Available online at www.elixirpublishers.com (Elixir International Journal)

Geoscience

Elixir Geoscience 69 (2014) 23293-23297

ISSN: 2229-712X

Gully Erosion Control: Lateritic Soil Region of West Bengal (India)

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ARTICLE INFO

Article history:

Received: 28 October 2013;

Received in revised form: 29 March 2014;

Accepted: 17 April 2014;

Keywords

Rill-gully erosion,

Vegetation cover,

Check dam.

ABSTRACT

A study in gully erosion management on lateritic soil is a critical issue in West Bengal. In this paper, we have used field plots data, in combination with vegetation and check dams, for all aspects of lateritic soil erosion management. A program for controlling gully erosion was carried out in Rangamati in lateritic soil region of western part of West Bengal from 2011 to 2012 include two approaches “Check dam” and “Vegetation cover”. Results indicated that at the initial stage, the percent of sand was maximum in the upper catchment of each gully basin and the concentration of silt and clay is less. Gradually as vegetation starts trapping the sediment composition of soil changes registering higher percentage of finer particles. Again, the nutrients detached from the upper catchment were arrested by check dams that induced nutrients supply and water storage, which in turn, increased the growth of vegetation. This result proved the significance of vegetation cover with check dams to curb soil erosion and it may help the planners and managers to take proper decision for the conservation of lateritic soil.

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Introduction

Soil is the most fundamental and basic resource, provides that food, feed, fuel, and fiber. It underpins food security and environmental quality, both essential to human existence. Essentiality of soil to human well-being is often not realized until the production of food drops or is jeopardize when the soil is severely eroded or degraded to the level that is loses it inherent resilience (Blanco and Lal, 2008).

Soil erosion by water is a complex mechanism which depends on various land-use, weather, hydrology, topographic and soil properties. The combination of these factors dictates the rates at which sediment detachment, transport and subsequence deposition (Meyer and Wischmeier, 1969). Soil detachment and transport system involves following four processes (Fig 1) (Kinnell, 2006):

Raindrop Detachment with transport by Raindrop Splash (RD-ST)

Raindrop Detachment with transport by Raindrop-Induced Flow Transport (RS-RIFT)

Raindrop Detachment with transport by Flow (RD-FT)

Flow Detachment with transport by Flow (FD-FT)

Raindrop Detachment with transport by Raindrop Splash (RD-ST) is the system that operates in what is commonly known as splash erosion (Fig 2). Raindrop Detachment with transport (RIFT) is a process where each drop impact causes soil particles to saltate underwater. Each drop impact causes soil material to be lifted into the flow and settle back to the bed some distance downstream. Flow transport (FT) occurs when loose particles travel with the flow without the aid of raindrop impact. Whether a particle detached by raindrop impact (RD) is transported by RIFT or FT depends on its size, density and the flow conditions.

Rill erosion is dominated by Flow Detachment with transport by Flow (FD-FT). The RD-ST, RD-RIFT, RD-FT and FD-FT systems are operating on upland area and upper catchments (Fig 3) where sediment discharge is largely by flow (Shit *et al.*, 2012). Hence, runoff is a factor in determining soil loss. Soil eroded from exposed upland areas near the watershed divide is from both rill and Interrill areas. Interrill areas extend between small channelised flows or rills (Fig 4).

