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Mass Wasting Processes in Khairna Basin: Kumaon Himalayas

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Abstract:

A geodynamically active and geomorphologically sensitive study area (the Khairna river basin) lies between 29^0 23' to 29^{0}31' North latitudes and 79^0 25' to 79^{0}39' East longitudes in the Kumaun lesser Himalayas and covers an area of about 125 km^2. The Khairna stream follows the NS tending strike dip Garampani fault and joins river Kosi at Khairna, which lies in District Nainital, Uttarakhand, India. Quantitative measurement of the mass wasting processes (From October 2004- 2007) reveals that about 105477432 m^3 material is present as loose material in various forms within the watershed. Out of which is 95160819 m^3 debris flow material; about 3544313 m^3 is in the form of rock fall material disposed by the active process and about 6736170 m^3 by landslide deposits, thus generating material at the rate of 843819 m^3/km^2 by the means of different mass wasting processes. These active processes in the study area add the mobilized material to the fluvial system and help estimate the denudation rate of the study area. All the processes are responsible for the occurrence of environmental hazards and in extreme conditions, disasters. Only understanding the ground truth related with the causes intensity and impact of these processes can help their planning, mitigation and prevention.

Keywords:

Geodynamic, tectonic, mass wasting processes, endogenic processes, environmental hazards, sediment mobilization

1.0 Introduction:

A complex combination of the processes acting upon the earth surface gives birth to different types of landscapes and landforms. Human beings play a crucial role as observers, admirers, interveners, explorers and researchers. The mass wasting processes are significant as far as the young and sensitive Himalayas are concerned. This young mountain system is going through topographical changes, which are observed through the active processes in the region. Active movements of Earth material from one place to another is either in the form of downslope movement due to gravitational forces or sediment flow in channels, which observed in their various forms in this dynamic region. These materials may be in the form of rock pieces, boulders, fine particles as well as loose debris of various shapes and sizes. The drainage basin selected as a geomorphic unit is a convenient and well-defined unit to conduct geomorphic as well as environmental studies. In the steep slopes of the Himalayan Mountains, mass movements not only change the shape, size and locality of the mobilized material but also alter the landscape and landforms because of the sheer continuity of these processes. Inaccessibility of these mountainous regions is one of the major causes that quantitative assessments are difficult.

The down slope movements of the eroded materials, which include not only fine materials such as clay but also large boulders and broken bedrock materials. These processes in different parts of the Uttarakhand Himalayan regions have documented in the form of debris flow, debris avalanche, rock fall landslides and mudflow. Hill slope processes start from the top of the hills and are active down the hill slopes passing through a series of landscape units. The present investigation aims to find out the role of different geomorphic processes in the mobilization of the sediment in hill slopes, transport of material down slope in different areas through various processes and quantitative measurement of the materials moving down slope through various forms in a particular period. To understand the complete process of how sediment moves from the lower unit to the higher one, there should be a well-defined unit. A drainage basin is widely recognized as a fundamental unit in the geomorphic milieu and is important for environmental management and sediment and water budget research. The drainage basin looses energy by various forms of denudation and biological processes. The gravity pull of the earth's material known as mass wasting is a universal phenomena especially in the dynamic and sensitive region like the Himalayas (Prasad and Verma, 1982; Valdiya and Bartariya, 1988; Shastri and Rawat, 1994; Sah and Bartariya, 2004).

However, studies related to the quantitative measurement and flow assessment through mass wasting processes have been limited. How sediment moves through hill slopes has always been a topic of study for the geomorphologists all over the world but in Indian context, these studies concentrate on post occurrence. In the past few years, awareness regarding the need of hazard zonation maps for specific areas suggested by several researchers and scientists work in the field. Due to the active geomorphic processes in the dynamic Himalayas, the experimental study has been done in a sixth order drainage basin that is very sensitive to these processes.

