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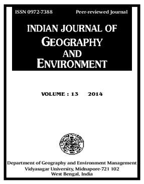

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Morphology and Development of selected Badlands in South Bengal (India)

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ABSTRACT

Field investigations on gully morphology and its inherent processes have been conducted in lateritic region in the western margin of Bengal Basin. At Here-Parvat, rilling and swelling processes produced deeply cracked surface drained by a finely textured network of shallow rills. At Rangamati, rilling and piping are differentially developed on slopes ultimately controlled by basal incision. At Ganganir Danga, vegetation cover is produced a sequence of badland development within which the relative importance of piping, mass failure and rilling varies through the sequence. Plots scale studies were examined and results showed simple overland flow is the dominant process; however, aspect influences rill network density and badland evolution. The factors controlling badland were effective over varying timescales, and implied morphological responses in different time period among the selected badlands.

1. Introduction

Badlands fascinated dissected topography, unconsolidated soils or poorly consolidated bedrock for the same reasons that inhibit agricultural uses, like lake of vegetation, steep slopes, high drainage density, shallow to non-existent regolith and rapid erosion rates (Bryan and Yair 1982; Howard, 1994; Poesen et al., 2003). Such areas are commonly effected by intense processes of soil erosion, including gulling, rilling, and sheet wash erosion (Nadal-Romero et al., 2008, 2010; Shit et al., 2013).

Gullying is one of the most important erosion processes; largely contribute to the sculpturing of the earth surface over the last decade. The advancement of gullies has many pessimistic impacts as it usually engrosses the loss and the deposition of a great amount of soil (De Ploey, 1990; Marzolff et al., 2011). Moreover, the development of gullies entails an amendment of overland flow, shortening of runoff lag time and an increase in runoff volume. The substantial cause of gully erosion is to damage economy and may represent a relevant constrain to the development of poor countries. In spite of the many efforts made to understand the main factors and processes originating gullies (Boardman, 2006). Deforestation played a major role for gully erosion in developing countries. Removal of vegetation by logging or cropland spreading out in humid areas, or by overgrazing in semiarid zones favours the advancement of gullies (Bull and Kirkby, 2002;

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Marzolff et al., 2011). Gullies are perhaps instigated and develop through different, concurrent factors. Poesen et al. (2003) stated that inter rill flow tends to concentrate down slope into pathways leading to a more efficient flow and to a decrease in flow resistance. It follows that the interaction between overland flow and ground surface roughness is a process relevant to gully initiation (Poesen et al., 2006; Govers et al., 2007; Campo-Besco et al., 2013). Expansion of gully continues being influenced by flow resistance and morphological characteristics of the features (Ries and Marzolff, 2003; Seeger et al., 2009). The analysis of their hydraulic geometry contribute to the understanding the processes acting on the development of gullies.

The appraisal of gully progression rates under different climatic and land use conditions offers imperative data for modelling gully erosion and envisaging impacts of environmental change in regards to soil erosion process. However, the main focus of investigations is to examine the morphology and temporal development of selected badland sites in South-Western part of West Bengal (India). Present study also examines the gully erosion processes on seasonal variations over a short term period.

2. Description of study sites

The study has been carried out on six gully basin landscapes which is located in Garhbeta block (Ganganir Danaga) and Bishunpur block (Here-Parvat) of Bankura district and Rangamati of Paschim Medinipur district, West Bengal (India) (Figure 1). The brief description of the study area is described in Table 1. Ganganir Danga one of the most extensive badland areas in south Bengal, extended between 22° 51'18" N 22° 51'30" N latitude and 87°20'20" E to 87° 20'28" E longitude (Fig 1). The area is covered by 3.5 km^2 of Pleistocene lateritic upland, and is noted for spectacular ravine development on the concave right (northern) bank of river Silai (Bandyopadhyay, 1988).

Table 1: Characteristics of gully sites

Gully site	Soil	Current land use/land cover	Gully catchment size (sq m)
Here-Parvat	Sandy loams with lateritic	Rangeland, recent afforestation	186
Ganganir Danga	Sandy loams with lateritic	Abandoned fields, recent plantations	1243
Rangamati-I	Sandy loams with lateritic	Rangeland, abandoned fields	198
Rangamati-II	Loamy sands	Grass land with grazing fields	212

The inter-gully areas of the micro catchment are usually undulating to rolling and the average slope angle is ranged from 5° to 60°. The cross-sectional shapes of the gullies are 'V' and 'U' shaped, with maximum sidewall of slope angles of 85° (mean 63° and standard deviation ±16.4) (Shit and Maiti, 2012) . Soil of the catchment is sandy and sandy loamy.

The Rangamati badlands is characterized by steep slopes developed between Quaternary pediments and have a restricted vertical extension with a maximum local relief of up to 50 m. They are relatively young and have only developed since the dissection of one of the younger surfaces of the Rangamati badland (Shit et al, 2012, 2013). Base surfaces on North facing slopes are rilled and there is local evidence of mud-sliding (Shit et al. 2013). South facing slopes have a vegetation cover (grass) and a thin and resistant lichen crust. Deep and shallow piping is related to lateritic layer and important in relation to rill generation.

