Hyperconcentrated flows as influenced by coupled wind-water processes

XU Jiongxin

Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences; Key Laboratory of Water Cycle and Related Land Surface Processes, Chinese Academy of Sciences, Beijing 100101, China (email: xujx@igsnrr.ac.cn)

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Abstract Using data from more than 40 rivers in the middle Yellow River basin, a study has been made of the influence of coupled wind-water processes on hyperconcentrated flows. A simple “vehicle” model has been proposed to describe hyperconcentrated flows. The liquid phase of two-phase flows is a “vehicle”, in which coarse sediment particles are carried as solid-phase. The formation and characteristics of hyperconcentrated flows are closely related with the formation and characteristics of this liquid-phase and solid-phase. Surface materials and geomorphic agents of the middle Yellow River basin form some patterns of combination, which have deep influence on the formation and characteristics of liquid- and solid-phases of hyperconcentrated flows. The combination of high percentages of relatively coarse material with low percentages of fine material appears in the area predominated by the wind process, where the supply of relatively coarse sediment is sufficient, but the supply of relatively coarse sediment is not. The combination of low percentages of relatively coarse material with high percentages of fine material appears in the area predominated by the water process, where the supply of fine sediment is sufficient, but the supply of fine sediment is not. In the area predominated by coupled wind-water processes appears the combination of medium percentages of coarse and fine materials, and thus both coarse and fine sediments are in relatively sufficient supply.

The manner in which the mean annual sediment concentrations of liquid- and solid-phases vary with total suspended sediment concentration is different. With the increased total suspended sediment concentration, mean annual sediment concentration of liquid-phase increased to a limit and then remained constant; however, mean annual sediment concentrations of solid-phase increased continuously. Thus, the magnitude of total suspended sediment concentration depends on the supply conditions of relatively coarse sediment and the ability of the flow to carry these relatively coarse sediment particles. In the area predominated by wind process, both the liquid- and the solid-phases cannot develop well, and their concentrations are low. In the area predominated by the water process, the mean annual sediment concentrations of liquid- and solid-phases are also low. Only in the area predominated by coupled wind-water processes, can the conditions most favor the development of both the liquid- and solid-phases, and then the peaks of mean annual sediment concentrations of liquid- and solid-phases appear.

Low values of suspended sediment concentrations appear in the areas predominated by the wind process or by the water process, a fact indicating that the predominating wind process or water process does not favor the development of hyperconcentrated flows. Peak values appear
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in the area where the coupled wind-water processes are predominated, indicating that the coupled wind-water processes most favor the development of hyperconcentrated flows.

Keywords: river sediment, hyperconcentrated flows, liquid-solid two-phase flows, wind process, fluvial process, Yellow River.

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Hyperconcentrated flow is a natural phenomenon, which is widely observed on the Loess Plateau of China\(^1\)\(^2\). So far, much research has been done with hyperconcentrated flows in China\(^1\)\(^–\)\(^7\), although hyperconcentrated flows are also observed in many rivers in other countries\(^8\)\(^–\)\(^10\). In the monograph edited by Chien\(^11\), hyperconcentrated flows were studied in depth, involving the physical properties, resistance, sediment-carry behavior and channel-forming processes. Wang and Chien et al.\(^12\) studied the formation of hyperconcentrated flows in the hillslope-gully coupling system. Xu\(^2\) studied the physico-geographical factors responsible for the formation of hyperconcentrated flows on the Loess Plateau, indicating that semiarid climate, sparse vegetation and thick, loose and highly erodible loess are three major factors. In his study\(^1\)\(^,\)\(^13\) he has noticed that the seasonally alternative wind and water actions have some influence on grain size characteristics of hyperconcentrated flows.

The distribution of annual suspended sediment concentration shows some spatial patterns. There is a high-value zone of mean annual suspended concentration \((C_{\text{mean}})\), averaged yearly maximum suspended concentration \((C_{\text{max}})\) and the record highest suspended concentration \((C_{\text{max,s}})\), located from northeast to southwest and covering the upper parts of Kuye, Tuwei, Wuding, Malian, Sandu and Hulu rivers (Fig. 1). Within this zone, the isolines of annual precipitation and sand-dust storm days are nearly parallel, and the boundary of this zone can be delineated by the annual precipitation isolines of 350 mm and 550 mm, or the isolines of annual sand-dust storm days of 15 days and 5 days. This is a typical area dominated by seasonally alternative wind and water processes. Thus, this coincidence indicates that there may be some cause-effect relationship between the development of hyperconcentrated flows and coupled wind-water processes. Xu\(^13\) has studied the seasonally alternated wind and water processes and named them coupled wind-water processes, in relation to erosion and sediment yield in the middle Yellow River. The present study will be focused on the relationship between hyperconcentrated flows and coupled wind-water processes, to get a better insight into the formation of hyperconcentrated flows in the middle Yellow River.

1 Outline of study area, data and methodology

1.1 Outline of study area

More than 40 rivers are involved, located in the middle Yellow River, mainly in the area between Hekouzhen and Longmen. These include all tributaries of the Yellow River in which long-term and systematical sampling and analysis of suspended sediment grain size have been done at hydrometric stations. The study area is located in a transitional zone from eolian sand to loess, and also a transitional zone from arid to semiarid and sub-humid climates. From northwest to southeast, mean annual precipitation increases from 200 mm to 600 mm, and mean annual number of sand-dust storm days decreases from 25 to 5. Apart from some bedrock outcrops, the types of surface material are closely related with wind actions. From northwest to southeast appears eolian sand, sandy loess, (typical) loess and clayey loess\(^14\). Between the eolian sand and sandy loess areas, a transitional zone can be seen, where loess is covered by eolian sand patches. The so-called “relatively coarse sediment producing area”\(^15\), the major sediment-contributing source area of the Yellow River, is located in the study area.

1.2 Data sources

In the study area, coupled wind-water processes are typical. Wind and water processes alternate seasonally. In winter and spring, wind action is dominant, and