Hydrological aspects of erosion on mountainous terrain — an example from the Himalayan region, India, based on photo-interpretation

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ABSTRACT The paper highlights the application of aerial photo-interpretation for qualitative analysis of erosional phenomena related to hydrological aspects in a selected pilot area of Uttar Pradesh Himalaya. In such terrain erosion, aggravated by different mass-wasting processes, is a common feature. Slates, dolomitic limestone and quartzite (Garhwal Group) of Silurian to Pre-Cambrian age and schist, gneiss and calc-silicate rocks (Central Crystalline) of Pre-Cambrian age are the dominant rock types. Structural and denudational hills are the major geomorphic units. Depending upon the rate and intensity of different mass-wasting processes, slope aspects, vegetational cover etc., the area has been divided into five erosional classes: high erosion, moderately high erosion, moderate erosion, moderately low erosion and low erosion. One of the important factors contributing to mass erosion in the higher Himalaya is high intensity rainfall leading to enormous surface runoff resulting in erosion on moderate to steep slopes.

INTRODUCTION

The lofty Himalayan mountainous terrain forms a conspicuous landscape in the northern part of the Indian subcontinent. It shows a variety of rock types, morphozones and different vegetational types. As the terrain is geologically young, mature landforms are rare. The effects of climatic and hydrological conditions on geomorphological processes, sculpturing the terrain, are conspicuous in many parts in terms of unstable slopes, immature soil and excessive erosion causing several mass-wasting phenomena such as slides. These invariably create environmental hazards.

In the past the region experienced heavy landslides which temporarily blocked the course of rivers and caused extensive flooding downstream. These unusual floods brought down enormous quantities of silt and detritus and caused a change in the regime of the main Alaknanda river. Slope failure is thus a hazardous phenomenon which has to be evaluated for future control measures.

An area of 453 km² in Chamoli district, Uttar Pradesh, India was mapped photogeologically, with stress on geotechnical and landslide aspects, using aerial photographs on a scale of 1:20,000 scale. Selective field checks were also carried out. The area is bounded by latitudes N. 30° 19' 19" to 30° 34' 7" and longitudes E. 79° 19' 41" to 79° 34' 32". Aerial photographs and selective field checks using
standard procedures were used to recognize the different mass-wasting processes and to give a broad categorization into 'active', 'old' and 'potential' slide zones. Interpretation of an active slide zone was made on the basis of sharp breaks in slope, the presence of slide scars, hummocky topography of displaced mass, disorganized drainage over slide zones, tonal variation and lack of vegetation as compared to the surroundings. Old slide zones were recognized on the basis of old slide scars, concave to convex (spoon-shaped) form of displaced mass, and some cultivated lands subsequently developed over old slide debris surfaces. Recognition of potential slide zones requires a wider study, which is beyond the limitations of the present paper. However, some of the important factors like slope aspect and potentially unstable conditions of slopes governed by geological, geomorphological and hydrological aspects of the region, were taken into prime consideration. Other mass-wasting processes like rill erosion, gully erosion, bank erosion, etc. likely to activate mass movement were also easily interpreted from aerial photographs, which provide a clear regional bird's-eye view of terrain features. These aspects have been made use of in the present study. Proper landslide studies and zonation are largely lacking in Himalayan terrain in India, and the present study should provide useful study examples.

GEOLGY

The rocks exposed in the study area consist of slate, dolomitic limestone and quartzite belonging to Garhwal Group of Silurian to Pre-Cambrian age. This group of rocks are thrust upon by Central Crystalline rocks along the Main Central Thrust which are predominantly composed of highly metamorphosed schist, gneiss and calc-silicate rocks (Fig.1). Structurally the area forms a doubly plunging anticline whose southern limb is highly folded and partly cut off by a fault running northwest to southeast.

GEOMORPHOLOGY

Most of the area falling under the Inner Lesser Himalaya forms structural and denudational mountains. The imprint of the geological structure and lithology are seen in the form of strike ridges and valleys while at other places denudational landscapes have given rise to steep scarps, peaks, deeply incised valleys and mass-wasted scree slopes. Debris slides, rock slides, rock falls, scree slopes etc. have been recognized in the area and are broadly categorized as active, old and potential landslide zones.

Slope

Flat-topped hills are rather rare in the area. The quartzites and limestones form mainly sharp ridges whereas slates and schists form smooth, rounded slopes. The hill slopes in softer rocks like slate show an increasing slope at the top, a relatively straight to concave upward midslope and a decreasing slope at the base. In
quartzites and other competent rocks like gneiss the slopes are rather steep. Limestone forms scarp slopes as seen in Birahi Ganga valley and around Pipalkoti village.

