



# Effects of Grass on Runoff and Gully Bed Erosion: Concentrated Flow Experiment **13**

Pravat Kumar Shit, Hamid Reza Pourghasemi, and Gouri Sankar Bhunia

## Abstract

Soil detachment by overland flow has mainly been studied using small samples with smooth surfaces. However, the inner mechanism for this process remains unclear. In the present chapter, an experimental study was conducted to evaluate the role of vegetation buffer strips on concentrated flow hydraulics and gully bed erosion downstream on gully headcuts. Six gully beds were selected for simulation runoff experiments, with an average vegetation cover of buffer strips of approximately 67%. The flow scouring tests on each gully bed lasted 60 min with a flow discharge of  $78.5 \text{ l min}^{-1}$ . Hydraulic parameters were calculated, including Reynolds number ( $Re$ ), Froude number ( $Fr$ ), hydraulic shear stress ( $\tau$ ), Manning roughness coefficient ( $N$ ), and Darcy-Weisbach friction factor ( $f$ ). Runoff samples were collected at the bottom part of each gully bed using a 0.5-l plastic bottle during the simulated runoff at 5-min intervals. The average parameter values for the vegetated buffer strips varied between 35% and 50%, which is lower than those for bare gully beds with a minimum value (74.53%) of  $\tau$ . The vegetated buffer strips in gully beds indicate that total gross deposit of sediment after experiments ranged between  $0.02$  and  $0.1 \text{ m}^3$  with an average of  $0.037 \text{ m}^3$ , which was 1.6 times higher than that of bare soil gully beds. The net erosion volume shows a negative relationship with time for all the experimental gully beds. Moreover, the area covered with dense vegetation cover had reduced surface runoff, sediment trapped with stems, and reinforcement of soil erosion and

stabilization of the gully. Hence, encouraging vegetation in gully beds has been confirmed as an active measure in monitoring the expansion of gullies.

## Keywords

Vegetation belts · In situ scouring experiment · Hydraulic properties · Gully bed · Runoff · Land management

## 13.1 Introduction

Soil or land degradation under rills and gullies is developed by concentrated flow erosion, resulting in the detachment and displacement of topsoil particles (Govers 1991; Govers et al. 2007). The soil loss includes (1) loosening and detachment of soil particles from the soil mass through the process of rilling and gully, (2) removal and transport of eroded soils downslope and downstream by overland flow, and (3) soil slumping under the impact of the increased volume of detached soils (Singh and Dubey 2002). Gully erosion is one of the forms of accelerated soil erosion. Its occurrence often indicates an extreme form of land degradation warranting special attention (Singh and Phadke 2004).

In India, an area of approximately 4 million ha is affected by rill and gully erosion (Sharda et al. 2007). The Ministry of Agriculture, Government of India (2000) reported the 12 - Indian states that were most seriously affected by rill, gully, and ravine erosion. Gully erosion in India has mainly focused on the morphological characteristics (Bandyopadhyay 1987, 1988; Das and Bandyopadhyay 1996; Sen et al. 2004; Ghosh and Guchhait 2015; Shit et al. 2012), hydrological processes (Shit and Maiti 2013), and controlling measures of hillslope gully and on the development process (Singh and Phadke 2004), features, controlling factors, and field monitoring methods of ephemeral gully channels (Singh and Dubey 2002; Shit et al. 2011, 2012), and the delineation and

P. K. Shit (✉)

Department of Geography, Raja N. L. Khan Women's College (Autonomous), Medinipur, West Bengal, India

H. R. Pourghasemi

Department of Natural Resources and Environmental Engineering, College of Agriculture, Shiraz University, Shiraz, Iran

G. S. Bhunia

Aarvee Associates Architects, Engineers & Consultants Pvt. Ltd, Hyderabad, India

monitoring of gully erosion lands (Pani and Mohapatra 2001; Ghosh 2015; Shit et al. 2015).

Moreover, relatively few studies have examined differences in the causes and influences of gully erosion in a subhumid lateritic belt in West Bengal, India (Shit et al. 2013). In this region, geomorphological features, controlling factors, and monitoring methods for ephemeral gullies have been studied (Sen et al. 2004; Shit et al. 2014; Ghosh 2015). Additionally, Shit et al. (2011) examined headward erosion of gully heads under different discharge condition, and Shit et al. (2013) studied the distribution and influencing factor of vegetation (above biomass and ground biomass) on gully erosion in this region.

Several studies have been carried out on rill and gully erosions, but only a few studies have concerned utilizing natural vegetation to control gully erosion as well as headward erosion. Vegetation has an obvious effect in reducing concentrated flow and controlling soil loss, affecting sediment yield of the overland flow in gully basins (Rey 2003; Spaan et al. 2005; Li et al. 2006; Su et al. 2014; Shit et al. 2012, 2013). However, most of the previous studies of vegetation in soil erosion were mainly conducted on hill slopes with few examining the effects on vegetation in gully erosion. Numerous researchers reported that the vegetation cover has a significant influence on surface runoff volume and sediment (Braud et al. 2001). Spaan et al. (2005) and Rey (2003) reported that vegetation could effectively slow the velocity of the flow, trap sediment, build up backwater, and promote sedimentation to reduce gully erosion. However, few studies focus on rill-gully erosion mechanisms and particularly the impact of vegetation cover on hydraulic properties of surface runoff in gully channel and beds, because of the complex development processes and the many influential factors compared with sheet erosion.

In this chapter we investigated the role of a vegetation belt on gully erosion. For this aim, six ephemeral gully channels were selected to (1) examine the dynamic changes of gully hydraulic properties and sediment yield in response to the grass cover in the gully beds and (2) analyze the relationship between runoff properties and sediment content.