At Here-parvat badland is developed on lateritic land with a maximum relief of 80 m. Surface processes are dominated by rilling, swelling and cracking in relation to base level. The study area experiences tropical monsoon climate having a prolonged dry period. Annual rainfall of the region is about 2111 mm, and almost 70% of total rainfall concentrates in the monsoon period. Temperature of the catchment area is varied from 48° C (May-June) to 10° C (Dec-January) (Shit et al, 2012). Mineralogical analysis of clays from Rangamati and Ganganir danga showed the differences in silica oxide (SiO_2) in lower basin of the Ganganir danga and iron oxide (Fe_2O_3) in upper basin areas.

3. Material and Method

In the present study three badlands topography were selected to carry out the study. Continuous observations have been made on gully erosion processes for last 6 years in each badland area. Field survey at Here-Parvat gully basin, Rangamati badland

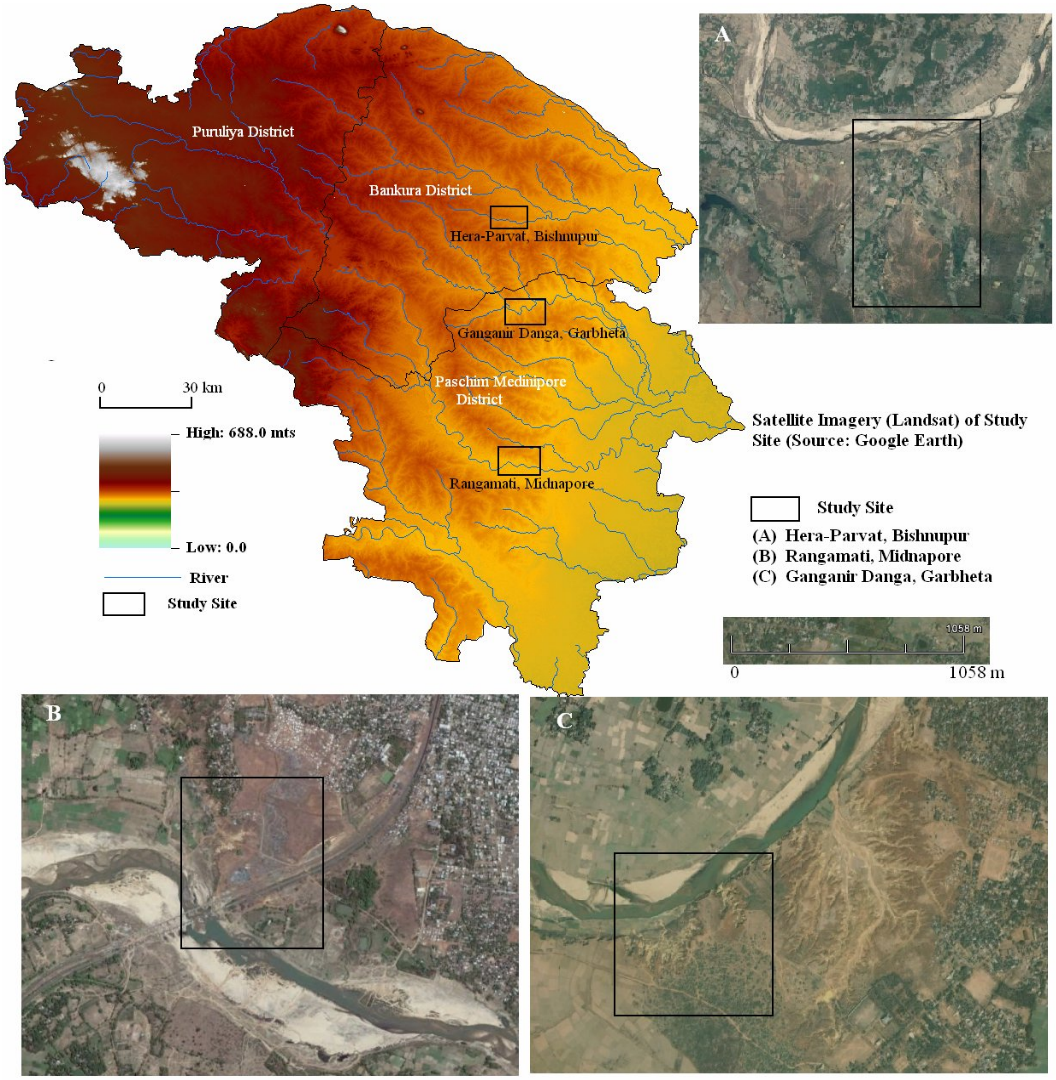

Fig. 1 : Location of study area

and Ganganir Danga was conducted between 2007 and 2012 respectively (Fig 1). In each gully basin area fixed points were demarcated by bamboo sticks (Shit and Maiti, 2012). The methodology of ground-based photographic monitoring that has been used for this analysis is based on work by Suwa and Okuda (1988); Calvo-Cases and Harvey (1996), Calvo-Cases et al., (1991), Boerma (1999), Grove and Rackham (2001), Hall (2001), Herweg and Steiner (2002), and Lätt (2004), and Shit et al. (2013). The sequential photographs were analyzed to represent temporal variations in surface properties, rill networks, gully head cuts, crack pattern, surface roughness and mass failures. Rill network on each photograph has been assigned an index value on an arbitrary scale (ranges 0 to 10) to express the degree of development based on rill density, bifurcation and continuity. For each index, low value relate to weak development of the particular property. Each set of photographs were cross-checked to ensure internal standardization. Every single set was checked again to achieve consistency throughout data. Daily precipitation data from two rainfall stations were used for analyzing the correlation of gully retreat to rainfall during the study period.

