Managing Soil Erosion on the Loess Plateau of China to Control Sediment Transport in the Yellow River-A Geomorphic Perspective

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Abstract: A key part of the strategy to manage the problems of flooding and sedimentation of the lower Yellow River in China is the control of soil erosion on the loess plateau. Land use practices are assumed to be the root cause of the high sediment yield and therefore able to be controlled. An analysis of the geomorphology of the loess plateau region shows that there are natural causes of high sediment yield. Loess is a highly erodible material, and the zonal distribution in China of the climatic factors which maximise erosion shows that the loess plateau is located where the potential for erosion, particularly of coarse sediment, is at a maximum. This area would be a zone of high soil erosion even if there were no loess present. Convex slope profiles are the predominant slope form in this landscape such that farming practices are confined to the plateau surface and the gentler upper slopes of the convex profiles. The lower ends of the convex slopes are too steep for farming and are often near vertical. These are therefore the locations of highest sediment production and are little affected by land use activities.

Changes to the social and economic basis of agriculture in China over the past 20 years have caused an increase in pressure on land resources and it is unlikely that farmers will manage their land to control sediment yield unless this also increases productivity. The extent to which it will be possible to mobilise the rural population to participate in land management activities for soil erosion control and environmental benefits is also a key issue in this debate.

The paper concludes that the reduction in sediment yield from the Loess Plateau by soil erosion control and revegetation is unlikely to be of sufficient magnitude to have a significant impact on the management of the lower Yellow River.

Keywords: yellow river, loess plateau, soil erosion

1 Introduction

Most contemporary analyses of the issue of soil erosion on the Loess Plateau of China tend to focus on the human dimensions of the problem. Soil erosion is seen as a problem of inappropriate land use practices and devegetation of the plateau over a long period under intensive human occupance, in the context of rural poverty and problematic and changing land ownership arrangements. Erosion on the Loess Plateau is not just a problem for local land management. The long term strategy for the management of the Yellow River, downstream on the North China Plain, requires a significant reduction in sediment yield from the Loess Plateau (Leung, 1996).

The question I wish to raise in this paper is whether a reduction in sediment yield from the loess plateau by revegetation, the management of agricultural soil erosion and associated reforms to the social organization and economics of the rural communities there, can be of sufficient magnitude to have the desired impact on sedimentation in the Yellow River. Certainly there are benefits to be had in reducing soil loss from agricultural land in terms of the long term viability of farming in these areas and the loss of nutrients which accompanies soil erosion. However, it can be argued that overall sediment yield from the Loess Plateau is determined by climate, the physical properties of loess and the geomorphology of the region as revealed in the forms of valley side slopes and that these will not be affected by land management practices. Both the history and the future of the North China Plain, in a geomorphological sense, are inextricably linked to the Loess Plateau. The question to be addressed is whether land management can have a sufficient impact to override the natural characteristics and operation of this system.

In this paper I begin with an outline of the geomorphic development of the North China Plain and the dependence of that development on the high sediment supply rate from the middle catchment of the Yellow River, i.e. the Loess Plateau. I will then briefly outline the geomorphological characteristics of the Loess Plateau as they influence its naturally high rate of sediment yield before going on to consider the relationships between farming on the Loess Plateau and the management of sediment yield. The concluding discussion will speculate on the relative importance of the natural geomorphological characteristics and land use practices as drivers of sediment yield and the relevance of this for the long term management of the Yellow River.

2 The Yellow River and the north China plain

Viewed from a global perspective, the Yellow River is unusual in terms of its sediment load. Large rivers with high per unit area sediment loads have catchment areas located in steep terrain with efficient slope-channel coupling and rapid tectonic uplift (Milliman and Meade, 1983) as is the case for the river with highest per unit area load, the Brahmaputra. The Yellow River ranks second after the Brahmaputra not because it has similar catchment characteristics but because of the unique combination of material, climate and geomorphic history on the Loess Plateau which occupies the middle catchment where most of the sediment is produced. Some 70% of the total sediment transported by the Yellow River is supplied to the river between Hekouzhong and Longmen (Fig. 1).

