GEOGRAPHIA POLONICA
2011, 84, Special Issue Part 2,
117–126

EVOLUTION OF THE PAGLAJHORA SLUMP VALLEY IN THE SHIV KHOLA BASIN, THE DARJEELING HIMALAYA, INDIA

SUBIR SARKAR
Department of Geography and Applied Geography,
North Bengal University, Dist. Darjeeling, Pin. 734013, India
E-mail: subirsnbu@yahoo.co.in

Abstract: The morphologic configuration of the Paglajhora slump valley is controlled by geologic structure and remodelled by the hydro-geomorphic processes. The slope forms exhibit a combination of convex – concave – irregular profiles with highly variable inclination (10° to 35°). Overland flow feeding the uppermost niche during heavy rains transformed into concentrated sub-surface flow over the permeable colluvium. The observed rills and cracks facilitate the piping and deep drainage towards the slumped areas. The high intensity of the processes as well as the relative heights and steep gradients are the limiting factors in the stabilization of the Paglajhora slumps. At present, the form reached quasi-unstable equilibrium. Each extreme rainfall (above 300 mm/day) causes substantial changes in its morphology.

Key words: landslide, slump, quasi-unstable equilibrium, colluvium slope, palaeo-landslides, high intensity rainstorm, Darjeeling Himalaya, India.

INTRODUCTION

The Shiv Khola River (a tributary to the river Mahananda) basin is situated in Kurseong sub-division of Darjeeling district at the margin of the Sikkimese Himalaya rising above the Bengal Plain (Fig. 1). The amplitude of the basin is 1,765 m (2,045 m at the source in Mahaldiram ridge and 280 m at the sub-basin mouth). The length of the master stream is 8.84 km and thus the average slope of the Shiv Khola River has been estimated to be 11.8°. The total basin area is 22.12 km^2, out of which 8.967 km^2 is under tea plantation, 4.31 km^2 is under reserve forest, and 7.48 km^2 is under shrubs and scatter terrace field. The upper part of the Shiv Khola valley, called Paglajhora, is occupied by a large landslide (Fig. 2).

The Hill Cart Road (NH-54) and Darjeeling Himalayan railway cross this area twice (lower and upper Paglajhora) travelling 10.5 km. A number of water pipe lines, telephone lines and power transmission lines also pass through the region. Linear pattern of settlement with moderate density developed along the road.

The hillslope around Paglajhora is notorious for its slump/subsidence history that was initiated during the 1950 landslips in Darjeeling hills (based on available records). Since 1980, the incidences of slumping have become regular phenomena, and by 1990 the Paglajhora slumps caused complete disruption of transport and communication. The situation has deteriorated further in recent years putting a big question mark on the very existence of this vital link between the hills and the plain.

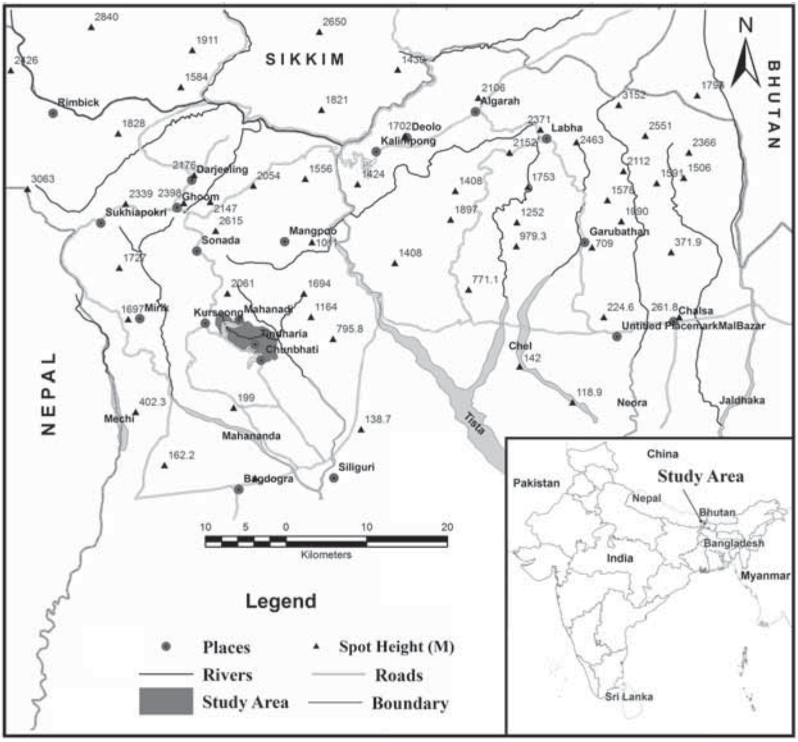

Figure 1. Location of study area.

