Short communication

Soil bioengineering application for flood hazard minimization in the foothills of Siwaliks, Nepal

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ABSTRACT

This study focused on soil bioengineering for stream bank stabilization. Both vegetative check dams and wire net check dams along with vegetation were used during May–June 2009. After three growing seasons, the banks of the ephemeral stream were almost fully stabilized. The effects of river edge cuttings were highly reduced, and flow channels of the river were also narrowed. Vegetation based solutions are found to be more effective than the mechanical methods of stream bank stabilization. Vegetation application on flood-damaged bare ground was also found to be very successful. Furthermore, some plants species showed almost equal growth performances on both flood-affected and unaffected bare ground.

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1. Introduction

Soil bioengineering techniques (SBT) have been carried out for centuries to control erosion problems on slopes and along riverbanks in different parts of the world (Schlueter, 1986; GEO, 2000; Fatahi et al., 2010; Bariteau et al., 2013). Sound engineering practices are employed in conjunction with integrated ecological principles, using living vegetation and other non living plant materials to stabilize slopes (hill-slopes, riverbanks, and lake/shorelines), to protect wildlife habitats, and to enhance the functioning of ecosystems (Gray and Sotir, 1996). In recent years, SBT have been extensively used because they are cost-effective, flexible, and applicable in remote areas by using locally available materials, and because they require low-cost labor in comparison to more elaborate civil engineering works (Li and Eddleman, 2002; Wu and Feng, 2006; Li et al., 2006; Evette et al., 2009; Rey and Burylo, 2014).

Vegetation-based techniques have been applied either alone or in conjunction with small-scale civil engineering structures to reduce shallow-seated instability erosion on slopes and stream banks. Engineering functions and hydrological effects of vegetation

are key factors to control soil erosion and to stabilize slopes (Dhital et al., 2013a). Vegetation efficiently mitigates erosion by active or passive protection (Rey et al., 2004). Active protection against erosive agents consists of rain drop interception (Woo et al., 1997), an increase in water infiltration in soil (Cerdà, 1998), and soil fixation by root systems (Gyssels and Poesen, 2003). Vegetation also has a passive action by trapping and retaining sediment inside the catchment due to its aerial parts (Abu-Zreig, 2001). Selection of plant species is very important due to potential weather scenarios in terms of its capacity of the root reinforcement and evapotranspiration (Normaniza et al., 2008; Stokes et al., 2010). However, species used for soil bioengineering should have pioneer plant character, and fast and simple propagation (Weigel et al., 1987). Furthermore, altitude range, local geology, light requirements, availability of plant species, and nutrients are other essential factors for the vegetation succession.

In river channels, vegetation reduces near-bed shear stress, and controls sediment erosion, transport and deposition processes by its resistance to flow and the capacity of roots to modify substrate cohesion (Brookes et al., 2000; Bennett et al., 2002; Corenblit et al., 2007). Stem density and diameter are key-parameters controlling bed load transport in open channels which may lead to significant sediment accretion in fluvial corridors during floods (Samani and Kouwen, 2002; Ishikawa et al., 2003). Furthermore, large structure of vegetation helps to reduce or minimize sediment supplied to the river by slumping and other types of mass failure (Williamson et al., 1996; Hubble et al., 2010). However, large woody debris

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sometimes may cause flooding during the time of high intensity of rainfall.

SBT have been widely used in Nepal to deal with erosion problems on slopes, especially for treatment of shallow-seated landslides associated with high way construction (Clark and Howell, 1992; Lawrance, 1994; Howell, 1999; Florineth et al., 2002; Sharma, 2004; Lammeranner et al., 2005; Devkota et al., 2006; Ojha and Shrestha, 2007; Mathema and Joshi, 2010). However, the majority of published literature is based on practical experience and not on scientific research that uses data about initial soil conditions and modes of failure. Compared to observations from the application of SBT to landslide treatment, very few soil bioengineering works have been done on stream bank protection, which requires the combined efforts of the local community, private consultants and the Nepal government. Furthermore, no scientific reports of SBT for flood hazard minimization in Nepal exist to this date. Bank cutting, farmland inundation, and extensive erosion of agricultural land are common problems during every annual monsoon in the Siwaliks and Terai regions of Nepal. In this context, an experiment was conducted with two objectives (1) understanding how to stabilize the banks of an ephemeral river and (2) minimizing the impacts of flooding on flood-damaged bare grounds in the foothills of the Siwaliks.

2. Study area

The study site lies in Hariwan Village Development Committee – 1 at the edge of ephemeral stream (Bilandhi Khahare River) in the lower watershed of Bagmati River Basin, Nepal, 36 km from District Headquarters, Sarlahi (Fig. 1). The surrounding region is called the foothills of the Siwalik, a region known as the most unstable and natural hazard prone area in Nepal because of its weak geological formation. Debris flows and landslides in the upper part and flooding in the lower of this region frequently occur during the main monsoon months of July and August (Dhital and Kayastha, 2013). Geologically, the Siwalik zone is bounded to the north by the Main Boundary Thrust and to the south by the Main Frontal Thrust. This region consists of combinations of mudstone, sandstone, and conglomerate at varying proportions and textures (Upreti, 1999). Climatically, the Siwalik has a sub-tropical climate, with a mean annual minimum and maximum temperature between 12 and 23°C, and an annual average and monsoon average rainfall of 2100 mm and 1700 mm, respectively (Dhital et al., 2013b). Torrential rainstorms and cloudbursts can bring over 400 mm rainfall in a single day. Vegetation in the area surrounding the study site is dominated by *Acacia catechu*. Poor land management

Fig. 1. Location of experimental site in Bagmati River Basin, Nepal.