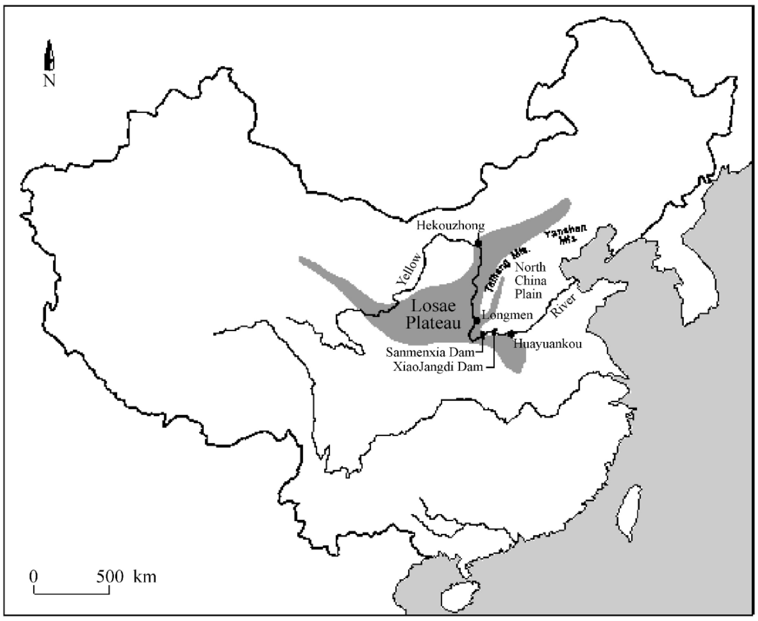

Fig.1 Location map

The North China Plain is an alluvial plain formed primarily by deposition by the Yellow River with contributions from many smaller rivers which drain from the Taihang and Yanshan Mountains. The distribution of sedimentation has been influenced by basement tectonics which have also partly controlled the changes in the direction of river flow. Quaternary sediments are up to 600m thick. 30m to 40 m of this sediment has been deposited in the past 25,000 yrs with the highest rates (0.23 cm yr) in the middle

Holocene (Xu *et al*., 1996). These high rates of sedimentation have persisted throughout the late Pleistocene, independently of human impacts on the Loess Plateau.

A characteristic of the Yellow River on the North China Plain is that it builds natural levees and the channel aggrades within those levees (Li and Finlayson, 1983). Channel changes for a river of this type are by avulsion, leaving a rich record of palaeochannels on the surface of the modern plain and in the sedimentary record (Wu Chen *et al*., 1996). The natural avulsive behaviour of the river has caused serious problems throughout recorded history for the communities living on the North China Plain which has stimulated management actions to try to reduce the impact (Xu Jiongxin, 1993). An important component of this response has been to artificially raise the levees to try to prevent these avulsive changes or at least reduce their frequency. Wu (1991) has estimated the bed height above the surrounding land at which avulsion will occur as 3m — 5 m for natural channels and 5m — 7 m for artificial channels. The Yellow River has remained in its present course since 1855 (with the exception of the period 1938—1947) and is now some 10 m above the surrounding land (Li and Finlayson, 1993). The present situation is therefore unstable and there is a high risk of an uncontrolled change of course.

A major response to the continuing threat of levee failure and flooding in the Lower Yellow River is the construction of the Xiaolangdi Dam (Fig. 1), a multipurpose dam with power generation and irrigation water supply purposes as well as the control of floods and sediment. Like the Sanmenxia Dam before it, the Xiaolangdi Dam is designed to store flood peaks generated in the Yellow River catchment upstream. It is also intended to store sediment for approximately 20 years and this will provide the Yellow River Conservancy Commission with a window of opportunity to find a more lasting solution to the problem of the sedimentation in the lower Yellow River. An alarmingly frank assessment of this issue appears in a web based news site:

Despite the cost in money and disrupted lives, Xiaolangdi does not offer a permanent fix to the Yellow River’s troubles. After 20 years, sediment will fill 40 percent of Xiaolangdi reservoir, and the riverbed will slowly rise.

“After 20 years, we will only keep the dam for floods, not for siltation,” said Wang Xianru, deputy director for the government company building the dam. “At that time our grandchildren will need to think of something.”

One solution, experts say, is extensive planting and flattening of steep hills in the Yellow River’s upper reaches. That would take 300 years.

It has also been proposed that the Xiaolangdi Dam could be used to artificially generate hyperconcentrated floods which would enable the sediment to be released and transported down the whole length of the lower Yellow River to the Bohai Sea (Qi and Zhao, 1993). While hyperconcentrated flows have been observed to occur naturally in some smaller streams on the Loess Plateau, whether of not they can be generated at will on the scale desired to be effective on the lower Yellow River is not known.

The official line of the Yellow River Conservancy Commission is that erosion control on the Loess Plateau will be effective within the 20 year period following the completion of the dam. It would appear therefore that erosion control is the major strategy for the control of the lower Yellow River.

