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Check dam infilling archives elucidate historical sedimentary dynamics in a semiarid landscape of the Loess Plateau, China

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ABSTRACT

The Loess Plateau in China exhibited high magnitudes of soil erosion, where multiple soil conservation schemes have been implemented over the past decades. Understanding the efficacy and rationality of conservation practices on erosion mitigation is critical for contemporary strategy adjustment, which currently is hampered by the unavailability of historical observations on sediment yields at most ungauged catchments. Check dams were built with the primary purpose of sediment retention, while the infilling archives register historical sedimentary dynamics. A 485-cm long sediment core was extracted from a check dam in a restored agricultural catchment in the hilly Loess Plateau. Sedimentary stratigraphy was defined at 5-cm resolutions by continuous equivalent sectioning, and differentiated according to absolute grain-size composition and Cesium-137 (^{137}Cs) profile. Discernable stratigraphic laminations, featured by a fine-grained layer overlying on a coarse-grained layer, were observed, which were conducted by particle selectivity associated with soil detachment and sediment transport processes. Erosion and sediment dynamics across this semiarid landscape is strictly defined by extreme summer storms with large magnitude, low frequency and short duration. Sediment chronology was determined by ascribing the identified laminations to historical storm events. We found that the core profile showed evidence of at least 11 depositional events, which finally were connected with 11 major storms over the time period 1981–1983. We concluded that integrating stratigraphy differentiation of equivalent core segments along depositional profiles with storm records is diagnostic for inferring historical sedimentary dynamics.

1. Introduction

Soil is an important natural resource and represents an essential component of ecosystems. It provides key substrates and habitats for organisms, supplies a range of ecosystem services and societal products, and plays a vital role in modulating global hydrological, biogeochemical, and ecological processes (Dominati et al., 2010). In addition to its significance as a natural property, its economic value has been increasingly recognized and evaluated to support policy-making tools in ecosystem management frameworks (Robinson et al., 2014).

Global soil resource has been constantly eroded by divers controls. The acceleration of modern continental denudation induces excess amount of soil loss to an unsustainable level, which undermines ecosystem integrity and its functionality. On the one hand, soil erosion deteriorates on-site land quality by depletion of fertile topsoils and leaching of biotic agents (nutrients, organic carbon), leading to decay in soil fertility, physical structure, and water-holding capacity, and ultimately decreases land productivity (Pimentel et al., 1995; Li et al., 2006; Quinton et al., 2010), whist, on the other hand, the transport of eroded sediment and bounded biogeochemical constituents to river channels imposes many off-site detrimental effects on the aquatic environment and its societal functions, such as high flooding risk, channel sedimentation, reservoir siltation, water pollution, aquatic habitat degradation, and increasing cost for water treatment (Collins et al., 2013; de Vente et al., 2013). Therefore, managing soil/sediment as essential components of ecosystems is critical for maintaining ecosystem integrity and sound environmental status, as well as enhancing socio-economic values claimed by many human uses (Apitz, 2012).

Soil erosion has been extensively studied at multiple spatial and temporal scales. At catchment scale, for example, sediment yields at a catchment outlet are integrated products of sediment supply from distal upland provenance areas and sediment redistribution through drainage networks, including mobilization, deposition, storage, and remobilization (Walling, 1983; Walling, 2006; de Vente et al., 2007). Change in

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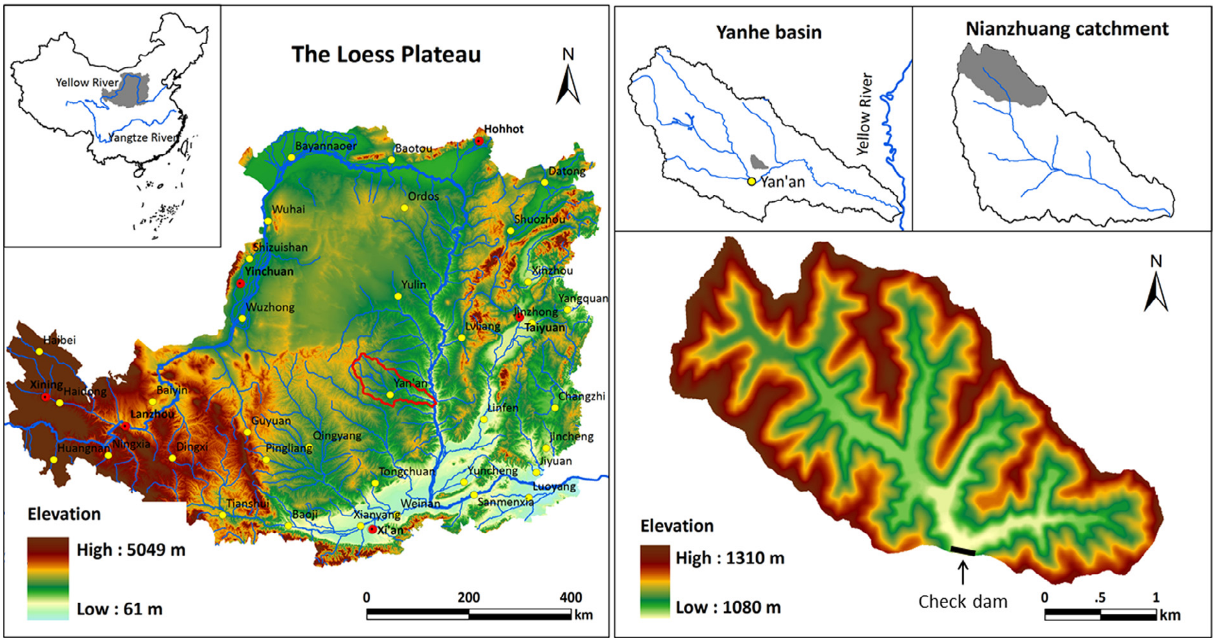