## 13.2 Materials and Methods

### 13.2.1 Study Area

All experiments were conducted at the Rangamati badland area (22°23' to 22°24' N latitude and 87°17' to 87°18' E longitude), which is a typical dissection of the landscape by dense and deep rills and gully erosion in the western part of West Bengal (Fig. 13.1). The average slope of this area is between 25% and 35%. The most frequent landforms are complex slopes and gullies. The average annual precipitation and temperature are

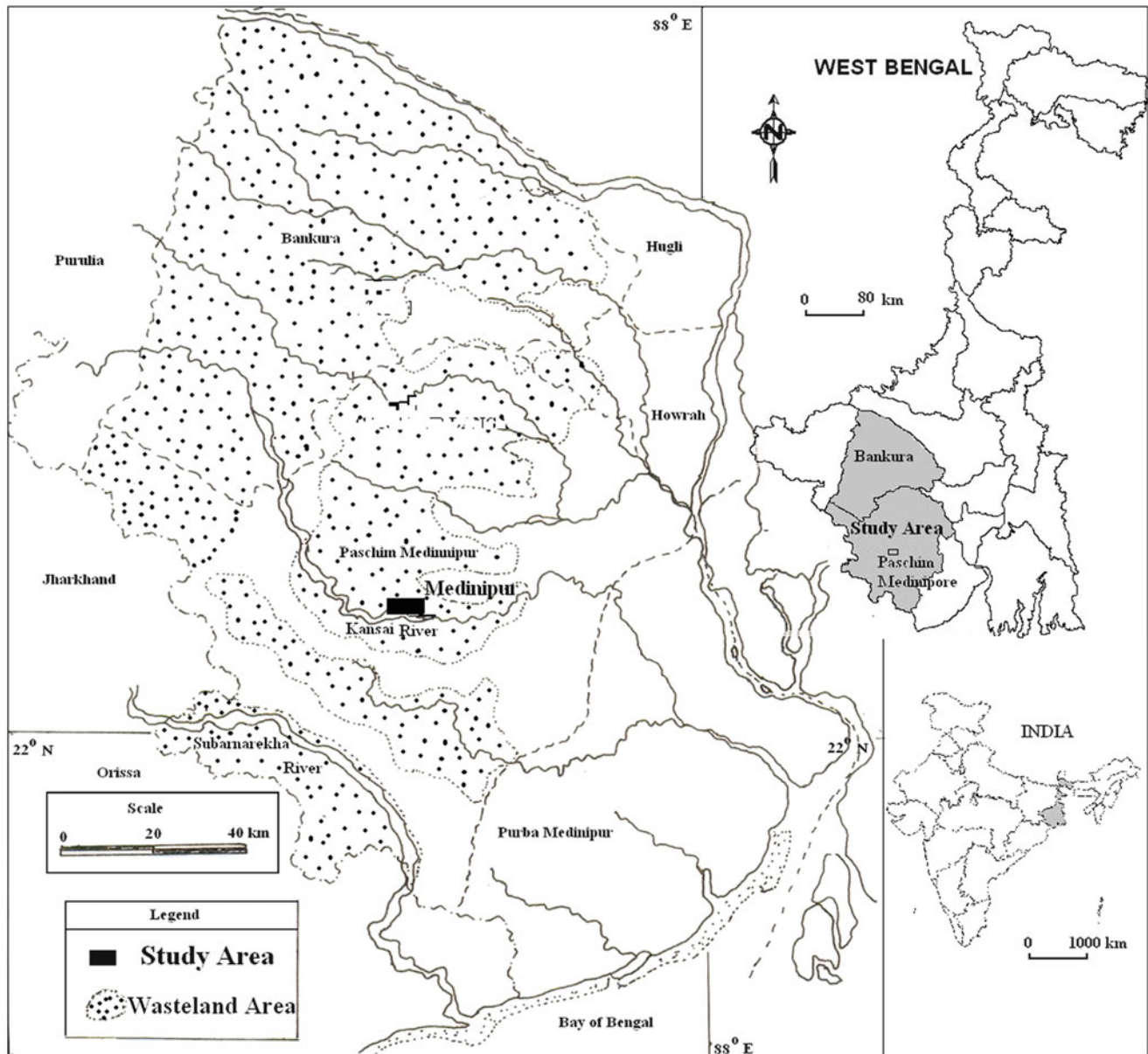
1500 mm and 23.5 °C, respectively. The dominant soils at the surface of the study area are dry red soil and vertisols (USDA soil taxonomy). Dry red soils often have high sand content by iron and silica; vertisols often have high clay content with a mean bulk density of 1.34 to 1.86 cm<sup>-3</sup>. According to a previous study (Shit and Maiti 2014), the region is dominantly herb species with *Eragrostis cynosuroides*, *Lantana camara*, and *Andropogon aciculatus* vegetation species in the gully bed (Shit and Maiti 2014). *Eragrostis cynosuroides* is a local species that can grow rapidly on gully beds in a subhumid tropical environment (Shit et al. 2013).

### 13.2.2 Field Monitoring and Measurement

Six gully beds were selected for simulation runoff experiments. The gully beds were 18 m long with width varying from 0.25 to 0.50 m, with an average slope of 18–20° on the gully bed. The six gully beds have similar topographical conditions, and headcut height was 0.3 m. The grain size distribution of soil is mainly gravel (30%), sand (40%), and silt and clay (30%). Dry soil bulk density ranges from 1.34 to 1.78 g/cm<sup>-3</sup>.

*Eragrostis cynosuroides* was growing naturally in four gully beds with similar density and an average height of vegetation of 20–50 cm during the experiments, and the average vegetation cover of buffer strips was 67%. However, vegetation buffer strips were selected at the bottom end of the gully beds extended up to headward direction. The only bare gully bed was selected for control measurement and also compared with the buffer gully beds. Six strip widths were established on gully beds: bare (0), 3, 6, 9, 12, 15, and 18 m, which were named Gully-A, Gully-B, Gully-C, Gully-D, and Gully-E, respectively (Fig. 13.2).

