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Disaster in Rudraprayag District of Uttarakhand Himalaya: A Special Emphasis on Geomorphic Changes and Slope Instability

Khanduri S*, Sajwan KS, Rawat A, Dhyani C and Kapoor S

Disaster Mitigation and Management Centre, Department of Disaster Management, Uttarakhand Secretariat, Dehradun-248001, Uttarakhand, India

Abstract

Deluge of June 2013 is the worst disaster faced by the nation in recent times. Changing rainfall pattern in the previous some years has made heavy localized precipitation all the more common in Uttarakhand and the same is a cause of concern for the state government, meteorologists and other researchers. These incidences cause enormous loss of human lives, property, infrastructures and natural resources. Moreover rainfall in the study area is highly variable even over short distances. Dissected topography and tectonically active nature of the area further promote mass movement and slope instability. Increased indiscriminate anthropogenic intervention along the river banks, on glacial sediments, thick colluviums zones and river borne materials on moderate to steep slope, has often resulted in devastation in the area. The study highlights causes of slope instability together with the geomorphic changes and suggestions for future developmental initiatives within the district.

Keywords: Mandakini valley; Cloudburst; Landslide; Future plan; Kedarnath; Uttarakhand Himalaya

Introduction

With the change in the climatic conditions world-wide, the hills in the recent times have been witness to abnormally heavy precipitation and associated disaster. The extreme weather events are catastrophic as they bring with them a lot of water. When this water runs down the hills is washes away whatever come in its way. Building and houses are razed down, people and animals become a casualty be getting entrapped in the debris.

Unlike other disaster landslides cause permanent loss of land that adversely affects the life support strategy of the affected people. Moreover availability of productive land in the hills is limited and landslides cause loss of this scarce natural resource.

In the year 1998 the state witnessed major landslides at Malpa and Okhimath that took toll of more than 350 human lives [1-3].

In the year 2010 Uttarakhand experienced unusually high rainfall between 16 and 20 September that resulted in a number of landslide, cloudburst and flash flood events throughout the state. Around 9,162 villages and many towns with population of 29.23 lakh were affected by these incidences that took toll of 214 human lives. More than 26,011 residential houses were damaged while around 1,771 farm animals were lost [4-6].

Then in the year 2012 particularly heavy rainfall was received between 4 and 6 August, 2012 in Uttarkashi and 13 and 16 September in Rudraprayag. Around 236 villages and some towns including Uttarkashi with population of 13,137 were affected by these incidences that killed 106 persons. More than 1,930 residential houses were damaged while around 567 farm animals were lost [7-10].

Similarly, in year 2013 the monsoon was early to arrive and interaction of the same with Westerlies resulted in heavy precipitation in the region. This caused massive devastation in the state on 16 and 17 June, 2013. More than 4000 persons went missing in these incidences that caused massive loss of infrastructure and property. More than 19,309 residential houses were damaged while around 11,091 farm animals were lost [11-16].

The study area experiences enough rainfall due to southwest monsoon during June to September. Heavy rains and associated deluge on 16/17 June 2013 in the catchments of the Mandakini river and its tributaries, caused immense loss of life, property and infrastructures in the area. Numerous studies are undertaken after disaster in the region [17-20].

Mandakini valley houses a number of pilgrim and tourist destinations that include Kedarnath, Trijuginarayan, Okhimath, Kalimath, Madhyamaheshwar, Makkumath, Tunganath and Chopata. The area is therefore visited by large number of people every year, particularly during the pilgrimage season that coincides with the monsoon period, rainy season in the Indian subcontinent. The economy of the region revolves round tourism and pilgrimage and disruption of the tourist or pilgrim traffic due to landslides has major adverse impact on the economy. Landslides are therefore a major cause of concern not only for the government but also for the masses.

Disruption of road connectivity causes immense hardships to the pilgrims and local public. In these situations the state has often to resort to extraordinary measures for evacuating stranded people and for ensuring availability of essential commodities and services. This puts heavy burden upon public exchequer and hampers the pace of development. In order to investigate the Rudraprayag district, the present paper provides causes of slope instability together with the geomorphic changes after detailed field work undertaken in the area after the disaster.

Methodology

In the present study critical locations were identified for priority assessment. With the help of Survey of India Toposheets and Handset

***Corresponding author:** Khanduri S, Disaster Mitigation and Management Centre, Department of Disaster Management, Uttarakhand Secretariat, Dehradun-248001, Uttarakhand, India, Tel: +919927721776; E-mail: sushil.khanduri@gmail.com

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GPS, locations of studied points were confirmed and the same were marked on the respective Survey of India toposheets (1:50,000). These include change in landscape, landslide and cloudburst distribution map and overburden material map. Lithology and structural data were collected and assessment was made to categorize the landslide. Apart from landslides information regarding localized rainfall/cloudburst events was gathered from the local people and the same were correlated and analyzed. Attempts were also made to assess the causative factors of the damage as to suggest control measures for the stability of affected structures.