Fig. 1. Geographical map of the Nizhuang catchment on the Loess Plateau, and location of the check dam that collects the headwater sub-catchment was also indicated.

sediment dynamics is driven by a complex interplay of climate, lithology, topography, land use, and human disturbances. Human's role in disrupting sediment signals increases significantly as the expansion and intensification of multiple human activities. Human practices, on the one hand, contribute to increased soil production from upland hillslopes by intensive land disturbance, such as forest destruction, land reclamation, tillage, grazing, mining, urbanization, whist, on the other hand, to decreased sediment conveyance ratio in fluvial systems by water withdrawal and dam construction (Dynesius and Nilsson, 1994; Vörösmarty et al., 2003; Walling and Fang, 2003; Nilsson et al., 2005; Petts and Gurnell, 2005; Syvitski et al., 2005; Walling, 2006; Wilkinson and McElroy, 2007; Syvitski and Kettner, 2011). Erosion mitigation represents a key regulating ecosystem service that can be reinforced by conservation practices, such as vegetation restoration, conservative tillage, land reformation, and crop management (Costanza et al., 1997; Maetens et al., 2012; Vanacker et al., 2014).

The Loess Plateau in northwestern China exhibited high magnitudes of soil erosion, which constitutes a principal source area for sediment pollution in the Yellow River (Fu, 1989; He et al., 2004). Massive soil loss threatens sustainable agricultural production and local ecosystem health (Zheng et al., 2005). Soil conservation represents a major management priority that has been proposed both by resilience scientists and policy-makers. During the past decades, multiple soil conservation measures have been performed, which aimed to reduce the extent and intensity of human disturbance and restore land cover. Those measures installed on upland hillslopes (e.g., terracing, conservative tillage, farmland abandonment, and reforestation) significantly reduce sediment production from uplands (Li et al., 2002; Huang et al., 2003; He et al., 2006), while widely-distributed check dams play an important role in gully stabilization and sediment regulation.

Although great conservation efforts have been made, there remain large uncertainties in sustainability and rationality of contemporary conservation schemes. Major concerns are related to: (i) how to maintain an optimum scale of reforestation in order to balance the many trade-offs between conservation and economic benefits in this undeveloped agricultural region (Chen et al., 2015), (ii) the need to refine replanting strategy to enhance vegetation adaptation to water scarcity in this semiarid region (He et al., 2003; Ma et al., 2004; Cao et al., 2009; Feng et al., 2016). Contemporary strategy adjustment depends largely on systematically evaluation of the effectiveness of these conservation practices on erosion regulation. But these attempts have been hampered by the unavailability of historical observations on sediment yield at most ungauged catchments, which is required as basic reference information. Although the significance of soil erosion and sediment yield has been reported either by experimental runoff plots at fixed field observation stations or by hydrological measurements on large rivers, observations are extremely scare in small ungauged catchments.

Sedimentary products that infill widely-distributed check dams afford a valuable opportunity to reconstruct historical sediment yields and infer human impacts (Owens et al., 1999; Bussi et al., 2013; Wang et al., 2014a), but it depends largely on whether reliable information on sediment age is available. A variety of dating proxies can be applied as time marker (Schillereff et al., 2014). ^{137}Cs, with a half-life being 30.17 a, is a fallout radionuclide derived from atmospheric nuclear testing that began in 1954 and peaked in 1963. It transports globally, deposits on surface ground mainly through precipitation, and closely bounds on surface soil particles. Movement and transport of soil particles is can be represented by ^{137}Cs. Depth distribution of ^{137}Cs along a sediment profile can be used to determine sediment chronology based on its temporal atmospheric input pattern. The year 1954 indicates the onset of detectable ^{137}Cs content along a sediment profile, while 1963 marks peak ^{137}Cs concentration of sediment horizon (Ritchie and McHenry, 1990). A secondary peak marking the Chernobyl nuclear leak in 1986 is observable. Numerous previous studies reported the occurrence of ^{137}Cs peak in check dam sedimentary profiles in the Loess Plateau (Zhang et al., 2006; Wang et al., 2014a).

Against the above background, this study aims to infer historical sedimentary dynamics in check dams, using ^{137}Cs chronology in combination with historical storm records. The specific objectives were: 1) to differentiate sedimentary stratigraphy across a 485-cm long sediment core, based on depth variation of particle size and ^{137}Cs content; 2) to determine sediment chronology and reconstruct historical sedimentary dynamics based on historical storm records; and 3) evaluate the applicability of continuous equivalent core sampling in sedimentation reconstruction.