Relief

The relief in the area is highly variable ranging from 1000 m near Chamoli to 4610 m at Pangarchula peak. More weathered and erodible slates and schists usually occupy lower relief areas. However, dolomitic limestones and quartzites, being harder and compact, form areas of high relief.

Drainage

The area is primarily drained by two major rivers, the Alaknanda and Birahi Ganga which join near the village of Birahi. The river Birahi Ganga generally follows the strike valley while the river Alaknanda flows across the strike of the country rocks.

HYDROLOGICAL ASPECTS OF EROSION

Considering the different elements of the hydrological cycle, it is generally observed that the parameters which are most dominant in causing erosion on hill slopes are running water and infiltration.

The area has been qualitatively divided into five erosional classes (Fig.2) based on observations of the rate and intensity of different active mass-wasting processes of the present and past.
These are areas of (a) high erosion, (b) moderately high erosion, (c) moderate erosion, (d) moderately low erosion, (e) low erosion.

High-erosion areas (H)

These areas are marked by active landslide zones. The erosional processes are seen in the form of rock slides, debris slides and rock falls. The main agents of rock slides and debris slides are found to be running water, infiltration gravity movement due to lubricating action of underground water and frost action.

The best examples of debris slides are seen around Patalganga river in the Dhaknala and Helangnala sections, where old landslide debris, deposited on steep slopes of hills, got mobilized after becoming saturated with water.

Frost action and chemical weathering from winter to the rainy season are important agents in disintegrating the rocks in the area of study. The products of weathering are removed by running rainwater and gravity action, the evidence of which is well pronounced in Birahi Ganga valley and the adjoining area between Pipalkoti village and Kamnasana where the rock formations are mainly limestone and calcareous slates. The effect of frost action is observed to be dominant in higher reaches around Kunwari Khal region where moisture and the lubricating effect of melting water provide a very strong mechanism for movement on hill slopes.

Notable zones of huge rock slides are observed around Gohna Tal in Birahi Ganga valley which took place in 1893 and dammed the Birahi Ganga river forming a natural lake known as "Gohna Tal"; between village Pakhi and Belakuchi where the permeable limestone
underlain by impermeable slate gets slid along weaker planes like joint and bedding which are lubricated by moisture. The heavy rainfall of July 1970 which caused a flash flood in Alaknanda river also resulted in large landslides and debris avalanches along Karmnasa, Patalganga and Birahi Ganga rivers in jointed and sheared rocks, indicating that the greatest erosion rates may be related to highest runoff rates.

Most of the major slide zones mapped in the area are confined within the limestone and slate units (Fig.1). The effects of weathering and erosion on quartzites are not so pronounced. With the above, it is evident that the landslides are due to different causes in different areas but some of the contributing factors which played a significant role are as follows:

(a) The excessive rainfall in the area causing enormous runoff and saturation with reduction of the coefficient of internal friction of the material.
(b) The effect of chemical/physical weathering in the rocks.
(c) The orientation of weaker planes in the rocks in relation to the direction and amount of slope.
(d) The removal of toe support by river erosion or high flash-flood discharge through the narrow valley causing bank erosion.
(e) The angle of hill slopes steeper than the angle of repose of the material.
(f) The crushed and crumbled nature of the rocks due to structural reasons or tight folds.

Moderately high-erosion areas (Mh)

The area is characterized by moderately steep slopes with sparse vegetation and high concentrations of gullies/streams. The phenomena of soil creep, gully erosion, bank erosion, solifluction etc. are common. It is interesting to note that all the potential landslide zones recognized on the basis of the concentration of fracture trends/gullies in the rock type, orientation of weaker planes in the direction of slope, steepness of the slope, competency of a rock type etc. fall into this category. However, all such areas (Mh) are not potential landslide zones. Some old landslide zones which have yet not fully stabilized and where the phenomenon of slumping/sinking is still occurring in places also come into this category.

The phenomenon of solifluction is generally observed at altitudes above 4000 m which are under perennial snow cover. The contact between the overlying mantle which melts during warm periods and the underlying permanently frozen ground provides a zone along which movement may readily take place. Solifluction lobes are found to occur on such hill slopes.

Soil creep and gully erosion are common features observed in the surrounding region of the Sunil-Joshimath hill complex which lies on an ancient landslide zone. Here, due to excess seepage, clays associated with the gneissic boulders as a weathered product slip down on moderate slopes and soil creep occurs. In some places this soil/debris creep occurs below the surface, resulting in sinking or subsidence of the upper part of the land, e.g. in the road section towards Tapoban.
Some potential slide zones adjacent to springs are also noticed.