The experiment on each gully bed consisted of five simulation runoff tests in the dry season (November 2018), during which no natural rainfall occurred. Clean water pumped through a 2-HP diesel pump from the nearby pond and a nylon water pipe was used to connect the adjustable opening to a flowmeter to measure the flow discharge during the experiment (Su et al. 2014). The flow scouring tests on each gully bed lasted 60 min with flow discharge of 78.5 l min<sup>-1</sup>. The discharge was adjustable according to average precipitation in the region. During these experiments, the hydraulic parameters and sediment yield were measured. The hydraulic parameters included the flow velocity ( $v$  in ms<sup>-1</sup>), flow width ( $w$ , in meters, m), flow depth ( $d$ , in meters, m), and temperature (in °C). The flow velocity was measured using the color tracer method (potassium permanganate solution); flow width and depth were measured with a ruler and measuring tapes (Shit and Maiti 2014). Water temperature was measured with a centigrade thermometer. All parameters were measured three times for each gully bed



**Fig. 13.1** Location of lateritic belt area (i.e., rill-gully-prone area) and experimental site (Shit and Maiti 2014)

section at 10-min intervals during the experiments (Fig. 13.3). Additionally, hydraulics parameters, including Reynolds number ( $Re$ ), Froude number ( $Fr$ ), hydraulic shear stress ( $\tau$ ), Manning roughness coefficient ( $N$ ), and Darcy-Weisbach friction factor ( $f$ ) were calculated according to Eqs. (13.1)–(13.4):

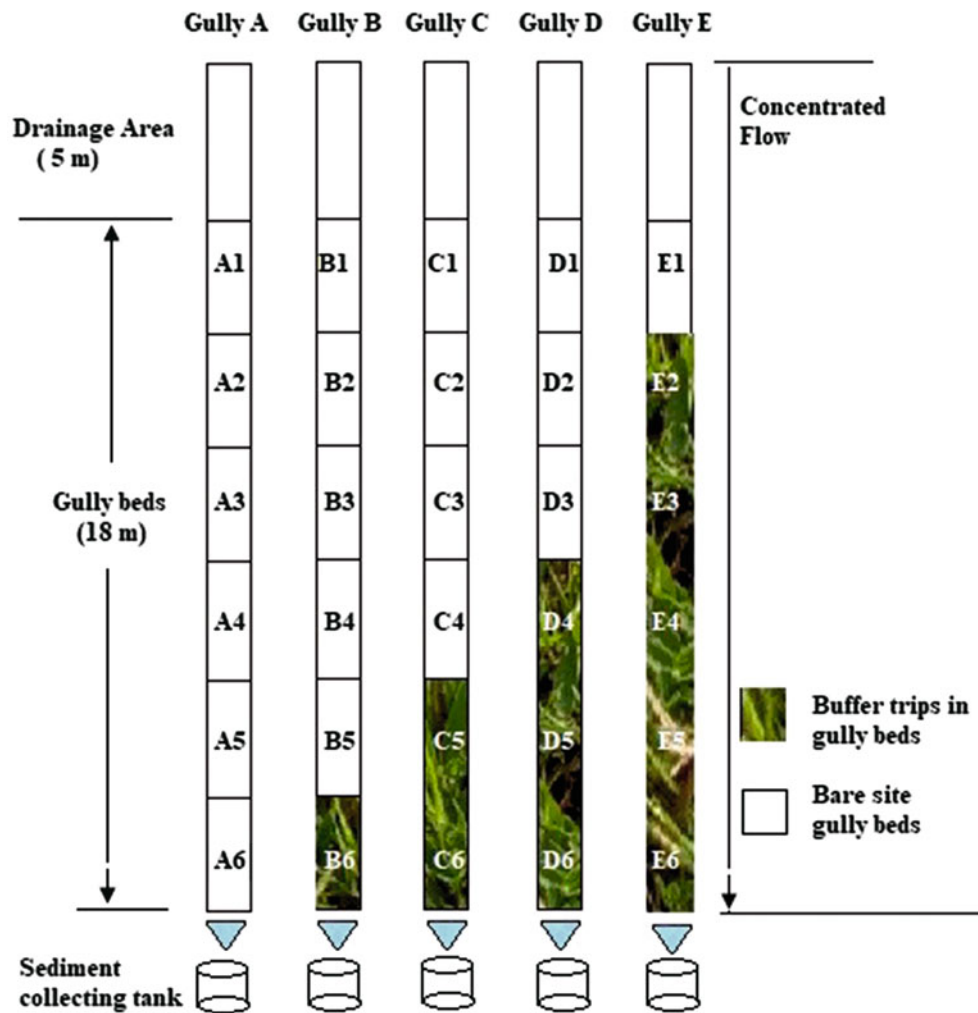
$$Re = \frac{vr}{\mu} \quad (13.1)$$

$$Fr = \frac{v}{\sqrt{gh}} \quad (13.2)$$

$$\tau = \rho grs \quad (13.3)$$

$$f = \frac{8grs}{v^2} \quad (13.4)$$

Where  $v$  is the flow velocity ( $\text{m s}^{-1}$ ),  $r$  is the hydraulic radius (m),  $s$  is the surface slope angle ( $\text{m m}^{-1}$ ),  $g$  is the gravitational acceleration ( $\text{m s}^{-2}$ ),  $h$  is the flow depth (m),  $\rho$  is



**Fig. 13.2** Sketch of experimental simulation concentrated flow and vegetation distribution of gully beds. The length of each section is 3 m, gully width varies from 0.2 to 0.25 m, and average slope of the gully bed is 18–20°

the water density ( $\text{kg m}^{-3}$ ), and  $\mu$  is the water kinematic viscosity coefficient ( $\text{m}^2 \text{s}^{-1}$ ).

Runoff samples were collected at the bottom part of each gully bed using a 0.5-l plastic bottle during the simulation runoff at 5-min intervals. These samples were deposited for 24 h and the clear water decanted; then, the sediment was oven dried at 105 °C for 12 h and weighed to determine the sediment loss (Kodamatani et al. 2017). Gully bed topography was monitored by paired photographs with field measurements based on terrain height (points) per square meter. Gully bed topography changes, including width, depth, volume, and elevation, were analyzed by subtracting the volumes of the digital elevation model (DEM) at 10 m spatial resolution before and after scouring using Raster math tools and spatial analyst tools of ArcGIS software. All statistical analysis was carried out using MS Excel and Origin 6.1 software.