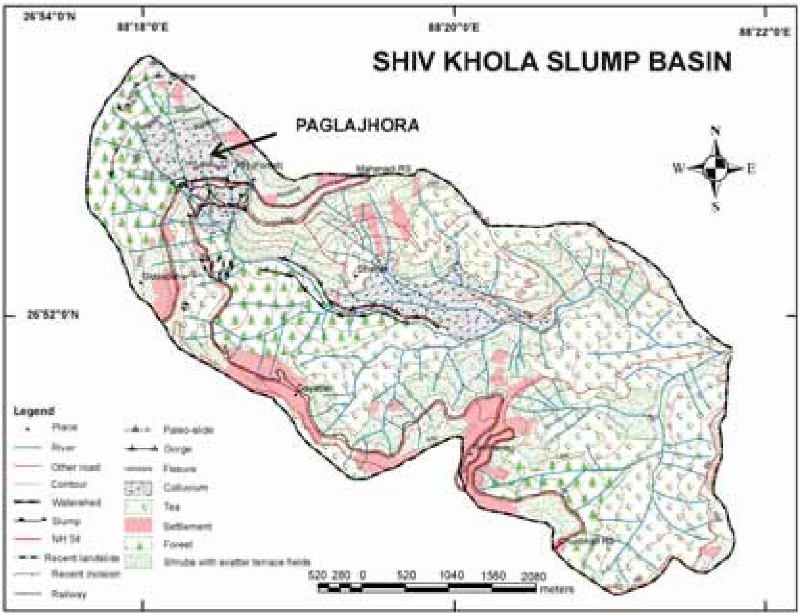

Figure 2. The Shiv Khola basin with the Paglajhora slump valley

PREVIOUS WORK

The subsidence of Paglajhora (23rd Mile Post), stretching to a length of 500 m, was first recorded by G.N. Dutta of Geological Survey of India (G.S.I.) in 1966. Dutta concluded that *evidences show that during 1950 disastrous landslips in Darjeeling hills, a moderate slip also occurred along the main jhora. Subsequently, the river follows an underground channel and drains between the impervious parent rock (gneiss) and course deposited materials. This led to creep which intensified during rainy period* (Dutta, 1966).

Author investigated the lower Paglajhora slump at regular intervals in between 1983–1987 and occasionally till 2010. The rate of slumping, as measured with reference to the Railway Benchmark at Lower Paglajhora, is shown in Table 1.

Table 1. Rate of movement of the Paglajhora slump.

Years	Rate of slump motion* (m)
1983–1984	1.10
1984–1985	0.82
1985–1986	1.03
1986–1987	1.51
1987–1993	8.07
1993–2003	14.54
2003–2010	11.52

* Measurement made at Lower Paglajhora from Railway BM

Thus, over 38.52 m subsidence took place during the last 27 years. The slumping has also been affecting the upper Paglajhora area, however, no precise measurements of such movement have been made so far.

GEOLOGICAL SETTING

The area is composed of rocks belonging to the Darjeeling gneiss. The rocks comprise golden-silvery mica schist and coarse-grained gneiss. They are also cut by quartz and quartzo-felspathic veins belonging to both post- and pre-tectonic periods. The rocks are well jointed and highly metamorphic in nature. The appearance of coarse textured golden-silvery mica schist with large flakes of yellowish brown biotite is rather abrupt though incipient development of biotite is noticed along the lower altitude. The schists are highly sheared and at places show prominent influx of quartzo-felspathic materials. The coarse-grained gneiss is found mostly as schistose and at some places in gneissic texture. The rock has attained very coarse texture due to influx of a considerable amount of quartzo-felspathic material. The constituent minerals are muscovite, biotite, quartz, orthoclase, plagioclase, and kyanite. Due to tectonic deformation and shearing, the rocks show variable dips and strikes: the dominant strike directions are SSW, SW and WWS, and dips vary from 30° to 75° towards the NNE, NE and ENE.