1.1 The Study Area:

The study area viz. the Khairna basin lies between 29^0 23' to $29^0$31' North latitudes and 79^0 25' to $79^0$39' East longitudes in the Kumaun Lesser Himalayas (Figure 1). The Khairna stream flows from south to north and joins river Kosi at Khairna. The said area lies in the Nainital district administratively. The Khairna stream follows the NS trending strike dip Garampani fault (Valdiya, K. S. 1976, 1980). The east west flowing river Kosi has carved out faulted zone of the Ramgarh thrust. It abruptly turns north from the confluence of Khairna and Kosi River covering a distance of about 2 km in district Nainital (Uttarakhand, India) between Khairna and Bhujan. The Ninglat stream and the Jakh Gadhera are the south north flowing streams while the Ramgarh stream flows east west. The area of the drainage basin is about 125 km^2. The drainage basin is geo dynamically very sensitive and tectonically very active. Earlier studies by the renowned geologist revealed that the slopes of the area are instable and the region is experiencing serious environmental hazards because of this instability. The result is massive landslides and deep erosion (Valdiya, K. S. 1988). Khairna river basin has the unique geomorphic setting, stream flow direction and environmental interest. The present geomorphic investigation therefore, started from this drainage basin lying in the Nainital hills, Lesser Himalayas.