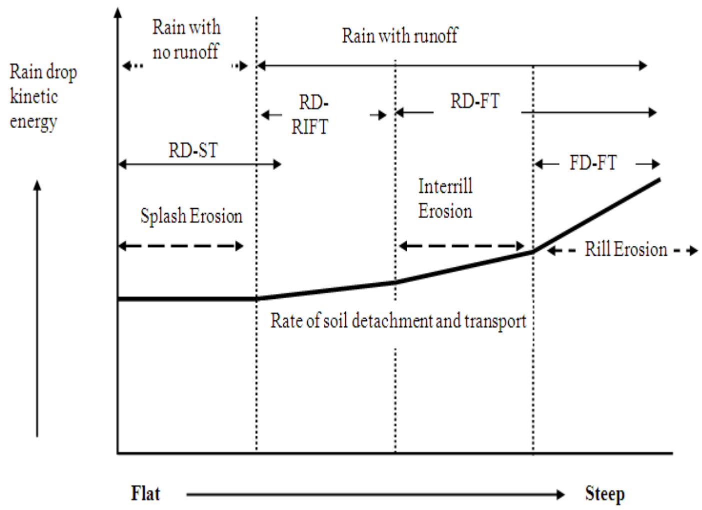

Figure 1. Detachment and transport of soil (After Kinnell, 2006)

Figure 2. Raindrop erosion

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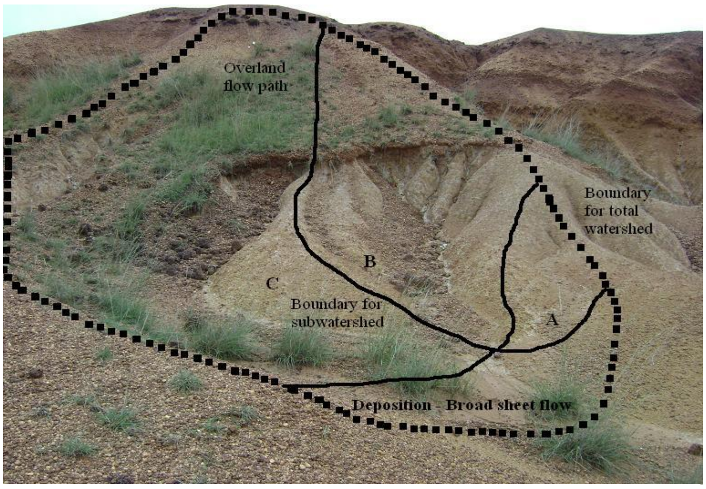

Figure 3. Simple and noted hierarchy watershed or catchments area (A and C is 1st order channel, B is 2nd order channel)

Interrill erosion occurs in those areas where flow is shallow overland or sheet flow and detachment forces are primarily from raindrop energy impacting on exposed soil. Interrill erosion is thus relatively independedent of slope gradient and slope length, after sufficient distance downslope to generate enough runoff to transport eroded sediment (Poesen *et al.*, 2003; shit *et al.*, 2012 , 2013). Because, interrill transport capacity from downslope splash and from overland flow increases slightly with slope. Interrill erosion on the other hand, is a linear function of slope steepness and slope length. Since, rill detachment results from shearing forces of concentrated flow, increasing runoff depth and velocity will cause an increase in rill erosion. Rills are generally parallel on a slope, with uniform spacing and dimension (Fig 4)

