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Original Research Article

Effect of land cover on channel form adjustment of headwater streams in a lateritic belt of West Bengal (India)

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ABSTRACT

Present work is exploring the influence of land cover on channel morphology in 34 headwater catchments of the lateritic belt of West Bengal. Non-parametric tests (Mann-Whitney U and Kruskal-Wallis) and multivariate analysis (Principal Component Analysis and Canonical Discriminant Function models) have successfully differentiated the performance of land cover on channel morphology adjustment among the three groups of headwater streams (forested, transitional, and agricultural) on the Kunur River Basin (KRB). Spatial Interpolation Techniques reveal that intense land-use change, particularly forest conversion to agricultural land, is significantly increasing channel widths (269%) and cross-section area (78%), whereas agricultural channels become shallower (40%) than would be predicted from forested streams. Catchments with the dominance of forest and agricultural land are classified as 'C' and 'B' types of streams respectively, as per Rosgen's Stream Classification Model. Finally, the work claimed that transitional stream group is the definitive area to exaggerate the river restoration plan to stabilize the anthropogenic deformation on channel morphology.

1. Introduction

Management of agricultural rivers, as well as forested rivers is a major research concern to the countries of southeast Asia, when about 94% of the areas suitable for agriculture have already been cultivated (Atapattu & Kodituwakku, 2009; FAO, 2002). To feeding the largest percentage of world population in the southeast area, the century-old practice (i.e. agriculture) is still expanding its coverage with significant deforestation for agricultural land (Atapattu & Kodituwakku, 2009). India lost nearly 7% of its forest cover in last two decades (1990–2010) due to a rapid transformation of land cover by anthropogenic activities (FAO, 2015). Thereby, river basins are considerably losing their canopy cover, and the immediate indirect and/or direct effects have been faced by headwater streams with the input of huge surface runoff and eroded soil. Apart from the deteriorating of river water quality and declining the biodiversity of a river (Alexander, Boyer, Smith, Schwarz, & Moore, 2007; Blann, Anderson, Sands, & Vondracek, 2009), expansion of agricultural land in the forested area may also significantly contribute to change the channel morphology of headwater streams (Lester & Boulton, 2008). From example, more than 98% of the North American prairie and vast areas of forest have been replaced with croplands under modern agricultural systems, which have been associated with extensive modifications to natural drainage networks (Blann et al., 2009).

Headwater streams (first order and second order streams, after Strahler, 1957) are generally recognized as major external links within the river system (Fritz, Johnson, & Walters, 2008) with contributing > 90% of catchment stream flow (Deschamps, Pinay, & Naiman, 1999; McIntosh & Laffan, 2005) and represents 50–70% of total stream length within a river basin (Leopold, Wolman, & Miller, 1964; Meyer & Wallace, 2001; Nadeau & Rains, 2007). According to McMahon and Finlayson (2003), headwater streams are more prone to natural drying than are downstream segments because they have smaller drainage areas with less recharge potential and higher topographic elevations. In addition due to drain over impermeable land with small source area than large rivers, headwater streams cannot maintain their base-flows for lower storage capacity (Burt, 1992). However, forested headwater streams are hydrologically as well as geomorphologically more stable than agricultural streams due to higher retention capacity, larger lag-time, lower discharge, less sediment and stable bank slope (Ruprecht & Schofield, 1991).

Since the expansion of human civilization, effect of land use – land covers change (especially deforestation for croplands) becomes a major research issue in fluvial geomorphology (Wang, Liu,

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Kubota, & Chen, 2007), due to significant influences on the alteration of chemical and biological characteristics of river water (Garman & Moring, 1991; Mullen & Moring, 1988; Schnitzler, 1997), basin hydrology (Harden, 2006; Hewlett & Helvey, 1970; Nagasaka & Nakamura, 1999; Zabaleta & Antiguedad, 2013), and sediment supply (Ausseil & Dymond, 2008; Dunne, 1979; Golosov, 2006; Restrepo & Syvitski, 2006; Vorosmartry et al., 2003). However, the effect of deforestation on the deformation in channel structure still needs more attention from fluvial geomorphologists.

Hack and Goodlett (1960) had reported the relationship between vegetation, topography and hydrological processes. Zimmerman, Goodlett, and Comer (1967) documented the influence of vegetation in the channel form of small streams. Wolman (1967) in a diagram represents a correlation between the land cover type, river channel condition and sediment yield within a river basin, wherein forested land cover makes channel stable but with the transformation of forest cover channel conditions have also altered significantly. The effects of land use – land cover change on the in-stream bar formation (Begueria et al., 2006; Hickin, 1984), channel planform (McKenney, Jacobson, & Wetheimer, 1995), channel side slope (Allan et al., 2002), migration rate of river meander (Begueria et al., 2006; Micheli, Kirchner, & Larsen, 2004), channel width (Gurnell, 1997; Harden, 2006; Sweeney et al., 2004), shape of the channel (Shepherd, Dixon, Davis, & Feinstein, 2011) have been well studied across the world.

