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An insight into the runoff generation processes in wet sub-tropics: Field evidences from a vegetated hillslope plot

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ABSTRACT

Understanding the physical processes of runoff generation from vegetated hillslopes in wet tropics and sub-tropics is critical for rainfall–runoff modelling. Limited field data often lead to poor process conceptualisation in hydrological models. Plot-scale runoff experiments are popularly used to characterise the runoff generation processes in hillslopes. In this study a vegetated hillslope plot, which typically represented the dominating soil and land cover class of the undisturbed natural hillslopes of north-east India, was selected to conduct runoff simulation experiments and to monitor rainfall–runoff processes over a long period of time (2005–2011). The empirical relationships representing the infiltration and surface runoff generation characteristics of the plot were evaluated for temporal deviations. Temporal vegetation dynamics of the plot showed significant control over the runoff generation processes. The natural rainfall–runoff response and measured soil moisture profile of the hillslope plot indicated strong threshold driven mechanism of runoff generation. The majority of storm runoff from the hillslope plot occurred through the subsurface route. Surface runoff events were rare and showed very low runoff coefficients. Rainfall depth, duration, maximum intensity, and antecedent soil moisture conditions primarily controlled the hillslope runoff response. The probability of runoff generation under wet antecedent conditions was high. The rainfall excess hydrographs predicted using the experimentally established empirical function for the hillslope plot compared well with the observed hydrographs only under similar wet antecedent soil moisture conditions.

1. Introduction

Conceptualising the physical process of runoff generation is the primary interest of the hydrologists working in different parts of the world. The factors which predominantly affect the runoff generation process are rainfall characteristics, topography, soil, land use and land cover, antecedent moisture condition, and infiltration. However, the rainfall–runoff relationships often show wide range of spatial and temporal variations. The complex interactions between the controlling parameters often lead to critical issues like accelerated overland flow generation, soil erosion and sedimentation, landslides, and flash flood in rivers. In order to develop physical understanding of the runoff generation processes several experimental investigations have been conducted under diverse physical and hydro-geologic conditions around the world. These experiments were usually conducted with different field or laboratory set-ups at varying spatial scales. Not only different hydrologic processes may be dominant at different spatial scales, but also the overall heterogeneity within a watershed can have significant impact on runoff generation at the catchment scale (Sharma et al., 1980; Negi, 2001). Therefore, as a prerequisite of watershed scale investigations, plot-scale studies are often conducted to evaluate the rainfall–runoff processes with better control over the controlling variables.

Runoff plot experiments have been used popularly to study runoff and/or sediment losses from different field sites in Himalayan and Sub-Himalayan regions (Singh et al., 1983; Negi et al., 1998; Sarkar et al., 2008a; Sarkar and Dutta, 2012). Yu et al. (1997) studied plot-scale rainfall–runoff characteristics at six sites in the tropical and sub-tropical regions of Australia and Southeast Asia. Wainwright et al. (2000) performed plot-scale (1 m^2 to 500 m^2) rainfall simulation experiments under different vegetation conditions in Southwest America. Their study stressed on the fact that plot-scale experiments allow better definition of the controlling factors and improves the understanding of complex hydrological systems. However, the need of comparing the experimental data with natural observations was emphasised. Holden and Burt (2002) simulated low intensity rainfall events (3–12 mm/h) on field plots to study infiltration and runoff generation processes. It was reported that rainfall–runoff responses from small plots varied with season. Sharpley and Kleinman (2003) performed plot-scale rainfall simulation experiments on 2 m^2 and 32.6 m^2 plots to investigate overland flow and phosphorus transport. Lane et al. (2004) performed large-scale rainfall simulation experiments on altered hillslopes of

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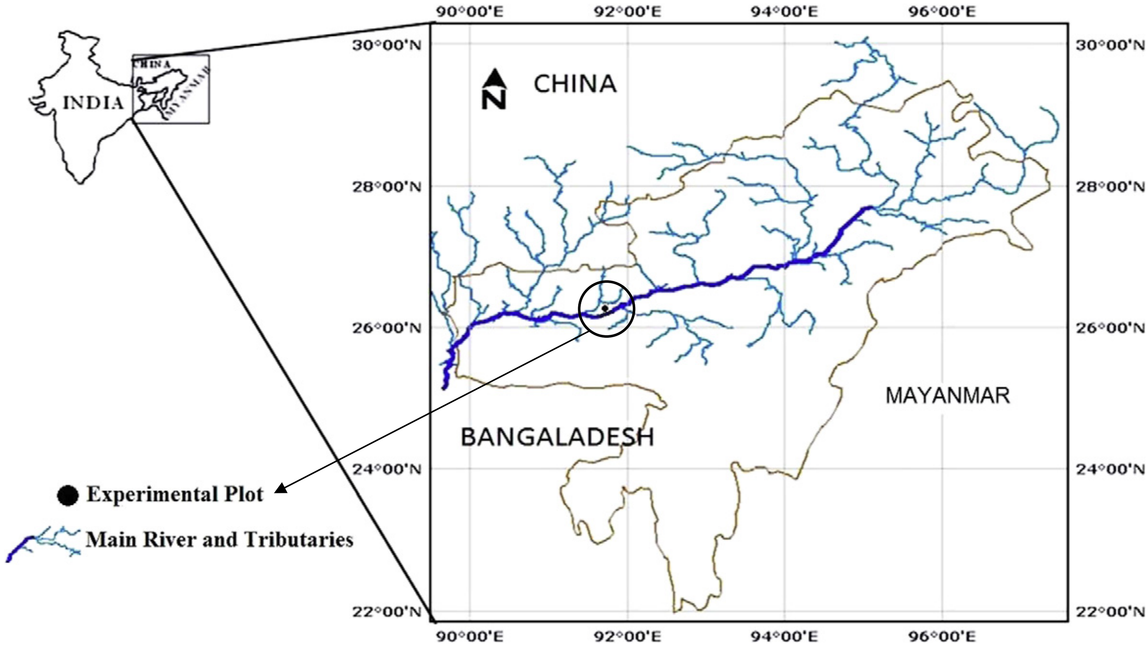