The study area

Present study covers Mandakini valley that falls in Lesser and Higher Himalaya and is bound by 30°10'36" N to 30°48'50" N latitudes and 78°48'46" E to 79°21'45" E longitudes and falls in Survey of India toposheet no 53N/2, N/3, N/6 and 53 J/15. Apart from Alaknanda, Mandakini is the major river draining this area and has confluence with the former at Rudraprayag (Figure 1).

Alaknanda has confluence with Bhagirathi at Devprayag and thereafter the river is known as Ganga. The area covers Rudraprayag district of Uttarakhand and being strategically important is well connected by road network of which Rishikesh – Badrinath (National Highway 58) and Rudraprayag – Kedarnath (National Highway 109) are an integral part.

Rudraprayag, Agastmuni and Okhimath are major townships of the area and Rishikesh is the nearest rail head while located in close proximity of Dehradun, the capital of Uttarakhand state, Jolly Grant is the nearest airport. Located close to the origin of Mandakini river, Kedarnath (3,581 m) is a Nagar Panchayat with population of 611. It is the seat of Lord Shiva and is highly revered by Hindus. It is a major pilgrim destination and is visited by people in large numbers.

Geomorphological set up

The area represents rugged and immature topography characterized by moderate to steep slopes that are intervened by narrow valleys. The topography of the region appears to be controlled by the structural and lithological factors. The major ridges present in the area include Bisuri Dhar (4,008 m), Khiri Dhar (3,768 m), Ragsi Dhar (2,818 m) while Sumeru Parvat (6,350 m), Bhart Khunta (6,578 m), Kedarnath (6,940 m), Mahalaya (5,970 m) and Hanuman Top (5,320 m) are some of the well known peaks.

Mandakini is the major stream of the study area and its N-S oriented basin is shaped between Higher and Lesser Himalayas. Mandakini joins Alaknanda river at Rudraprayag. This valley has witnessed as many as four glaciations in the previous 15,000 years and evidences of galciations in the valley are observed till Rambara [21].

Landforms present in the Mandakini valley upto Rambara are observed to have distinct glacial characteristics. On the upstream side valley is narrow and deep while to the downstream side it becomes wide and sinuous. It forms a gorge between Rambara to Munkatiya while downstream of Kundchatti the valley is wide. Based on the field work done in the area overburden map of the area is constructed (Figure 2). The glacial sediments are observed mostly up to Rambara and include moraines and glacial cones/fans that indicate a major phase of glacial

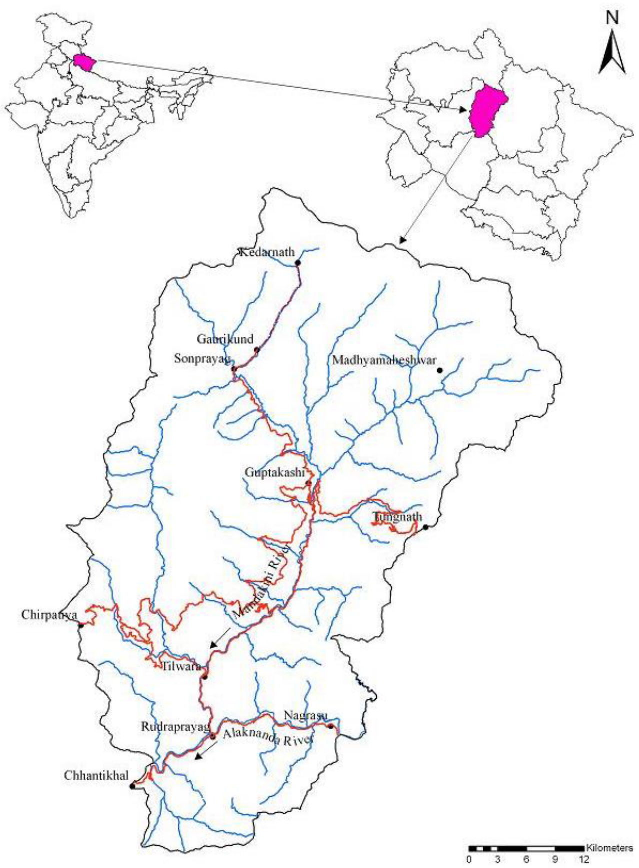

Figure 1: Location map.

