plateau and the Yellow River: (A) large increase in water discharge (m^3/s) and sediment concentration (mg/m^3) in the Yellow River after it runs through the Loess Plateau (after Ren and Zhu 1994); (B) geographical location of the Loess Plateau and the Yellow River (after Xu 1999); (C) geological relations between the Gobi Desert in the northwest, the central Loess Plateau, and the eastern coastal plain (after Rutter 1992; Derbyshire and Wang 1994).

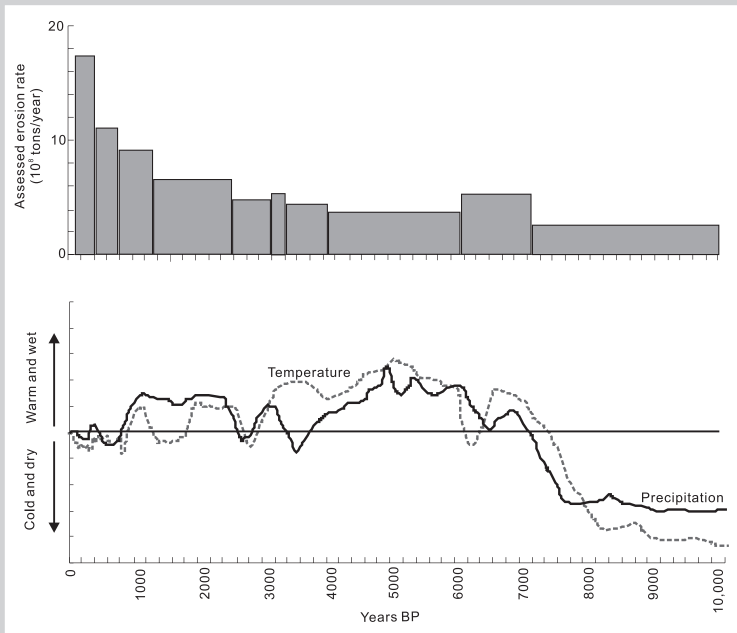
silty or sandy loess and more clay-rich paleosols, has been interpreted as reflecting Quaternary glacial/interglacial episodes. It has been widely investigated for past geological, biological, and climatic changes, including dust deposition, soil formation, and soil erosion processes (Liu 1985; Rutter 1992; He et al 2002). The present study chronologically analyzes soil erosion on the Loess Plateau over the past 10,000 years, using various data such as stratigraphic and archaeological evidence, written historical records, and hydrological records. The relationship between climate change, human activities, and soil erosion is demonstrated.

Study area

The Chinese Loess Plateau is a subsystem of the interlinked feedback system of the Gobi Desert in the northwest, the Plateau in the middle, and the eastern alluvial plain (Bowler et al 1981; Liu 1985; Rutter 1992; Figure 2). It is located in the middle reaches of the Yellow River and extends over 6 degrees of latitude (35°–41°N) and 12 degrees of longitude (102°–114°E), with a total area of more than 600,000 km^2 and a population of 82 million people (Zhu 1989; He et al 2003). The Yellow River traverses it from west to east, finally flowing into the Bohai Sea. The high sediment concentration in the Yellow River originates mainly in sediment erosion in the Loess Plateau (Tang et al 1991). The Plateau area is 1000–1600 m above sea level and its surface is covered by an average of 100-meter thick loess/paleosol layers. The loess has been transported from the northwestern Gobi Desert by winds and has been accumulating on the Loess Plateau since about 2.5 million BP (Liu 1985; Zhu 1989).