Fig. 1. Location of the experimental hillslope plot in the Brahmaputra river basin.

Australia to study the effect of antecedent moisture conditions on surface and subsurface runoff generation mechanisms. Puigdefábregas (2005) studied the role of vegetation on runoff and sediment fluxes by conducting rainfall simulation experiments on large plots. Schmocker-Fackel et al. (2007) used rainfall simulators to perform plot-scale sprinkling experiments for characterising the runoff processes. Leys et al. (2010) studied the effect of scale on runoff generation and soil erosion on hillslope plots using an inflow–outflow method. The experimental data were used to model the effect of transmission losses on runoff and erosion. Mügler et al. (2011) investigated overland flow characteristics on a 10 m × 4 m plot using a rainfall simulation system. Garel et al. (2012) performed large scale rainfall simulation experiments on a 100 m^2 hillslope plot in south-east France with low rainfall intensity (10 mm/h) for a long duration (66.4 h) to study the infiltration and runoff processes.

The study of available literature shows that plot-scale rainfall–runoff experiments have been used popularly to investigate different aspects related to infiltration, overland flow, soil erosion, chemical transport, and subsurface flow. Most of the experimental set-ups used either rainfall simulators or inflow–outflow methods for evaluation of plot-scale hydrologic responses. These observations are often a prerequisite to developing any regional hydrological model. The humid subtropical region of northeast India is rich in land and water resources. The hydrology of the region is a part of the mighty Brahmaputra river system. However, severe constraints related to field data availability on runoff generation process is a matter of concern for the hydrologists. In fact, no systematic primary data describing the rainfall–runoff mechanisms from these vast vegetated hillslopes of the region are available. The primary objective of this investigation was to capture and analyse field level hydrologic data on runoff generation from an ungauged vegetated hillslope which typically represented the dominating soil and land cover class of the region. As social and political issues often limit the access to the remote locations of the region for primary data collection from multiple locations, efforts were made to systematically collect and analyse detailed data from the selected hillslope plot over a reasonably long time frame (2005–2011). These observations should help to explain the hitherto unexplored dominating runoff generation processes from the hillslopes of the region. As part of this, the results of the

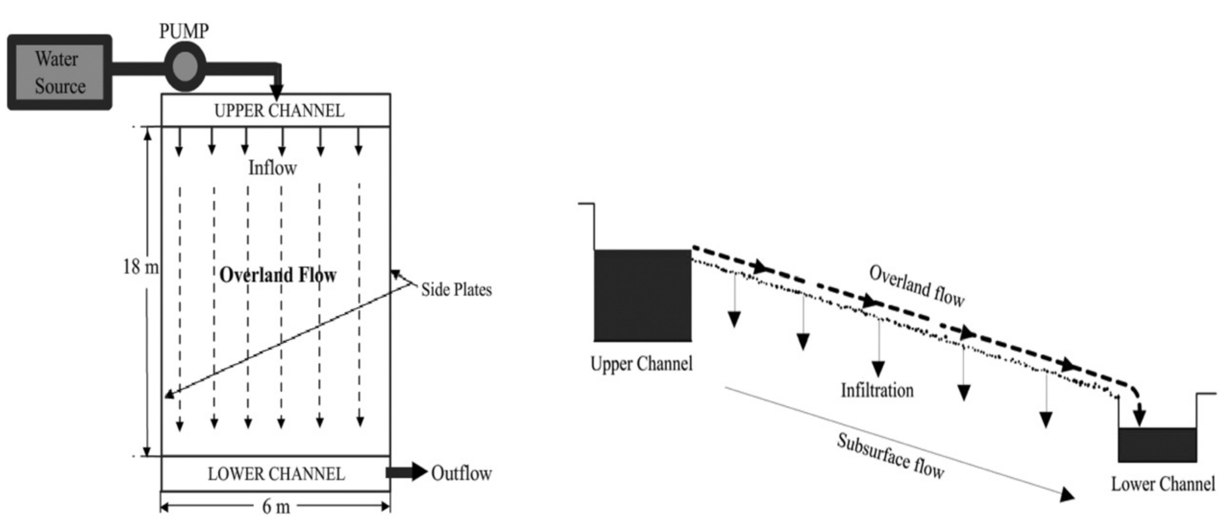

Fig. 2. The runoff simulation system used in the hillslope plot.