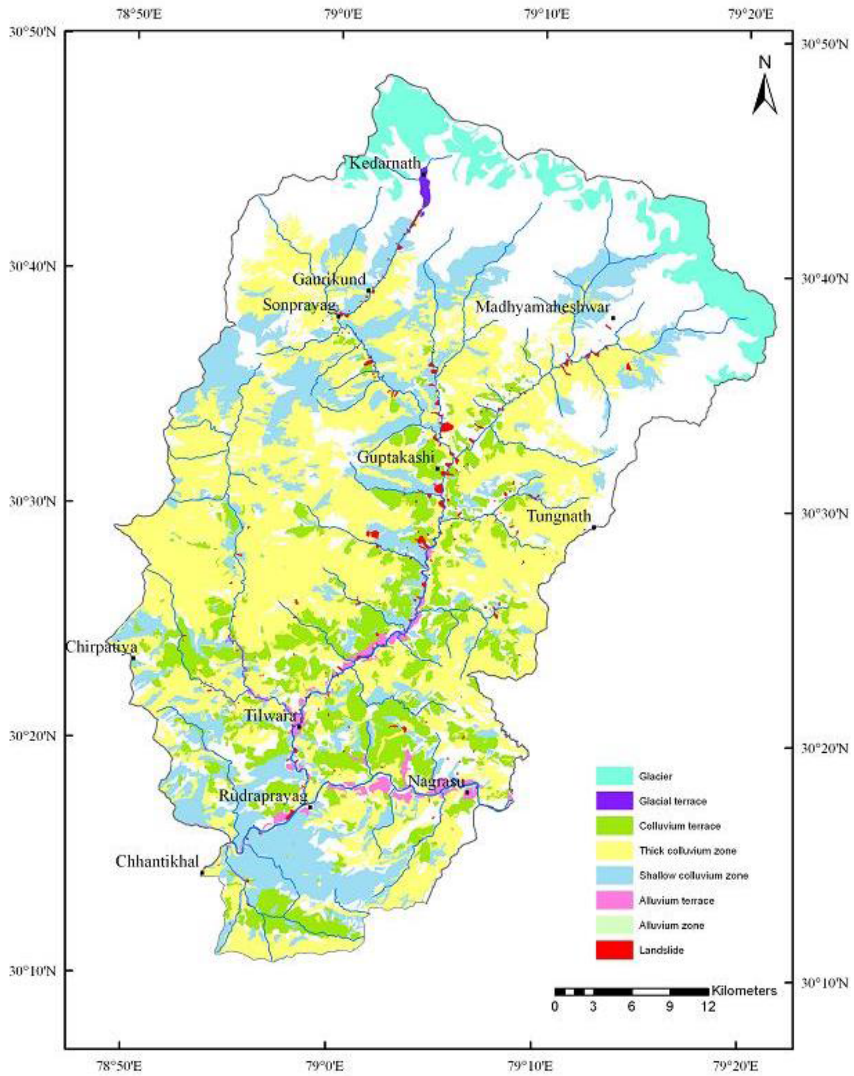

Figure 2: Overburden map of the study area.

activity in the area. Thick pile of alluvium terraces are observed to be well developed all along the Mandakini valley, especially around Bhiri, Chandrapuri, Tilaknagar, Agastmuni, Vijaynagar and Tilwara.

Flash flood of June 2013, in the Mandakini valley has considerably modified the original topography and geo-environment of the area. Major geomorphic changes have been introduced in Kedarnath (Figure 3). Hitherto abandoned course of Mandakini, to the east of the temple has become active and the level of the channel to the west of the temple has been elevated due to aggradation. Relief between the temple township, that has now become waterlocked, and the river has thus been greatly reduced. Large portion of the temple township, particularly to the north has been overrun by debris and boulders. The lake to the north of the temple has vanished and instability has been induced in the entire hill slope to the north of the temple. Scarp has been formed at many places along the course of the river. General landscape of the area has thus changed.

Downstream side to Kedarnath, Rambara town was washed off together with pedestrian trek. Besides, Gaurikund, Sonprayag, Sitapur, Barasu, Khat, Semi, Gaundar, Jal Talla, Kalimath, Kunj, Taljaman, Banswara, Syalsaur, Chandrapuri, Sauri, Pathalidhar, Ganganagar, Jawaharnagar, Vijaynagar, Agastmuni, Silli (Chaka), Sumari, Tilaknagr, Tilwara are adversely affected.

It is well known that river bank retreat occurs both by continuous fluvial erosion as well as abrupt bank failure [22,23]. River bank-toe erosion causes to increase the bank height and the slope of the bank to the extent that eventually riverbank mass failure occurs [24]. High discharge of all the tributaries of Mandakini river is observed to have resulted in excessive erosion and collapse of the banks. A number of landslides are observed to have initiated. The failure mass of the slides washed off by the floodwater has resulted in increased rate of sedimentation in the streams.