## 13.3 Results and Discussion

### 13.3.1 Vegetation Effects on Concentrated Flow Hydraulics in Gully Beds

Summaries of the statistics of all experimental results are presented in Table 13.1. Hydraulics parameters (i.e.,  $v$ ,  $Re$ ,  $Fr$ ,  $F$ ,  $t$ , and  $N$ ) for vegetation buffer strips were clearly shown to be smaller than those for bare gully beds. The average parameter values for the vegetated buffer strips varied between 35% and 50%, which is lower than those for bare gully beds with a minimum value (74.53%) of  $\tau$  (Table 13.1). Concentrated flow resistance values were presented by Darcy-Weisbach friction factor ( $f$ ) and Manning roughness coefficient ( $N$ ). The results showed that these values for



**Fig. 13.3** Layout of experimental plots: (a) simulation of water supplied by 2-hp diesel pump; (b) Gully-A; (c) Gully-C; (d) Gully-B; (e) Gully-E, (f) Gully-D

**Table 13.1** Summary of the statistics of hydraulic parameters on bare sites and gully beds with vegetation buffer strips

Hydraulic parameters	Descriptive statistics	Bare gully beds	Buffer strips in gully beds
Number of the section	–	19	11
$v$ (m s <sup>-1</sup> )	Mean	0.66	0.47
	Range	0.31–1.04	0.29–0.61
	SD	0.24	0.10
$h$ (m)	Mean	0.05	0.04
	Range	0.03–0.11	0.03–0.06
	SD	0.02	0.01
$w$ (m)	Mean	0.24	0.54
	Range	0.12–0.52	0.28–0.67
	SD	0.24	0.21
Re	Mean	13,822	8817
	Range	6478–19,321	4841–12,873
	SD	4153	2724
Fr	Mean	0.63	0.51
	Range	0.29–1.27	0.39–0.63
	SD	0.27	0.09
$\tau$ (N m <sup>-2</sup> )	Mean	207.14	74.53
	Range	54.35–354.19	53.87–97.80
	SD	98.05	14.69
$f$	Mean	7.17	9.95
	Range	0.78–17.24	3.45–16.84
	SD	4.59	4.38
$n$	Mean	0.15	0.18
	Range	0.04–0.27	0.12–0.26
	SD	0.10	0.12

vegetated buffer sites were 1.2 and 1.4 times higher than those for bare gully sites, respectively (Table 13.1).

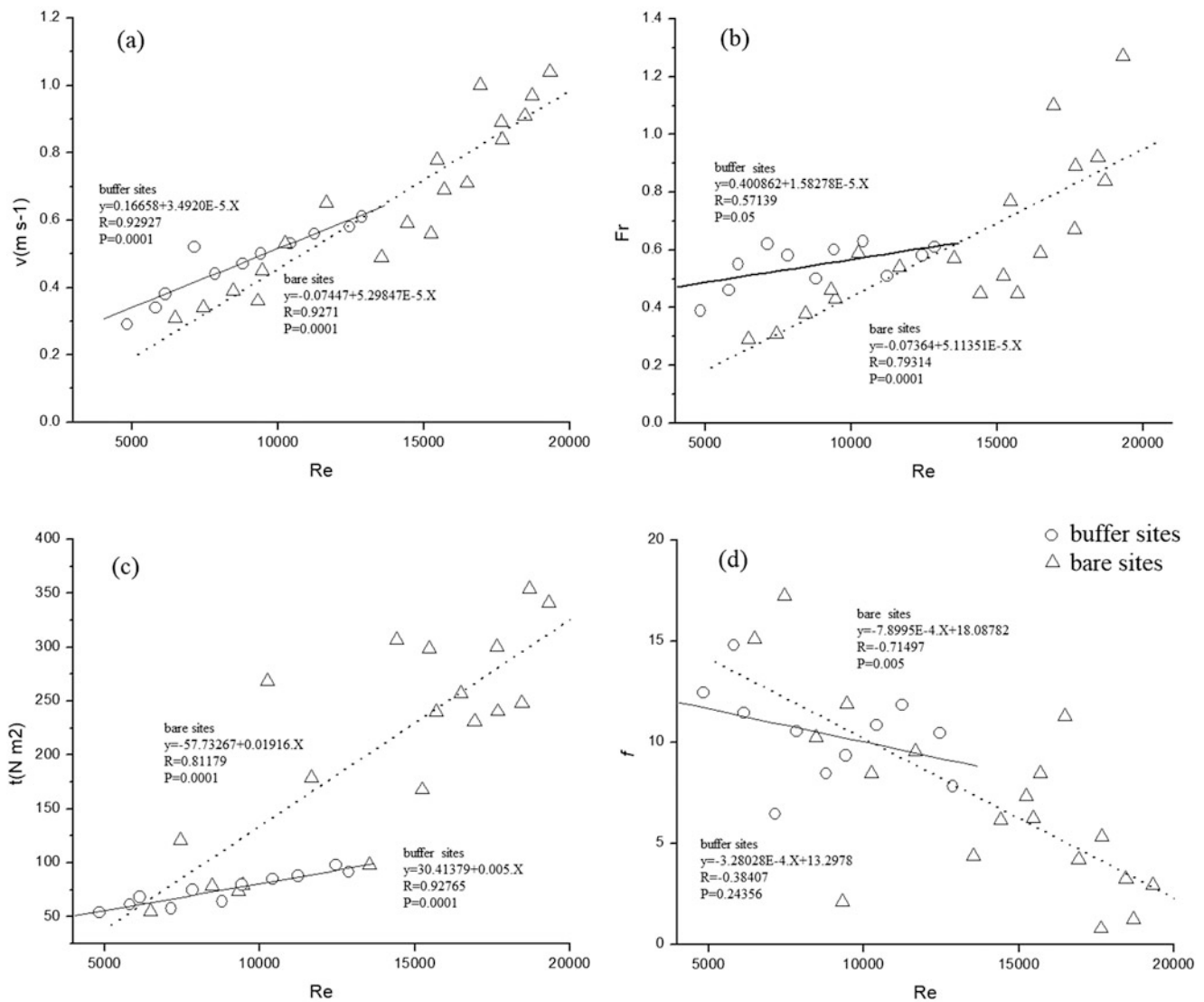
### 13.3.2 Relationship of Different Hydraulic Factors Between Vegetated and Bare Sites

Figure 13.4 represents a relationship between Reynolds number (Re) and several hydraulic factors in vegetated and bare gully beds. The increasing regression lines of Re- $v$  were illustrated for both bare soil and vegetated gully beds, but the Re- $v$  trends line for bare soil has a steeper gradient than that of vegetated buffer gully beds (Fig. 13.4a). The equal value was also calculated for Re-Fr (Fig. 13.4b). The increasing trends lines with values of flow shear stress for bare sites of gully were significantly higher than that for vegetated buffer strips (Fig. 13.4c). Figure 13.4d shows a negative relationship between Re- $f$  and indicated that bare sites have a steeper slope than vegetated sites. However, these results revealed that vegetated buffer strips usually have higher

values of hydraulic flow resistance and lower values of flow hydraulics parameters (i.e., Re, Fr,  $t$ ) than bare gully beds.

