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Research Article

ROLE OF LITHOLOGICAL COMPOSITION AND LINEAMENTS IN LANDSLIDING: A CASE STUDY OF SHIVKHOLA WATERSHED, DARJEELING HIMALAYA

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ABSTRACT

The lithological composition and lineaments plays a significant role in landslide activities over mountain slope. In the present study of the Shivkhola Watershed, Darjeeling Himalaya, the existence of lineaments in seven lithological groups and their varying response to atmospheric processes have made the concerned study area more vulnerable to landslip. The lithological map of Shivkhola Watershed was collected from *Geological Survey of India* (GSI) and it was incorporated with *landslide inventory map* to assess the *landslide potentiality* for each lithological unit. The lineament map was extracted with the help of remote sensing (RS) and Geographic Information System (GIS) and it was also compared with distribution of landslides. The study revealed that the potentialities of landslides in the Shivkhola Watershed are closely associated with fragile lithological composition and high intensity lineaments.

Keywords: *Shivkhola Watershed, Lithology, Lineaments, Landside Potentiality, RS and GIS*

INTRODUCTION

Tectono-statigraphically, the study area, Shivkhola Watershed (Fig.1) is located in the southern escarpment slope of Darjeeling Himalaya, where high grade metamorphic rocks of the Darjeeling and Chungthang groups are thrusted over low grade metamorphic rocks of the Daling Group along the *MCT* (Main Central Thrust, Mallet, 1875; Sinha-Roy, 1982). Main Central Thrust *(MCT)* and Main Boundary Thrust *(MBT)* are passing through the study area (Fig.2). The *MCT* (a major ductile shear zone) has divided two major litho-tectonic units, the Higher Himalayan Crystalline Sequence *(HHCS)* and the Lesser Himalayan Sequence *(LHS) in Darjeeling Himalaya*. The *HHCS* comprises quartzo-feldspathic gneisses of both igneous and sedimentary origin which suffers high grade of metamorphism (Neogi *et al.*, 1998 and Catlos *et al.*, 2001). The *LHS* is dominated by garnet-biotite-mica schist and chlorite schists in the upper and slates and phyllites in the lower part. The picturesque landslide affected areas are Paglajhora, Tindharia, Mahanadi, Jogmaya and Shiviter. In these areas, the rock foliation and orientation of faults are favourable (Paglajhora top) which are dipping towards the road and are favourable for the initiation of slide. During rainy season water percolates through the exposed rock joints and entrains the finer particles and reduces the cohesive strength of the soil.

Researchers (Ghosh, 1950; Nautiyal, 1951, 1966; Dutta et al, 1966; Roy and Sensharma, 1967; Basu, 1985, 1987 and 2001; Paul, 1973; Sinha, 1975; Sengupta, 1995; Basu and De, 2003; Pal, 2006; Maiti, 2007; Ghosh, 2009b; and Sarkar, 2011) carried out a demand oriented studies in Darjiling Himalaya and identified the causes and consequences of major landslide occurrences phenomena. In the Shivkhola Watershed, Lower Paglajhora, Tindharia, Shiviter and Mahanadi are the major and prominent landslide location sites where settlement, communication lines, and tea garden area are being affected severely by frequent occurrence of landslide phenomena. Since 1968, Paglajhora alone received 10 landslide events out of total 16 landslide events year and most of the landslides became risk full as in most of the events Hill Cart Road (NH-55) got affected and there was a complete cut-off of the communication linkage between Siliguri and Darjiling from few days to few months. Recently, Paglajhora sinking zone faced few massive slope failures in 1998, 2002, 2005 and 2011 which has proved the region as more dynamic in nature due to gradual and continuous spatial expansion of the slided area.

