Science of the Total Environment 548–549 (2016) 410–420

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Flow regulation manipulates contemporary seasonal sedimentary dynamics in the reservoir fluctuation zone of the Three Gorges Reservoir, China

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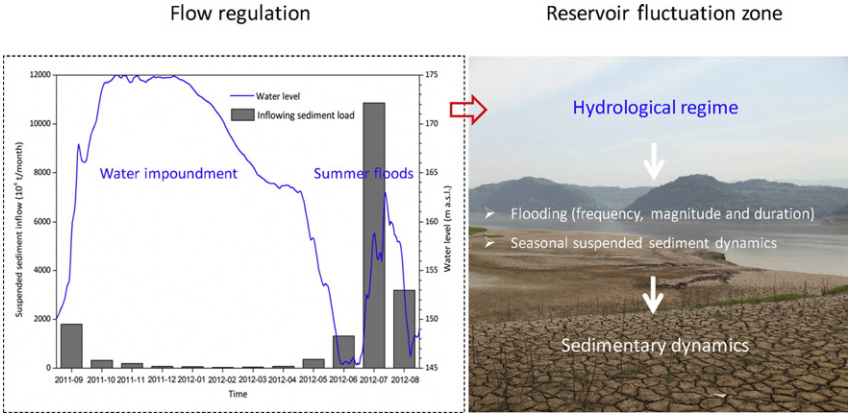
HIGHLIGHTS

- Hydrological regime in the reservoir fluctuation zone has been significantly altered.
- Grain-size variations are diagnostic for sedimentary stratigraphy differentiation.
- Post-dam sedimentation processes were reproduced by chronology determination.
- Regular flow regulation controls contemporary seasonal sedimentary dynamics.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 October 2015
Received in revised form 29 December 2015
Accepted 30 December 2015
Available online 21 January 2016

Editor: Simon Pollard

Keywords:
Flow regulation
Water level fluctuation
Sedimentary dynamics
Stratigraphy differentiation
Reservoir fluctuation zone
Three Gorges Dam

ABSTRACT

Since the launch of the Three Gorges Dam on the Yangtze River, a distinctive reservoir fluctuation zone has been created and significantly modified by regular dam operations. Sediment redistribution within this artificial landscape differs substantially from that in natural fluvial riparian zones, due to a specific hydrological regime comprising steps of water impoundment with increasing magnitudes and seasonal water level fluctuation holding a range of sediment fluxes. This study reinterpreted post-dam sedimentary dynamics in the reservoir fluctuation zone by stratigraphy determination of a 345-cm long sediment core, and related it to impact of the hydrological regime. Seasonality in absolute grain-size composition of suspended sediment was applied as a methodological basis for stratigraphic differentiation. Sedimentary laminations with relatively higher proportions of sandy fractions were ascribed to sedimentation during the dry season when proximal subsurface bank erosion dominates source contributions, while stratigraphy with a lower proportion of sandy fractions is possibly contributed by sedimentation during the wet season when distal upstream surface erosion prevails. Chronology determination revealed non-linear and high annual sedimentation rates ranging from 21.7 to 152.1 cm/yr. Although channel geomorphology may primarily determine the spatial extent of sedimentation, seasonal sedimentary dynamics was predominantly governed by the frequency, magnitude, and duration of flooding. Summer inundation by

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http://dx.doi.org/10.1016/j.scitotenv.2015.12.158

natural floods with enhanced sediment loads produced from upstream basins induced higher sedimentation rates than water impoundment during the dry season when distal sediment supply was limited. We thus conclude that flow regulation manipulates contemporary seasonal sedimentary dynamics in the reservoir fluctuation zone, though little impact on total sediment retention rate was detected. Ongoing reductions in flow and sediment supply under human disturbance may have profound implications in affecting sedimentary equilibrium in the reservoir fluctuation zone. The results herein provide insights of how big dams have disrupted the sediment conveyance processes of large scale fluvial systems.

1. Introduction

Dams represent the most significant disturbance by human activities to global rivers (Nilsson et al., 2005; Walling, 2006). To reconcile expanding demand in energy and water resources consumption associated with economic development and the goal for mitigating global climate change, growing numbers of dams have been constructed or continue to be constructed since the 1950s (Vörösmarty and Sahagian, 2000). Dam construction in developed countries (e.g., North America, Europe) peaked in the 1960s, while it has been accelerated in developing countries (e.g., Asia) since the 1990s (Petts and Gurnell, 2005; Wang et al., 2011; Fan et al., 2015). Dams can supply multiple societal services, such as hydropower generation, flood manipulation, water diversion for agricultural, domestic, municipal and industrial use, improved navigability and recreation. However, increasing attention has focused on dam impacts on channel modification, hydrological alteration, fluvial geomorphological adjustment, biogeochemical sequestration, water quality deterioration, habitat fragmentation and ecosystem degradation as the construction of cascade giant dams on large rivers expands (Humborg et al., 1997; Vörösmarty et al., 1997; Vörösmarty et al., 2003; Walling and Fang, 2003; Nilsson et al., 2005; Petts and Gurnell, 2005; Syvitski et al., 2005; Zhai et al., 2010; Skalak et al., 2013; Fan et al., 2015).