The Loess Plateau belongs to the continental monsoon region with annual mean temperature of 3.6–14°C, and annual precipitation ranging from 300 to 700 mm, both decreasing from southeast to northwest. The loess, being loose, porous, and homogeneous, can easily be cultivated and turned into fertile farmland. Agriculture commenced on the Loess Plateau about 7000 years ago and hence it can be considered one of the important birthplaces of Chinese and world agriculture (Zhu 1989). It still occupies a special position in Chinese national economic development (ESD-CAS 2001). Ongoing soil erosion on the Loess Plateau resulting from unique geological and geomorphologic characteristics, easily eroded loess, rainstorm disasters, and human activities, is the main environmental constraint on local agricultural and socioeconomic development (Jing and Chen 1983; Tang et al 1991; He et al 2003).

FIGURE 3 Climate change (from Sun et al 1991; He 1995) and assessed soil erosion rates on the Loess Plateau during the Holocene. (Sources: Ren and Shi 1986; Ye 1990; Zhu 1990)



Methodology

The loess/palaeosol sequence of northwestern China, characterized by alternations of silty or sandy loess with more clay-rich palaeosols, is widely distributed and well preserved on the Loess Plateau (Liu 1985). It not only records climate change, but also the past changes in rates of erosion and deposition (Liu 1985; Rutter 1992; Porter and An 1995; He et al 2002). A well developed and preserved palaeosol profile may indicate a weak erosion period. A truncated palaeosol profile may indicate the occurrence of soil erosion, and stratigraphic discontinuities in the loess/palaeosol profile may be evidence of heavy erosion of the land surface. A number of studies on loess deposition, soil formation and soil erosion during the Holocene (Tang et al 1991; He 1999; He et al 2002; Huang et al 2002) provide valuable information about soil erosion.

The morphology of river gullies and river terraces, and a diachronic analysis of a fluvial system can provide valuable information on soil erosion rates on hillslopes, as the sediment in the Yellow River mainly comes from the Loess Plateau (Jing and Chen 1983; Tang et al 1991; Figure 2). The sediment yield in the Yellow River is closely related to heavy floods (Ye 1990; Zhang 1999). Therefore, the frequencies of floods and breaks of riverbanks throughout history are employed as proxy indicators of intensive surface erosion on the Loess Plateau. Hydrological data are a direct illustration of erosive activity on the Loess Plateau.

Agricultural history and large-scale modern activities to guarantee food security are closely linked to local Holocene environmental changes. This has provided a basis for investigating soil erosion responses to regional land surface change, climate change, and human activity. The present article collects these data to demonstrate the relations between sediment yield in the Yellow River, and climate change and the history of human activity on the Loess Plateau.

Results and discussion

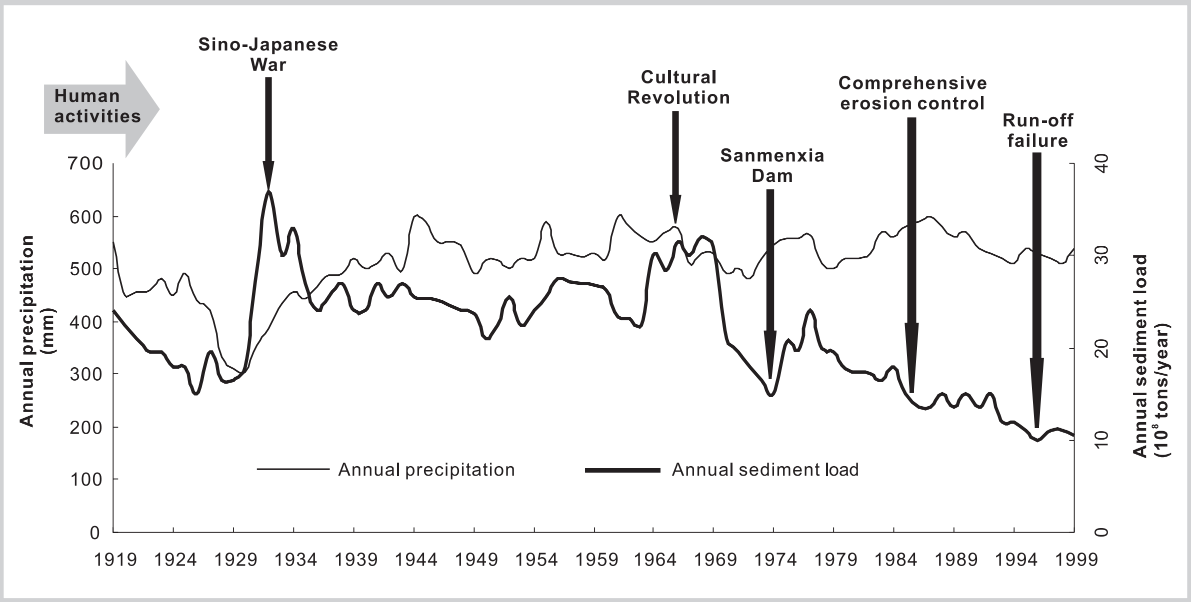
Soil erosion and bio-climatic change during the Holocene