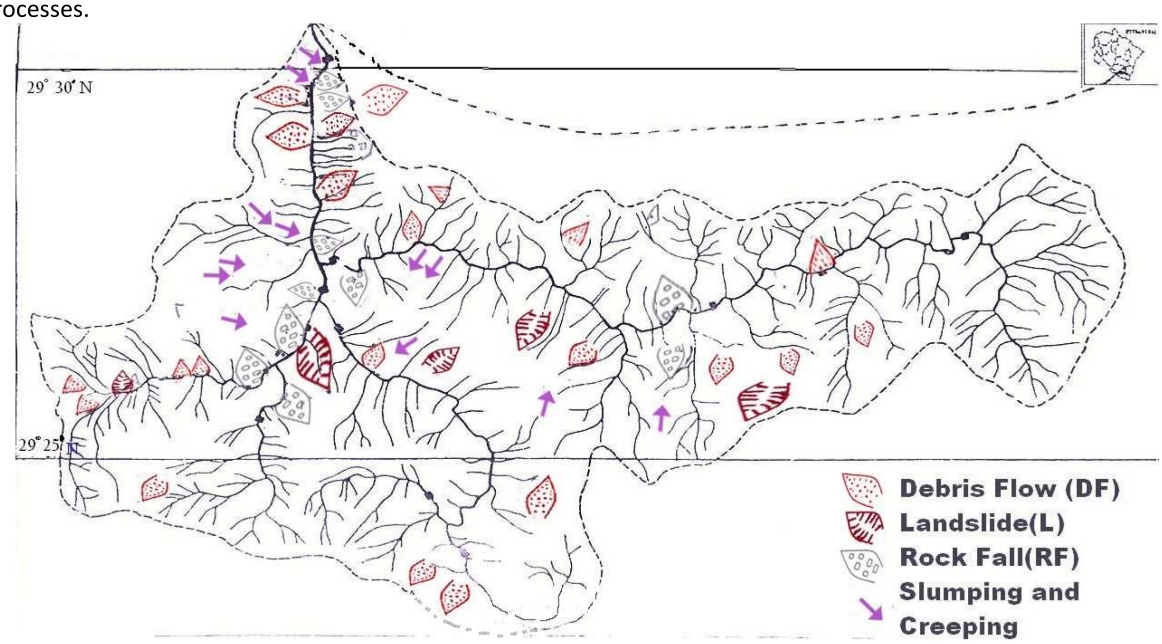

Figure 1: Mass-Wasting Processes in the Experimental Watershed

2.0 Materials and Methods:

The following materials and methods used for the study helped to find the location and extent of the mobilization and movement of mass in various forms in the study area. Topographical Sheets No.53 0/7 and 53 0/11 published by Survey of India used as base maps for the present study. During the first phase of the work, detailed field investigations carried to identify the areas prone to different processes. The study period was October 2004-2007. Field visits in the total basin area helped to map the geomorphic features showing the role of various processes. A geomorphologic map with location of areas prone to mass wasting was prepared which marked the locations of the different mass movement processes in the basin area. The field investigations reveal that landslides, rock fall and continuous debris flow are the processes, which are the major contributors for the movement of sediment down the hill slopes. The second phase of the study was to quantify the material moving down the slopes through different processes in the area. Measurement of the length, width and depth of the active mass wasting processes helped in finding the volume of material mobilized due to gravitational pull in different areas within the experimental watershed during the study period. Estimation of total material deposited below the scar was possible with troughs installed below the scars of the debris flow areas at some selected sites. The last phase of the study was to find out the role of different mass wasting processes in slope failures in quantitative terms. With the help of the geomorphic map and analysis of individual processes, volume of the total loose material generated within the basin was calculated. Table 1shows the details of sediment stored in varied forms within the study area. Table 2, 3, 4 and 5 present details of morphometric parameters, rock type and vegetation characteristics of mass wasting processes at different localities within the experimental watershed. Further research regarding these processes finds that debris deposits cover about 11.5 km^2; landslide deposits cover about 2.5 km^2 area, rock fall debris cover about 1.25 km^2 area of the experimental watershed. Thus, the study included identification of different mass wasting areas and quantification of storage, role of individual process in sediment mobilization and collective movement of material in the study area through these processes.

3.0 Results and Discussion:

Geomorphic mapping of the study area reveals that most of the landforms of the drainage basin are either tectonic or tectonically controlled. The role of tectonic processes is in the form of mass wasting processes in the study area. Table -1 show the sediment storage in different forms within the experimental watershed with the estimated amount of sediment mobilized through different processes in quantitative terms.

Debris fall, a continuous process in the study area, is the major source of loosening of the earth material and sediment mobilization in hill slopes (Figure - 2). This process mobilizes sediment in the present study area largely. Crushed quartzite and slates on either side of the fault planes in the experimental watershed are the debris flow areas. In the selected localities, About 283,000 m^3 total debris deposits confined within different places where debris flow areas are concentrated (Table - 2). Thus, the large area covered by debris flow deposits generated about 95160819 m^3 of debris in the study area (Table - 1).

Table 1: Sediment storage in the Khairna river basin

Processes	Storage form	Estimated amount in m^3
Debris Flow/Fall	Debris fans / cones	95160819
Landslides	Loose materials including rock pieces, plants etc.	6736170
Rock fall	Pieces of rocks collectively found at any place specially down slopes	3544313
Alluvial Channels	a. Alluvial fans / cones	380
	b. Terraces	35750

