Assessment of soil erosion and flood control measures in a small Siwalik Hill catchment of Nepal Himalaya

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This paper presents findings of an evaluation study that focused on soil erosion, changes in land use, and stream morphology and the effectiveness of erosion control measures in a small degraded catchment of the Siwalik Hills in Nepal. The study was based on a spatial analysis of historical aerial photographs (1964-2010) and several field measurements and observations (1998-2012). Analysis of historical aerial photographs indicated that noticeable deforestation occurred during the period between 1964 and 2003 as a result of expansion of agricultural land. However, during the period from 2003 to 2010, no significant changes in land use were noticed. Several types of morphological changes in the fluvial system were observed both from aerial photographs and field observation. The stream channels were characterized by active bank erosion with an increase in width, particularly from 1964 to 2003. There was a noticeable sediment accumulation in the lower reach while a combination of bank erosion, channel widening and lateral movement of the active channel were observed in the middle reach. It is suggested that appropriate conservation measures should be implemented to control sediment supply from the upper reaches where key sediment sources such as landslides and gullies are located.

Key words: Land use change, channel change, bank erosion, mitigation, Siwalik Hills

1. BACKGROUND

The Siwalik Hill is considered one of the most fragile and vulnerable ecosystems in the Himalaya [*Higaki*, 2003] where soil erosion and landslide processes are very active despite the large area under forest cover. This is mainly due to its location within the zone of active crustal movement [*Hurtrez et al.*, 1999]. Compared to the Middle Hills, knowledge on soil erosion rates and processes is very limited in this region and studies related to long-term monitoring of sediment mobilisation and channel morphological changes are scarce. The geomorphological responses of the stream channels have been controlled by the interplay of numerous factors including the tropical climate, geology, land use and topography along with the influence of human actions. Intense monsoon-driven rainfall regime and steeper topography coupled with a weak geological formation has led to the formation of degraded landforms such as rills, gullies, shallow landslides and stream cut banks which form the dominant sources of sediment [*Ghimire et al.*, 2006]. Because of these active erosion processes, the streams transport significant amount of sediment downstream leading to land degradation within the region itself and also sediment deposition further downstream on the lowland Terai plain [*Ghimire and Higaki*, 2005; *Upreti*, 2001].

The main objective of this paper is to report on the soil erosion rates and assess the effectiveness of erosion control and flood mitigation measures. A tributary catchment of the Trijuga River (Khajuri watershed) was taken as a study area where a pilot scheme was implemented during 1997-1998 to address soil erosion, sediment transport and flooding issues. Several types of erosion control measures and flood embankments were implemented for reducing soil erosion and flooding. The field data and information and the output from this study would be helpful for planning and designing erosion control measures in order to prevent land degradation and protect the geo-physical environment of the Siwalik Hills.

2. STUDY AREA

The study catchment (Khajuri Stream, ~ 4.6 km^2) is a sub-catchment of the Trijuga River valley in the eastern region of Nepal (Figure 1). The Trijuga River originates from the Siwalik Hills and joins the Koshi River to the east. The catchment area of the Trijuga River is ~ 640 km^2 extending east-west The valley floor elevation ranges from 130 to 200 m above mean sea level. There are mainly three types of formation in the Siwalik Hills: Lower, Middle and Upper Siwalik group [*Kimura*, 1997].

The Lower Siwalik formation is generally comprised of fine-grained claystone and siltstone. The Middle Siwalik is mostly composed of coarse sandstone and mudstone. Coarse boulders and conglomerates dominate the Upper Siwalik formation. The area was characterized by a monsoonal rainfall regime with an annual average rainfall of ~1900 mm and an extremely humid and hot climate.

The catchment had several small tributary watercourses and drainage flow paths mostly in the upper and middle reaches. There was a prevalence of several types of landforms as a result of gully erosion, incised stream banks and landslides.