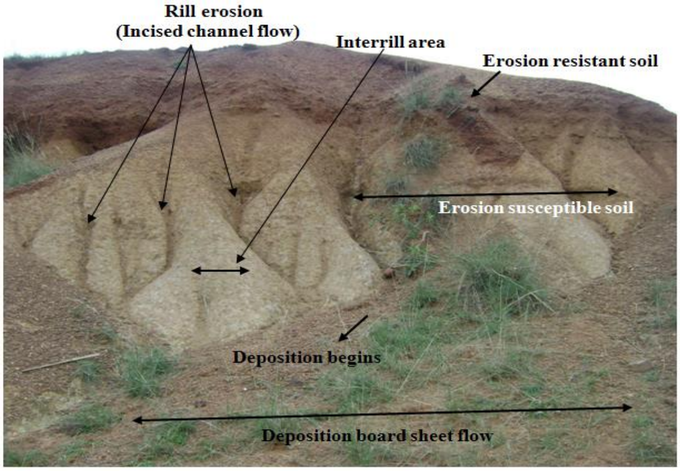

Figure 4. Intense rill erosion on basin area

Rill erosion occurs when flow is concentrated in microrelief channels with sufficient depth and slope to cause channel incision (Fig 5). Gully erosion, the removal of soil from narrow channels via the accumulation of surface runoff, tends to produce more sediment loss than other forms of soil erosion such as overland flow or rilling (Wasson et al., 2002; Poesen *et al.*, 2003; De Vente *et al.*, 2005; Huon *et al.*, 2005; Wells *et al.*, 2009; Shit *et al.*, 2012). Gullies are generally defined by their channel depth, which for permanent gullies can range from 0.5 to 30 m (Soil Science Society of America, 2001).

Deposition of sediment can happen anywhere down slope of the point of erosion, occurring when transport capacity of the flow is less than soil available for transport. Since transport capacity is a monotonic function of flow velocity, anything that reduces velocity in a flow segment increase deposition. Vegetal filter, terrace channels and check dams are examples of sediment control practices that reduce velocity and increase deposition (Fig 6). Components of soil erosion and deposition process are interrelated as shown in figure 6. Soil available for transport at any slope segment is the sum of that carried from upslope plus that detached in the slope increment.

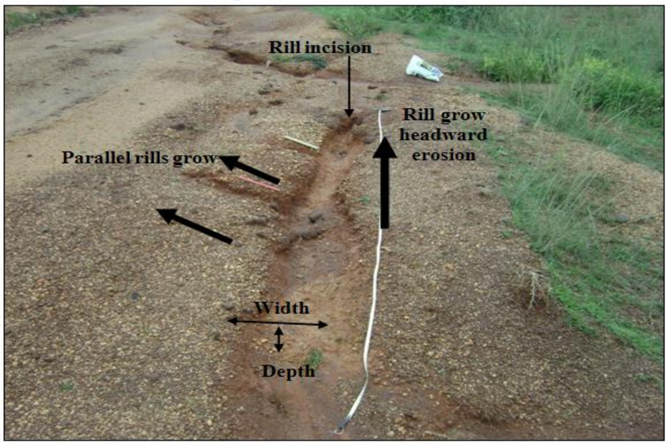

Figure 5. Rills Development during rainy season at Rangamati (July, 2012, width 12 cm and 6 cm depth)

Rill-gully erosion plays a crucial role in soil erosion process; inflicts multiple and serious damages in managed ecosystems such as crops, pastures, or forests as well as in natural ecosystems (Zuazo *et al.*, 2006; Zuazo and Pleguezuelo 2008). Tropical badlands are affected by concentrated flow erosion along intensively spread rills and gullies. Soil or land degradation through rill-gully erosion is studied with increasing attention by geographers specially geomorphologists and soil scientists. Accelerated rate of soil erosion through rill-gully is a serious endemic long term environmental problem in the humid tropical, subtropical, and temperate region (Singh, 2002). Increased rate of erosion affected by human activities through land use changes is defined as accelerated erosion (Singh, 2002). Rills and gullies are developed due to concentrated flow erosion, resulting the detachment and displacement of top soil particles (Fig 8) (Govers *et al.*, 1991, 2007).