The Yangtze River, in China, ranks ninth globally in terms of drainage area, third in terms of channel length, fifth for water discharge, and fourth for suspended sediment yield (Fig. 1). It serves a population of 450 million, produces 40% of national GDP, and provides many essential socioeconomic benefits and ecological services to local communities (Yang et al., 2015). Of the more than 5000 dams that have been built across the basin, the Three Gorges Dam is the world's largest hydropower project and the most important water regulation scheme (Fig. 1). It has a full water storage capacity of 39.3 km^3 and a flood regulation capacity of 22.1 km^3, which permit it to provide hydropower production, flood mitigation, navigation improvement, and recreation (Fu et al., 2010; Zhang and Lou, 2011). The construction of the dam was commenced in 1993 and completed in 2009. Water pooling began in June 2003 and full impoundment was completed in October 2010. During this period, four steps of water impoundment were carried out, with inundation magnitudes to 139 m in November 2003, 156 m in October 2006, 172 m in November 2008, and 175 m in October 2010 (Fig. 2). On a hydrological year basis (i.e., October–September), the reservoir water level fluctuates between the base level of 145 m during the wet season (i.e., May–September) for flood control and the peak level of 175 m during the dry season (i.e., October–April) for hydropower generation (Jiang et al., 2014). Seasonal water level fluctuation has created a reservoir fluctuation zone, which refers to all geomorphological features that fall into the elevation ranges between the base and peak levels (Bao et al., 2015a). The reservoir fluctuation zone, commonly also referred to as water-level fluctuation zone (Schreiber et al., 2011; Ye et al., 2011), littoral zone (Li et al., 2011a; Yuan et al., 2013), transitional area, drawdown zone (Lu et al., 2010; Su et al., 2012), or disturbance zone (Bao et al., 2015a), represents a unique artificial landscape that was originally composed of terrestrial uplands with diverse land use and which was transformed to a transitional area undergoing seasonal flooding and exposure. This zone differs substantially from well-recognized natural riparian zones in unmanaged river systems (Table 1).

Impoundment of the Three Gorges Reservoir has raised many unprecedented environmental challenges (Wu et al., 2003; Shen and Xie, 2004; Fu et al., 2010; Li et al., 2013; Xu et al., 2013), many of which

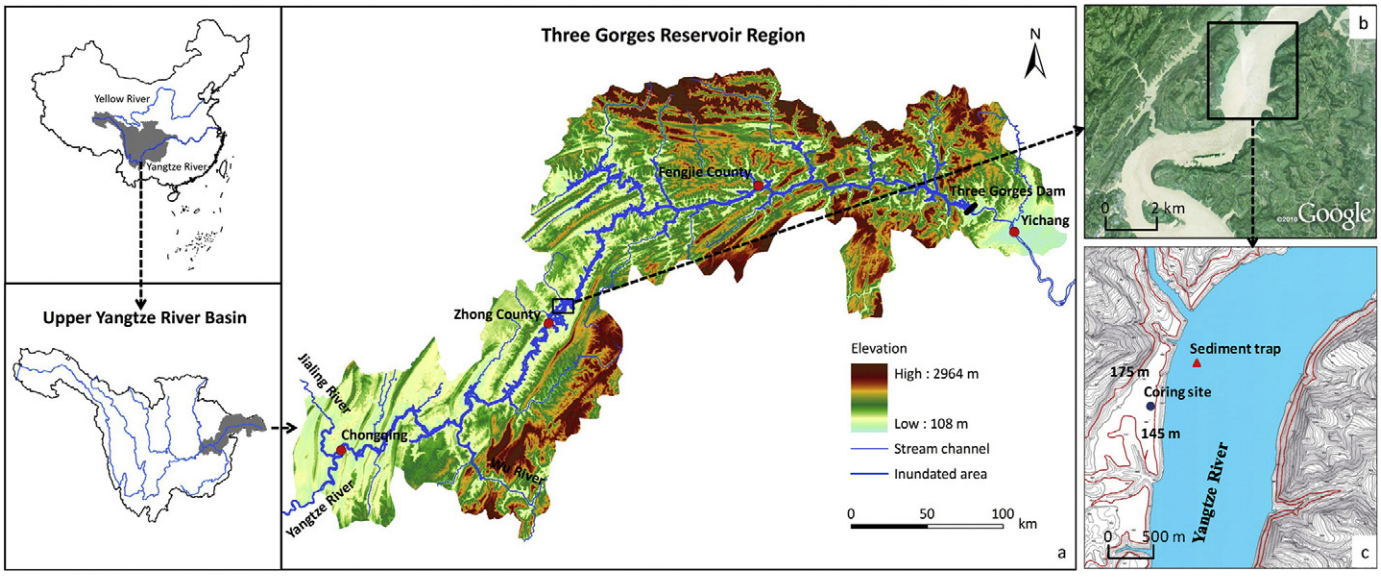

Fig. 1. a. Geographical map of the Three Gorges Reservoir and location of the study site, b. channel planform of the study section, and c. Local pioneer topography before flooding disturbance, location of the coring site and time-integrated suspended sediment trap.