One of the reasons for such a high sediment contribution is because the catchments of these rivers contain extensive old landslide deposits that were generated during 1999 cloudburst [25,26]. These sediments have been dumped at various places along the river course and the river has also changed its course in many areas. This has made many areas highly vulnerable. The observations make it clear that most devastation has taken place on the river borne material terraces, particularly

Figure 3: View of Kedarnath after the disaster of 16-17 June 2013.

Figure 4: Deluge of June, 2013 events caused devastation in these towns; (a) Sonprayag, (b) Chandrapuri (c) Tilaknagar, (d) Ganganagar, (e) Vijaynagar, (f) Tilwara. All these towns situated over river borne materials (RBM) terraces along the banks of Mandakini river.

around Sonprayag, Chandrapuri, Tilaknagar, Ganganagar, Vijaynagar and Tilwara towns along the course of Mandakini river (Figure 4). These observations related to change and deposition are summarized in Table 1.

Geological setting

In the study area Central Crystalline rocks are thrust over rocks of Lesser Himalaya along Main Central thrust (MCT) which is a northerly dipping major tectonic discontinuity exposed across the Mandakini river at Kund near Okhimath (Figure 5). The rocks of Lesser Himalaya are observed to comprise of low grade metasediments that are intruded by acidic and basic igneous rocks. The lithological units have been refolded, faulted during various phases of the tectonic activity [27]. These consist of thick succession of low grade metasediments made up of quartzite along with penecontemporaneous metabasics and carbonate rocks. The main rocks observed in the area include phyllite, quartzite, limestone, slate, granite and metabasics [28,29].

Granites exposed in the area are observed to be tourmaline and at places chlorite rich and these intrude quartzites of Rudrapryag Formation to the west of Tilwara. These are largely observed to be very course grained, none-foliated and generally porphyritic. Lithological successions of the investigated area are given in Table 2.

The Higher Himalayan Central Crystalline rocks are observed to comprise of low, medium and high grade rocks. In the study area high grade rocks are observed to be thrust over low to medium grade rocks along Vaikrita Thrust (VT). It is observed to the north of Gaurikund. The main rock types observed in the area include gneiss, schist, quartzite, crystalline limestone, marble and granite [30]. The areas in the proximity of tectonic boundaries are observed to be covered with large fans and cons of landslide debris. Apart from landslides, subsidence zones are also observed around tectonic discontinuities.

Apart from the MCT, VT and Banswara Thrust, other tectonic contacts observed in the area include Madhyamaheshwar fault, Mandakini fault, Rawan Ganga fault, Laster fault, Kyunja fault and Alaknanda fault are the major faults aligned along the main channel course of these valleys. These faults act as a major factor in the mass movement processes in the Mandakini valley [31].

Slope instability

Human activities particularly that related to construction of buildings, transportation routes, dams and reservoirs, canals and communication systems disturb large volume of earth material. These are recognized as having major role in initiating slope failure and increasing the magnitude of damages [32]. Habitation and infrastructure development initiatives in close proximity of streams and rivers, as also over Quaternary deposits, and unplanned debris disposal of excavated rock and debris are observed to aggravate the fury of both, landslide and flash floods in the region.

While undertaking fieldwork assessment of major losses inflicted to key infrastructure was also done. Rudraprayag Bypass Bridge, Sonprayag Girder Bridge, Ganganagar (Phalai) Girder Bridge and Silli Pedestal Bridge have been completely washed off due to the flooding of Mandakini river.

Besides road network the disaster has resulted in massive damage to Son, Phata - Byung, Singoli

- Bhatwari and Kali Ganga Stage - I hydroelectric projects that are run of river schemes on Songanga, Mandakini and Kali Ganga rivers. Excavated muck of Singroli-Bhatwari HEP was observed to be dumped at various places along the river bank of Mandakini. During flash flood, the same aggravated erosional power of the stream water and caused massive loss of infrastructure and property. The area was investigated after the deluge and traverses were taken around affected sites to examine the slope instability. Details of the same are described in the sections below.

Cloudburst incidences

The high intensity rainfall of more than 100 mm/hour in a few square kilometer area is generally defined as cloudburst [33]. Mostly cloudburst activities occur between Main Centre Thrust and Main