### 13.3.3 Role of Vegetation in Soil Erosion of Gully Beds

Table 13.2 illustrates the erosion processes of gully beds during concentrated flow experiments. All gully sections studied were clearly eroded after six experiments: average gully erosion volume was about 0.33 m<sup>3</sup> and 0.27 m<sup>3</sup> for bare soil gully beds and vegetated gully beds, respectively. These results indicated that sedimentation was 1.24 times higher than that in vegetated buffer strips in respect to bare soil gully beds. The vegetated buffer strips in gully beds indicate that total gross deposit of sediment after experiments ranged between 0.02 and 0.1 m<sup>3</sup> with an average of 0.037 m<sup>3</sup>, which was 1.6 times higher than that of bare soil gully beds. The net erosion volume ranged from 0.22 m<sup>3</sup> to 0.55 m<sup>3</sup> via an average of 0.31 m<sup>3</sup> in bare soil gully beds, whereas vegetated buffer strip beds varied from 0.05 m<sup>3</sup> to 0.15 m<sup>3</sup> by



**Fig. 13.4** Relationship between vegetated sites and bare sites for different hydraulic factors: (a) Reynolds number (Re), (b) Froude number (Fr), (c) flow shear stress ( $t$ ), and Darcy-Weisbach friction factor ( $f$ ) (d)

an average of  $0.23 \text{ m}^3$  (Table 13.2). These results showed that vegetated buffer strips significantly reduce flow velocity, control gully incision, and trap sediment in gully beds.

### 13.3.4 Relationship Between Experimental Time (Minutes) and Soil Erosion

Figure 13.5 illustrates the experimental gully beds, both vegetated and bare soil, sediment concentration, and net erosion volumes against concentrated flow times. The net erosion volume shows a negative relationship with time for all the experimental gully beds. Higher erosion at the beginning time was observed in Gully-A. All gully beds were

relatively stable during the experimental time, except Gully-A (Fig. 13.5a). The presence of the vegetation buffer did not significantly reduce soil erosion during the first 30 min. Similarly, a negative relationship could be observed on sediment concentration against time (Fig. 13.5b). The maximum total erosion volume was observed at Gully-A, whereas vegetation cover had zero percentage (i.e., bare gully beds), and minimum total erosion volume was observed at Gully-E, whereas vegetation cover was 66.67% (Table 13.3). The vegetation buffer strips showed that erosion rate is 3.1 times less than in bare soil gully beds (i.e., Gully-A). These results indicated that the percentage of vegetation buffer significantly controls erosion rate and sediment deposit in gully beds (Table 13.3).

**Table 13.2** Landscape changes at different sites of gully beds during experiments

Gully sites	Gully section ID	Gross erosion volume (m <sup>3</sup> )	Gross deposition volume (m <sup>3</sup> )	Net erosion volume (m <sup>3</sup> )	Upstream net erosion volume (m <sup>3</sup> )
Bare gully beds	A1	0.58	0.03	0.55	0.12
	A2	0.34	0.05	0.29	0.10
	A3	0.54	0.02	0.52	0.21
	A4	0.46	0.00	0.46	0.13
	A5	0.31	0.02	0.29	0.14
	A6	0.28	0.03	0.25	0.10
	B1	0.45	0.01	0.44	0.08
	B2	0.4	0.04	0.36	0.12
	B3	0.58	0.00	0.58	0.07
	B4	0.35	0.02	0.33	0.20
	B5	0.28	0.03	0.25	0.34
	C1	0.24	0.00	0.24	0.08
	C2	0.31	0.01	0.3	0.14
	C3	0.26	0.03	0.23	0.16
	C4	0.23	0.01	0.22	0.17
	D1	0.29	0.00	0.29	0.11
	D2	0.28	0.00	0.28	0.10
	D3	0.23	0.01	0.22	0.09
	E1	0.26	0.00	0.26	0.11
	Vegetation buffer strips/ gully beds	B6	0.18	0.10	0.08
C5		0.16	0.08	0.08	1.00
C6		0.15	0.10	0.05	1.23
D4		0.22	0.07	0.15	0.85
D5		0.15	0.08	0.07	0.75
D6		0.12	0.06	0.06	1.10
E2		0.23	0.03	0.20	0.23
E3		0.18	0.04	0.14	0.82
E4		0.12	0.03	0.09	0.76
E5		0.1	0.05	0.05	0.14
Drainage area	A	0.67	0.01	0.66	–
	B	0.54	0	0.54	–
	C	0.49	0.02	0.47	–
	D	0.37	0.01	0.36	–
	E	0.32	0	0.32	–
Average bare gully beds		0.33381	0.023333	0.310476	–
Average vegetated gully beds		0.269286	0.037143	0.232143	–