Moderate erosion areas (M)

This unit is generally characterized by old landslide zones with vegetation cover, gentle to moderate slopes, and cultivated land especially on south-facing slopes. Sheet flow, concentrated and diffused runoff with and without loss of soil, creep, and rill and gully erosion are seen to varying degrees. The processes of gully and rill erosion occur with varying rate and intensity. Such zones are seen around Lasi, Harmari, Mayasur and Karchhigaon villages. Most of the slopes are stable except where there is heavy gully/rill erosion.

On gentler slopes viscous material consisting of a mixture of water and earth moves down as a mudflow. Such a flow results not only in the removal of detritus but also in ploughing up its track and breaking up of hard rocks. In Khulara and Auli region the treeless schistose areas are plagued with mudflows.

Moderately low erosion areas (M1)

This unit is recognized on aerial photographs where the development of rills and gullies is much less or almost absent or where concentrated lateral soil-water movement causes erosion due to the formation of pipes. These are the areas of low to moderate slopes with development of medium density forest and cultivated land on northern slopes, old landslide zones which have stabilized and where forest growth has occurred and with gently sloping thaches i.e. grassland. Peculiarly, it is also observed that on steep scarps with little or sparse vegetation and no development of gullies the erosion rate is also that appropriate for this category.

On slopes where rills are not developed, unconcentrated overland flow causes the surface erosion.

Atkinson stated that under conditions of heavy rainfall, movement of soil moisture may be through the soil matrix, in the intergranular pores and smaller or larger structural voids. The most common of these larger voids are pipes, which are open passageways in the soil (see Kirkby, 1978, p. 73). These pipes have also been stated to exist on steeper slopes, where drainage occurs through them at times of heavy rainfall and initially high moisture content as reported by Knapp (quoted by Kirkby, 1978, p. 24) while working on the Plynlimon basin. Probably the same may hold true on the steep scarps of limestone in Birahi Ganga valley.

In thaches, since the impact of falling raindrops is reduced by grass cover and the infiltration capacity of a grass surface is high, the erosional rate due to surface runoff is considered to be moderately low, e.g. around Sartoli region.

Low erosion areas (L)

More than half of the total area is under this category. It is characterized by open or dense mixed forest. The slopes are reasonably stable at present but any imbalance due to human activity
like deforestation may cause unstable slopes. Some old landslide zones falling in this type of area can also be recognized around Tarak Tal which as a result of slumping have given rise to the formation of natural lakes, e.g. at Tarak Tal (Tal signifies lake).

**PROFILE STUDY OF DIFFERENTIAL EROSION ON SOUTHWESTERN SLOPES OF THE RIVER DHauliganga**

A slope profile (Fig.3) 5.75 km long was prepared along the hill slope to the southwest of Dhauliganga river and was compared with the erosional map (Fig.2). Four erosional zones can be marked on the profile: low erosion, moderate erosion, moderately high erosion and high erosion.

The slope zone of low erosion is characterized by dense forest cover and the rock types exposed in this region are quartzite and augen gneiss with minor bands of schist and amphibolite. The average slope is of the order of 17°. The following reasons may be advanced to account for the low erosion.

(a) The zone is covered by dense forest, hence part of the rainfall is intercepted, hindering splash erosion.

(b) The rock types exposed, mainly gneiss and quartzite, being hard and competent, are resistant to erosion.

(c) Since the depth of flow is zero at the crest and increases downslope, there should be no erosion until the depth and slope have attained a value sufficient to provide the necessary erosive force (Leopold et al., 1964, p. 358).

The zone of moderate erosion is identified by bare rock exposures and some farming land with slopes ranging between 9° and 21°. The rock types exposed are mainly garnetiferous mica schists and
gneisses with minor bands of amphibolite. Erosion in this region is generally in the form of sheet-wash or mudflow. Due to farming and the harder gneissic rocks, the erosion rate is not high. Most of the moderately high erosion zone is under terrace cultivation with slopes varying between 11° and 33°. Gneiss with amphibolite and schistose bands are the main rocks. Soil creep, rill and gully erosion are the common geomorphic processes. The following factors may be responsible for the moderately high intensity of erosion in this zone.

(a) Comparatively longer and steeper slopes, where erosion due to surface runoff might be expected to be greater.
(b) Low permeable rocks of less infiltration capacity.
(c) Development of clayey sandy soils, amenable to erosion.

The zone of high erosion is marked by active landslides along the left bank of the Dhauliganga river. Since the left bank hill slopes are predominantly composed of slid masses, the bank erosion basically causes a toe erosion of the slid material further aggravating erosion.

CONCLUSION

The rate and intensity of erosion in the higher Himalaya can be qualitatively categorized by recognizing different mass-wasting processes using aerial photo-interpretation techniques. Erosion in the higher Himalaya is found to be a function of many factors but high intensity rainfall resulting in enormous surface runoff and infiltration gravity movement due to the lubricating action of underground water aggravate erosion on moderate to steep slopes.

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