3 The loess plateau

3.1 Sediment yield

The location of the Loess Plateau, in the middle reaches of the Yellow River basin, is shown in Fig.1. Xu (1994) has analysed the distribution of erosion and sediment yield in China. Xu concludes that sediment yield is distributed zonally in China is in response to climatic factors following the principles set out by Langbein and Schumm (1958). Xu has plotted the relationship between sediment yield (in $t \cdot km^{-2} \cdot yr^{-1}$) and mean annual runoff (here used as a measure of climatic moisture status) to show that sediment yield is at a maximum in the range of annual runoff from 20mm to 60 mm. This relationship defines a zone in central China extending from northeast to southwest as shown in Fig. 2 and is largely coincident with the Loess Plateau.

The influence of the material properties of loess on this distribution of sediment yield was also investigated by Xu (1994). He separated the Chinese sediment yield data into two groups of rivers, one with catchments largely underlain by loess and one with catchments free of loess. The loess-free catchments which lay in the zone of maximum sediment yield as determined climatically have much lower sediment yield than those catchments underlain by loess (Fig. 3). He has also compared the Chinese relationships between sediment yield and climatic moisture status with those of Langbein and Schumm (1958) for the USA to show that maximum sediment yields in China are nearly 10 times higher than those in Langbein and Schumm's data, a difference he attributes to the presence of loess catchments in the Chinese data set.

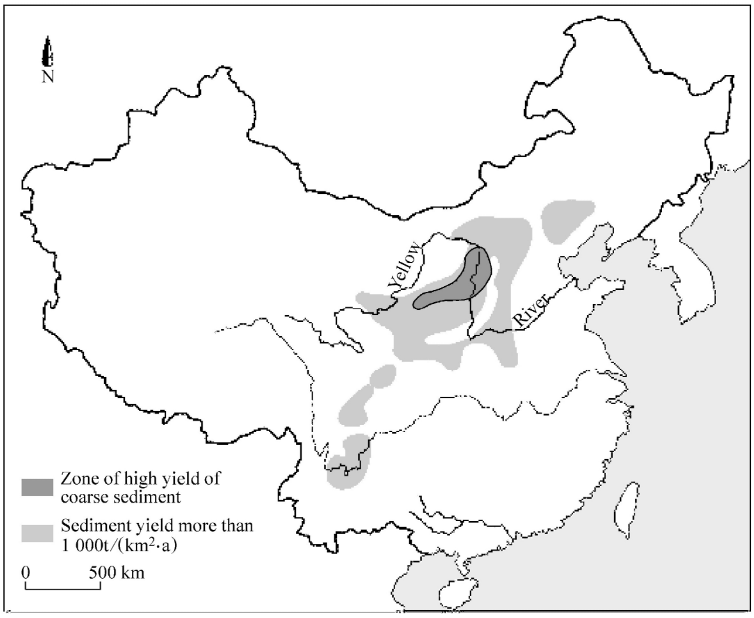

Fig.2 The zone of naturally high sediment yield in China (Xu, 1994) and the zone of high yield of coarse sediment (Qian *et al*., 1980)

The conclusion from Xu's analysis is that the distribution of sediment yield in China can be explained by zonal factors but that the coincidence of the Loess Plateau, in the middle reaches of the Yellow River, with the zonal maximum greatly enhances sediment yield in that area.

Aggradation of the channel bed in the lower Yellow River is predominantly caused by the deposition of coarse sediment with a diameter greater than 0.05mm (Qian *et al*., 1980). Some 200 — 400 millions tons ofcoarse sediment, one fifth of the total sediment load, is delivered to the lower Yellow River annually and management of this fraction of the sediment is therefore considered to be the most important aspect of controlling the aggradation of the lower Yellow River (Qian *et al*., 1980). Loess which is currently being eroded from the Loess Plateau shows a regional change in grainsize distribution from coarser in the north to finer in the south.

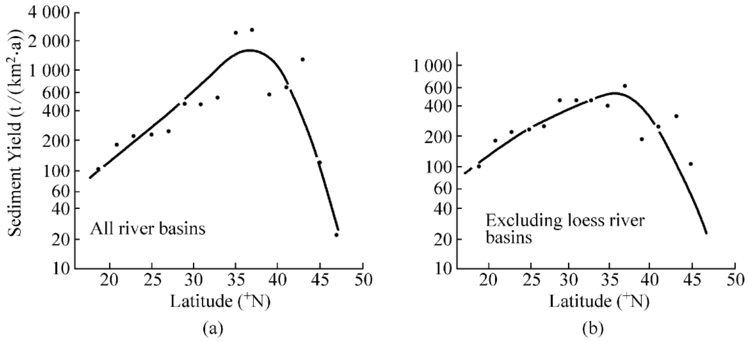

Fig.3 The zonal distribution of sediment yield in China for all catchments (a) and for those without loess (b) (Xu, 1994)