4. Results and discussion

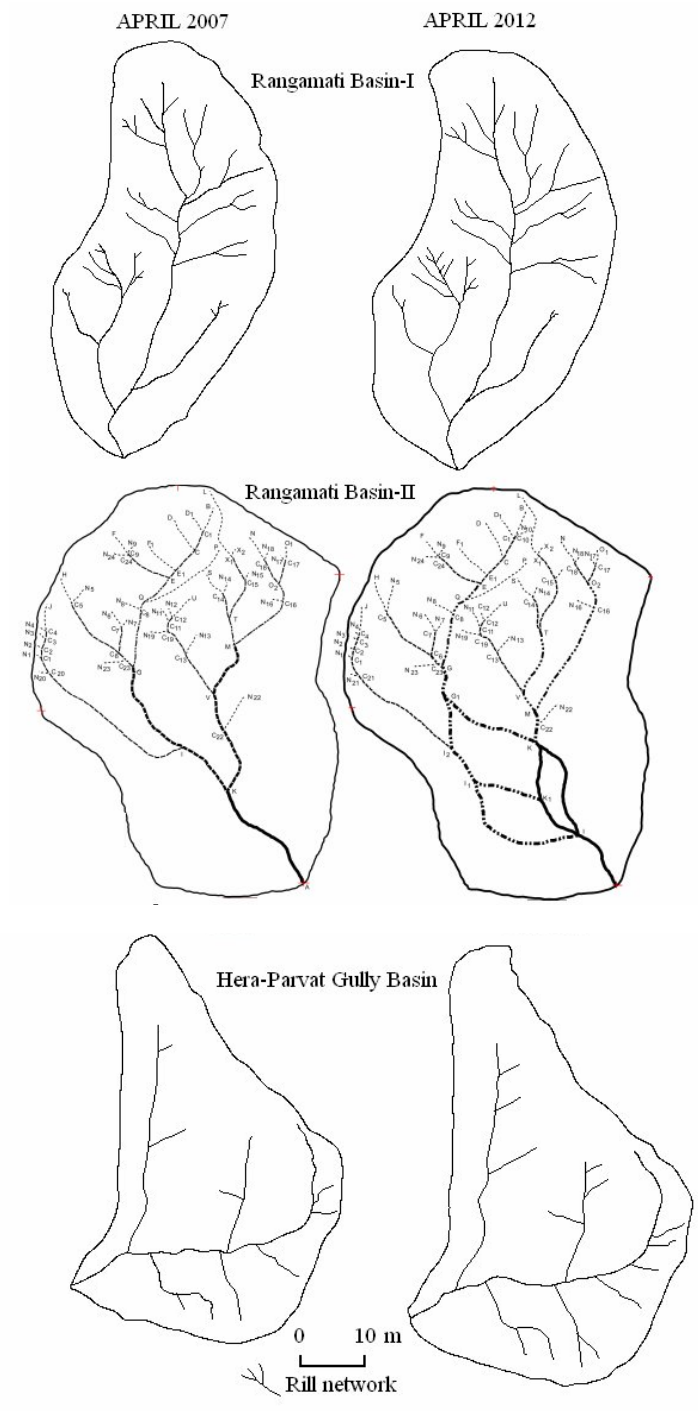

Fig. 2 : Rill networks at beginning and end of the study period

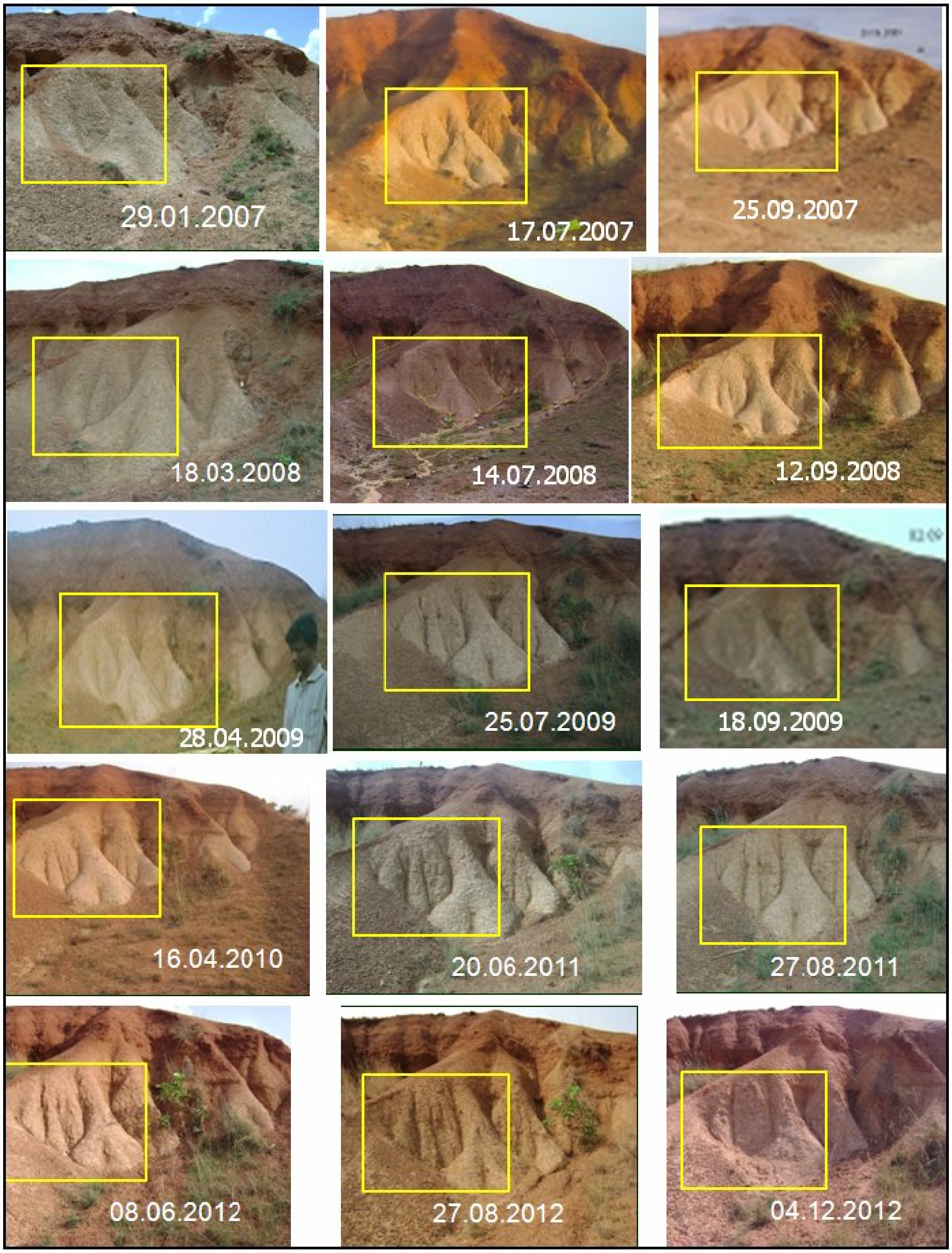

Fig. 3 : Selected sequence of morphological change at Rangamati Plot-I

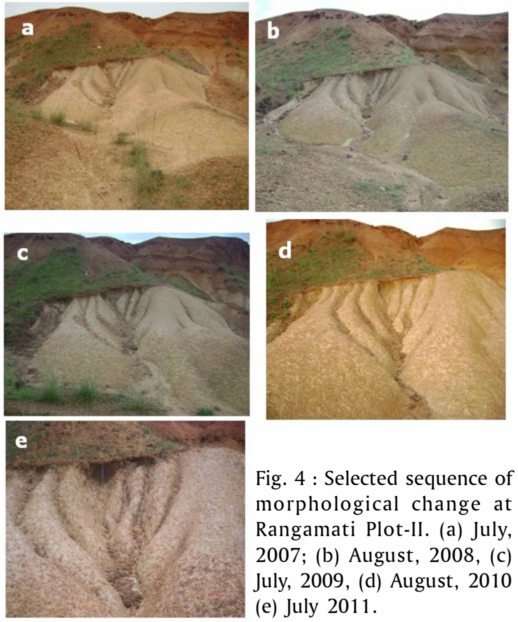