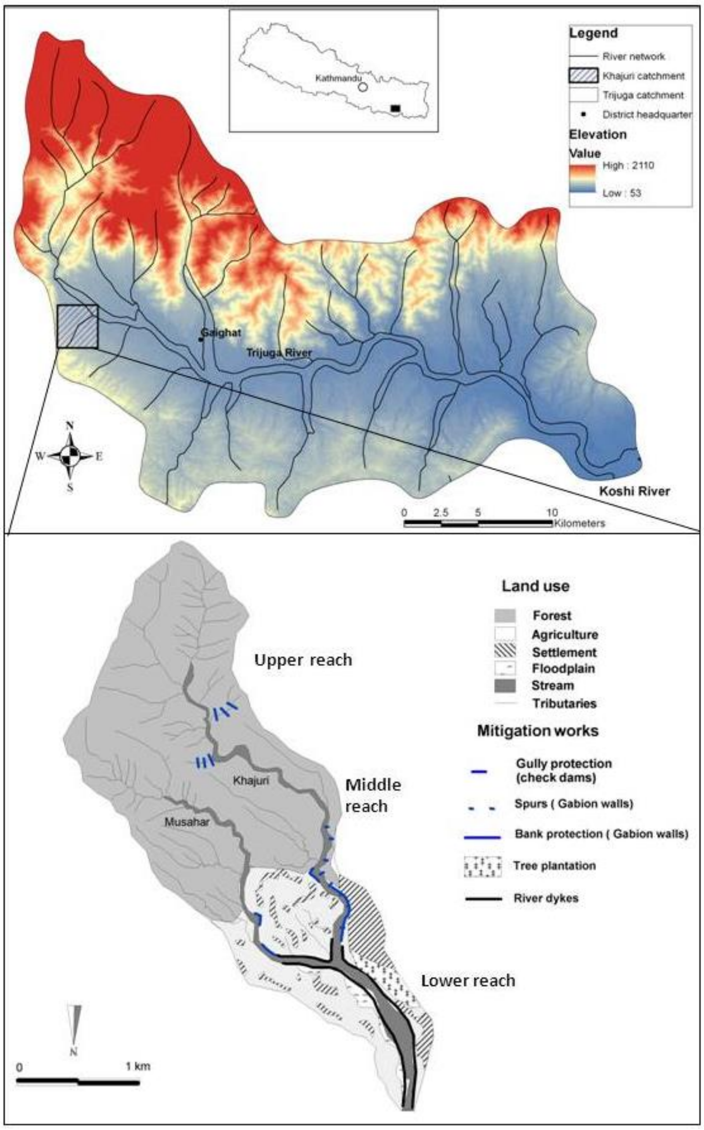

Fig. 1 Location map

3. METHODOLOGY

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3.1 Measurement of erosion

Erosion pins were used to monitor temporal and spatial patterns of erosion from ground surface (sheet erosion), gullies, landslides and stream banks. Erosion pins made up of iron nails with a length ranging from 30 to 50 cm and diameter of 8 to 12 mm were used. Many studies have employed this technique to measure different types of soil erosion [e.g. *Couper et al*., 2002; *Lawler et al*., 1997].

For the measurement of sheet erosion, a total of four monitoring sites (10 to 35 degrees and slope length from 9 to 38 m) were established. Erosion pins were inserted into the soil along five slope transects with 3–5 m intervals across the slope. The lengths of the pins that were left exposed above the soil surface were measured two times a year (during summer and winter) using a measuring tape with a precision of 1 mm. As monitoring was done only two times a year, the measurement might not give the entire processes of erosion such as sediment movement without changes in bed elevation. In such circumstances time series photographs were used to monitor changes in stream bed and side slopes. Gully erosion was monitored by repetitively measuring the distance between the edge of the gully head and benchmark pins established around the gully. Erosion of channel side walls was measured by inserting iron pins normal to the side slope surface and repeatedly measuring the exposed segment. Three active landslides were selected for monitoring erosion. Erosion pins were inserted on the landslide slopes at a spacing of ~2 m. Surface area of each of the landslides was determined from landslide mapping using the 1992 aerial photograph. The amount of eroded sediment from a landslide was then estimated by multiplying the surface area of the landslide and mean erosion depth. Details about the measurement techniques are given by *Ghimire et al.* [2013].