RAINFALL

The upper Shiv Khola basin (called Paglajhora) is one of the rainiest parts in the Darjeeling Himalaya, thanks to its particular topographic position. Being situated along the southern slope of the towering Mahaldiram massif (2,200 m a.s.l.), the Shiv Khola valley (headwater of the Mahananda River) allows rain-bearing southwest monsoon wind to enter and strike, causing large amount of rainfall. Table 2 shows mean annual rainfall records available from the following nearby recording stations.

Table 2. Annual totals of precipitation in the study area.

Rainfall recording stations	Mean annual rainfall (mm)
Mahaldiram Tea Garden	4897.3
Victoria School	4257.9
Divisional Forest Office	4654.8
Goomti Tea Garden	3985.7
Lizziepur Tea Garden	3756.2
Goyabari Tea Garden	3641.0

Thus, on an average 4,198.8 mm rain falls in this area. The upper slopes receive more rain (above 4,500 mm) than the lower slopes (below 3,700 mm). Analysis of available rainfall data reveals that about 70–90 days experience only 1 to 10 mm rain per day out of the total 140 – 160 rainy days/year. Days having rainfall in between 10 to 80 mm/day contribute to 60% of the mean annual rainfall. Such rains often fall over consecutive days and cause good conditions for a continuous feeding of the groundwater reservoir. However, the most catastrophic events are initiated by the rains lasting for 2–3 days, amounting to as high as 800 mm with intensity reaching up to 100 mm/hour (based on 15 minute pluviometric chart at Dilaram), which often provide trigger mechanism for slope movement and slumping.

MORPHOLOGY OF THE UPPER SHIV KHOLA (PAGLAJHORA) SLIDING ZONE

The Shiv Khola basin exhibits a mosaic of micro-topographic forms developed by complex geomorphic processes. Slopes are very steep (25–43°). The valley slopes are more flat and open towards the ridge, but attain a steep gorge-like character along the lower slopes. The physical configuration is largely controlled by geological structure and remodelled by the hydro-geomorphic processes. A detailed map based on field observation has been prepared and depicted in Figure 2. Two kinds of slope forms have been identified: i) slope developed over bedrock, and ii) slope developed over colluvium.

i) Bedrock slopes are found to be steep (35° to 43°) and uniform in slope pattern. The bedrock slope is also found partially stable, as only a few mass movement scars have been identified during field survey. Bedrock slopes remain free from slip/slump even along the Hill Cart Road (2 km up and down of Mahanadi Railway Station). An attempt has been made to identify and locate such a kind of slope and to map it. It is also interesting to note that most of these parts retain dense vegetation cover. As such, no immediate conservation is recommended for these areas.

ii) During field survey, the North Bengal University team identified thick and extensive colluvial deposits that were precisely delineated. The deposits consist of gigantic gneissic boulders of above 40 m diameter strewn in the upper part of such slope. The size appears to be smaller (10–15 m diameter) in the middle and lower parts. The slope forms developed over such deposits have been found to be complex in nature and exhibit a combination of convex – concave – irregular form with highly variable inclination (10° to 25°). Abundant field evidence suggests that the Paglajhora active mass movement including slumping is directly related to this colluvial hill slopes form. A detail discussion in this regard is provided in the following section.

GENESIS OF PAGLAJHORA COLLUVIUM

The investigator, based on his earlier study in Bunkulung and Ambootia (Froehlich et al., 1992; Starkel and Froehlich, 2000), strongly believes that such colluvial material/debris was the product of gigantic palaeo-mass movements that took place along the southern margin of the Mahahaldiram massif even during the close of the Pleistocene. Such mass movements were probably caused by a catastrophic rainstorm. Existence of large palaeo-scars in the Mahahaldiram ridge (concavity in convex slope element) proves such contention (Fig. 3).