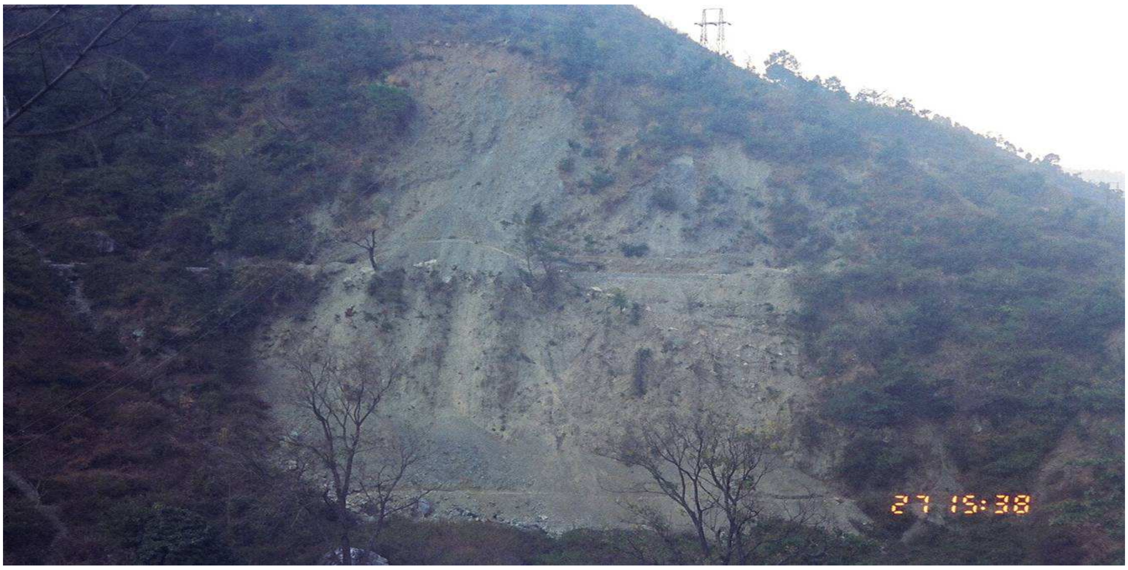

Figure 2: Debris flow near Jarmila (Garampani).

Table 2: Morphometry, Rock Type and Vegetation Characteristics of Debris flow (DF) at different localities in the Khairna river basin

Location	Area Covered (m^2)	Mean depth (m)	Material removed volume in m^3)	Rock Type	Vegetation cover upslope
DF_1	15000	5.0	75000	Quartzite	Pine with thin grass cover
DF_2	2000	6.0	12000	Volcanic	Bare Rocks
DF_3	3750	8.0	30000	Slate and Quartzite	Bare Rocks
DF_4	6000	20.0	120000	Quartzite	Bare Rocks
DF_5	3000	5.0	15000	Slate and Quartzite	Shrubs and Pine cover
DF_6	2000	10.0	20000	Slate and Quartzite	Shrubs
DF_7	1250	4.0	5000	Quartzite	Bare Rocks
DF_8	1200	5.0	6000	Quartzite	Bare Rocks

Landslides are another active process active in the drainage basin area, which removes huge amount of materials down slopes. The landslide scars are mainly devoid of vegetation (Figure 3). Table-3 shows the areas covered by landslides and their mean depth at different localities. From seven localities, about 63320 m^3 material were deposited because of landslides. Based on the material removed from selected landslide deposits and the total area covered by landslide deposits, it can be deduced that about 6736170 m^3 sediment has been mobilized by landslides in the Khairna watershed.

Figure 3. Landslide near Ratighat

A

B

Figure 4. (A) Rockfall areas along Bhowali Ramgarh; Road **(B)** Slumping Areas in the study area

Table 3: Morphometry, Rock Type and Vegetation Characteristics of landslides at different Localities (L) in the Khairna river basin

Location	Area Covered (m^2)	Mean depth (m)	Material removed (volume in m^3)	Geology Formation On Rock Type	Scar	Slope	Vegetation cover upslope
1L	2500	8.0	20000	Nagthat	Quartzite	50^0	Oak and Pine shrubs
2L	3000	2.0	6000	Blaini	Slate	80^0	Bare hill slopes
3L	6000	1.5	9000	Blaini	Slate and Quartzite	80^0	Shrubs and grass
4L	5000	2.0	10000	Nagthat And Blaini	Slate and Quartzite	60^0	Bare hill slopes
5L	5600	3.0	16800	Nagthat and Blaini	Quartzite	50^0	Agricultural land
6L	800	1.0	800	Krol	Slate	60^0	Bare hill slopes
7L	600	1.2	720	Blaini	Ramgarh Phyrophyroid	50^0	Mixed Forests

Table 4: Morphometry, Rock Type and Vegetation Characteristics of Rock Fall (RF) at different localities in the Khairna river basin