The prime objective of our study is to explore how the catchment level variation in land cover may affect the channel morphology. The main comparison is among the forested, transitional, and agricultural headwater streams on the lateritic belt of Ajay-Damodar Interfluve or Kunur River Basin in particular. The study has hypothesized that forested headwater streams with the least amount of anthropogenic impact will generate a lower volume of discharge with greater sinuosity and width – depth ratio. As the land use shifts from dense forest to degraded forest to agricultural land with an associated increase of anthropogenic pressure, the volume of discharge will increase, width – depth ratio will decrease, and sinuosity will approach straightness.

2. Materials and methods

2.1. Description of study sites

A total 34 sub-basins (SBs) of the headwater streams have been studied throughout the lateritic belt of Ajay-Damodar Interfluve, which administratively comes under the Barddhaman District of West Bengal, India (Fig. 1). In Q-GIS, online mapping tool has been enabled to extract land cover characteristics of all 34 micro-watersheds after opening the recent view of Google Earth. Multilayer GIS analysis helps to delineate the boundaries of selected sub-basins using ASTER GDEM (30 m), Topographical Sheets of Survey of India (1: 50, 000), Google Earth View. In dense forest area, field mapping using GPS has been used to track the basin coverage. The area of sub-basins varies from 0.23 to 18.67 km^2 and the range does not follow the normal distribution with the Skewness of 1.84 (SE 0.41) and Kurtosis of 2.71 (SE 0.79). The sub-basins are intentionally selected from single geological lithotop to exclude the effect of varying geology among the study sites. Geologically, the focused area is covered by the Cenozoic laterite of Lalgarh formation, an oldest formation consists of reddish brown latosol with iron-nodules (disintegrated duricrust) underlain the lateritic hard pan and lithomarge clay parts having light pinkish white sandy clay with few quantities of iron nodules (Roy & Banerjee, 1990). Soil type is predominantly sandy-loam and facing the problem of severe soil erosion in the form of rills and gullies (Roy, 2013).

The climate of the region is typical humid subtropical and influenced by monsoon-fed rain. Annual average rainfall observed is 1380 mm and mean temperature is 25.8° C in the last 100 years, where about 70–80% rainfall is falling from June to September only (IMD, 2014). Studied streams are ephemeral in nature and contain water only during the rainy season and no woody debris has been observed in these streams. Sites are numbered randomly within the Kunur River Basin, a major right-bank sub-basin of the lower Ajay River Basin. The Kunur River originates in the western upland of the district at about 100 m of altitude, flowing latitudinally from west to east for a length of ~114 km. There, elevation ranges from 20 to 131 m throughout the basin. The drainage pattern is nearly dendritic and catchment extends over an area of about 915.60 km^2, having an elongated and asymmetrical shape.

The basin has a forest cover (mainly wet deciduous type with Sal species - *Shorea robusta*) spreading over almost 31.35% area, water body holds around 10.35% area, 13.82% area is for human settlement, 41.74% for agricultural land and 2.73% area comes under barren land or unsuitable areas for agriculture (Roy & Sahu, 2015). The region is also facing huge anthropogenic pressure due to very high population density about 1100 person/km^2, where nearly 58% of populations are still engaged in the agricultural sector (Census of India, 2011). Single cropping system is basically following over the district with 64.74% of net sown area and *Kharif* rice as the principal crop type (Neetu, Prashanani, Singh, Joshi, & Ray, 2014).

2.2. Procedures to collect the information of channel geometry

Several intrinsic channel parameters (i.e., w – channel width; d – average depth; D – maximum depth; ER – entrenchment ratio; s – slope; a – cross-section area; w/d – width-depth ratio; Q – bankfull discharge capacity; SI – sinuosity index; τ_0 - shear stress and ω - unit stream power) have been computed from each sub-basin. All channel cross-sections and longitudinal profiles were surveyed using Auto level (Sokkia C410 – with 2.5 mm standard deviation for one km double run leveling) followed by the standard protocols of VDFW (2009). Bankfull indicators have been preferred for cross-section survey across the riffle area. A total 40X length of bankfull channel width has been selected for sinuosity index (SI) of all sample sub-basins. Visual to quasi-quantitative interpretation have been also done to analysis reach wise variation in channel conditions, such as bed materials, pool – riffle distances, area of the pool etc. Bankfull discharge, stream power and shear stress values have been estimated from the survey data to aid the analysis of stream form and processes. The Manning's equation (Eq. (1)) has been followed to calculate reach wise stream velocity (v) (m/s) and associated discharge (m^3/s). Reach wise shear stresses (τ_0) (N m^{-2}) and unit stream powers (ω) (W m^{-2}) are also estimated using the Eqs. (2) and (3), respectively (Shepherd et al., 2011).

$$v = (1/n)R^{2/3}s^{1/2} \text{ and } Q = (v \times a) \tag{1}$$

where, v is velocity, n is the roughness coefficient, R is the hydraulic radius, s is channel slope, Q is discharge and a is channel cross-section area.

$$\tau_0 = \gamma_w Rs \tag{2}$$

where, τ_0 is shear stress and γ_w is specific weight of water.

$$\omega = \gamma_w Q\, s/w \tag{3}$$

where, Q is discharge and w is channel width.