Hyperpycnal flows at the Mouth of Huanghe (Yellow River): Past, Present and Future

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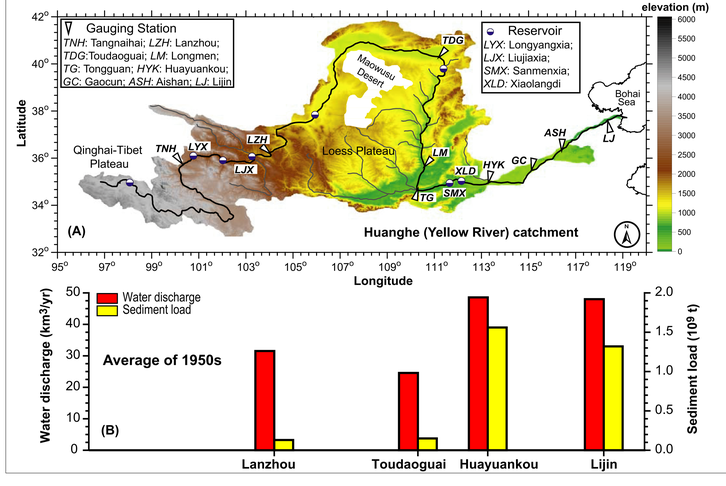
ABSTRACT:

Rapid increase in the Huanghe (Yellow River) sediment yield from the Loess Plateau at 3000 yr BP was caused by the human interventions. As a result, the sediment load delivered to the sea increased to approximately ten folds of the pristine level (100 MT/yr) with suspended sediment concentration (SSC) high up to 25 kg/m^3 at the river mouth that is favorable for the formation of hyperpycnal flows in the coastal environment.

Observations from cruises in the 1980s and 1995 suggest that hyperpycnal flows off the Huanghe mouth are maintained by high concentration of river sediment and modulated by tides. The hyperpycnal flows start at the slack before high water, and during the developing stage the bottom suspended sediment concentration increases rapidly while the salinity drastically decreases and the median grain size of suspended particles within the hyperpycnal layer increases, creating a sediment-stratified water column due to the straining effect from tides. Because of the momentum dissipation, they begin attenuating at the slack before low water while the stratification of the water column becomes collapsed owing to the enhanced tidal mixing. As a result, both the sediment concentration and median grain size of suspended particles within bottom layer decreases. As coarser sediment particles are dumped on the seafloor, the hyperpycnal flows are no longer maintained because of density loss. Nearly 90% of the river-laden sediment is delivered to the sea during the period when the hyperpycnal flows are prominent. Given the extremely high SSC at the river mouth during the past thousands of years, hyperpycnal flows have been a dominant pattern for the terrestrial sediment dispersal in the coastal ocean.

However, construction of large reservoirs and soil-conservation practices within the river basin during the past several decades have reduced the sediment flux to the sea by ~90% and increased the grain size of suspended sediment delivered to the sea (30 um now versus 18 um before in median grain size). Scouring of the channel in the lower reaches has added a new sediment source to those derived from the loess region of the middle reaches. Those conditions are unfavorable for the formation of hyperpycnal flows at the river mouth. Observations from cruises after the operations of the Xiaolangdi Reservoir, suggest that buoyant hypopycnal plumes, rather than hyperpycnal plumes, have occurred at the river mouth since the dramatic changes in concentration and grain size of suspended sediment discharged to the sea.

Climate change (ENSO events impacted regional precipitation) and human activities in the river basin have altered the 'Source-to-Sink' pattern of the Huanghe sediment as indicated by the infrequency of hyperpycnal flows at the river mouth. The Huanghe has becoming an artificially regulated river, and the delta, similar to the example of the Nile, will be starved. As a result, the delta erosion by monsoon activities will probably be a dominant source for sediment exporting to the distal mud deposition on the continental shelf. The perturbations from climate change and human activities propagate throughout the sediment dispersal system from source to sink.