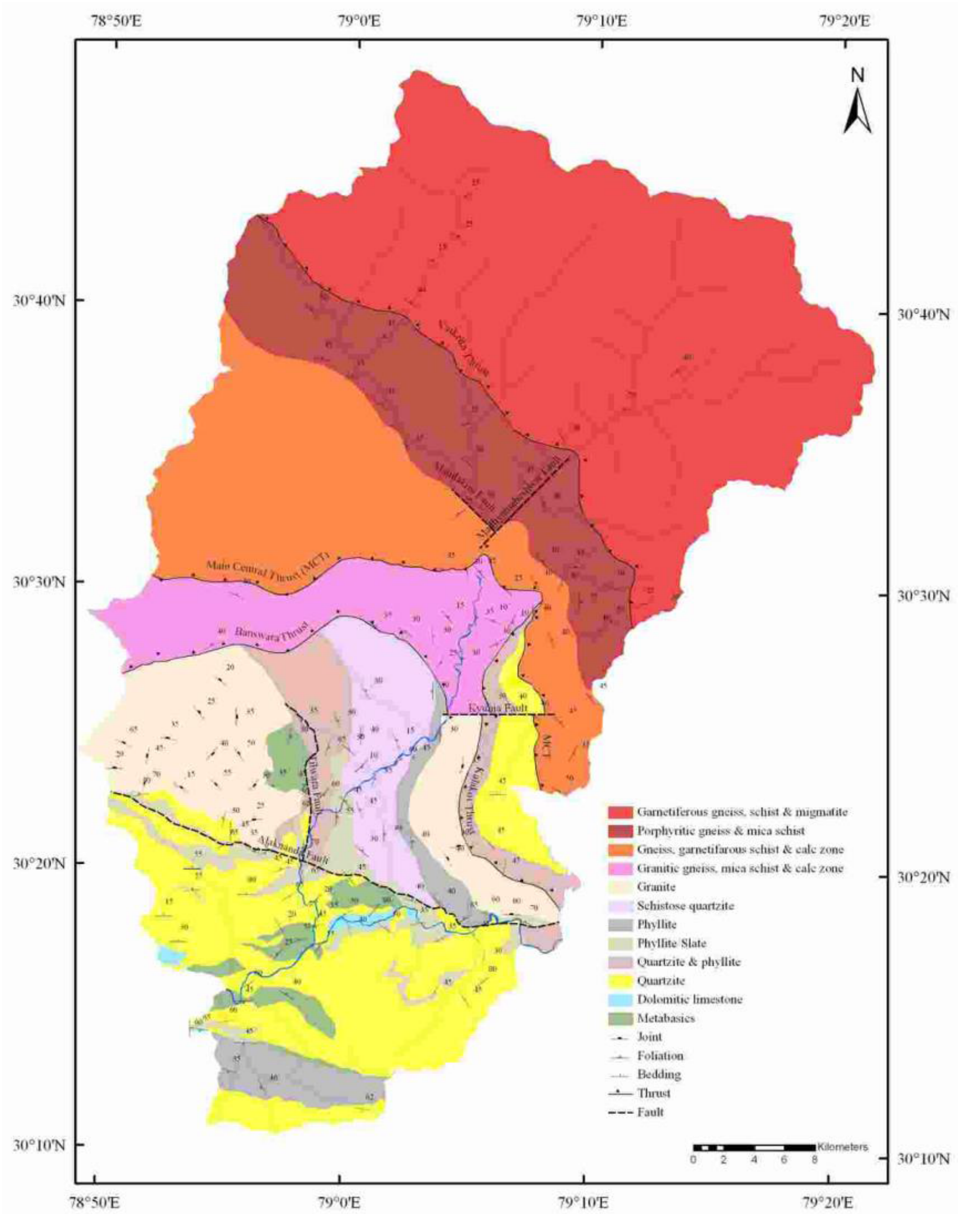

Figure 5: Map showing geology of the study area.

S. No	River/Stream	Location	Deposited sediments thickness (in meters)	Shift in channel course (in meters)	Bank on which change in river course is observed
1	Mandakini	Sonprayag	5-6	2-5	Left bank
2		Sitapur	3-4	5-7	Right bank
3		Banswara	2-3	8-10	Right bank
4		Syalsaur	1-2	5-8	Right bank
5		Chandrapuri	3-4	10-15	Right bank
6		Gabni	1-2	2-3	Left bank
7		Ganganagar	2-3	3-5	Right bank
8		Vijaynagar	4-5	10-15	Left bank
9		Rampur	1-2	3-5	Right bank
10		Tilwara/Sumari	2-3	3-5	Right bank
11	Madhyamaheshwar	Gaundar	3-4	3-5	Left bank
12		Paundar (near iron bridge)	5-6	2-4	Right bank

Table 1: Details of the places where river courses has changed and sedimentation has occurred.

