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Exploring the influence of vegetation cover, sediment storage capacity and channel dimensions on stone check dam conditions and effectiveness in a large regulated river in México

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ABSTRACT

Check dams are widely used for soil conservation at the watershed scale. When structurally sound, these engineering control works retain sediment as planned. However, there is limited information describing the influence of site characteristics on post-construction condition including structural stability and sediment retention capacity. More specifically, the effects of channel morphology, check dam geometry and vegetation characteristics as potentially influencing factors on sediment retention capacity at the watershed level are poorly understood. Thus, an investigation applying field and remotely sensed measurements, multi-regression models, redundancy and sensitivity analysis, and correlation analysis was conducted in a Mexican watershed where the characteristics of 273 check dams were evaluated 3–5 years after construction. Vegetation cover and dimensions of the channel were found to be the most important factors influencing check dam fate. Taller structures experienced the greatest failure risk, in contrast to lower and wider structures and associated vegetation cover that retained long and wide sediment wedges, which helped to stabilise the check dams. The potential sediment storage capacity of the check dams mainly depends on the downstream height of the structure, but also on the vegetation cover near the structure walls; check dams constructed across a range of channel dimensions are able to effectively store sediment. Overall, this study provides a quantitative evaluation of the dominant factors influencing the post-construction conditions of check dams and their ability to store sediment, and thus provides land managers insights into the best strategies for soil conservation at the watershed scale using check dams.

1. Introduction

Check dams are made of various materials, including concrete blocks, loose stones, rocks in gabion baskets, or wood, and they can be identified as a small barriers built across a drainage channel to control runoff and sediment transport, and enhance sedimentation (Nyssen et al., 2004). These stream control works are widely used around the world, often as one component of watershed scale efforts to control runoff, erosion, and sediment transfers (Mekonnen et al., 2015; Quiñonero et al., 2016). They often have been installed throughout drainage networks covering extensive regions. For instance in torrents of Calabria (Southern Italy), where up to 6 check-dams per km^2 (Bombino et al., 2007) were installed, more than 75% of the hydrographic network has been treated. Guyassa et al. (2017) report extensive installation of check dams during the last three decades in gullies of the Highlands of Northern Ethiopia as soil and water conservation practices. In ephemeral channels of southeast Spain, check dams were used to stabilize hillslopes by inducing deposition and forming flat sediment wedges that reduce runoff slopes (Conesa Garcia and Garcia Lorenzo, 2010). In addition to their use in soil conservation,

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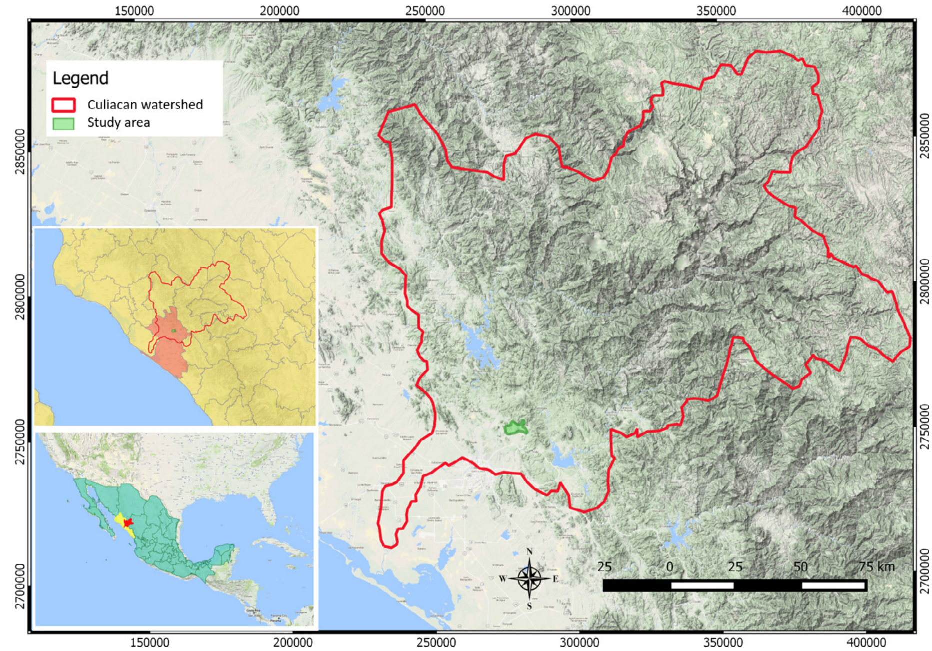

Fig. 1. Geographic location of the stone check dams investigated in the Culiacan watershed (Mexico).

check dams have been constructed in gullies to retain sediment and form farmland in Loess Plateau in China (Xu et al., 2004).