Huge materials released from the bedrock moved downhill, destroying the pre-existing hillslope equilibrium and drainage system and were finally deposited along the break of slopes. A modified hillslope with convexo-concave form was produced, on which drainage became re-established. Hillslope hydrological processes started to re-establish its balance.

Figure 3. Paleo landslide scar in the upper Shiv Khola basin (Mahaldiram Range)

Under favourable environmental conditions, re-vegetation took place rather quickly and the hillslope form reached the stage of an **unstable equilibrium.** Each extreme events (1 in each 500 to 1000 years as revealed from the analysis made by the author in other parts of the Darjeeling hills) of rainstorm caused substantial change in its morphology. Existence of boulder terrace, lichen rings, presence of illuvial horizon and decomposed tree trunk identified during field investigation proves such contention. However, precise dating of such an event has not been attempted due to lack of technical and infrastructure support.

Considering the importance of slope covered by matrix of loose coarse materials in Paglajhora area, a detailed mapping was done during the field survey. It has also revealed that most of slips and slumps along Hill Cart Road have been taking place on slopes mantled by colluvium.

HYDROLOGY

The rainfall is transformed partially into runoff due to high infiltration rate in the colluvium and deeply jointed bedrock in the study area. The short-distance overland flow on gentler colluvium/talus slope starts to occur after heavy rains, exceeding 50 mm. Measurements made at Ambootia and Bunkulung revealed that the soil can absorb 100 mm of rain. The daily rainfall exceeding 300 mm is a threshold value for the hydrologic capacity and for starting of flow of silt-sandy deposits as well as partly weathered bedrock including boulders (Starkel, 1972; Sarkar, 1999; Starkel and Basu, 2000; Froehlich et al., 2000). The increased seepage pressure enables the piping, too. At the margin of break of slope, the infiltration is even higher because of many cracks and fissures identified during the field survey.

Intermittent rains have facilitated the observation on the water circulation in the Paglajhora slumping zone during the field survey. These include the establishment of sources of subsurface feeding in the slumping zone by ground water, which flows out at various levels in the slump niches and forms a linear runoff in the valley.

To the northwest and northeast, a V-shaped valley exists being cut in the bedrock with perennial *jhora* (creek). In between these, the colluvial slope is drained by a number of non- uniform? *jhoras*. Some sections of these rivulets look dissected while gushing muddy water flows through the other sections. This conclusively proves that part of rainwater is distributed by a gravi-

Figure 4. Visible cracks and fissures facilitate the piping and deep drainage

tational water pipe in the upper Paglajhora valley. The run-off along the whole length of such dry channels follows only during heavy rainfalls and is of short duration.

Based on field observation it is suggested that overland flow feeding the uppermost niche during heavy rains transformed into concentrated sub-surface flow over the less permeable gneissic bedrock. The observed fissures and cracks facilitate the piping and deep drainage towards the slumped areas (Fig. 4). Thus, the sub-surface flow is connected with the continuous beds in the colluvial sequence and jointing of bedrock. It is probably much higher during heavy rains with superposition of an overland flow and with seepage pressure. The existing topography of the flattening suggests a subsurface runoff towards the SSE.

FORMATION AND STAGES OF EVOLUTION OF THE SLUMPED VALLEY

As already mentioned, the origin and stages of evolution of the Paglajhora slumped valley are probably related to gigantic palaeo-mass movements. Topographic expression including valley forms and slope morphology indicate that the Paglajhora (upper Shiv Khola) is an erosion valley over complex colluvium (Fig. 5). A valley form developing by long lasting mass movements was differentiated in space and time. Its continuous formation is controlled by very favourable coincidence of various factors:

- lithological (permeability),
- tectonic and neotectonic uplift (deep incision),
- palaeo-geomorphological (steep multi-stair slope),
- hydrological (groundwater reservoir in thick colluvium),
- meteorological (heavy rainfall with very high intensity).

The present-day variety of processes reflected in the forms and deposits indicate also that the various parts of active and instable valley and hillslopes are modelled by different leading processes and represent various stages of evolution.