Fig. 4 : Selected sequence of morphological change at Rangamati Plot-II. (a) July, 2007; (b) August, 2008, (c) July, 2009, (d) August, 2010 (e) July 2011.

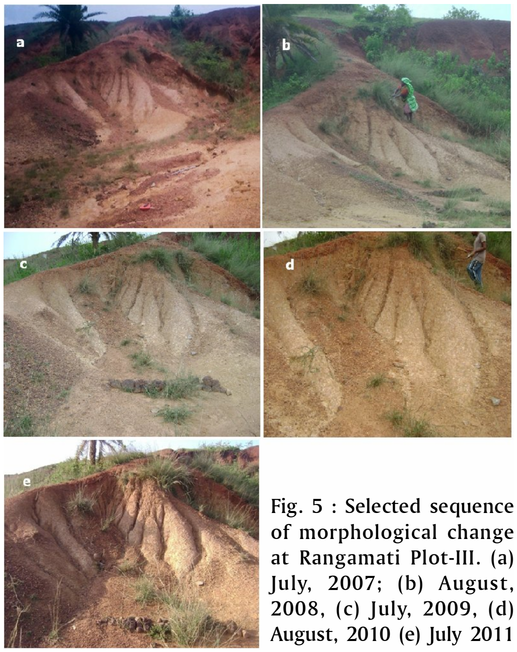

Fig. 5 : Selected sequence of morphological change at Rangamati Plot-III. (a) July, 2007; (b) August, 2008, (c) July, 2009, (d) August, 2010 (e) July 2011