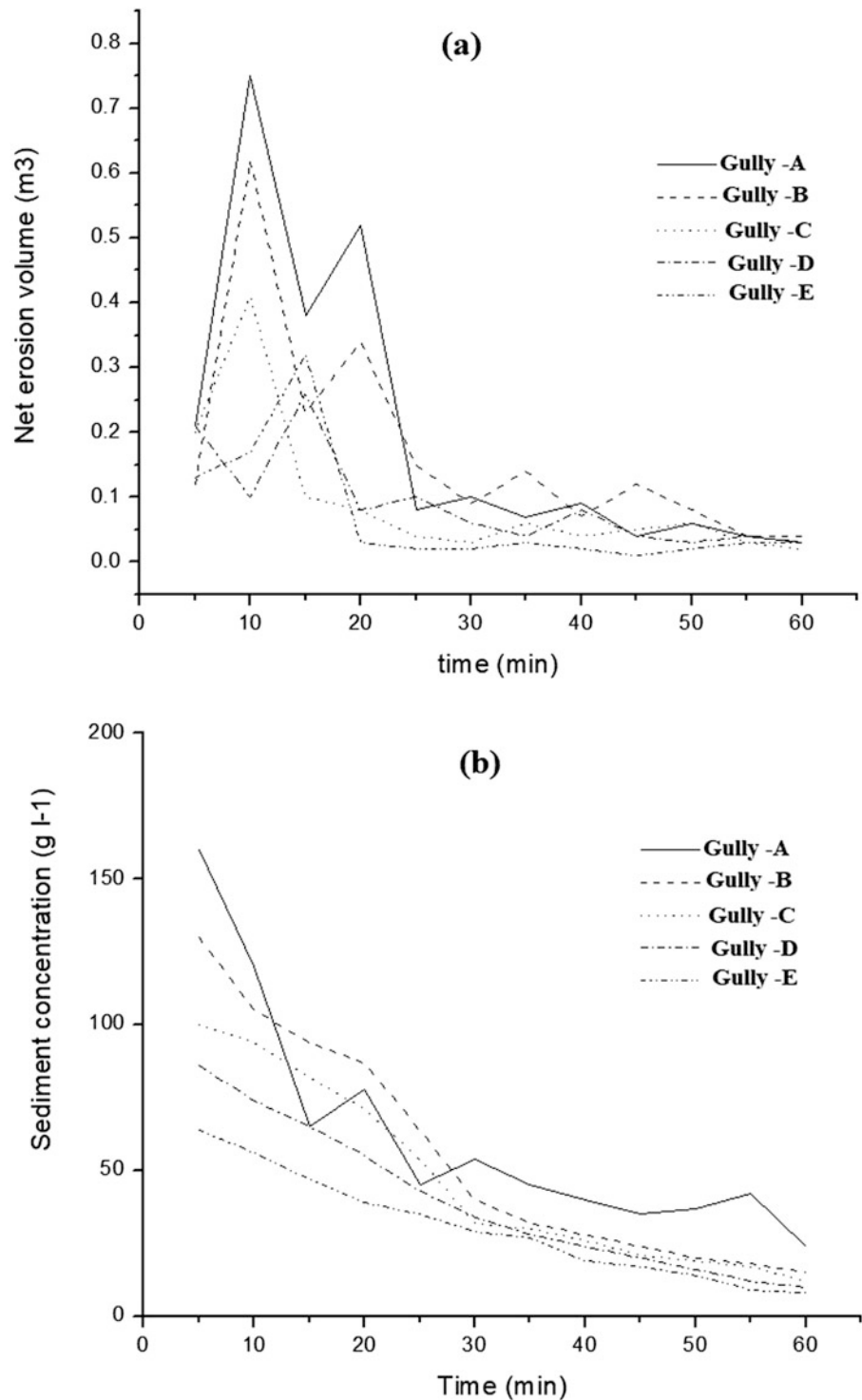
### 13.3.5 Effects of Vegetation on Hydraulic Processes and Soil Erosion of Gully Beds

Figure 13.6 represents the relationship between hydraulic parameters and net erosion volume on gully beds. Runoff velocity ( $v$ ), Reynolds number ( $Rn$ ), and Froude number ( $Fr$ ) showed negative trends with net erosion volume. A similar relationship between hydraulic parameters and soil erosion resulted from vegetation buffer strips, but the relationships were not statistically significant (Fig. 13.6). A similar poor relationship was found for friction factor ( $f$ ) and erosion loss (Fig. 13.6d). Our result was in line with a

previous study by Gimenez and Govers (2008), who showed that a poor correlation existed between flow hydraulic parameters and rill detachment rate in buffer strips. Figure 13.7a clearly represents that during the rainy season abrupt gully incision occurs without vegetation cover, but Fig. 13.7b shows that vegetation is growing along gully beds. These photographs indicate that increasing vegetation cover also reflects the increasing root system (i.e., length, density, mass) in gully beds. Moreover, the area covered with dense vegetation had reduced surface runoff, sediment traps by stems, and reinforcement of soil erosion and stabilization of the gully (Fig. 13.7c).



**Fig. 13.5** Relationship between experimental time (min) and soil erosion: (a) net erosion volume; (b) sediment concentration ( $\text{g l}^{-1}$ )