Given climate fluctuations on the Loess Plateau, the processes of loess deposition, soil formation and soil erosion were continual throughout the Quaternary, acting as alternating predominant processes that formed today's plateau and the special loess erosion geomorphologic landscape on the underlying ancient landform (Liu 1985). Over the past 2.5 million years, the Loess Plateau has been subjected to 8 episodes of intensive natural erosion (He 1995). The fauna, distinctive mineralogy, soil formation features, and pollen assemblages in the Holocene loess/palaeosol sequence record deposition/erosion processes as well as bio-climatic change (He et al 2002). The Holocene climate on the Loess Plateau was subject to a cold and dry period in the early Holocene, a warm and wet period in the Middle Holocene Climatic Optimum, and a cool and dry period in the later Holocene (Figure 3). In the early Holocene, soil erosion was very weak because precipitation was very low (Sun et al 1991; He 1995). During the middle Holocene, the soil erosion rate was lower than the soil development rate, because a luxurious vegetation cover protected the soil from erosion through water, although precipitation was high. Around 3,000 BP, the climate turned cooler and drier, leading to natural forest degradation. Sediment data in the Yellow River delta (Ren and Shi 1986), the volume of Holocene loessic sediments on the continental shelf of the Bohai Sea (Ye 1990), and river terrace development (Zhu 1990) show that in the early and middle Holocene, sediment load in the Yellow River was about 5×10^8 tons per year (Figure 3). An increase in soil erosion began about 5000 BP, when hunting and pastoral life began to change gradually to sedentary life. With the rapid growth of population, human activity started to affect the environment at a scale comparable with powerful natural processes. Although the soil erosion system was not exclusively affected by anthropogenic factors, erosion rates reached their highest point. Modern soil erosion is 4 times greater than the normal geological erosion rate (Figure 3).

Soil erosion in the last century

Sediment yields in the Yellow River recorded in hydrological stations directly reflect the intensity of soil ero-

FIGURE 4 Relations between climate change, sediment load and significant events on the Loess Plateau at Huayuankou Station on the Yellow River. (Sources: Liu et al 1993; Zhang 1999)



sion on the Loess Plateau (Liu et al 1993; Zhang 1999). Figure 4 shows the relation of annual precipitation to the amount of sediment load at Huayuankou Station on the Yellow River (Liu et al 1993; Zhang 1999). Intensive soil erosion occurred in the 1930s and 1960s. During World War II, the levees holding back the Yellow River were broken. The river at that time flooded a huge area with the highest sediment load. At the end of the 1930s and in the early 1940s, the center of the Loess Plateau was densely populated, leading to mass devastation of forest and grass vegetation. From October 1966 to 1969, the Great Proletarian Cultural Revolution (CR) took place. This event resulted in almost complete cessation of economic development and agricultural production. Because there was a great increase of population (39 million in 1949; 82 million by 1989) without any efficient land management or erosion control measurement, soil erosion was continual, causing the high peak of sediment load in the Yellow River in the 1960s.