Location	Area Covered(m^2)	Mean depth (m)	volume in m^3	Scarp slope	Rock Type	Vegetation cover upslope
RF_1	3040	5.0	15200	80^0	Quartzite and Slate	Pine with thin grass cover
RF_2	6000	4.0	24000	85^0	Quartzite	Bare rocks
RF_3	4750	2.5	11875	70^0	Quartzite	Bare rocks
RF_4	5080	1.5	7620	65^0	Quartzite	Bare rocks
RF_5	4000	2.0	8000	60^0	Quartzite	Shrubs and Pine cover
RF_1	600	1.8	1080	60^0	Quartzite	Shrubs
RF_1	940	1.5	1410	60^0	Quartzite	Bare rocks

Rock fall takes place when rock beddings are cracked, and the pieces of rocks start falling from the areas having steep slopes (Figure 4a). With the help of area covered by rock fall deposits and the amount of material removed from the selected sites it was estimated that about 3544313 m^3 material is deposited by rock fall (Table-4). Distribution of the slumping and creeping areas reveal that the processes are active mainly along the fault scraps, convex terraces. About 0.5% area of the total drainage basin is suffering from creeping and slumping (Plate 4b). Slumping is frequently available process observed on the crown of the landslides, steep slopes, terraces and on man made features such as road walls and agricultural terraces. Creeping is a very slow process, which is a non-accelerating down slope movement (Bloom, 1979; Carson and Kirby, 1972). The documentation of the rates of creep requires long term monitoring. In the present experimental study, all the creeping areas have been mapped (Figure 1).

These processes are natural and can be understood properly by dividing them in different groups. Attempts to understand the processes based on Landslide hazard zonation in different parts of the world, where they are active can help in this regard Ghosh and Bhattacharya (2010) have suggested a knowledge based landslide zonation system. In the northeastern part of India, zonation with the help of thematic layers using geology, geomorphology and Land use with the help of GIS and Remote sensing techniques has been done in Lunglei town Mijoram by Lallianthanga and Laltanpuia (2013). Jaiswal et al. (2011) estimated the risk of landslides in the Nilgiri hills with the help of debris slides down the slopes. One of the case studies by Pandey (2013) of such sensitive areas in the Uttarakhand Himalaya where damage to life and property was caused by landslides (Malpa village) also emphasized on the need of risk assessment of the areas where the possibilities of occurrence is greater.

Islam et al. (2014) wanted to find out the causes and risk assessment of damaged areas with a combination of field details and remote sensing techniques. Mass wasting processes are very common along roads and in the areas with urban area expansion in the mountainous region of the Himalaya, which Marrapu and Jakka (2014) analyzed, are causing more damage due to the increasing phase of human activities. Identification of landslides along highways by Mehta et al., (2010) emphasizes on preparing a hazard zonation map that may include geological aspects as well as meteorological inputs of the selected area. Another study by Jean Philips Malet and other scientists emphasized in their study the need of spatial temporal information on landslides in European countries. Thus, different studies suggest that landslide prone zones have to be specified and mapped (Kumar, 2000; Oliver-Smith, 2006). The mass wasting processes cause severe damage along highways and linking roads of the mountainous regions. Similar studies in different parts of the Himalayan region and other mountains of the world reveal that identification of areas, field investigation, zonation of areas prone to mass wasting and impact of these processes on society are the major aspects which have to be studied and analyzed carefully (Wisner, 1993). Most of the studies related to mass wasting processes in recent years concentrate on the situations after their occurrence and their negative impact on society due to their consequences. Thus, instead of the study and analysis of the various hazards caused due to mass wasting process post their occurrence, a pre-occurrence study may help in better mitigation and prevention of damages caused by such processes. Thus, this process is a significant process responsible for mobilization of sediment in hill slopes either as free fall of debris or as debris channels, which contributes 90 percent of the total mass movement processes. The landslides of the Khairna drainage basin are active along the fault planes mainly on the area composed quartzite and slate rock of the *Nagthat Blaini* and *Krol* formations. The slope of the landslide scraps ranges between 50^0 and $80^{0.}$ These scars are mainly devoid of vegetation. The road-induced landslides because of also generate large amount of loose material in the study area.