4.1 Rangamati badland

At Rangamati badland, we observed two gully basins and three plots are reflected by the contrasted behavior. Rill network developments are represented in figure 2 to 5. Rills are well developed during the pre-monsoon period and these were destroyed during the monsoon period (rainy season) due to the higher swelling rates, and causing increases in surface roughness. Rangamati-I and II is on a low gradient slope with vertical pipes related to tension cracks and a thin regolith cover (Fig 6). The clarity and development of the rills varies intensely with cracks index, as the cracks inlets open. Surface roughness behavior shows a similar temporal change, but on this plots it is more closely related to erosonal pinnacles and splash processes than to swelling. Plots are represents conditions on steep slopes with rills and rill pipes and a deeper regolith (Fig 3, 4 and 5). In both the plots and gullies basin studies, the development of rills is strongly correlated with rainfall ($r^2 = 0.75$), local base level ($r^2 = 0.51$), surface materials ($r^2 = 0.62$), and slope gradient ($r^2 = 0.78$). The main changes of rill network during monsoon period were started through down cutting and concentrated runoff on the main gullies seems to be the most important factor controlling the evolution at Rangamati badlands topography. The geomorphic factors reveal that rill initiations are caused by the flow, the roughness of the soil surface, the slope gradient, and the erodibility of the soil. Similar results obtain by Favis-mortlock *et al.,* (2000), and Mancilla *et al.,* (2005), who studied the geomorphic factors influencing the location and geometry of rills and are also related to the variability of soil properties and the landscape. Shit et al., (2013) reported that rill detachment potential includes three processes, i.e. rill incision (rill deepening), headwall cutting (rill lengthening) and sidewall soughing (rill widening) (Fig 3, 4, 5). As soon as a channel develops, vertical head cuts are formed. Subsequent periods of incision can cause the head (or Knick) of the initial erosion feature to progress up-gully. Concentration of flow during storms and intense monsoon spells increases peak flow and so the severity of gullying processes is increased. Thus, once the gully is formed it rapidly develops and extends up-slope. The growth and development of the gullies is auto catalytic and regenerative in nature, the large they grow, and the more flow they attract and faster they develop and extend in Rangamati badland.

4.2 Here-Parvat badland

The analysis of our results shows sixty (60) morphological sequences with very low temporal variations at Here-Parvat gully basin area (Fig 7, 8). Rill network development is represented in figure 2. The result shows very little net change, consisting only of the disappearance of some tributary rills and the formation of other new ones. The rill sequence to