During the 1980s, China undertook social and economic reforms to control the most serious soil erosion in the world and to guarantee food security for the inhabitants of the Loess Plateau. Over the past century, local people have planted trees and grass to implement tillage and dryland farming techniques, and to build terraces and dams. Good progress has been achieved in erosion control and food production since the 1980s. About 24% of the eroded area is now under control (Li 1997). Consequently, soil erosion on the Loess Plateau is well controlled and the sediment load in the Yellow River has decreased correspondingly. In the early 1970s, a number of dams, including the biggest one at Sanmenxia, were built in the middle reaches of the Yellow River and its tributaries. They have retained a lot of sediment (Table 1), as documented by the low sediment load in 1974 (Figure 4). In 1977, the sediment load rose to 2.4 billion tons because a few dams broke in the Yanan area due to a heavy rainstorm (Tang et al 1991).

Since the 1980s, the Yellow River has run dry more and more frequently because of increasing water consumption by the agricultural, residential, and industrial sectors (Derbyshire and Mellors 1988; Li 1997; Brown and Halwei 1998; He et al 2003). Runoff in the Yellow

TABLE 1 Sediment decrease resulting from soil and water conservation measures on the Loess Plateau. Statistical results based on hydrological records. (Source: Zhang 1999)

Periods	Sediment decrease (10^8 tons) resulting from different control measures					Total sediment decrease
	Terraces	Forest	Grass	Earth dams[a)]	Reservoirs	
1980–1989	0.459	0.465	0.075	9.695	4.877	15.572
1990–1997	0.759	1.367	0.158	5.562	2.926	10.772

[a)] Earth dams are built to retain sediment on farmland.

River has decreased from 3.8×10^{10} m^3 in 1989 to 2.0×10^{10} m^3 in 2002. Sediment load has thus also decreased.

Conclusion

The thick and fertile soil and the luxurious forest and forest–steppe vegetation developed in the Climatic Optimum of the Middle Holocene were favorable to human settlement on the Loess Plateau. This allowed the early Chinese civilization to flourish. Since 3000 BP there had been progressive environmental degradation owing to climate change and human disturbance such as forest clearance and land cultivation. Deforestation and cultivation exposed the fragile soil to water erosion. The almost exponential population growth and extensive clearance and cultivation of highly erodible slopes that have taken place particularly during the past 100 years have made soil erosion on the Loess Plateau more serious than anywhere else in the world.

Modern soil erosion on the Loess Plateau is a combination of intensive natural erosion and human-induced erosion, the latter being 4 times greater than the former. Accurate assessment of modern erosion and prediction of future erosion are unfortunately limited by a lack of systematic data and synthetic method for multi-scale modeling. Great progress has been made in erosion control and food production since the 1980s. About 24% of the eroded area has been stabilized. Grain yield has increased greatly and sediment load in the Yellow River has decreased by about 25%. However, advancing sustainable development further, or even maintaining the current situation, will be a great challenge given the burgeoning socio economic development of the area and the phenomenon of global climate change.