	Group	Formation	Member/Rock type
Higher Himalaya	Vaikrita	Gaurikund	Garnetiferous gneiss, schist, quartzite and migmatite
	Vaikrita Thrust (VT)		
	Jutogh	Kalimath	Porphyritic gneiss and mica schist
		Okimath	Gneiss, garnetiferous schist and calc zone
	Main Centre Thrust (MCT)		
Lesser Himalaya	(Pre-Cambrian to Sillurian) Garhwal	Patroli	Granite
			Patroli quartzite
		Gwanagarh	Dobri dolomite, Dobri phyllite, Bhishna (Lameri B), Massive dolomite (Lameri A) quartzite, Dhanpur dolomite
		Lameri	Massive dolomite (Lameri C), Phyllite/slate
		Rudraprayag	Orthoquartzite-volcanic association with metabasics, phyllite and slate member
	North Almora Thrust (NAT)		
	Dudhatoli (Pre-Cambrian)	Maithana quartzite Pauri phyllite	Khirsu quartzite Pauri phyllite, Bhainswara quartzite

Table 2: Lithotectonic succession of the investigated area.

boundary Thrust [34]. Bheti-Paundar (August, 1998), Phata (July, 2001) and Okhimath (September, 2012) in Rudraprayag districts are the evidence for cloudburst events.

Besides, in the year 2005, close to national highway (NH 58), Rudraprayag to Kedarnath national highway (NH 109), Agastmuni and Vijaynagar villages in Mandakini valley were affected by cloudburst. Several people had been reported to be buried under the debris and many were wounded due to the sudden torrential rainfall [31,35]. It is observed that the debris flow was the main cause of devastation in all the previous cloudburst incidences in Mandakini valley.

Apart from field observations information regarding past incidences of heavy and localized rainfall events were gathered from the local people. Semla, Pathali, Paldwari (Kakra Gad), Kirora Malla (Chak Gad), Kusum Gad, Phata, Panjan, Chhantikhal and Bajira were reportedly devastated by such rainfall events in the past.

In September, 2012 heavy rainfall induced landslides and debris flows reportedly devastated Giriyagaon, Salami, Mangoli, Chunni, Premnagar, Brahmankholi and Jua Kimana villages around Okhimath.

In the year 2013 Panjan and Bajira are observed to be devastated by cloudburst events while Taljaman, Senagarhsari, Sounda, Dhaunda, Udu, Barangali, Kimana and Khaduli are adversely affected. As many as 22 locations of cloudburst events are thus identified during the field work in Rudraprayag district (Figure 6). Most of these (41 percent) are located in Okhimath tehsil.

Geomorphic features like funnel shaped valleys with high relief difference and dense forest cover especially oak trees with average height of 1600 to 2200 meters provide suitable conditions for its occurrence. It has been observed that cloud burst generally occurs along the more isolated slope generally facing towards west and south direction and in general occurs during the late hours of the day [36].

Accordingly, distribution of various geomorphic and physiographic factors like altitude, affected face, relief, landuse, stream order and valley shape were correlated and analyzed where cloudburst events were identified. Valley in most cases (73 percent) is observed to be funnel shaped and NW-SE (50 percent) to NE-SW (80 percent) oriented.

Area to the upslope of most places (64 percent) is observed to be forested. Altitude in most cases (77 percent) is observed to range between 1400 and 2200 meters. Most of these areas fall in the higher reaches in the catchment first and second order streams. Heavy downpour is observed to cause fast erosion of the agricultural lands and ensuing debris flow is largely responsible for the devastation.

Landslide incidences

Landslide is nothing but downslope movement of rock mass and debris with varying proportion of water [37-39]. Landslides take a heavy toll of human lives and cause irreparable harm to cultivable land besides causing damage to infrastructure and property.

In June, 2013 precipitation in the area was significantly higher than average and large number of landslides are observed to have been triggered at various places; mostly along both the banks of Mandakini river. Observed landslides are classified on the basis of movement and rigidity of material comprising the slide mass; bed rock, debris and earth.

Many workers have carried out the studies of landslides in different part of Garhwal and Kumaun regions of Uttarakhand using various methods and techniques [40-45]. A landslide inventory is an important database extent and amount of landslide occurrences [46]. It is also the simplest form of landslide map and therefore the same has been utilized for this study.

Based on field work, the macro scale landslide inventory database of the area (1:50000 scale) has been prepared. In total, 290 landslides have been geotechnically assessed (Figure 6). Of these, 188 numbers are debris slide, 83 numbers debris cum rock slide and 19 numbers rock slide/fall.

Analysis to data pertaining to the landslide observed in the field shows that the majority (65 percent) falls in the category of debris slide (Figure 7). This makes it amply clear that the overburden or debris material was saturated by prolonged heavy rainfall and the same was the responsible for the initiation of landslides.

Field observations suggest that the landslides in the study area are largely concentrated in close proximity of the road and stream networks. Change in slope geometry for road construction and toe erosion by stream are the reasons thereof. The relationship of these two parameters on the distribution of landslides is therefore accorded special attention.

Out of total landslide incidences recorded in entire district, 219 numbers are caused by change in slope geometry for infrastructural developments and toe erosion by stream. Another 71 numbers are however also caused by other factors that include heavy rainfall, lithological and structural condition of the bed rocks, surface and sub-surface water and deforestation. Majority of landslide incidences in this area largely (76 percent) are observed to be triggered either by change in slope geometry or toe erosion (Figure 7).