3.2 Aerial photographs

Google Earth images were used to identify land use changes in the recent past, from 2003 to 2010, which were then compared with the land use changes since 1964. Also the images were used to identify recent morphological changes within the fluvial system. The land use polygons traced on the images were converted into shape format to enable overlay with other images by using ArcGIS [10.1].
In order to estimate the error on the 2010 images, field measurements were undertaken at five cross-sections across the Khajuri Stream. The comparison between the image and field measured distances indicated that the difference ranged from 6m to 11m and the relative errors were within 10% of the measured distances. These error estimates in the Google images were considered reasonable and therefore utilized without any further corrections. Google Earth images were used to identify land use changes in the recent past, from 2003 to 2010, which were then compared with the land use changes since 1964. Also the images were used to identify recent morphological changes within the fluvial system. The land use polygons traced on the images were converted into shape format to enable overlay with other images by using ArcGIS version 10.1. In order to estimate the error on the 2010 images, field measurements were undertaken at five cross-sections across the Khajuri Stream. The comparison between the image and field measured distances indicated that the difference ranged from 6m to 11m and the relative errors were within 10% of the measured distances. These error estimates in the Google images were considered reasonable and therefore utilized without any further corrections.

4. RESULTS AND DISCUSSIONS

4.1 Soil erosion

The erosion rates derived from field measurement is presented in Fig. 2. The figure indicates that landslides had the greatest erosion rate (~26 t ha^{-1} y^{-1}). Sheet erosion and gully erosion rates were 16 t ha^{-1} y^{-1} and 14 t ha^{-1} y^{-1} respectively. Similarly, an erosion rate of 8 t ha^{-1} y^{-1} was estimated from stream bank erosion.

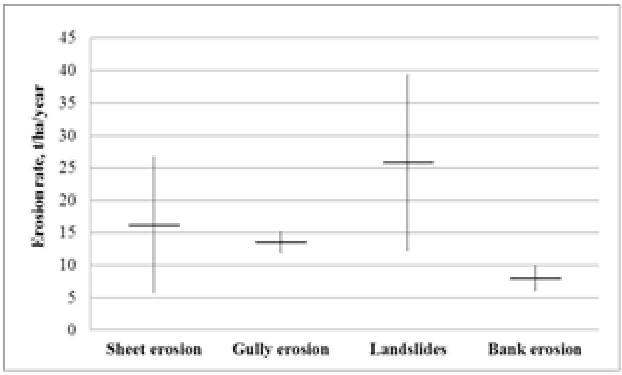

Fig.2 Mean annual erosion rates in the Khajuri catchment. The horizontal bars indicate mean values and the vertical bars indicate 95% confidence limits.

Based on these mean erosion rates, it was estimated that ~64 t ha^{-1} (~5mm y^{-1}) of sediment was being eroded within the catchment annually. In the Middle Mountain region, studies have quantified erosion rates that vary from 1.2 mm y^{-1} to 1.6 mm y^{-1} and where summer monsoon reaches its peak intensity up to 5000 mm y^{-1}, an erosion rate of 5 mm y^{-1} has been reported [*Garzanti et al.,* 2007]. In the Higher Himalaya, some studies reported erosion rates that varied from 0.1 mm y^{-1} to 2 mm y^{-1} [e.g. *Gabet et al.,* 2008]. This suggests that erosion rates of the study area were significantly higher than the rates in the other regions of the Nepal Himalaya.

4.2 Analysis of historical land use change

Four categories of land cover were distinguished: forest, agricultural land, area of settlement and river/stream channels. An analysis of land use change indicated that there was a significant decline in the forest area as a result of increase in agricultural land. The change was significant from 1964 to 2003 (Figure 3).

The forest area declined from circa 76% to circa 49% whilst agricultural land noticeably increased from circa 19 % to 34% during this period. There was also a remarkable increase in settlement from 1964 to 2010. The major trade-off among the land cover types was the conversion of forest into agricultural land which was also evident in other parts of Nepal [e.g. *Bhattarai et al*., 2009]. During the period from 2003 to 2010, however, there was no significant decline in the forest area. There was also a minimal change in the area of the agricultural land during this time. It is also important to note that river channels widened significantly with about twofold increase in the area from 1964 to 2003.