Fig. 2. Stabilization of the bank of ephemeral stream with combination of vegetative check dams and *I. fistulosa* plants (5th December 2012).

Fig. 3. Effects of vegetation on edge cuttings and flow channels of ephemeral stream (5th December 2012).

and over-grazing by cattle reduces vegetation cover and exposes the soil to high erosion.

3. Materials and methods

A small catchment area (48 ha) with severe flood damages was selected for the experimental study with the cooperation of District Soil Conservation Office, Sarlahi, Nepal. A monitoring committee at the local level with the collaboration of local government bodies was formed in June 2009. A social vulnerability flood hazard map was prepared to identify unstable sections of both river banks and nearby flood-affected bare grounds. Initially, the monitoring committee managed a controlled cattle grazing and later on, coordinated the collection of raw materials (stones, sands, and bamboo cuttings) for SBT application. Local people were involved in most of the work of experimental site preparation including wire net constructions. Vegetative check dams (local known as chanchar) of varying sizes from 1.92 m^3 ($4 \text{ m} \times 0.6 \text{ m} \times 0.8 \text{ m}$) to 7.68 m^3 ($16 \text{ m} \times 0.6 \text{ m} \times 0.8 \text{ m}$) were built in the front part along the most of the unstable section of stream banks. These check dams were built with bamboo wattlings on both sides and sand bags were placed in the middle, where *Ipomoea fistulosa* stem cuttings were continuously planted on both sides of dams. However, wire net check dams were also built in the front part along some of the unstable sections. Bamboos were planted behind the check dams with certain spacing, and bamboos wattlings were also placed in some middle parts. Finally, some groups of plants (*Thysanolaena maxima*, *Dalbergiasisso*, *A. catechu*, *Moringa oleifera*, *Eucalyptus camaldulensis*, *Leucaena species*, *Mangifera indica*, *Zizyphus mauritiana*, *Wendlandia puberula*, and *Salmalia malabarica*) were planted on flood-affected bare grounds and other nearby bare grounds too.

Fig. 4. Effects of wire net check dams on bank stabilization of ephemeral stream (6th December 2012).

Fig. 5. Growth performance of plant species (sample size, $n = 10$ for each plant species) on both flood-affected and unaffected area (FUA = flood-unaffected area; FDBG = flood-damaged bare ground; SD = standard deviation).

4. Results and discussion

After three growing seasons, it was found that the banks of the ephemeral stream were almost fully stabilized and most parts of the bare ground were covered with more shrubs and grasses than had been planted. Vegetative check dams were very effective in controlling soil erosion and as a flood control mechanism, with *I. fistulosa* stem cuttings continuously extending on both sides of the check dams (Fig. 2). The effects of edge cuttings were highly reduced, and flow channels of the river were also narrowed (Fig. 3). Bamboo combinations for check dam construction, as well as plantings behind the check dam, were both found more effective for stream bank stabilization. Wire net check dams were found less effective in comparison to vegetative check dams for the stream bank stabilization at a small scale (Fig. 4). Corrosion on the wire net and dislocation (movement) of stones inside the wire net reduced the effectiveness of wire net check dams, as observed during the field monitoring.

Growth performance of selected shrub or tree species ($n = 10$ for each species) on both flood-damaged bare grounds and nearby flood-unaffected areas were analyzed after three growing seasons (Fig. 5). Plant species on flood-unaffected areas showed slightly higher growth performance than flood-affected bare grounds, a result that might reflect the effects of past flooding on bare grounds. However, some plant species (*W. puberula* and *Z. mauritiana*) showed almost equal growth performance on both flood-affected and unaffected areas. Furthermore, plant species like *W. puberula*, *L. species*, and *S. malabarica* showed high growth performance, whereas *E. camaldulensis* and *Z. mauritiana* grew more slowly. In sum, the analysis indicated that differences in vegetation succession between flood-affected areas and unaffected areas were small.

According to District Development Committee of Sarlahi, if civil engineering works alone were used for flood hazard minimization in the experimental site, the total capital cost would be increased by nearly four times. Participation of local people in the experimental site preparation as well as in regular monitoring and control of extensive cattle grazing, contributed significantly to desirable vegetation succession. From the communication of the local people, it was also found that plant species like *Saccharum*

pontaneum, *W. puberula*, *L. species*, *S. malabarica* can grow properly without human cultivation in these areas when cattle grazing is controlled. Furthermore, it was also observed that some fodder grasses like *Stylosanthes guianensis* and *Pennisetum purpureum* grow well in areas between large trees such as *Dalbergia sisso* and *A. catechu*, and that fruit farming for species such as *Psidium guajava* and *Musa paradisiaca* can succeed on flood-damaged bare grounds along with other large trees.

5. Conclusions and recommendations

SBT such as live vegetative check dams appear to be one of the best solutions for flood hazard minimization in the foothills of Siwaliks, Nepal. *I. fistulosa* plants are very effective as a flood control mechanism when combined with vegetative check dams. Bamboo combinations for check dam construction and planting of bamboo behind check dam are both very useful for stream bank stabilization. Furthermore, vegetation-based solutions are also very cost effective compared to mechanical methods for stream bank stabilization at small scales. Vegetation application on the flood-affected areas can also be successful. Plant species like *D. sisso*, *A. catechu*, *L. species*, *W. puberula*, *S. malabarica*, *T. maxima*, and *M. oleifera* can be planted successfully on flood-damaged bare grounds. This study demonstrates that soil bioengineering should be considered as part of an agro-forestry system, yet more detailed study is needed to demonstrate the full range of technical, social, and economic benefits of bioengineering for local communities.

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