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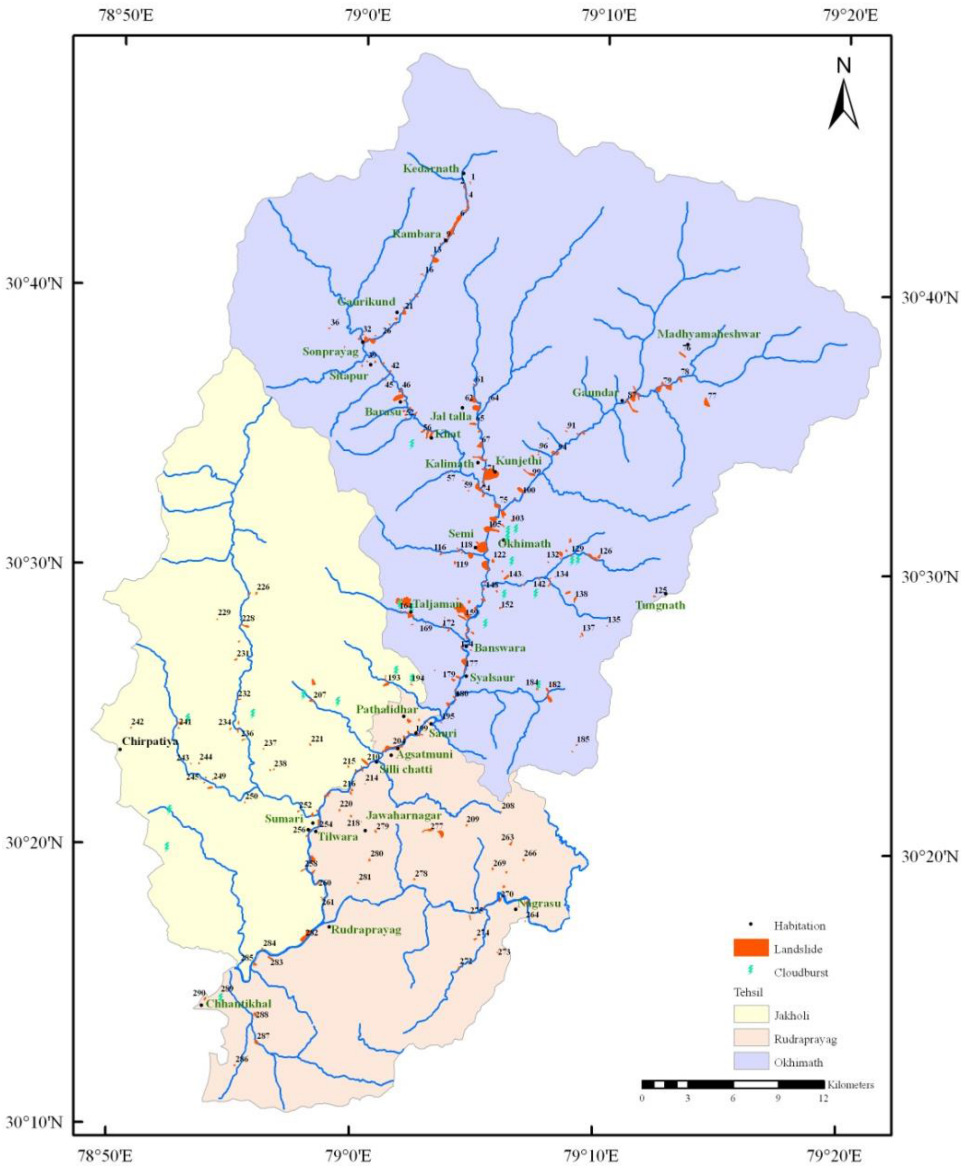

Figure 6: Distribution map of landslide and cloudburst.

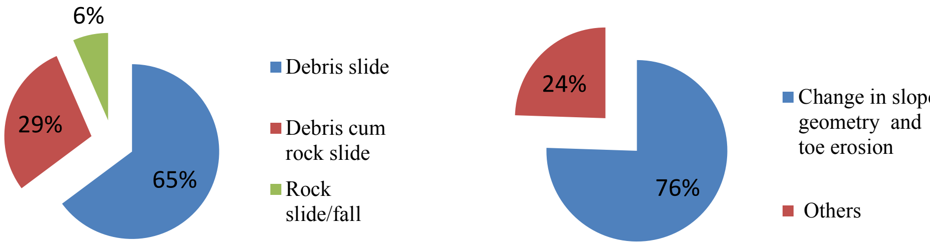

Figure 7: Landslide types (left) and their triggering factors (right) percent observed in the area.