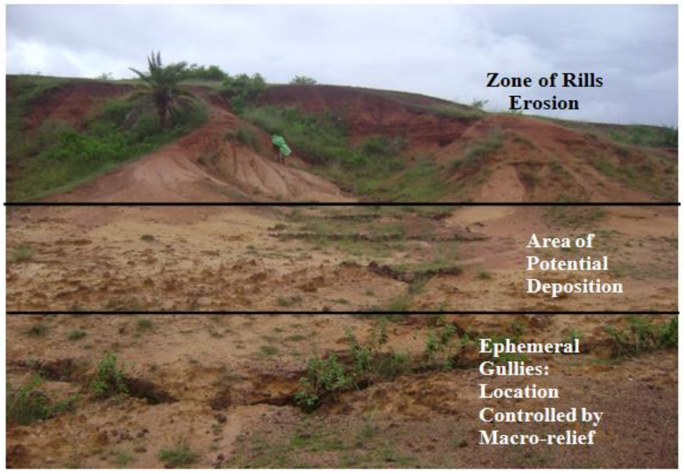

Figure 6. Illustration of rills and ephemeral gullies

Gully erosion: soil loss and sediment production

The soil loss involves the processes of (i) loosening and detachment of soil particles from the soil mass through the process of rilling, and gullying, (ii) removal and transport of eroded soils downslope and downstream by overland flow, and soil slumping under the impact of increased volume of detached soils (Singh and Dubey, 2002). Gully erosion is one of the forms of accelerating soil erosion. Its occurrence often indicates an extreme form of land degradation warranting special attention (Daba *et al.*, 2003).

Figure 7. Rill gully development through concentrated flow (i.e rill-gully erosion) and sediment production

Soil loss rates by gully erosion may represent more than half of the total sediment yield caused by water erosion (Valentin *et al.,* 2005). The contributions of gully erosion to overall soil loss and sediment production are varied in various temporal and spatial scales and under different climatic condition and land use pattern. Poesen *et al.*, (2003) shows that in different parts of the world rates of soil loss by gully erosion represent from minimal 10% up to 94% of total sediment yield caused by water erosion. Land degradation through rill-gully erosion is studied with increasing attention from geographers specially geomorphologists and soil scientists in India as well as in abroad in a situation where 53% (175 M.ha.) of India's geographical area is subjected to environmental degradation, of which, 150 M.ha. is experiencing soil erosion by either water or wind (Ministry of Agriculture, Govt. of India, 2000). Gullies have attracted considerable scientific attention from geomorpholgists, because they provide the most ideal geomorphic situation for understanding the evolution of landforms and drainage, for three reasons (Bryan and Yair, 1982):

- The gullies and the associated badlands develop rapidly, facilitating monitoring.
- The gullies are analogous to the large river systems except in scale; and represent the river system in the juvenile stage, and
- The geomorphic processes are relatively simple and thus easy to understand.

Table 1. Problems of soil erosion and land degradation in India

Sl No.	*Particulars or descriptions*	*With 1981-82 land utilization statistics and report till 1996-97 (area, million hectors)*
1	Geographical area	328.78
2	Area subject to water and wind erosion	144.12
3	Area degraded through special problems	29.52
	Water logged area	8.53
	Alkali soils	3.88
	Acid soils	4.50
	Saline soil including coastal sandy areas	5.50
	Rills, gullies and Ravines erosion	3.97
	Area subject to shifting cultivation	4.91
	Riverine and torrents	2.73

Source: Ministry of Agriculture, Govt. of India, 2000.

Rill-Gully Erosion: Geo-Environmental Problem in India

In India, approximately 4 million hectare area is affected by rills and gullies (Sharda *et al.*, 2007) (Table 1). The Ministry of Agriculture, Govt. of India (2000) reported that, the Indian 12 states most seriously affected by rill, gully and ravine erosion are Uttar Pradesh (12.30 lakh ha), Madhya Pradesh (6.82 lakh ha), Bihar (6.00 lakh ha), Rajasthan (4.52 lakh ha), Gujarat (4.00 lakh ha), Panjab (1.20 lakh ha), Orissa (1.13 lakh ha), and West Bengal (1.04 lakh ha).

In West Bengal, about 14% of the area is affected by water erosion, of which Puruliya is affected to the extent of 328 thousand ha, followed by West Medinipur (218 thousand ha), Bankura (199 thousand ha), Koch Bihar (174 thousand ha) and Jalpaiguri (132 thousand ha) (Pandey *et al.,* 2011) (Fig 8).

The aim of this paper is to explore the current erosion–vegetation dynamics, examine the processes involved and to control the erosion. Secondly, to evaluate check dams for control/reduced the gully erosion in the gully basin area.