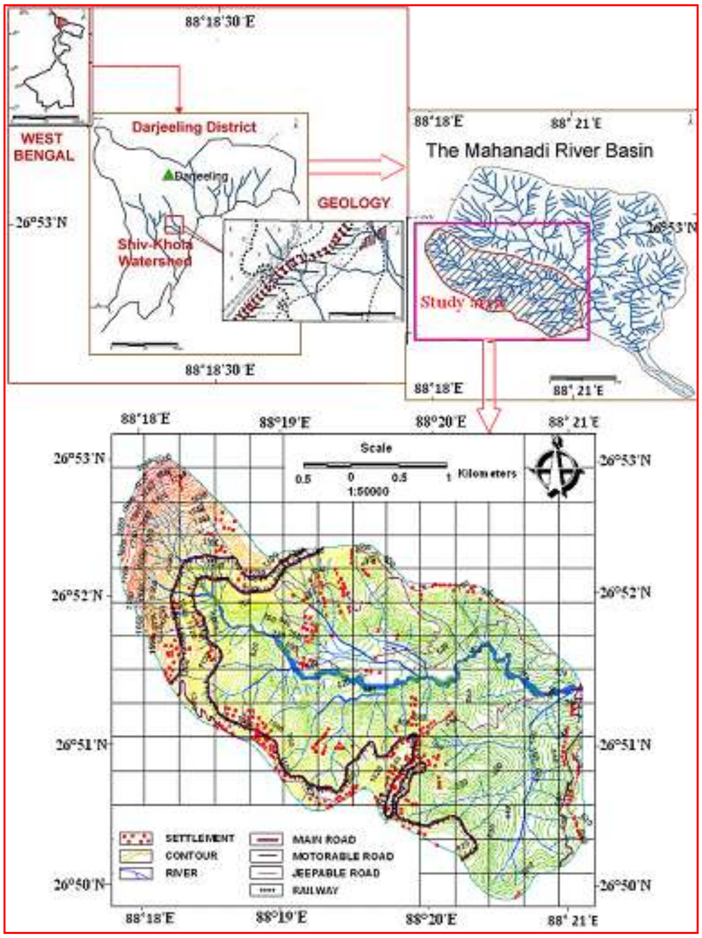
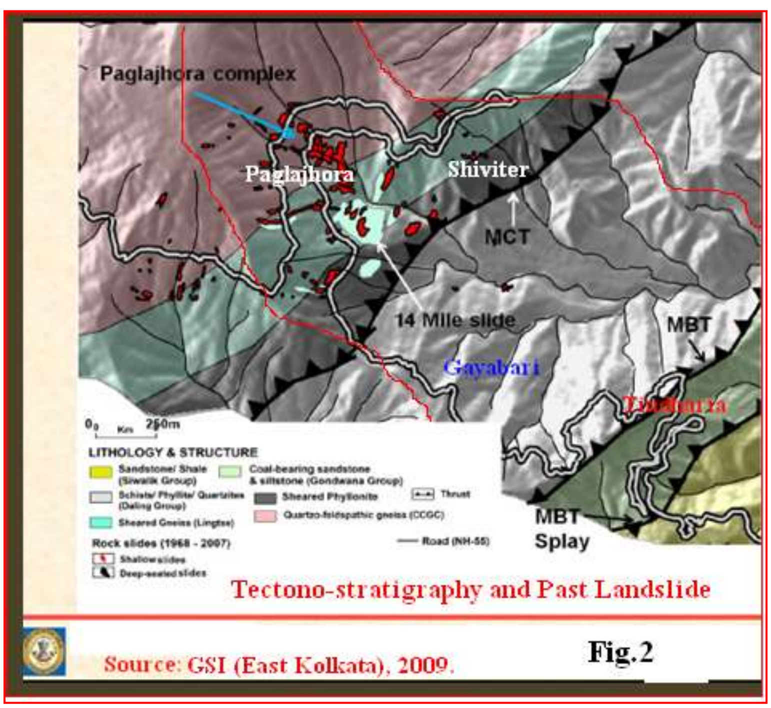


Figure 1: Location map of the Shiv-Khola Watershed



Physiographic configuration (arcuate) which provides a favourable condition to produce hydrostatic pressure, proximity to Main Central Thrust (MCT) and Main Boundary thrust (MBT), intensely fractured and sheared nature of the bed rock, toe cutting and headward erosion of debris covered slope by first flowing tributaries, immense pressure over the fragile slope materials by man-made concrete structure, moderate to steep slope gradient, improper drainage network orientation and accumulation of highly anisotropic materials with a great thickness and low shearing resistance have made the Shivkhola watershed most unstable to landslide.