Check dams, which are usually build to control water and sediment fluxes along stream channels (e.g. Heede, 1978; Nyssen et al., 2004) also exert important effects on channel morphology, bed sediment and vegetation (Conesa Garcia and Garcia Lorenzo, 2010; Xu et al., 2004; Boix-Fayos et al., 2007; Zema et al., 2014, 2018). In the Mediterranean environment of southern Italy, Bombino et al. (2009) showed the positive effects of check dams on headwater mountain channels affecting both physical adjustments and the extent and development of riparian vegetation. Boix-Fayos et al. (2007) evaluated the effects of check dams on river channel morphology in Spain and found that after 30 years, most of the check dams lost much of their trap efficiency, and erosion of the alluvial deposits upstream of check dam had begun. Xu et al. (2012) performed a series of calculations to quantify the effects of conservation managements in terms of retaining soil, water, and especially nutrients 50 years after implementation in a representative catchment on the Loess Plateau (China). This research resulted in recommendations of preferred conservation practice in the area. An evaluation of check dams constructed in two small semi-arid watersheds in the south-western United States revealed that check dam failures were minimal, however loss of sediment retention capacity was rapid, within seven years, due to high sediment loads (Polyakov et al., 2014; Nichols et al., 2016). Nyssen et al. (2004) reported that soils influenced the rate of check dam failures with higher rates in areas with smectite-rich soils that are prone to swelling. However, although check dams are widely used as a watershed management tool, often in combination with complimentary engineering works, for enhancing watershed and grade stabilization and their impacts have been investigated in various ecosystems, information describing and quantifying the watershed factors affecting check dam stability and efficacy is limited.

From the previous examples, it appears that after construction, one of the most important features influencing the effectiveness of check dams on the watershed system is their sediment storage capacity. Storage capacity is directly related to structural condition, but the efficacy of check dams is also related to biotic and abiotic factors, such as channel geometry, land use, soil type, and vegetation cover. In particular, the scientific literature has evidenced the basic role of vegetative cover for an ecologically sound regulation activity of rivers (e.g. Gurnell and Petts, 2002, 2006; Allmendinger et al., 2005; Corenblit et al., 2007). In our study, we hypothesised that, vegetation cover percentage and type may significantly influence sediment transfer and channel deposition, which in turn affects check dam stability and failure. We expect that lower vegetation cover will result in higher sediment transfers and thus the likelihood of stone check dam failure will increase. Therefore, in view of an integrated management of regulated watersheds, there is a need to investigate which of the factors mentioned above are the most influencing on both the condition of check dam structures and their ability to store sediment with particular stress on the role of the vegetation cover. This information is important to maximize the likelihood of successful conservation works. Failure to account for high intensity rainstorms, upstream areas with highly erodible soils, absence of vegetation cover in the watershed, inadequate channel dimensions for a check dams installation or steeped channels may generate high quantities of sediment transfer and drawing attention to the risks posed by these structures as they fill with sediment and deteriorate (Wang et al. 2009). Check dams failure and the sudden or gradual erosion of previously deposited sediment can reintroduce large quantities of sediment for subsequent transport (Brooks and Lawrence 1999).

To address these issues, a large regulated watershed in Mexico is presented as a case study. Here, more than 250 check dams, recently built to slow runoff and retain sediment, are intact, but many other structures have failed. A large dataset describing the condition and functioning of the check dams was compiled and reported by Cruz Hernandez et al. (2014). This dataset is combined with remotely sensed data to interpret possible cause-effect relationships between sub-watershed characteristics and the structural condition and functioning (in terms of sediment storage capacity) of the check dams. Specifically, a combination of analytical techniques (stepwise regression, redundancy analysis, increase-rate-analysis and correlation analysis) to the check dam dataset collected in the watershed. The subsequent interpretation identifies and quantifies the most influential watershed factors (channel dimensions, vegetation cover, characteristics of the check dams and others) affecting both the structural condition and functioning of check dams; finally, the role of the vegetation is focussed as a co-factor synergetic with the actions of check dams towards ecologically sound regulation of the studied river.