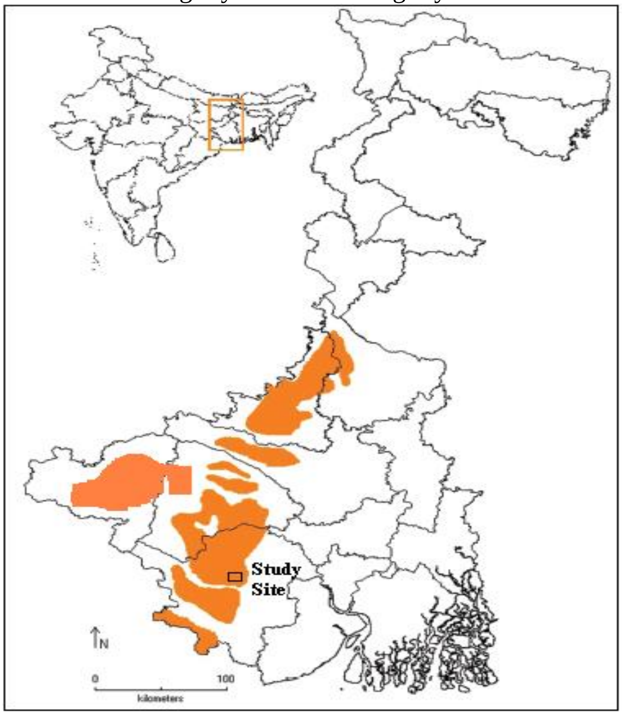

Figure 8. Lateritic region of West Bengal, India

Material and Methods

Study Area

Our study area is a hot dry sub-humid agro-ecological sub-region comprising the fringes of Chotonagpur Plateau and includes the district of southern parts of Bankura, and Medinipur. It covers an area of about 0.87 million ha representing 13 per cent of the total area of the state of West Bengal, India. Geomorphologically, the area is associated with the eastern plateau fringe of Chotonagpur. It is the lateritic interfluves portion of Darakeswar, Silai and Kasai rivers. This area is most affected by surface runoff, (i.e. rills, gullies and badland topography) and soil erosion. The land surface in this region is characterized by hard rock uplands, lateritic covered area, and flat alluvial and deltaic plains. Extremely rugged topography is seen in the western part of the region and rolling topography is experienced consisting of lateritic covered area. These rolling plains gradually merge into flat alluvial and deltaic plains to the east and south east of the region.

The regional climate is characterized by cold and dry winters and warm and humid summers. The average daily maximum temperature is 35°C in the summer, and the daily minimum temperature is 16°C in the winter. The mean annual rainfall is about 1,500 mm, of which more than 70% of the rainfall occurs from June to September (Jha *et al.*, 2009). The soils have developed on parent materials of sedentary nature. They vary from shallow to deep reddish to yellowish red, loamy to clayey and are imperfectly to well drain. The soil of the lateritic region is characterised by nutrient-poor acidic (pH 5–6.4) sandy loam, clay loam to sandy clay loam with varying levels of sand(48.3–85%), silt (2–28.3%), clay (10.1–29.1%) and organic carbon (0.21–9.89%) (Ghosh and Maji, 2011; Pradhan *et al*, 2012 and 2013).

Relatively less aggregated red and laterite soils are prone to frequent development of surface encrustation. Poor capacity for retention of rainwater leads to severe runoff and soil loss (Shit *et al.*, 2013). The seasonal fluctuations of temperature and humidity have a great impact on laterisation processes and badland development over the study area (Sen *et al.*, 2004).