In the Shivkhola Watershed, all the landslides are closely associated with lithological composition and existence of lineaments. The lineament exhibits the zone of weakness surface providing some linear to curvilinear features such as fracture, joint, fault etc. in the geological structure. The occurrences of fractures, faults and joints in connection to the geology play an important role in initiating landslide phenomena in the hilly areas. In the present study, all the plane of weakness was being mapped with the help of satellite data using digital image enhancement technique on GIS platform. The joint, fracture, fault etc. not only destabilize the land surface but also encourage the different weathering processes to disintegrate and decompose the rock beds. Consequently, the weathered materials easily are being saturated and decrease its consistency and become more vulnerable to slope instability condition. The existences of lineaments in different lithological units were studied and a relationship was established between landslide, lithology and lineaments. The study revealed that the probabilities of landslides are high at the places characterized by high density of lineaments and fragile lithological composition.

MATERIALS AND METHODS

Lineament Extraction:

For the extraction of the lineament of the Shivkhola watershed PCI-GEOMATICA Software of GIS has been used. In the extraction process 3 bands of wavelength have been taken into consideration viz. Band-I (Infrared), Band-II (Red) and Band-III (Green). But, in the study Near Infrared (0.7-1.3 µm), Red (0.6-0.7 µm) and Green (0.5-0.6 µm) have been used as Red, Green and Blue respectively. The infrared band is very much suitable for lineament extraction, but other two bands have been used here to get the same. The common occurrences of lineament from the later two bands and the lineament from the infrared band have been applied to prepare the final lineament map. The algorithm used in preparing the lineament map is 'lineament extraction'. To extract the lineament *Isotrophic* and *Anti-isotrophic* filter were taken into account as the parameters of algorithm.

Lithological composition:

The lithological map of the concerned study area was collected from Geological Survey of India (GSI), Kolkata (Eastern Region) and then necessary modifications were being incorporated after thorough field investigation. Final lithological map was prepared with seven rock groups and transformed into raster value domain on ARC GIS platform. Each and every lithological group responds differently whenever it exposes to atmospheric processes and also produces varying magnitude of landslide susceptibility/Landslide Potentiality. Darjiling Gneiss (A), Reyang formation (E) and Swialik (G) associated with highly foliated gneiss, mica-schists and occasional bands of flaggy quartzites and granulitic rocks, slates phyllites with occasional quartzite, quartz-schists and greywake schists, soft grayish sandstone, mudstone and shales and conglomerate along with thin bands of marly shales and lignite almost cover > 60% area of the Shivkhola watershed. Chungtung Formation (B) with Calc-granulitie, marble, Quartz-granulite and mica-schist; Lingtse Granite (C) with Foliated granite or mylonitised granite with several close space sub-parallel thrust; Gorubathan Formation (D) with Low grade phyllite and silvery mica-chlorite-schist, grey sericite, and Damuda Formation (F) with Coarse grained hard sandstones, quartzites, carbonaceous shales and slates, thin seams of crushed and powdery coal share almost same area (around 8%) each.

Landslide Potentiality:

Landslide potentiality Index Values (LPIV) were derived incorporating *landslide inventory map* (Fig.3) with lithology and lineament by means of a ratio (eq.1) between the number of cells/pixels affected by landslides and the total number of cells/pixels in each class (Fernandes, Guimaraes, Gomes, Vieira, Montgomery and Greenberg, 2004). More details concerning these procedures were obtained in other studies (Vieira *et al.*, 1998, Guimaraes *et al.*, 1999; Guimaraes).

$$\mathrm{LPIV} = (\mathrm{F2} \div \mathrm{F1}) \times 100\text{-----------------------------------}(1).$$

Where, F1 = total number of pixels/cells or grid in each class.
F2 = number of pixels/cells or grid with landslide in each class.