Deforestation was evident as the key issue in the area. There are mainly two reasons of this. First, a cement factory was constructed near the catchment during the late 1980s. Second, a national highway linked the area with the district headquarter- Gaighat and the town of Lahan in the Terai plain. These developments enabled many migrated people from other areas to settle permanently. As a result, there was a significant increase of population which led to an increase in the demand for more timber and firewood from the forest. There was no significant decline in forest area from 2003 to 2010 possibly due to the positive impacts of sustainable forest management such as community forest adopted in the catchment. The success of community forestry policy in preserving forests has been widely reported in Nepal [*Gautam et al*., 2002].

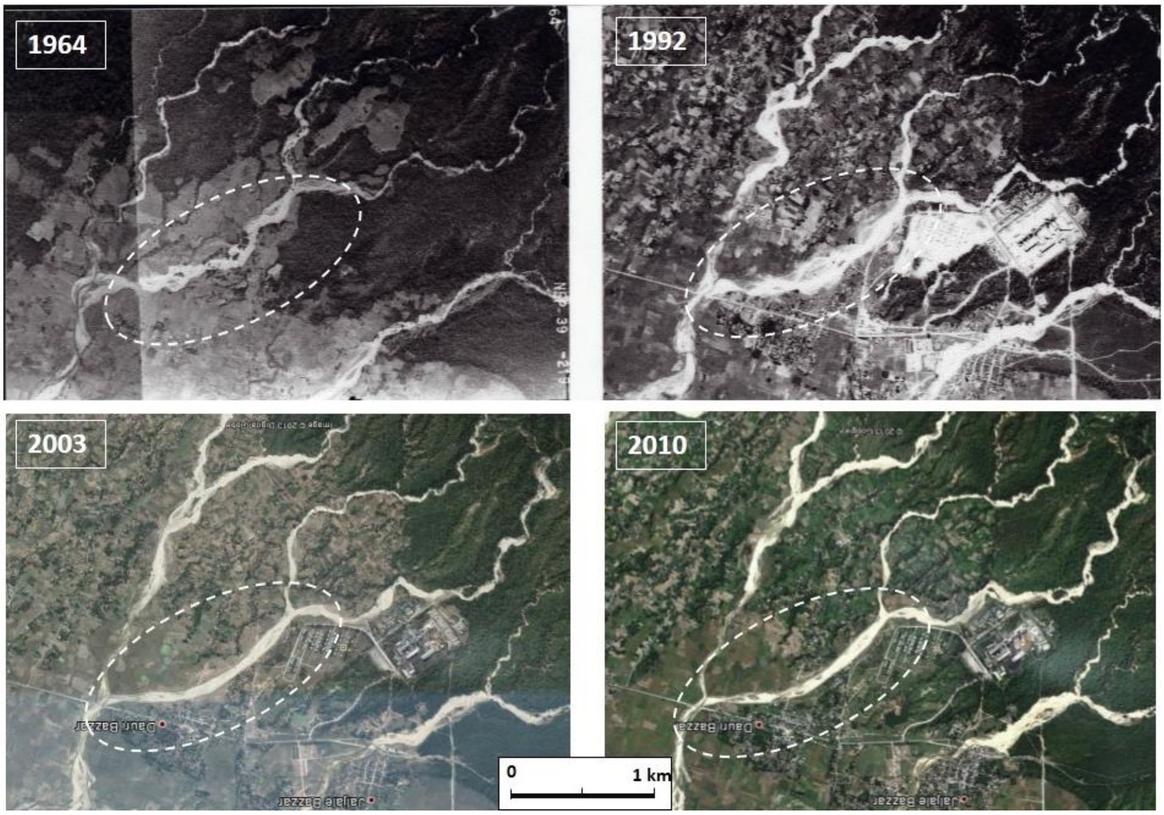

Fig. 3 Time series aerial photographs of the Khajuri catchment and surrounding area. The aerial photos of 1964 and 1992 were obtained from the Department of Survey of Nepal and the 2003 and 2010 images were taken from the Google Earth (Image©2014 DigitalGlobe). The dashed boundary line highlights the main channel of Khajuri Stream.