Figure 5. Paglajhora (upper Shiv Khola) slump valley

EVOLUTIONARY HISTORY

The gigantic palaeo-mass movement (as mentioned earlier) along the southern margin of the Mahaldiram massif (elevation 1,700 to 2,200 m a.s.l., as revealed from the palaeo-scars) caused the transport of huge amount of debris towards the lower segment of the Shiv Khola/Paglajhora basin. Portion of this debris was deposited along the mid-slopes and transformed the pre-existing topography and drainage. Field observation reveals numerous sites with huge gneissic boulders even at an altitude of 1,550 m a.s.l. (Fig. 6).

The rivers started to incise rather rapidly under favourable conditions (supply of good amount of rain water and unconsolidated slope materials) and developed dendritic drainage pattern. The favourable climatic condition helped rapid re-vegetation, giving an apparent stability to the slope materials. Thus, a condition of unstable equilibrium in the Paglajhora had been achieved. Such stability often found to be disturbed by extreme events (very high-intensity rainstorms). Numerous pieces of evidence of palaeo-scars along the upper-middle segment of the valley and step-like forms bear mute testimony to such events. However, the recurrence interval of such events was perhaps at the magnitude of millennium. Hence, the relaxation period would be enough to maintain the unstable equilibrium among the hydro-geomorphic and biological processes.

A new chapter of intervention within the unstable equilibrium in the Paglajhora was initiated with the construction of the Hill Cart Road and Siliguri – Darjeeling Railway line, cutting across the Paglajhora colluvial slope twice. The history of the following years was dominated by unscientific, unplanned and illogical human intervention (settlements, slope cuts, terracing, tea garden and arable farming, modification of natural waterways, etc.). The accumulative stress reached the threshold limit causing series of slope movements including slumping in 1950.

Since 1950, the Paglajhora colluvial slope has experienced deleterious effect on man's inadequate intervention (retaining

Figure 6. Colluviums in the Shiv Khola basin

Figure 7. The Lower Paglajhora active slump

walls and other protective structure) on the one hand and ever increasing interference (settlements, arable farming, deforestation, overgrazing, heavy vehicle movement, diverting of *jhora*, etc.) on the other, with the natural hydro-geomorphic processes. The outcome has been found disastrous. Since 1980 onwards, the incidences of slumps have become a regular feature (Fig. 7).

During the field investigation, an attempt was made to demarcate the contact zone between the gneissic bedrock and the colluvial debris slope, fissures and crack zones, palaeo- and recent landslips and slumps, concentrated seepage, recent incision, land use and cover patterns (Fig. 2). Such an investigation not only helps to understand the mechanism, but also exerts decisive influence on suggested remedial measures.

There is enough circumstantial evidence (as mentioned above) to believe that the Paglajhora slides and slumps are essentially natural phenomena, common in other parts of the lower Darjeeling hills with such unstable equilibrium of slope processes. However, the very threat to the existence of the vital communication line between the hill and the plain is essentially man-induced.

PREDICTION AND RECOMMENDATIONS

The intensity of the processes as well as the relative heights and steep gradients are the limiting factors in the stabilization of the Paglajhora slumps. At present, the form reached quasi-unstable equilibrium. Extreme rainfall event (above 300 mm/day) causes substantial changes in its morphology. The expanding incised valley and reactivated scar along the upper section is a danger to the villages, Hill Cart Road and railway line. There is every possibility of further sliding and slumping in this area until the slip surface reaches bedrock, that is 5 to 10 m below the present surface.

The protection of the whole Paglajhora valley would be extremely difficult because of the cost and the continuous downcutting and undermining of the slope. The high delivery of coarse debris from the upper slopes could very easily destroy all anti-erosion work.

The Paglajhora active slip/slide and slump are found activated and aggravated by the combination of the following factors:

- steep slopes, thick (5 to 10 m) colluvium, bedrock cut by fractures and fissures,
- high-intensity rainfall,
- subsurface flow and piping,
- as well as anthropogenic factors, like: deforestation, overgrazing and heavy traffic.