Experimental design

Two small gully catchment (with vegetation and with check dams) areas were monitored during January, 2012 to September, 2012. In December, 2011 constructed two collectors through partial flume for sediment and runoff collectors, at mouth of the gully basin (Figure 9 and11). Runoff volumes are influenced primarily by the total amount of rainfall. However, runoff rates resulting from a given rainfall, including peak rate or discharge, are influenced primarily by the rainfall's distribution, which is how the rainfall rate or intensity varies over a period of time. A rainfall may be evenly distributed over a time period or can vary widely within that same period. These different types of rain events can produce extremely different runoff volumes and peak discharges. Water level is recorded through the scale in the gully catchment area. Sediment yield and runoff was measured at the outlet of each gullied catchment area after each runoff producing rainfall events by ngalvanized metal sheets. During the monitoring period the soil loss were collected and measured after each rainfall event. The climatic data were taken from a Medinipur meteorological station and self-recording raingague in the field during the study period.

Result and Discussion

Vegetation Cover

The vegetation cover approach was adopted regarding gully erosion. *Eragrostis cynosuroides* grass and others grasses were planted on the bank and bottom of the gully. Now gully basin-I (Fig 9) is covered with *Eragrostis cynosuroides* grass and some wild species, in the study area and we began to measure it in 2010, the average gully erosion rate decreased about 25% after the vegetation cover. Generally the vegetation cover approach seems has good effect to control gully erosion. However, the gully headcut retreat is not control vegetation cover. The high rate of headcut retreat may be covered by waterfall effect (Fig 10), which scours the soil where it lands, leads soil at this part to be eroded away, leaving the top soil overhanging. The top soils lose the support force from the bottom and tend to collapse.

Figure 9. Vegetation covers of Gully Basin-II, at Rangamati, Paschim Medinipur

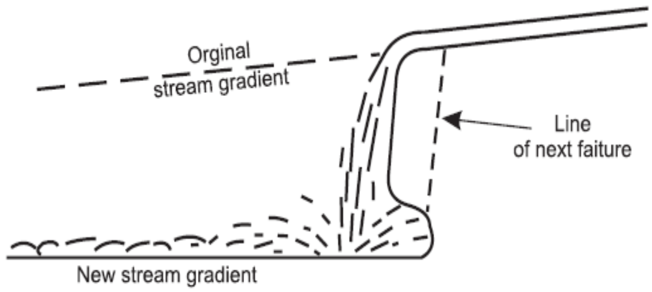

Figure 10. Waterfall effect at gully head

Check-dams

Check-dams in the study area have played an extremely imperative role in dropping sediment yield by trapping sediment and minimizing the frequency and intensity of soil loss (Fig 11). Furthermore, in case of sediment trapping, check-dams lowered the sediment yield by reducing the frequency and intensity of hyper-concentration flows and by reducing soil erosion in gullies through raising their erosion base level. To attain a high preservation of fine sediments it is suggested that porous check dams are assembled towards the lower catchment sections rather than in upper catchment sections. And, the construction of check dams in the study area may also aid to increase the soil fertility that helps to grow the vegetation in the nearby region.

Figure 11. Check dams constructed across the gully of basin area

Conclusion

Our results also suggest that vegetation coverage played significant role on the sediment volume in the study area, while rainfall volume showed negative association. In contrast, the percentage of sediment trapped by the vegetation is highest in the lower catchment of gully basin area and is lowest in the upper catchment area. Consequently, the growth of vegetation coverage is also very important factor in the lower catchment areas by increasing the soil nutrient contents through sediment trapping by check dam construction. Vegetation coverage is effective in filtering sediment from surface runoff. This also substantiates the good recital, in terms of retention of fine sediments through vegetation coverage in the lower catchment areas.

However, the present work is highly relevant in the context of degradation of land resource and to increase productivity by retaining as well as increasing quality of land. There is increasing awareness of the need to protect our natural environment in order to meet present and future requirements. In this circumstance, the intensive study on the mechanism of rill-gully erosion with spatio-temporal variation is necessary for remedial measures of rills and gullies erosion. The function of check-dams in soil conservation measures should be remunerated ample concentration in the future. It is essential to fortify construction and management of check-dams for preserving and even promoting their sediment trapping capacity and reducing the frequency of high sediment yield in lateritic badland topography.

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