Fig. 4 Widening of an active channel of Khajuri Stream from 2003 to 2010 traced from Google images.

4.3 Changes in channel morphology

Analysis of the Google images indicated various types of morphological changes from 2003 to 2010 especially within the middle reach (Figure 4). A few abrupt changes in stream planform were also noticed possibly as a result of the catastrophic events, such as a dramatic channel widening in response to a large storm event. Also, several cases of progressive change in channel width were observed which led to many types of morphological changes, for example, a meander growth leading to a meander cut-off (Figure 4). There were also several cases where an active channel course deviated from its normal course resulting in side bank erosion and stream widening. The assessment of the long-term trends showed that the channels had undergone active erosion, alteration of channel flow paths and lateral movement over the last few decades.

The streams were characterized by extremely movable boundaries mostly associated with channel widening and in some occasion complete channel course migration (Figure 5).

Increase in width varied from a few meters up to 300 m. The bed materials were composed of a combination of coarse sand and gravel. The extent and pattern of these morphological changes widely varied both in space and time.

It was evident that significant sediment deposition occurred within the lower reach of the catchment where flood embankments were constructed. The amount of deposition varied spatially across the channel. Up to ~ 0.60 m of deposition had occurred since the construction of the embankments in 1998 (Figure 6).

Fig. 5 A recent occurrence of bank erosion and course widening in the middle reach of Khajuri Stream.

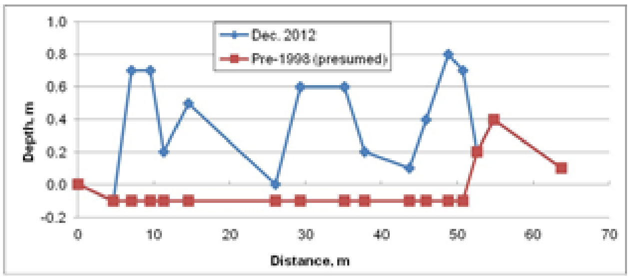

Fig. 6 Change in bed level of Khajuri Stream in the lower reach following the implementation of embankments in 1998. Note that the bed level pre-1998 is approximate and is assumed based on the current level of embankment footprint.