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REFERENCES

Bowler JM, Chen K, Yuan B. 1981. Systematic variations in loess source areas: Evidence from Qaidan and Qinghai Basins, west China. *In:* Liu TS, editor. *Aspects of Loess Research*. Beijing: China Ocean Press, pp 164–174.
Brown LR, Halwei B. 1998. China's water shortage could shake world food security. *World Watch* 11:10–21.
Cai Q, Wu S, Wang X. 1999. Soil and water conservation and sustainable agricultural development [in Chinese with English abstract]. *Geographical Research* 18:17–26.
Derbyshire E, Mellors TW. 1988. Geological and geotechnical characteristics of some loess and loessic soils from China and Britain: A comparison. *Engineering Geology* 25:135–175.
Derbyshire E, Wang J. 1994. Case studies of human impact: China's Yellow River basin. *In:* Roberts N, editor *The Changing Global Environment*. Oxford: Blackwell, pp 417–439.
ESD-CAS [Earth Sciences Division of Chinese Academy of Sciences]. 2001. Advice on the ecological construction and industrial structure adjustment in speeding up the development of western China [in Chinese with English abstract]. *Advance in Earth Sciences* 16:1–4.
He X. 1995. Soil erosion intensity on the Loess Plateau in different time scales [in Chinese with English abstract]. *Journal of Soil and Water Conservation* 19:71–76.
He X. 1999. Pedogenesis of loess profile and evolution of erosional environment on the Loess Plateau since 0.2 Ma. B.P. [in Chinese with English abstract]. *Journal of Soil Erosion and Water Conservation* 5:92–95.
He X, Li Z, Hao M, Tang K, Zheng F. 2003. Down-scale analysis for water scarcity in response to soil/water conservation on Loess Plateau of China. *Agriculture, Ecosystems & Environment* 94(3):355–361.
He X, Tang K, Tian J, Matthews JA. 2002. Paleopedological investigation in three agricultural loess soils on the Loess Plateau of China. *Soil Science* 167(7):478–491.
Huang CC, Pang J, Huang P. 2002. An early Holocene erosion phase on the loess tablelands in the southern Loess Plateau of China. *Geomorphology* 43:209–218.
Jing K, Chen Y. 1983. Preliminary studies on the erosion environment and erosion rates in the Loess Plateau [in Chinese with English abstract]. *Geographical Research* 2:7–10.
Li Y. 1997. Relation between control in Loess Plateau and no-flow in the

Yellow River [in Chinese with English abstract]. *Bulletin of Soil and Water Conservation* 17:41–45.
Liu B, Tang K, Jiao J, Ma X. 1993. *Spatial and Temporal Data and Graphs of Run-off and Sediment in Yellow River* [In Chinese]. Beijing: Science Press.
Liu TS. 1985. *Loess and the Environment*. Beijing: China Ocean Press.
Morgan RPC. 1995. *Soil Erosion and Conservation*. London: Longman.
Porter SC, An Z. 1995. Correlation between climate events in the North Atlantic and China during the last glaciation. *Nature* 375:305–308.
Ren ME, Shi YL. 1986. Sediment discharge of the Yellow River (China) and its effect on the sediment action of the Bahai and Yellow Sea. *Continental Shelf Research* 6:785–810.
Ren M, Zhu X. 1994. Anthropogenic influences on changes in the sediment load of the Yellow River, China, during the Holocene. *The Holocene* 4:314–320.
Rutter N. 1992. Chinese loess and global change. Presidential address, XIII INQUA Congress, 1991. *Quaternary Science Reviews* 11:275–281.
Sun J, Ke M, Zhao J, Wei M, Sun X, Li X, Liu S, Chang P. 1991. Palaeoenvironment of the last glacial stage in the Loess Plateau [in Chinese with English abstract]. *In:* Sun J, Zhao J. editors. *Quaternary of the Loess Plateau*. Beijing: Science Press, pp 154–184.
Tang K, Zhang P, Wang B. 1991. Soil erosion and eco-environment changes in Quaternary [in Chinese with English abstract]. *Quaternary Research* 4:49–56.
Xu J. 1999. Erosion caused by hyperconcentrated flow on the Loess Plateau of China. *CATENA* 36(1/2):1–19.
Ye QC. 1990. *Sediment Transport and Changes of Yellow River Outlet Using RS* [In Chinese]. Beijing: Science Press.
Zhang S. 1999. *Analysis of Benefits of Soil/Water Conservation in the Middle Reaches of the Yellow River* [in Chinese]. Zhengzhou: Huanghe Press.
Zhu X. 1989. *Soil and Agriculture on the Loess Plateau* [In Chinese]. Beijing: Agricultural Press.
Zhu Z. 1990. Hydrogenic sediments–paleosol sequences and climatic-tectonic cycles [in Chinese with English abstract]. *Loess, Quaternary Geology and Global Change* 1:62–70.