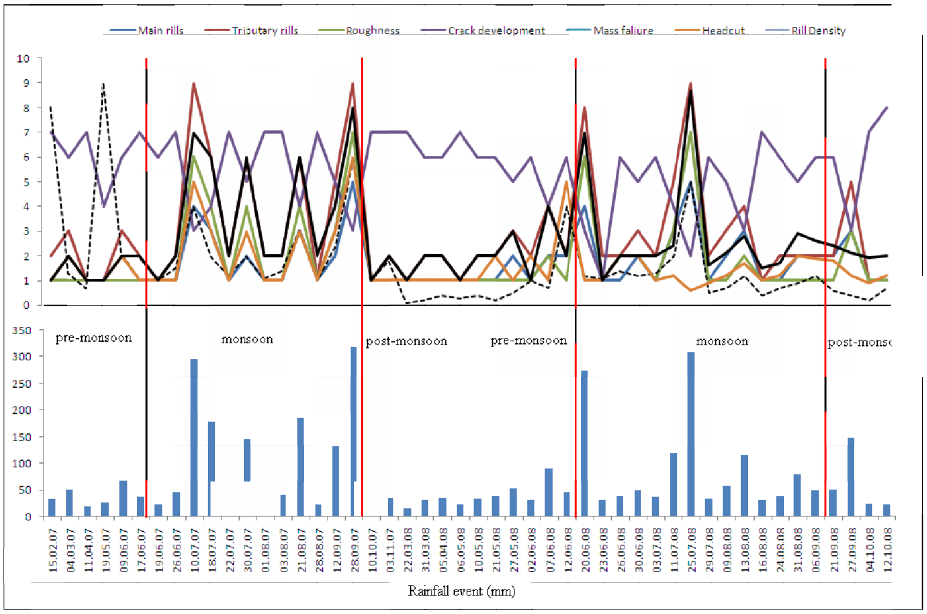

Fig. 6 : Rainfall event (mm) and morphological change at Rangamati Badland

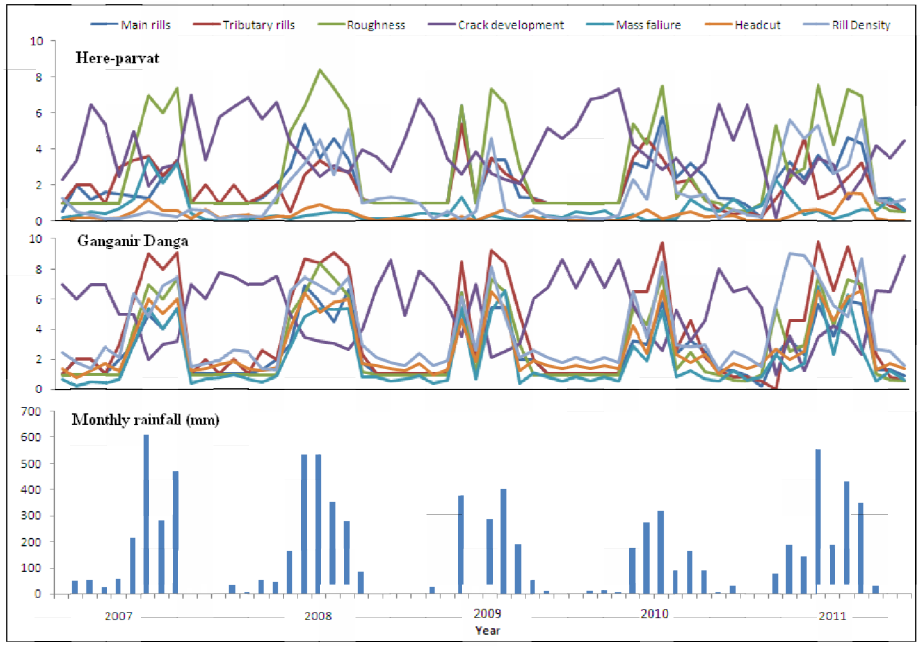

Fig. 7 : Rainfall (mm) and morphological change at Ganganir Danga and Here-parvat Badland

rainfall illustrates only small fluctuations of rill index over the study period. Generally, rills are developed rainy season (July to august) in every year (Fig 7). The low rate of swelling is evidenced by the few changes in rill density, rill headcut, crack density and surface roughness. Despite the low rate of morphological change, erosion rates were high which demonstrated by the temporal changes in accumulation of sediments on the main gully bottoms.

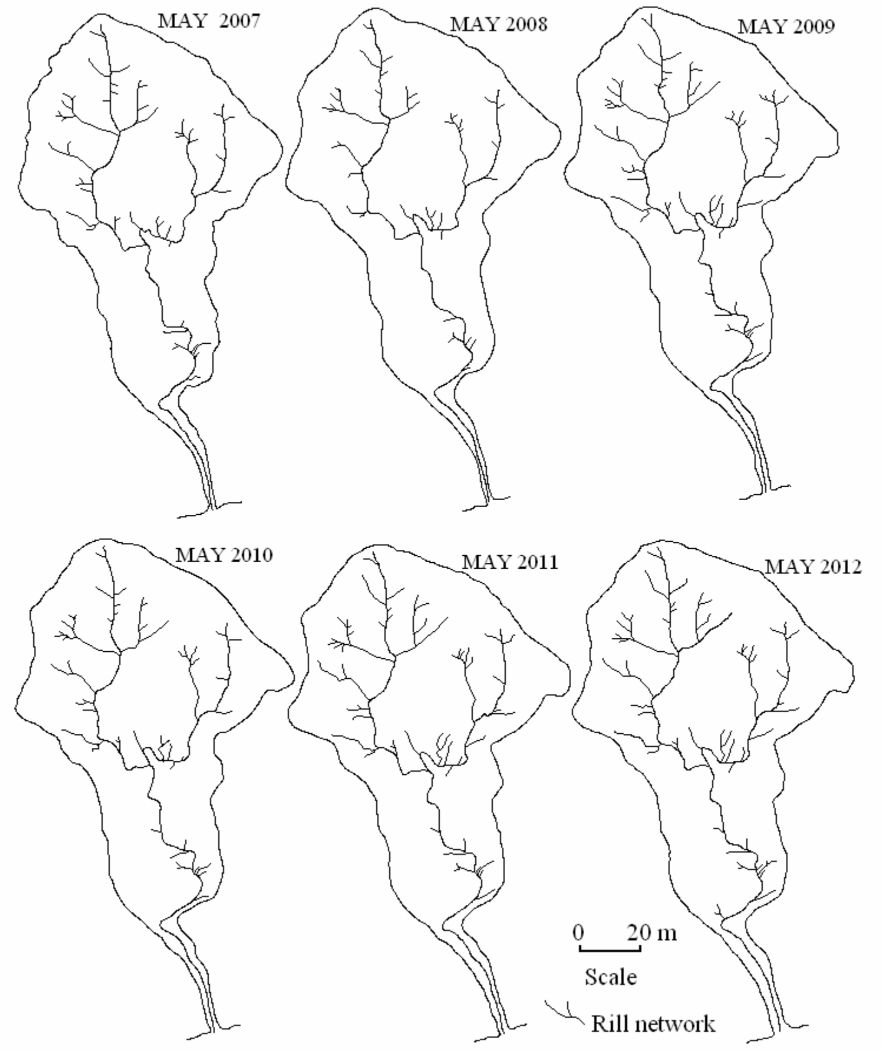

Fig. 8 : Sequence of rill networks change at Ganganir Danga (Garbheta)

4.3 Ganganir Danga badland

At Ganganir Danga the range of morphological situations were reflected especially by regolith thickness (Fig 9). The available sixty dataset during 2007 to 2011 shows short-term changes in gully morphology (Fig 8). Together with climatic characteristics, intrinsic geomorphological factors also seem to be responsible for the morphological changes. During the rainy period with some storms, there were failures and the removal of regolith cover. Heavy rains events (Table II and Fig 9) produced subsidence and mudflows that removed surface materials and filled up the main gully bottoms. Subsequent rains started to generate new tributary rills or gullies and complete the sequence of morphological change (Fig 7).