Qian *et al.* (1980) have analysed the suspended sediment data collected by the Yellow River Conservancy Commission for rivers in the Loess Plateau region. These data confirm the spatial pattern of sediment yield identified by Xu (1994) as discussed above and shown in Fig.2. Xu has pointed to the coincidence of the zonal maximum of sediment yield with catchments composed of loess and Qian *et al.* have shown that it is in precisely the region of this coincidence that the loess is dominated by the coarse fraction. In Figure 2 I have overlain the map of the distribution of coarse sediment delivery from Qian *et al.* (1980) on the map of high sediment yield from Xu (1994). The point of this discussion is that rates of sediment yield, very high by world standards, occur on the loess plateau as a consequence of natural conditions there and that it is in precisely the area where the coarse sediment, which constitutes the main threat to the lower Yellow River, occurs that rates of sediment yield are the highest.

3.2 Slope morphology

The Loess Plateau, as its name implies, is an undulating surface dissected by stream incision. The farmland of the plateau is located primarily on the plateau surface. The valley side slopes of the incising streams are convex in profile form (Fig. 4) and this is the case over most of the Loess Plateau as shown in the Geomorphic Map of Loess Plateau in China (Institute of Hydrogeology and Engineering Geology, 1986). The slope profile forms of the Loess Plateau are consistent with what would be expected in an area undergoing tectonic uplift. The upper sections of these convex slopes are commonly terraced and cultivated but lower down they usually become too steep for any productive land use activity and cliffs can be found in these sections of the slopes. The distribution of erosion on these slopes is primarily a function of slope angle and this is compounded by the fact that the steeper slopes are often too steep for any significant vegetation cover to grow. In terms of sediment delivery, this is most efficient where there are steep slopes adjacent to the stream channel (Davis, 1996) as is the case over much of the Loess Plateau.

This problem was highlighted by Jiang and Liu (1992) in a paper presented to the 7th ISCO Conference. They investigated the impact of erosion control measures on sediment yield in a small (8.27 km^2) catchment on the Loess Plateau in Ansai County, northern Shaanxi Province, which is located in the area of high sediment yield and coarse-grained loess identified in Fig.2. While Jiang and Liu identify a reduction in sediment yield over the five-year period 1985 to 1990 which they attribute to soil conservation measures, their results are compromised by what appears to be only one year of pre-treatment record. Nevertheless, they conclude that: ‘Although the erosion degree of the ZVW(Zhifang Valley Watershed)has been decreased and gained great benefits, the steep sloping farmland and natural waste valley sides are still the main sources of sediment yield, so these areas are key part of erosion control in the future’ (p. 5). What, then, are the prospects for significantly reducing sediment yield from the steep sections of the valley side slope profiles (the “natural waste valley sides” of Jiang and Liu)?

Fig.4 Slopes on the Loess Plateau in the Jing River valley

3.3 A perspective on land management

Since the late 1970s the organization of rural production in China has undergone significant changes in a process that is still continuing. Hershkovitz (1993) has identified three general features of these changes which impact on the potential for improved management of rural land, environmental management and for off-site benefits such as reduction of sediment input to the lower Yellow River. These three features are:

(1) Organization of rural production along market lines where farmers are now encouraged to meet market demands rather than centrally determined production criteria. This, in the context of increasing application of "user pays" principles in all areas of Chinese life means investment in activities which do not produce an economic return is not likely to be a high priority.

(2) While land continues to be collectively owned within the village, agricultural production has become the responsibility of the individual household, each of which is now a separate profit making unit. The diversion of household labour and other forms of investment away from the generation of profit for the household (and meeting state and local tax demands) is unlikely to occur.

(3) Farming families are also being encouraged to shift away from subsistence agriculture and to move into commercial production for the market and to non-farming commercial production activities. This also makes it unlikely that investment in not-for-profit environmental management will occur.

During visits to farming villages on the Loess Plateau I have had the opportunity to ask farmers about the relations between their farming activities and the reduction of sediment yield. I need to stress that my pursuit of this issue does not constitute a formal survey on the subject. However, the farmers I have interviewed have never indicated any involvement in actions which are designed to reduce sediment yield. Reforms in agricultural practices always appear to be primarily driven by a desire to increase income and the terracing of the upper sections of the convex valley side slopes is done to bring additional marginal land into production. The eroding steep lower slopes of the valley sides are not managed by these household farmers in any way. From my conversations I am compelled to agree with Hershkovitz (1993) and conclude that the direction of social and economic change in the farming villages of the Loess Plateau is not conducive to the establishment of a management regime which will significantly reduce sediment yield into the Yellow River.