Before Xiaolangdi Reservoir

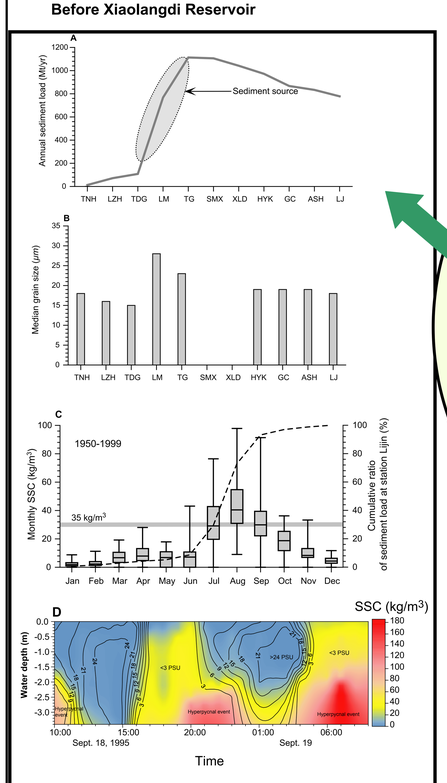
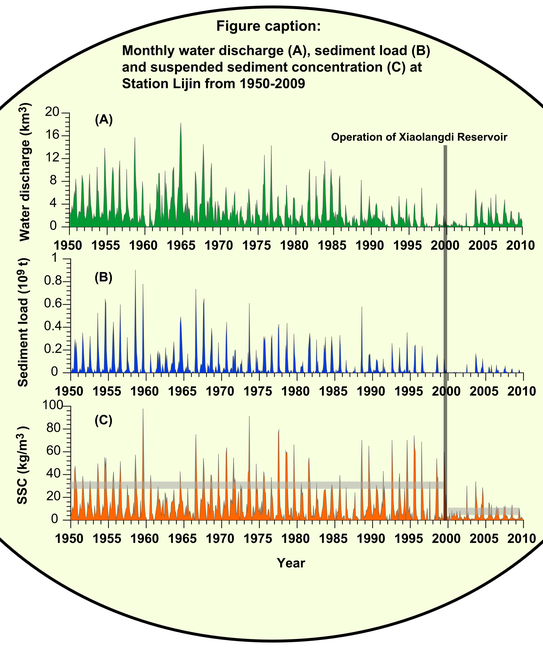


Figure caption: Annual sediment load at stations along the main stream 1950-1999 (A); Annual median grain size at stations along the mainstreas 1950-1999 (B); Monthly SSC at station Lijin 1950-1999 (C) and hyperpycnal plumes observed at the river mouth in September 1995 (D)

Figure caption:
Monthly water discharge (A), sediment load (B) and suspended sediment concentration (C) at Station Lijin from 1950-2009



After Xiaolangdi Reservoir

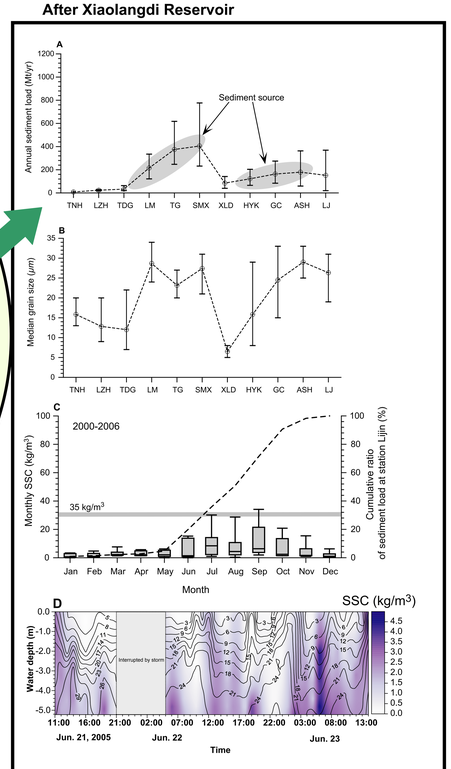


Figure caption: Annual sediment load at stations along the main stream 2000-2006 (A); Annual median grain size at stations along the mainstreas 2000-2006 (B); Monthly SSC at station Lijin 2000-2006 (C) and hypopycnal plumes observed at the river mouth in July 2005 (D)

Before high intervention from human activities on the river system, nearly 90% of the Huanghe-laden sediment is delivered to the sea during the period when the hyperpycnal flows are prominent. Since the middle Holocene, high-SSC drevied hyperpycnal flow at the river mouth has been a dominant pattern for the terrestrial sediment dispersal in the coastal ocean, and has acted as a driving force for the rapid accretion of the mega-delta.

Intensive human activities during the past several decades including dam-orientated flow regulation, sediment entrappment and soil-conservation works have altered the river system. The SSC decreased drastically and sediment became much coarser than ever. Those are unfavorable for the formation of hyperpycnal flows at the river mouth. Significant changes have happened for the delta morphology.

Sediment transfer within the framework of Source to Sink has been controlled by the different behaviors of human activities, such as the high sediment yeild due to agriculture since the middle Holocene and rapidly decreasing sediment load to the sea due to dam operation during the past several decades.

In the future, delta erosion will be a dominant pattern instead of the rapid accretion due to insufficient sediment supply. The delta will be more vulnerable than ever to the sea-level rise and attack from storm surges, as well as to the natural and accelerated subsidence.