In designing protective measures, one must keep in mind the mechanism of hillslope hydrological processes operating in colluvial slope – a unique of the Paglajhora kind. At this stage of study the following recommendations in this regard may be suggested:

i) The structural measures would not be effective unless the foundation laid into the solid bedrock, which is 5 to 10 m below the surface. It also puts additional stress, hinders free movement of water and increases pore water pressure. Unless extremely necessary, such structural measures should be avoided.

ii) The surface drainage of the Paglajhora is uneven, hummocky, and cut by deep fissures (as observed during field observation). Thus, all streams and temporary water courses are to be diverted from the threatened area. All springs issuing within the area, especially those at the base of break of slope, must be contained and diverted away through designed waterways. The ground surface should be levelled and un-drained depression be filled along with all cracks, so that a continuous runoff of surface water is ensured without disturbing grass cover.

iii) Prevention of un-regulated percolation should be ensured at every place by covering up the portion of the slopes (fissure, crack zone and depression as identified in Fig. 2), which may be protected by a layer of impervious materials like clay. Turfing should be encouraged on every bare and degraded slope. Afforestation is also beneficial as secretion from plant roots help the formation of soil. Small shrubby undergrowth affords better protection against infiltration. Rocky slopes with open joints can be made impervious by grouting.

CONCLUSIONS

It is now understood that slope instability vis-a-vis slumping in Paglajhora is essentially a natural hydro-geomorphic process operating on colluvial slope under the condition of unstable equilibrium. The extreme events cooperate in the transformation of slopes and river channels, and are followed by the formation of regoliths and armoring of channels. For the creation of large gaps on the slopes there are needed not only catastrophic landslide events but also the relaxation and transformation time with instability and continuous outflow of sliding masses.

Deleterious and extreme human intervention during the past hundred and fifty years into such unstable equilibrium system of the Paglajhora colluvial slope reduced the threshold limit of catastrophic process (i.e., slope instability and slumping), recurrence interval and the relaxation time for physico-biological adjustment.

Inadequate and half-hearted intervention (protective measures as adopted so far in this area) in this complicated system would be counter-productive. In fact, the structural measures so far taken in this area instead of improving the situation rather aggravated the problem as it happened since 1980 onwards.

Perhaps, only catchment area treatment based on sound plan of vegetation-slope-water management would help to obtain sustainable improvement of the situation that would provide long lasting impact. The aim of such an improvement programme would be:

- reducing deep penetration of rain water and sub-surface piping,
- ensure uninterrupted surface run-off,
- reducing run-off velocity.
- reducing of human intervention.

These would ultimately increase the threshold limit, recurrence interval of events and, thereby, relaxation time for physico-biological processes to achieve unstable equilibrium.

REFERENCES

Dutta, G.N. (1966), Landslides and soil erosion in the Kalimpong Subdivision, Darjeeling district, and their bearing on the North Bengal Flood, *Bulletin of the Geological Survey of India,* Series B, 15, 1: 62–69.

Froehlich, W., Starkel, L. and Kasza, I. (1992), Ambootia landslide valley in the Darjeeling hills, Sikkim Himalaya, active since 1968, *Journal of Himalayan Geology*, 3, 1: 79–90.

Froehlich, W., Soja, R. and Sarkar, S. (2000), *Generation of flood and sediment load,* in: Starkel, L. and Basu, S.R. (eds), *Rains, Landslides and Floods in the Darjeeling Himalaya*, Indian National Academy of Sciences, New Delhi, 115–123.

Sarkar, S. (1999), Landslides in Darjeeling Himalaya, India, *Transactions of the Japanese Geomorphological Union*, 20 (3): 299–315.

Starkel, L. (1972), The role of catastrophic rainfall in the shaping of the relief of the Lower Himalaya (Darjeeling Hills), *Geographia Polonica*, 21: 103–147.

Starkel, L. and Basu, S.R., (eds.) (2000), *Rains, Landslides and Floods in the Darjeeling Himalaya*, Indian National Academy of Sciences, New Delhi.

Starkel, L. and Froehlich, W. (2000), *Ambootia – An Example of Active Landslide Valley* in Starkel, L. and Basu, S.R. (eds.), *Rains, Landslides and Floods in the Darjeeling Himalaya,* Indian National Academy of Sciences, 88–96.

Paper first received: April 2011
In final form: August 2011