Landslide incidences have severally damaged the transport infrastructures in the area. These includes Rudraprayag – Gaurikund (NH 109) road, Bhainsari – Kalimath road, Kund - Okimath

– Chaupta road, Okhimath – Ransi road, Jakholi – Vijaynagar road, and Nagrasu - Kaliyasaur (NH 58) road.

June 2013 floods have resulted in development of a number of major landslides, particularly in the Mandakini valley. These include Gaurikund, Sonprayag, Barasu, Khat, Semi, Kund Chatti, Jagi-Bedula, Kunjethi, Jal-Talla, Nagjagai and Tilaknagar. Translational and circular failures are commonly observed in the area.

Slide around Jagi - Bedula and Nagjagai are observed to have potential of blocking the stream course and thereby threatening safety of human habitations and infrastructure in downstream area. Lake formation is observed in the field around Jagi-Bedula slide zone. It is however in an initial stage but further downslope movement of debris and rock mass has the potential of posing a serious threat.

Discussion and Conclusion

Heavy rains and associated deluge on 16/17 June 2013 in the catchments of the Mandakini river and its tributaries, caused immense loss of life, property and infrastructures in Rudraprayag district. Field work carried out in the area suggests that landslides have been largely (in 76 percent cases) caused either by slope modification for infrastructure development or toe erosion by streams, mostly during spells of high discharge. Besides zones of old landslide material, glacial sediments, colluvium and alluvium deposits are identified as being most vulnerable to slope failure. Together with these the slopes occupied by highly weathered, fractured and jointed rocks are also observed to be vulnerable. Structural disposition of rocks is also observed to facilitate mass movement.

Most devastation has taken place on the river borne material terraces, particularly around Sonprayag, Chandrapuri, Tilaknagar, Ganganagar, Vijaynagar and Tilwara towns along the course of Mandakini river. It is therefore that some portions of these towns required to be relocated.

River bed level has grown up at various locations. Sonprayag (05-06 meters), Sitapur (03-04 meters), Gaundar (03-05 meters), near Paundar (05-06 meters), Chandrapuri (02-03 meters), Vijayanagar (03-05 meters) etc., are the locations where thick pile of debris deposited by the river. There is thus a pressing need to remove the transported debris and channelize the water. Besides, Mandakini river is observed to have shifted towards the left bank by approximately 10 to 15 meters due to bank erosion of the river borne material (RBM), at Banswara, Chandrapuri and Vijaynagar township. It is recommended that the areas where the banks have collapsed, be provided with suitable bank stabilization measures.

It is highly recommended that all the constructions in the townships located along the Mandakini river should maintain respectable distance from recent high flood level (HFL). Appropriately designed awareness drive is highly recommended for persuading people to maintain a respectable distance from streams and rivers when deciding to settle down. As a rule of thumb, message has to be sent across that the structures should be sited 50 to 100 meters from river bank. These however depend on the specific site conditions.

Roads in the area are observed to be aligned in close proximity of the river; either over the river borne material terraces (RBM) or over colluviums. In case the banks are not adequately protected there exists high probability of such roads being disrupted during high floods. The new alignment should maintain respectable distance from the streams. Where alignment in the proximity of the streams becomes a compulsion adequately designed bank protection works should necessarily be provided.

Cloudburst is controlled by the distinguished geomorphic and physiographic parameters of the high altitude mountainous terrain. In these parameters, high relief area, funnel shape valley, cirque, hanging valley and streams etc plays an important role. These geomorphic and physiographic parameters can thus be considered as being responsible for promoting heavy and localized rainfall and these can in turn be utilized for identifying areas that are likely to be affected by such events. This is sure to pave way for the preparation of cloudburst vulnerability maps for the area.

Landslide inventory map can be helpful in clear demarcation of relatively safe and unsafe zones. It is highly recommended that any constructional activities in the close proximity of landslides should necessarily be backed by appropriate geological-geotechnical assessments.

Slides around Jagi - Bedula and Nagjagai are observed to have potential of blocking the river course and thereby threatening safety of human habitations and infrastructure in downstream areas. Special attention is therefore required to be paid for monitoring these and other major slide zones along the river banks. Geological and geotechnical investigation of such zones should be carried out on a scale of 1:5,000/2,000.

In order to build safe and economical infrastructural facilities on or near slopes, it is important to recognize and equally stress the importance of using current scientific and technological developments in the design of structures and control measures.

Landslide is a complex phenomenon and its management requires a multidisciplinary approach and regular consultation amongst different stakeholders. Effective interaction therefore needs to be promoted between geoscientists, civil engineers, physical planners and decision makers.

Despite common occurrence of landslides trained manpower for preparing sound landslide mitigation plans is lacking. Specially designed integrated training programme to produce trained personnel that are competent to plan and execute landslide mitigation related works.

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