4 Concluding discussion

In this paper I have tried to show that the physical basis of soil erosion in the Loess Plateau is such that rates are high for reasons largely unrelated to land management. This geomorphological assessment indicates that a strategy for reducing sediment supply to the lower Yellow River in order to stabilise it is not likely to succeed. Just how much sediment yield can be reduced by land management is also unknown. The prevailing social and economic conditions in the farming lands of the Loess Plateau are such that farmers are only going to participate in soil conservation and environmental management projects if they bring with them tangible on-farm benefits.

This leaves a serious gap in the long term strategy to control the lower Yellow River. The channel is already well above the height limits identified by Wu (1991) and there is a danger of levee failure and channel shifting which would be a disaster of unprecedented proportions in the affected areas along the Yellow River floodplain. There is also some question about the ability of the Xiaolangdi Dam to prevent flooding in the lower Yellow River even before it loses storage volume by sedimentation. The largest flood in the gauge record at Huayuankou occurred in 1958. The peak height of this flood at Shanxian, upstream of the gorge tract in which both the Sanmenxia and the Xiaolangdi dams have been built, was 9540 m^3/sec and the peak at Huayuankou was 22,300 m^3/sec. 57% of the floodwaters were generated in tributaries which join the Yellow River downstream of the Xiaolangdi Dam. This dam therefore provides only partial protection from flooding in the lower Yellow River.

Given this analysis, it is clear that a new approach to the management of the Yellow River is needed. I do not presume to be able to provide a solution, but the present strategy of attempting to maintain the Yellow River in its present channel appears to carry with it a very high risk of failure. Wu Chen (1991) makes an interesting observation in this context. In discussing the palaeochannels of the Yellow River on the North China Plain, he points out that prior to the construction of the Grand Canal, which runs south to north across the plain, the Yellow River crossed the North China Plain to the sea in nine separate channels and that during this period the river was stable for one thousand years. A new approach based on the deliberate relocation of the Yellow River into a number of separate channels may be worth investigating.

References

Davis J.A., 1996, Catchment Management for the Control of Sediment Delivery: The Case of the Eppalock Catchment, Victoria, Unpublished PhD Thesis, Department of Civil and Environmental Engineering, The University of Melbourne.

Hershkovitz L., 1993, Political ecology and environmental management in the Loess Plateau, China, Human Ecology, **21:** 327-353.

Institute of Hydrogeology and Engineering Geology, China Academy of Sciences, 1986, Geomorphologic Map of Loess Plateau in China, Geological Publishing House.

Jiang Zhongshan and Liu Zhi, 1992, Soil erosion and benefits of sediment reduction by integrated controlling measures in Zhifang Valley Watershed, Proceedings of the 7th ISCO Conference, 1-5.

Langbein W.B. and Schumm S.A., 1958, Yield of sediment in relation to mean annual precipitation, Transactions of the American Geophysical Union, **39:** 1076-1084.

Leung G.Y., 1996, Reclamation and sediment control in the middle Yellow River Valley, Water International, **21:** 12-19.

Li Shu and Finlayson B.L., 1993, Flood management on the lower Yellow River: hydrological and geomorphological perspectives, Sedimentary Geology, **85:** 285-296.

Milliman J.D. and Meade R.H., 1983, World-wide delivery of river sediment to the oceans, Journal of Geology, **91:** 1-21.

Qi Pu and Zhao Yean, 1993, Characteristics of sediment transport and channel formation by floods at hyper-concentrations of sediment in the Yellow River, International Journal of Sediment Research, **8:** 69-84.

Qian Ning, Wang Keqin, Yan Linde and Fu Renshou, 1980, Source of coarse sediment in the middle Yellow River Basin and its effect on aggradation downstream, Proceedings of the International Symposium on River Sedimentation, Guanghua Press.

Wu Chen (ed.) 1991, A Study of Ancient Channels on North China Plain, China Science and Technology Press.

Wu Chen, Xu Qinghai, Zhang Xiuqing and Ma Yonghong, 1996, Palaeochannels on the North China Plain: types and distributions, Geomorphology, **18:** 5-14.

Xu Jiongxin, 1993, A study of long term environmental effects of river regulation on the Yellow River of China in historical perspective, Geografiska Annaler, **75A:** 61-72.

Xu Jiongxin, 1994, Zonal distribution of river basin erosion and sediment yield in China, Chinese Science Bulletin, **39:** 1356-1361.

Xu Qinghai, Wu Chen, Yang Xiaolan and Zhang Ningjia, 1996, Palaeochannels on the North China Plain: relationships between their development and tectonics, Geomorphology, **18**: 27-35.