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RESEARCH ARTICLE

SOME SIGNIFICANT ASPECT OF CLOUDBURST WITH ESPECIAL REFERENCE TO DEVASTATING LANDSLIDES AT BASTARI, NAULRA AND DIDIHAT REGION, PITHORAGARH DISTRICT, KUMAON HIMALAYA, UTTARAKHAND

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ABSTRACT

In recent times extreme rainfall events as cloudbursts are dominant phenomenon trigger large scale mass movement and flash floods in the Himalayan region. Cloudburst is a natural and common phenomenon in the Himalaya, especially in Garhwal and Kumaon region of Uttarakhand. Cloudburst and associated disaster affect thousands of people every year and cause loss of life, property, livelihood, infrastructure and environment. Slope failure incidences took place at many places in Pithoragarh district on 1st July 2016 amid heavy rainfall. According to District Emergency Operation Centre (DEOC) and local persons, 160 mm rainfall recorded within 4 - 5 hours in Didihat area. Bastari, Naulra (Kumalgaon) and Didihat were amongst the worst affected regions. Total 160 families of 15 villages with Didihat town are affected in Thal, Munsiyari and Didihat tehsils of Pithoragarh district, 24 persons were killed in this incidence. Due to torrential rainfall Thal - Munsiyari road was cut-off and dozens of vehicles remained stranded on both sides. Since the area is tectonically active, heavy localized precipitation and anthropogenic activities play a major role in triggering landslides and flash floods. Changing pattern of rainfall that it makes heavy localized precipitation or cloudburst all the more common in this region is a cause of concern for the state government, meteorologists and other researchers. The present study focuses on some significant aspect of cloudburst and associated hazards in Uttarakhand Himalaya.

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INTRODUCTION

Almost every year several parts of Uttarakhand Himalaya experience cloudburst and associated hazards. Cloudburst during August 1998 at Ukhimath (Rudraprayag) and Malpa (Pithoragarh), August 2001 at Phata (Rudraprayag), August 2002 at Burakedar (Tehri), August, 2012 in Asi Ganga (Uttarkashi), September, 2012 at Ukhimath (Rudraprayag) and June 2013 at Kedatnath (Rudraprayag) are some of the examples of recent cloudburst incidences associated with flash floods and landslides in Uttarakhand Himalaya (Sah and Bisht, 1998; Sah, 1999; Paul *et al*., 2000; Naithani *et al*., 2001; Sah *et al*., 2003; Rana *et al*., 2012; Bisht and Rautela, 2012; Gupta *et al*., 2013, Rautela, 2013 and Asthana & Asthana, 2014). In 2016 monsoon season, Bastari, Naulra and Didihat (Pithoragarh), Kothiyara (Tehri), Markhola (Pauri) and Ghat (Chamoli) were badly damaged by cloudburst and subsequent landslides as well as flash floods. The Cloudburst is a natural phenomenon that generally occurs during monsoon period over many regions of the Himalaya. Generally, cloudburst refers to particularly heavy precipitation in a short period of time over limited geographical area. It is often defined as more than 100 mm/hour rainfall within a limited geographical area of a few square kilometres. The landforms of the Uttarakhand Himalaya located above 1200 meter altitude are extremely sensitive for the cloudburst induced landslides during monsoon season (Table 2). Monsoon winds blow very frequently from S – N from Bay of Bengal through Indian plains. The clouds enter narrow valleys and their further movement is restricted by cirque/cliffs and the clouds get trapped in these features and precipitate water in very short period (Sharma *et al*., 2002).

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Cloudburst incidences over many areas of Himalaya often go unnoticed due to the absence of meteorological observatories. Many a times these come to notice only when these are accompanied by losses and casualties. In the absence of losses these can only be identified on the basis of inundation occurring along streams. Mostly upper reach of first order and second order drainages (seasonal streams) have been observed to be overwhelmed by debris flow during these incidences. Slope failures and bank erosion are common during this phenomenon which result sedimentation and sometimes block the river course, turn them into big lake and create flood condition.