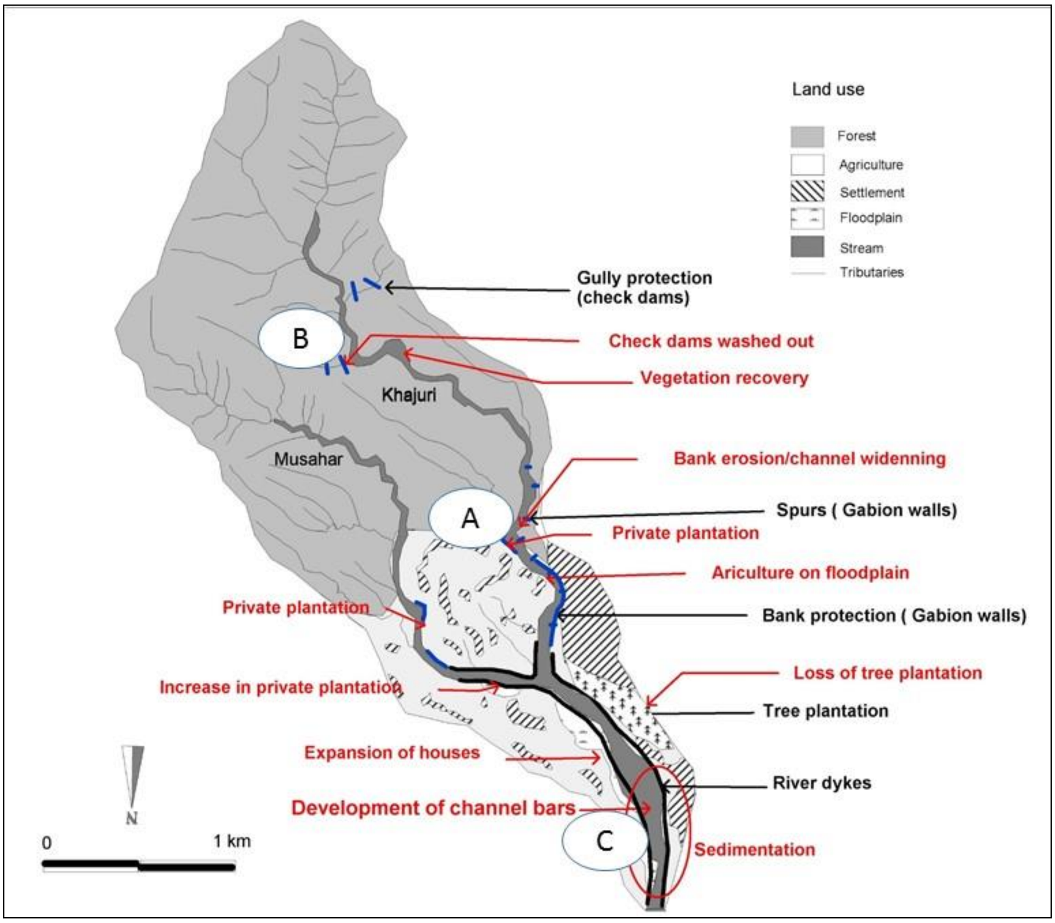

Fig. 7 Adopted erosion and flood control measures and their impacts over the last 13 years of project implementation.

4.4 Impact assessment of erosion control mitigations

Key morphological changes identified in the field as a consequence of these measures are shown in Figure 7. In the upper reach, none of the check dams for gully erosion control which were adopted in early 2000's existed during the 2012 field survey (Location B in Figure 7). Significant channel bed incision (up to ~2m) was noticed along the gully channel bed (Figure 8). It was noticed that these structures could not survive against the incision process on the alluvial cone due to riverbank erosion along the Khajuri stream (Figure 9).

The bank protection measures mostly implemented in the middle reach were found to be very effective in controlling progressive bank erosion of the stratified banks. In the lower reach, gradual sedimentation has led to the stream bed being raised with the risk of flooding across the floodplain.

In addition, several cases of local bank scoring were observed as a result of changing flow paths within the main channel which could damage the embankments.

The embankments with gabion launching aprons to protect against scouring erosion have been well functioning without significant riverbed aggradation and degradation in the upstream half of the Lower reach for 15 years since 1998.

Fig. 8 Failure of a check dam as a result of channel bed incision along a gully channel (Photo: Dec 2012).

Fig. 9 Upper: Alluvial fan of an active gully. Lower: Bank erosion of the alluvial fan by the Khajuri main stream (Photo: Oct 2013).

Fig. 10 Embankment with series of spurs and aprons (Photo: upper; June 1998, lower; Oct 2013)(Location C).

In this segment, the river width was designed same as that of natural river course before the channel works, and the height of the embankment was decided from the discharge designed from the slope-area method and expected rate of riverbed raising within five years based on the interview to local people [*Water induced Disaster Prevention Technical Centre*, 1999] (Figure 10). This positive effect for flood control is possibly due to maintaining the channel width same as the width in natural condition.

5. CONCLUSIONS

This paper presents findings of an evaluation of soil erosion, changes in land use and stream morphology and impacts of various erosion control measures in a degraded catchment of the Siwalik Hill. Deforestation occurred between 1964 and 2003 as a result of expansion of agriculture. On the other hand, no significant changes in forest and agricultural land were noticed from 2003 to 2010. The streams continued to undergo several morphological changes over the entire period between 1964 and 2010 for which historical photographs were available. Recent field monitoring indicated noticeable changes in stream bed level in the lower reach where sediment deposition of up to 0.60 m was observed. Increased bed level has resulted in a potential risk of flood inundation. Key morphological changes in the upper reach included a combination of stream bank erosion, channel bed incision, channel widening and lateral displacement of the active channel. Based on the findings it is suggested that appropriate conservation measures should be implemented to control sediment mobilisation in the upper reaches where key sediment sources such as landslides, gully erosion and surface erosion are located. Focus should be given to landslide stabilization works to reduce sediment supply downstream. Also, maintaining the existing mitigations such as embankments, bank protection walls and spurs and riparian vegetation is equally important.

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