Figure 9 represent the mass failures occur at channel head and along steep sidewalls of gullies. Failure of near vertical walls at the steam head results in channel extension, while widening of gullies due to bank slumping contributes to total gully sediment yield. Sidewall erosion has been shown to be responsible for more than half of the gully volume in Ganganir Danga badland (Shit et al., 2013). Failure of steep channel heads and sidewalls occurs when the driving forces exceed resisting forces. Similar results were obtained by Bradford and Piest (1985) who studied

Table-2 : Subsidence / Landslide areas (Ganganir Dnaga)

Rainfall events (days)	Rainfall (mm)	Subsidence (Area sq m)	Landslide / Subsidence days
6	319.00	72	28.09.2007
11	309.80	92	25.07.2008
2	189.80	110	27.05.2009
1	100.80	58	25.08.2009
14	352.60	119	14.08.2011

Fig. 9 : Selected sequence of morphological change at Ganganir Danga. (a) Mass failures at along gully sidewall, (b) Channel head extension due to subsidence on 27.05.2009, (c) Subsidence on 14.08.2011, (d) Undercutting at gully wall and gully head.

the gully morphology. Gully heads and walls are loaded by three different forces: (i) the weight of the soil, (ii) the weight of water added by infiltration and (iii) seepage forces of percolating water. The change in water content is important, because it has a strong influence on the shearing resistance of the soil and the shear strength is also influenced by wetting-drying cycles in the present studies. Vertical tension cracks tend to decrease the overall stability by reducing cohesion and when these cracks are filled with water the pore water pressure increases dramatically, often resulting in failure. The stability of sidewalls can also be influenced by undercutting during periods of flow, even if flows do not reach bankfull of gully.

However, field observation indicated that abrupt gully heads (vertical headwall) developed from secondary

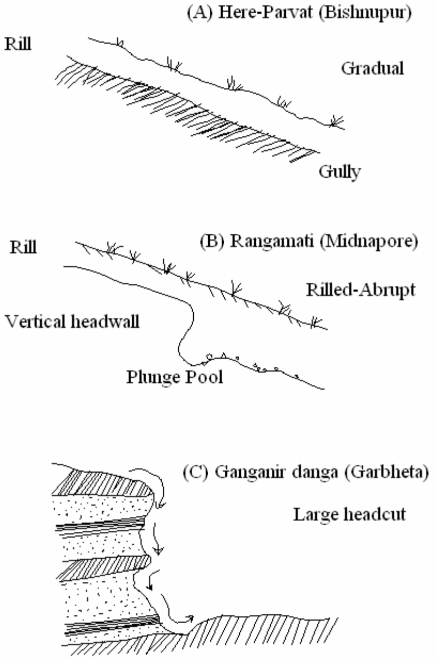

Fig. 10 : Development of Rill or Gully

headcuts (knick points) in the channel, which migrated upstream gradually during rainy season at Ganganir danga. The abrupt gully heads were always formed in more than one soil layer, of which one was a resistant (lateritic or stony) layer (Fig 10). Field data also indicated that gradual type headcuts were essentially controlled by fluvial processes, whereas abrupt headcuts were controlled by a combination of fluvial and mass-wasting processes. The rilled abrupt types at Rangamati are still actively retreating until the knick point reaches the most upstream point of incision.

5. Conclusion

Gullying is a complex and relatively frequent process. Results from field investigations indicated that badland morphology influenced by material properties, climatic condition. Climatic condition at Rangamati badland and Ganganir danga work as a trigger for specific processes dry period with low frequency heavy rains causes rill destruction, leading to more uniform percolation of water, favour rill or gully development. Further studies are necessary in order to define improved models of gully expansion and to design valid countermeasures, but the hydraulic processes involved in gully formation and growth should be taken into more consideration than in the past.

References

Bandyopadhyay S. 1998. Drainage Evolution in Badland Terrain at Gangani in Medinipur District, West Benagl," Geographical Review of India, 50(3):10-20.

Boardman J. & Poesen J., 2006. Soil Erosion in Europe.Wiley, Chichester, UK: 855 pp

Boerma, P. 1999. Seeing the wood for trees: deforestation in the Central Highlands of Eritrea since 1890. Unpublished PhD thesis, Oxford University.

Bradford, J.M., and Piest, R.F. 1985. Erosional development of valley-bottom gullies in the upper Midwestern United States, In: Coates, D.R. and Vitek, J.D. (Eds.) Thresholds in Geomorphology, Allen & Unwin, London, 75-101.

Bryan, R.B., Yair, A., 1982. Badland Geomorphology and Piping. Geobooks, Norwich. 407 pp.

Bull JL and Kirkby JM. 2002. Channel Heads and Channel Extension, In: L. J. Bull and M. J. Kirkby, Eds., Dryland River: Hydrology and Geomorphology of Semi-Arid Channels, Wiley, Chichester, pp. 263-287.

Calvo-Cases, A., Harvey, A.M., 1996. Morphology and development of selected badlands in SE Spain: implications of climatic change. Earth Surface Processes and Landforms 21, 725 – 735.