The rock falls in the Khairna drainage basin are confined mainly on the on the areas composed of quartzite rock or quartzite inter bedded with slates. These rocks are fractured and broken into pieces due to the tectonic activities especially along the Main Boundary Fault, which is presently active. The slope of the crown of the rock fall is always steep which ranges between 60^0 and 85^0. These crowns are mostly deforested. At some places shrubs, grasses or some trees cover them. Distribution of the slumping and creeping areas observed but not quantified. Mass wasting processes become potentially very dangerous in the tectonically active areas such as the Khairna river basin. These processes are the indicators of the tectonic activities along the main boundary fault, their distribution and rate of mass movement at particular places in a particular period. These studies can develop models for landslide planning and natural resource management in a sensitive and dynamic region like the Himalayan mountain systems. The study reveals that in the mountainous region, due to the active tectonic processes, mass movement of earth surface is very common. Using watersheds as natural boundaries, with the systematic information obtained about the mass movement down the hill slopes, gathering down slope and ultimately becoming part of the fluvial system so that we can develop a better relationship with the Himalayas. Identification of areas prone to mass wasting processes and estimation of kinetic energy of the heavy rainstorms that result in the slope failures can be helpful for the prevention of the damage to human life and property.

4.0 Conclusion:

The Himalayan mountain system is experiencing several changes, as it is young and dynamic. Different forms of mass-wasting processes are the indicators of the geodynamic activeness of the selected watershed of the mountainous region. Recent studies have suggested that hazard zone mapping using remote sensing and geographical information system studies is urgently required but the question arises that sharp variations occur in different parts of the Himalayan mountains and each area has a unique geomorphic setting. Therefore, detailed and more specific studies are required. Natural boundaries in the form of drainage basins can help to connect the link in between individual processes and their interrelationship with the whole system. The experimental watershed is a sixth order stream having an area of 125 km^2. Starting from the top, these processes carry down the earth material in various forms. The speed and rate of movement of every process varies with space and time. The present study was an attempt towards understanding the mass wasting processes, which include the dynamic processes that directly affect the people living in the study area and indirectly the entire country. The area selected was a drainage basin with the frequent occurrence of these active processes. Quantification of different processes within the study area reveal that continuous debris flow is a process, which has mobilized the largest amount of material within the experimental drainage basin, which was about 95160819$m^3$from about 11.5km^2area. Landslides cover about 2.5 km^2 of the drainage basin area and mobilize about 736170m^3 materials. About 3544313 m^3material is mobilized in the form of rock fall material from 1.25km^2 areas within the drainage basin. Large part of the material removed from steep slopes where the rocks show crushing and shearing. Field investigations reveal that the material mobilized in the areas prone to these processes is on due course transported by running water during the summer monsoon. This study was an attempt to provide the estimated amount of sediment mobilization and down slope movement of earth material in a part of the dynamic Himalayas. Overall, mass wasting processes mobilized about 105477432m^3 materials from the Khairna watershed. These materials become part of the fluvial system down slopes and add the mobilized material to stream waters as sediment load. Thus, identification of mass wasting areas, role of individual processes in quantitative terms helped in understanding the dynamics of the study area largely, which was the major purpose of the study. These processes cause hazards and disasters in extreme cases. Similar studies in different parts of the Himalayas may help in understanding the impact of different processes in various forms. We cannot stop these processes but mitigate the adverse effects by understanding the source areas, frequency and occurrence in different parts of the Himalayas. In this way, the present experimental study may provide a base for earth scientists as well as environmentalists to explore and analyze not only the mass movement processes but interrelationship of different forms and processes of nature and how their changes have impact on the human beings in different parts of the earth.

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