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Scale effects on specific sediment yield in the Yellow River basin and geomorphological explanations

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Abstract

Based on data from 199 stations in the Yellow River drainage basin for which more than 5 years of data are available, the relationship between specific sediment yield (Y_s) and drainage area (A) has been studied. This relationship for the Yellow River basin is different from those for many other rivers of the world, both at the scale of whole basin and at local scales. With increasing basin area, the specific sediment yield increases, reaches a maximum, and then declines. The non-linear variation in the Y_s–A relationship can be explained by, first, surface material distribution; second, adjustment of the basin at macro time- and space-scales; and the third, the variation of energy expenditure with drainage-basin scale. As the loess deposits in the high-relief headwater areas is thin, it can be exhausted much more rapidly by flowing water erosion than in other areas, so the underlying erosion-resistant bedrock may be exposed much earlier. In many rivers in the study area, bedrock is exposed in the upper part of the drainage basin, and loess appears in the middle part, with a thickness that increases downstream to a peak, followed by a decline. Due to the influence of these spatial patterns of surface material distribution, a spatial pattern of specific sediment yield appears. The non-linear Y_s–A relationship may be interpreted as an indication that the fluvial system of the Yellow River is still at the stage of strong adjustment to the environmental change of Pleistocene–Holocene transition, especially to the change of dominant geomorphic agency from wind to flowing water. This non-linear relationship can also be explained by the variation of stream power with the drainage basin scale. The stream power increases with drainage area to a peak value, and subsequently decreases, a trend that is similar to the trend of the Y_s–A relationship.

Keywords: Specific sediment yield; Geomorphic adjustment; Scale effect; Stream power; Yellow River

1. Introduction

Scale effect has been an important theoretical issue in earth sciences, and many results have been published in hydrology and geomorphology (Burlando et al., 1991; Osterkamp, 1995; Andrle, 1996; Hennrich et al., 1998; Imeson and Lavee, 1998; Yin and Wang, 1999; Becker et al., 1999; Blöschl, 1999). Fluvial processes depend strongly on spatial and temporal scales. Almost all process variables of river basin are closely related with basin area. Many researchers all over the world have found for long

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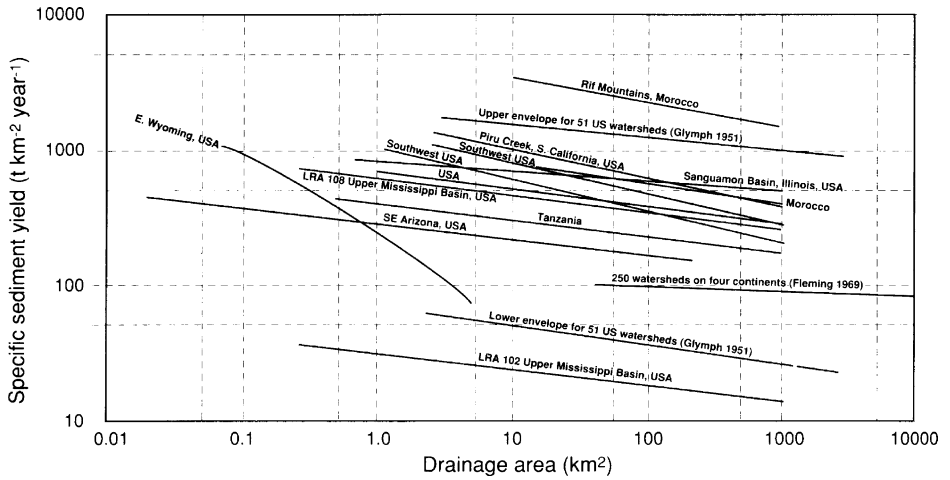

Fig. 1. The relationship between sediment yield and basin area based on data all over the world (source: based on Owens and Slaymaker, 1992).

that a negative correlation exists between specific sediment yield (Y_s) and basin area (A) (Fig. 1). According to Chorley et al. (1984) and many others, the following three factors are responsible for this: (1) small basins have high relief ratio, which leads to high intensity of erosion; (2) a single rainstorm may easily cover a small basin entirely, but cannot cover a large one; (3) with an increased basin area, sediment has much more opportunities to deposit on floodplains. Additionally, sediment delivery process along hillslopes also plays a role. The sediment eroded in the upper part of the hillslope may be deposited at the footslopes when slope steepness becomes gentler and therefore colluvium forms. This factor may also lead to a decline in specific sediment yield of the ravines when the drainage area increases.

However, drainage basin geomorphologic processes are complicated. The spatial pattern of surface materials may control the spatial pattern of processes. Moreover, every large river has a complex history, especially for those who underwent dramatic environmental changes since the Quaternary. In past ages, under agencies different from those in present time, huge quantities of material have been stored within the drainage basin. In case that exdogenic agencies change, especially under the influence of human activities, the previously stored material may be removed rapidly, leading to a spatial pattern of geomorphic processes quite different from those in Fig. 1.

The objectives of this study are to examine the relationship between drainage area and specific sediment yield in the Yellow River basin, and to explain this relationship in terms of geomorphological and other controlling factors. Based on the data from the Yellow River basin, we have plotted the relationship between specific sediment yield (Y_s) and drainage area (A). It has been found that the variation of Y_s with A is non-linear, a result similar to what has been found by Church and co-workers (Church and Slaymaker, 1989; Church et al., 1999). An explanation for this will be given in this paper.

2. Outline of Yellow River basin and data sources

Yellow River (Fig. 2) is one of well-known large rivers in the world. 752,443 km^2 in area, the river stretches from west to east in north China, covering three large-scale landform units: Qinghai–Tibet Plateau, Loess Plateau and North China Plain. The middle Yellow River basin is covered by a loess mantle, which is 275,600 km^2 in area and 100–200 m in thick (Dungsheng, 1985). The mean annual precipitation ranges from 300 to 700 mm, and most of the basin is located in temperate semi-arid zones. The middle Yellow River basin is regarded as the region where erosion intensity is the highest of the world in a large-scale space. The mean annual river flow and suspended sediment load of the Yellow