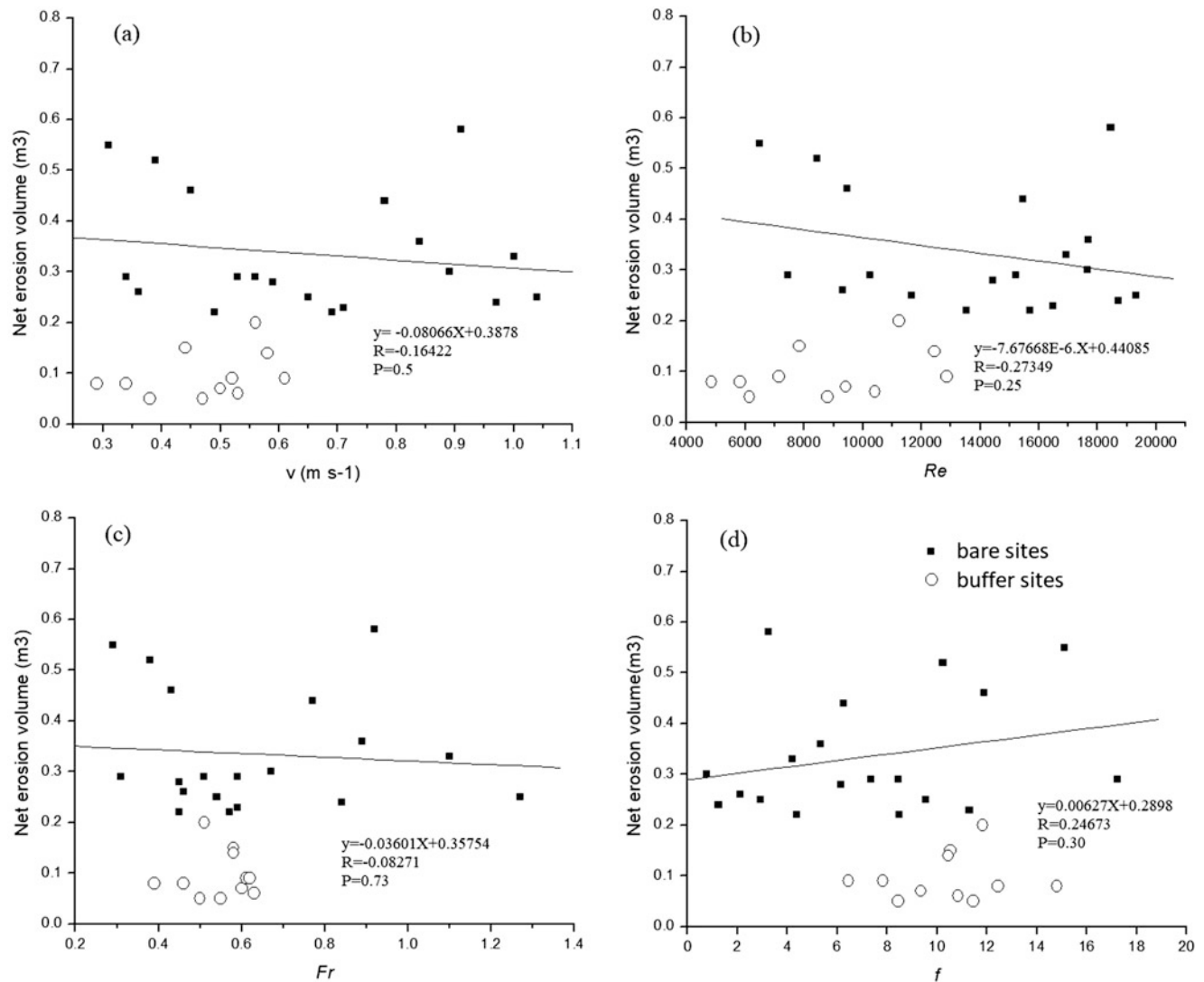
### 13.4 Conclusion

Our field experimental results showed that a vegetation buffer on the gully floor significantly influences hydraulics parameters, and it could increase resistance to concentrated

flow. The consequences of sediment entrainment rates are reduced, and sediment is trapped by vegetation roots in gully beds. Results of the hydraulics parameters (velocity, Reynolds number, Froude number, and Darcy-Weisbach friction factor) of bare soil gully beds showed the vegetation buffer strips in gully beds are 35–50% smaller and have 1.2 to

**Table 13.3** Net erosion volumes and erosion rate of each gully beds under flow discharge ( $78.5 \text{ l min}^{-1}$ ) during 1 h

Gully sites	Percentage of vegetation buffer strips in gully beds	Total erosion volume ( $\text{m}^3$ )	Total deposition volume ( $\text{m}^3$ )	Net erosion volume ( $\text{m}^3$ )	Erosion rate ( $\text{m}^3 \text{ h}^{-1}$ )
Gully-A	0.00	2.51	0.15	2.36	0.31
Gully-B	16.67	2.24	0.2	2.04	0.27
Gully-C	33.33	1.35	0.23	1.12	0.21
Gully-D	50.00	1.29	0.22	1.07	0.14
Gully-E	66.67	1.00	0.17	0.83	0.10

**Fig. 13.6** Relationship between hydraulic parameters and net erosion volumes: runoff velocity ( $v$ ) (a), Reynolds number ( $Re$ ) (b), Froude number ( $Fr$ ) (c), and Darcy-Weisbach friction factor ( $f$ ) (d)

1.4 times higher concentrated flow resistance in Darcy-Weisbach friction factor ( $f$ ) and Manning roughness coefficient ( $N$ ), respectively. The total sediment deposit and net erosion volume on five gully beds produced a significant negative exponential, decreasing with increasing

experimental time and vegetation cover. The vegetation cover shows that the erosion rate is 3.1 times less than in bare soil gully beds. Thus, this study showed that vegetated buffer strips significantly reduce flow velocity, control gully incision, and sediment loss in gully beds.



**Fig. 13.7** Influence of vegetation cover at different location of Rangamati badland area: (a) gully incision without vegetative cover, (b) gully stabilized by gully beds vegetation, and (c) reduced gully erosion by growing the vegetation along the gully channel and beds

**Acknowledgments** We are grateful to the Department of Geography, Raja N.L. Khan Women's College (Autonomous), affiliated to Vidyasagar University, Midnapore, West Bengal, India for supporting this research. The author (P.K. Shit) gratefully acknowledges University Grant Commission (UGC-ERO, Kolkata), Govt. of India for financial support through Minor Research Project [No. F.PHW-171/15-16 (ERO)]. Many people helped with the originally field data collection, including Sumanta Dinda, Sumana Jana, and Bhanishikha Bhattacharya.