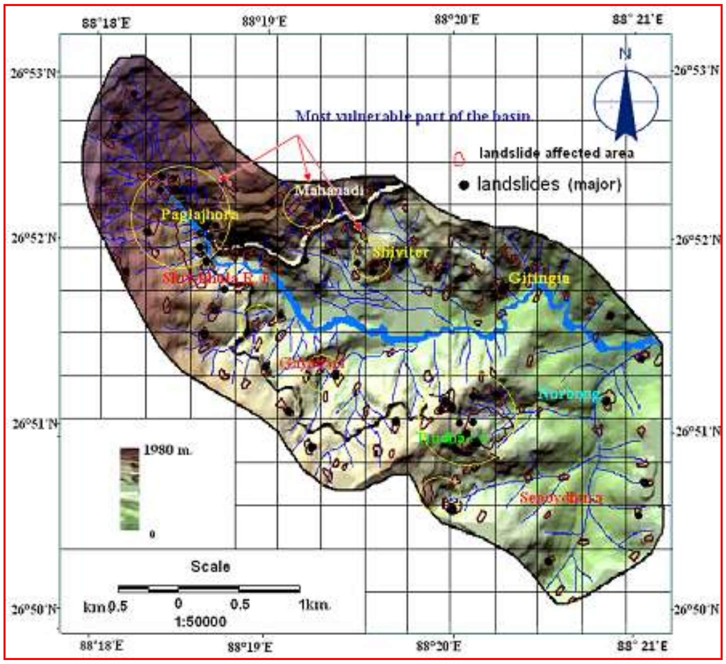


Figure 3: Landslide affected area and major landslide

RESULTS AND DISCUSSION

The lineaments at the places of Lower Paglajhora, Gayabari lower, Tindharia, 14 Miles Bustee, Shiviter Lower slope, Sepoydhura, and Norbong T.E. are closely spaced (Fig.4). The lineaments are absent at extreme north, north-east and eastern marginal part of the Shivkhola Watershed. The LPIV of each lineament class exhibits that the greater the distance from the lineaments lesser is the probability of landslide phenomena (Table.1).

Table 1: Lineament and landslide potentiality index

Class (dist. Of lineament in m.)	Number of pixels[F1]	No. of landslide affected pixels[F2]	Landslide Potentiality Index(LPI)= [F2/F1×100]
0.00-57.42	3381	624	18.46
57.42-126.32	3786	668	17.64
126.32-229.68	3695	451	11.37
229.68-356.00	3252	522	16.05
356.00-528.26	4799	444	9.25
528.26-723.45	4141	286	6.91
723.45-964.65	3887	221	5.67
964.65-1251.75	3921	120	3.06
1251.75-1642.20	1419	37	2.61
1642.20-2925.40	850	0	0