Calvo-Cases, A., Harvey, A.M., Paya Serrano, J., 1991. Process interactions and badland development in S.E. Spain. In: Sala, M., Rubio, J.L., Garcia-Ruiz, J.M. (Eds.), Soil Erosion Studies in Spain. Geoderma Ediciones, Logrono, pp. 75 – 90.

Campo-Besco´ S, M. A., J. H. Flores-Cervantes, R. L. Bras, J. Casalý´, and J. V. Gira´ ldez. 2013. Evaluation of a gully headcut retreat model using multitemporal aerial photographs and digital elevation models, J. Geophys. Res. Earth Surf., 118, 2159–2173, doi:10.1002/jgrf.20147.

De Ploey, J. (1990), Threshold conditions for thalweg gullying with special reference to loess areas, Catena Suppl., 17, 147–151.

Favis-Mortlock, D.T.; Boardman, J.; Parsons, A.J.; Lascelles, B. 2000. Emergence and erosion:a model for rill initiation and development. Hydrological Processes 14: 2173–2205.

Govers, G., Giménez, R., & Oost, KVan. 2007. Rill erosion: exploring the relationship between experiments, modelling and field observations. Earth Science Reviews, 84(3-4), 87-102. http://dx.doi.org/10.1016/j.earscirev.2007.06.001.

Grove, A.T., Rackham, O., 2001. The Nature of Mediterranean Europe: An Historical Ecology. Yale University Press.

Hall, F., 2001. Ground-based photographic monitoring. Gen. Tech. Rep. PNW-GTR-503. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 340 pp.

Herweg, K., and Steiner, K., 2002. Impact monitoring and assessment. 48 p. Bern, CDE, and Eschborn, GTZ.

Howard, A.D., 1994. Badlands. In: Abrahams, A.D., Parsons, A.J. (Eds.),Geomorphology of Desert Environments. Chapman and Hall, London, pp. 213–242.

Lätt, L., 2004. Eritrea re-photographed. Landscape changes in the Eritrean Highlands 1890–2004. Unpublished MSc thesis, University of Berne.

Mancilla, G. A., Chen, S., & McCool, D. K. 2005. Rill density prediction and flow velocity distribution on agricultural areas in the Pacific Northwest. Soil and Tillage Research, 84, 54-66. http://dx.doi.org/10.1016/j.still.2004.10.002.

Marzolff I, Poesen J, Ries J.B. 2011. Short to medium-term gully development: Human activity and gully erosion variability in selected Spanish gully catchments. Landform Analysis, 17: 111–116

Marzolff I., Ries J. B. & Poesen J., 2011. Short-term vs. medium-term monitoring for detecting gully-erosion variability in a Mediterranean environment. Earth Surface Processes and Landforms 36: 1604–1623.

Nadal Romero, E., Latron, J., Lana-Renault, N., Serrano-Muela, P., Martí-Bono, C., Regüés, D. 2008. Temporal variability in hydrological response within a small catchment with badland areas, Central Pyrenees. Hydrological Science Journal, 53, 629-639.

Nadal Romero, E., Regüés, D. 2010. Geomorphological dynamics of subhumid mountain badland areas - weathering, hydrological and suspended sediment transport processes: A case study in the Araguas catchment(Central Pyrenees) and implications for altered hydroclimatic regimes. Progress in Physical Geography 34 (2):123-150.

Poesen J., Nachtergaele J., Verstraeten G. & Valentin C., 2003. Gully erosion and environmental change: importance and research needs. Catena 50: 91–133.

Poesen J., Vanwalleghem T., de Vente J., Knapen A., Verstraeten, G. & Martínez-Casasnovas J.A.,2006. Gully Erosion in Europe. In: Boardman J. & Poesen J. (eds.) Soil Erosion in Europe. Wiley: 515–536.

Ries J.B. & Marzolff I., 2003. Monitoring of gully erosion in the central Ebro Basin by large-scale aerial photography from a remotely controlled blimp. Catena 50: 309–328.

Seeger M., Marzolff I. & Ries J.B., 2009. Identification of gully-development processes in semi-arid NE Spain. Zeitschrift für Geomorphologie 53(4): 417–431.

Shit P K. and Maiti R K. 2012. Mechanism of Gully-Head Retreat—A Study at Ganganir Danga, Paschim Medinipur, West Bengal. Ethiopian Journal of Environmental Studies and Management. 5(4). 332-342.

Shit P K. and Maiti R K. 2012. Rill Hydraulics—An Experimental Study on Gully Basin in Lateritic Upland of Paschim Medinipur, West Bengal, India. Journal of Geography and Geology, 4(4):1-11. doi:10.5539/jgg.v4n4p1

Shit P K., Bhunia G. and Maiti R K. 2013. Assessment of Factors Affecting Ephemeral Gully Development in Badland Topography: A Case Study at Garbheta Badland (Pashchim Medinipur. International Journal of Geosciences 4(2) 461-470. doi: 10.4236/ijg.2013.42043.

Suwa, H. and Okuda, S. 1988. Seasonal variations of erosional processes in the Kamikamihori Valley of Mt. Yakedale, Northern Japan Alps', in Harvey, A. M. and Sala, M. (Eds), Geomorphic Processes in Environments with Strong Seasonal Contrasts, Vol. II Geomorphic Systems, Catena, Suppl. 13, 61-77.