## References

- Bandyopadhyay, S. (1987) Man-Initiated Gullying and Slope Formation in a Lateritic Terrain at Santiniketan, Geographical Review of India, 49 (4), 21–26.
- Bandyopadhyay, S. (1988) Drainage Evolution in Badland Terrain at Gangani in Medinipur District, West Benagl. Geographical Review of India, 50 (3), 10-20.
- Braud, I., Vich, A. I., Zuluaga, J., Fornero, L., & Pedrani, A. (2001) Vegetation influence on runoff and sediment yield in the Andes region: Observation and modelling. *Journal of Hydrology*, 254, 124–144.
- Das K., and Bandyopadhyay, S. (1996) Badland Development in a Lateritic Terrain: Santiniketan, West Benagl. *National Geographer*, XXXI (1&2), 87–103.
- Ghosh D (2015) Mapping and Monitoring of the Impact of Gully Erosion in the District of Medinipore (west), West Bengal, India. *International Journal of Novel Research in Humanity and Social Sciences*, 2(4):73-89.
- Ghosh S, Guchhait SK (2015) Characterization and Evolution of Laterites in West Bengal: Implication on the Geology of Northwest Bengal Basin. *Trans* 37(1):93-119.
- Gimenez, R., Govers G. (2008) Effects of freshly incorporated straw residue on rill erosion and hydraulics, *Catena* 72(2):214-223. DOI: <https://doi.org/10.1016/j.catena.2007.05.004>.
- Govers G. (1991) Rill erosion on arable land in central Belgium: rates, controls and predictability. *Catena*, 18:133–155.
- Govers G., Giménez R. and Oost, K. Van. (2007) Rill erosion: exploring the relationship between experiments, modelling and field observations. *Earth Science Reviews*, 84 (3–4): 87–102.
- Kodamatani H, Maeda C, Balogh SJ, Nollet YH, Kanzaki R, Tomiyasu T. (2017) The influence of sample drying and storage conditions on methylmercury determination in soils and sediments. *Chemosphere*. 173:380-386
- Li, P., Cai, W. B., & Zheng, L. Y. (2006) Effects of vegetative cover on runoff hydraulic characteristics and erosion. *Science of Soil and Water Conservation*, 4, 55–59.
- Pani P, Mohapatra SN (2001) Delineation and monitoring of gullied and ravenous lands in a part of lower Chambal valley, India using remote sensing and GIS. In: Proc. ACRS. Singapore
- Rey, F. (2003) Influence of vegetation distribution on sediment yield in forested marly gullies. *Catena*, 50, 549–562.
- Sen, J., Sen, S., Bandyopadhyay, S. (2004) Geomorphological investigation of badlands- a case study at Garbheta, West Medinipur District, West Bengal, India. In Singh, S., Sharma, H.S., and De, S.K (eds). *Geomorphology and Environment*. acb publication, Kolkata. 204-234.
- Sharda, V.N., Juyal, G.P., Prakash, C., and Joshi, B.P. (2007) Training Manual Soil conservation and watershed management, Vol-II, (soil water conservation engineering). Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehradun, Uttarakhand, pp. 1–410.
- Shit, P.K, Maiti R., Pati C.P. (2011) Methodological Framework to Select Grass Species for Controlling Rill and Gully Erosion. *Science Cruiser, Institute of Science, Education and Culture*. Vol-25(2), 32-37.
- Shit, P.K., Bhunia G.S., Maiti R. (2012) Effect of Vegetation Cover on Sediment Yield: An Empirical Study through Plots Experiment, *Journal of Environment and Earth Science*, Vol 2, No 5 , 32-40.
- Shit P.K., Bhunia G.S., and Maiti R. (2013) Assessment of factors affecting ephemeral gully development in badland topography: A case study at Garbheta badland (Pashchim Medinipur, West Bengal, India), *International Journal of Geosciences*. 4 (2) 461–470. doi: <https://doi.org/10.4236/ijg.2013.42043>.
- Shit P.K., Bhunia G. S, and Maiti R. (2014) Morphology and Development of selected Badlands in South Bengal (India), *Indian Journal of Geography and Environment*, 13, 161-171.
- Shit P.K., and Maiti R. (2013) Management Techniques of Rill-Gully Erosion in Badland Topography: Experimental Research at Laboratory, Plot and Catchments Scale. LAP Lambert Academic Publishing, Germany. (ISBN: 978-3-659-32409-3), pp 136.
- Shit PK, Nandi AS, Bhunia GS (2015) Soil erosion risk mapping using RUSLE model on jhargram sub-division at West Bengal in India. *Model Earth Syst Environ* 1(28):1-12
- Shit P.K. and Maiti R. (2014) Gully Erosion Control: Lateritic Soil Region of West Bengal, *Indian Science Cruiser*, 28(3), 54-61.
- Singh S., Dubey A. (2002) Gully erosion and management methods and applications (A Field Manual). New Academic Publishers, Delhi, 1 - 248 pp.
- Singh, R, Phadke, V.S. (2004) Assessing soil loss by water of the erosion in Jamin river basin, Bundelkhand region, India. *Geographical Review of India*, Vol. 66, No-2, pp. 143-152.
- Spaan, W. P., Sikking, A. F. S., & Hoogmoed, W. B. (2005) Vegetation barrier and tillage effect on runoff and sediment in an alley crop system on a Luvisol in Burkina Faso. *Soil & Tillage Research*, 83, 194–203.
- Su, Z. A., Xiong, D. H., Dong, Y. F., Li, J. J., Yang, D., Zhang, J. H., & He, G. X. (2014) Simulated headward erosion of bank gullies in the Dry-hot valley region of Southwest China. *Geomorphology*, 204, 532–541.

**Pravat Kumar Shit** received his PhD in Geography (Applied Geomorphology) from Vidyasagar University (India) in 2013, MSc in Geography and Environment Management from Vidyasagar University in 2005, and PG Diploma in Remote Sensing and GIS from Sambalpur University in 2015. He is Assistant Professor in the Department of Geography, Raja N. L. Khan Women's College (Autonomous), Gope Palace, Midnapore, West Bengal, India. His main fields of research are soil erosion spatial modeling, badland geomorphology, gully morphology, water resources and natural resources mapping, and modeling. He has published more than 45 international and national research articles in various renowned journals; also, he has published three books. His research work has been funded by the University Grants Commission (UGC), India and Higher Education Science and Technology and Biotechnology, Government of West Bengal. He is Associate Editor and on the editorial boards of three international journals in geography and earth environmental sciences.

**Hamid Reza Pourghasemi** is an Associate Professor of Watershed Management Engineering in the College of Agriculture, Shiraz University, Iran. He has a BSc in Watershed Management Engineering of the University of Gorgan (2004), Iran, an MSc in Watershed Management Engineering, from Tarbiat Modares University, Iran (2008), and a PhD in Watershed Management Engineering from the same University (Feb 2014). His main research interests are GIS-based spatial modelling using machine learning/data mining techniques in different fields such as landslide, flood, gully erosion, forest fire, land subsidence, species distribution modelling, and groundwater/hydrology. Also, Hamid Reza works

on Multi-Criteria Decision Making methods in Natural Resources and Environment. He has published more of 90 peer reviewed papers in high-quality journals, with three chapters in Springer. Also, he published two books in Springer (<https://www.springer.com/gp/book/9783319733821>) and Elsevier (<https://www.elsevier.com/books/spatial-modeling-in-gis-and-r-for-earth-and-environmental-science/pourghasemi/978-0-12-815226-3>).

**Gouri Sankar Bhunia** received his PhD from the University of Calcutta, India, in 2015. His PhD dissertation work focused on environmental control measures of infectious disease (visceral leishmaniasis or kala-azar) using geospatial technology. His research interests include

kala-azar disease transmission modeling, environmental modeling, risk assessment, data mining, and information retrieval using geospatial technology. He is Associate Editor and on the editorial boards of three international journal in Health GIS and Geosciences. He worked as a 'Resource Scientist' in Bihar Remote Sensing Application Centre, Patna (Bihar, India). He is the recipient of the Senior Research Fellow (SRF) from Rajendra Memorial Research Institute of Medical Sciences (ICMR, India) and has contributed to multiple research programs kala-azar disease transmission modeling, development of customized GIS software for kala-azar 'risk' and 'non-risk' area, and entomological study.