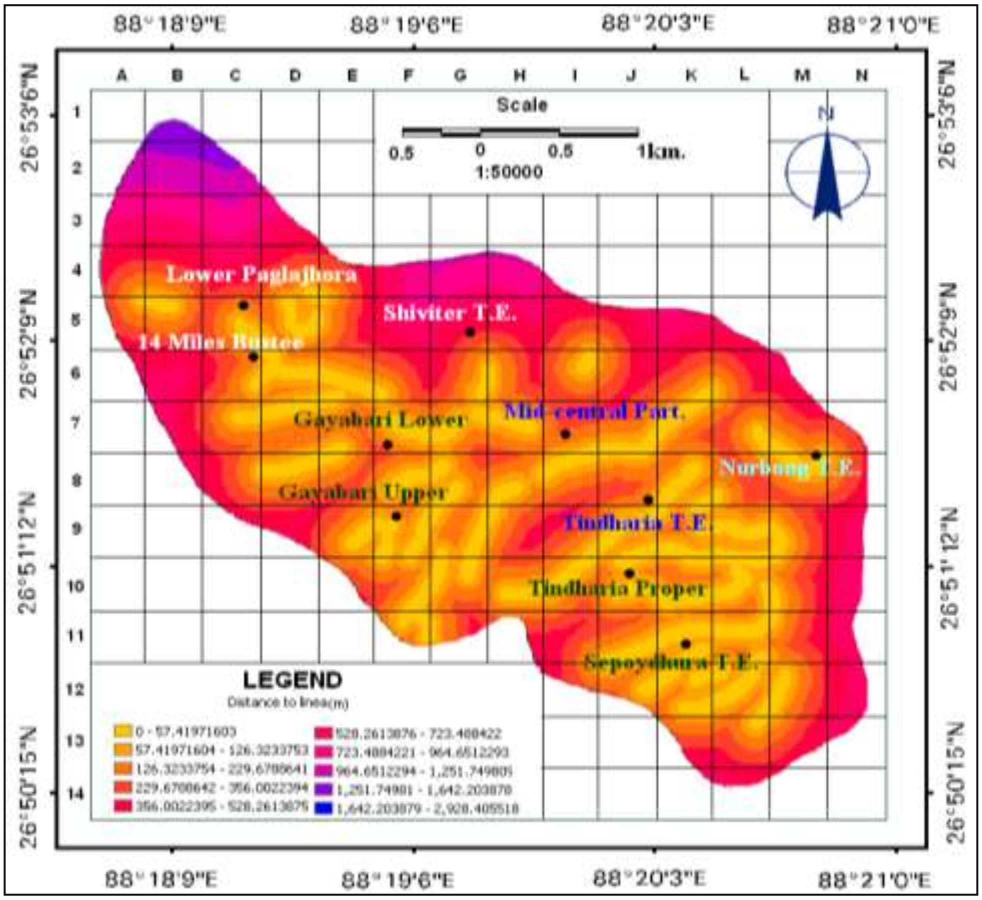


Figure 4: Lineament Density Map of Shivkhola Watershed

Landslide occurrences phenomena as well as landslide potentiality index value are very high for the lithological composition of Gneiss, mica-schist and granulitic rocks, Mylonitised granite with sub-parallel thrust**,** Phyllite, silvery-mica-chlorite-schist, grey sericite, and Slate phyllite with quartzite, quartz-schist and greywake schist at Lower Paglajhora, 14 miles bustee, Gayabari, Jogamaya, Tindharia, Shiviter and Mahanadi where the lineament density is high to very high. The following reasons are also responsible for making the slope unstable

- Seepage through heavily disintegrated and decomposed materials and formation of clay minerals, which induces slope instability.
- Rocks are traversed by quartz and quartzo-felspathic veins and the rocks are often highly metamorphosed and jointed.
- Recrystallisation and cataclastic deformation have destroyed the clastic texture with intense granulation along narrow zones of fracture.
- The apexes of the sliding zones are predominated with good amount of organic matter which encourages high water holding capacity and volume expansion.
- The apexes of the sliding zones are deforested and are susceptible to both sheet and gully erosion.
- Both Damuda and Swialik provide intensively deformed sandstone which destroys the clastic texture and promotes slope instability.

The estimated landslide potentiality of Gneiss, mica-schist and granulitic rocks (A), Mylonitised granite with sub-parallel thrust (C), Phyllite, silvery-mica-chlorite-schist, grey sericite (D) are 73.07, 61.54 and 69.23 respectively. All these three lithological groups are mostly dominated by lineaments and landslide occurrences phenomena (Table.2).

Table 2: Lithological Composition and Landslide Potentiality Index Value (LPIV)

Lithological composition	**Number of cells (F_1)**	**Number of cells in %**	**Number of landslide occurrence cells (F_2)**	**Number of landslide occurrences cell in %**	**Landslide occurrence ratio.**	**Landslide potential index (LPI)= F_2/ F_1×100**
Gneiss,mica-schist and granulitic rocks (A)	26	18.57	19	22.09	0.73	73.07
Calc-granulie, marble, quartz-granulite and mica schist (B)	16	11.42	9	10.47	0.56	56.25
Mylonitised granite with sub-parallel thrust (C)	13	9.28	8	9.30	0.61	61.54
Phyllite, silvery-mica-chlorite-schist, grey sericite (D)	13	9.28	9	10.47	0.69	69.23
Slate phyllite with quartzite, quartz-schist and greywake schist (E)	29	20.71	19	22.09	0.65	65.52
Sandstone, quartzites, shales, thin seams of crushed coal (F)	16	11.42	7	8.14	0.43	43.75
Soft sandstone, mudstone, shales, conglomerate and marly shales and lignite (G)	27	19.29	15	17.44	0.55	55.56

Conclusion

In the Shivkhola Watershed, the places of Lower Paglajhora, Tindharia, Gayabari and Shiviter are characterized by high density of lineaments. The presences of lineament over steep mountain escarpment slope of the concerned study area are the outcome of active compressive force and tectonic instability which ensure seepage and reduce the cohesion of slope materials. As a result, during monsoon high intensity rainfall for few days invite the landslide activities because of the existence of lineaments. The sheared lithological composition such as mica-schist and granulitic rocks, quartz-granulite, mylonitised granite with sub-parallel thrust, and phyllite is greatly affected by percolation of rain water and vibration caused by plying of heavy loaded vehicles as well as landslides. To make the study area less vulnerable to landslide phenomena, all sorts of fractures are to be identified and filled up by cementing materials to resist the percolation of water. Besides, the human intervention over the weak lithological composition is to be checked and minimized for reducing the weight on the slope materials.

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