MATERIALS AND METHODS

Pithoragarh district is the easternmost frontier district of the Uttarakhand and falls in Kumaon division of the state. Pithoragarh district of Uttarakhand falls in Lesser and Higher Himalaya, and like any other hilly terrain of the state it is also vulnerable to natural disaster. The areas devastated by cloudburst and heavy rainfall are located in Thal, Munsiyari and Didihat tehsils of Pithoragarh district and fall in the catchments of East Ramganga and Charma rivers respectively (Figure 1). Bastari (29º 43' 48.83" N & 80º 17' 41.22" E), Naulra (29 º 52' 20.70" N & 80º 09' 54.12" E) and Didihat (29º 48' 8.84" N & 80º 15' 9.44" E) amongst the worst affected areas during July 2016 heavy rainfall induced landslide disaster. Survey of India topographical sheets (62 C/1, C/5 and C/6) on 1:50,000 scale have been used for the preparation of base map and geo-morphological map of the area.

Regional tectonics

Geologically the study area falls in Lesser Himalaya and earlier works of Auden (Auden, 1937) and Heim and Gansser (1936) suggest that the rocks of Pithoragarh area belong two tectonic units; one belonging to the Almora Crystalline Zone and the other belonging to the sedimentary zone of Garhwal Group (Figure 2). In the study area the rocks of Almora nappe are observed to be thrust over quartzites and limestones of Garhwal Group along North Almora Thrust. Granites and augen gneisses of Almora Crystallines are observed around Didihat and Bastari area. Quaternary deposits (RBM) and limestones of Garhwal Group are observed around Naulra landslide zone. The rocks exposed around the area are traversed by numerous joints that comprise important structural discontinuities affecting the strength of the rock mass and stability of slopes. The phylites exposed in the slide zone of Bastari are generally observed to strike NW – SE and dip towards northeast at angle of around 35°. Prominent joints observed in the area are also observed to strike NW – SE parallel to the foliation and dip at moderate to high angles (55°) towards SSW. At Naulra landslide area exposed limestone rocks are observed to strike E - W and dip towards south at an angle of around 50°. These rocks are observed to be well jointed.

Physiography and climate

The study area is represented by dissected hills, valleys and a typically rugged topography with high relief. The prominent drainages flowing in the area are Kali and Ramganga river. Charma river originating from an approximate elevation of 1950 m above msl and confluence with Kali river at upstream side to Dwalisera. The main land use practice in the study area is terrace farming. The climate of the area is moderate and tropical characterised by hot and dry summer from March to middle of June. Due to southwest monsoon precipitation mainly arises during June to September. The scattered rains and snowfall arise during winter months. The heavy precipitation during monsoon season on the overburden material, fractured, jointed and sheared rocks develops variety of slope failure. The rainfall data of the Didihat Tehsil of July 2016 was given in Figure 3. The Fig. shows that maximum rainfall was occurred on 1st July 2016 and disaster was occurred on the same day.

Devastating landslides of 1st July 2016

According to eyewitness accounts cloudburst incidence took place around Bastari village on 1st July 2016 in two phases. Debris flow occurred after heavy rainfall in the morning hours (around 0430 hrs) in which one house was damaged. The inhabitants of the same were rescued by the villagers. Thereafter most people of the village (around 24) took shelter in a well constructed house in the village that was perceived to be safe by the people. While they were still waiting for rain to stop another debris flow took place around 0600 hrs. This engulfed the very house in which people had taken shelter. All the persons were thus buried under the debris that flowed down along a first order drainage passing through Urma village, which is situated below Bastri village (Figure 4, a). 19 persons were killed in this incidence. Of these bodies of 08 could not be recovered. Total 16 buildings were destroyed or damaged and 174 cattle were lost. Heavy rainfall also accelerated gulley erosion on river born material (RBM) and debris flow took place at Naulra as well. 03 persons were killed in this incidence while houses of 05 families were buried under the debris. Around 70 animals were lost in the incidence. 2.5 - 3.0 m thick pile of debris was observed at the site. Damage and destruction due to heavy rainfall is also observed around Didihat area and nearby villages. According to list provided by Nagar Panchayat Didihat, a total of 232 families were affected by the slope failure in Didihat town out of 101 families live in GIC Ward alone. This is followed by 92 in Tehsil Ward, 32 in Ambedkar Ward and 07 in Shiv Mandir Ward. Besides, several other villages were affected by slope failure around Didihat area.

Analysis of field observation

Rocks exposed in the Bastari area are dominated by fractured and jointed granitic gneisses of Almora Crystallines and phyllites of Garhwal Group. Slope in the uphill side of village have steep gradient. This area is observed to have predominance of boulders that are embedded in thick cover of debris. The slope in the area is generally observed to dip towards southwest at steep angles (55° - 60°). This has facilitated fast down slope movement of debris. A number of agricultural fields along with houses were thus damaged due to debris flows in the Bastari area (Figure 4, a and b). The thickness of the debris accumulated in the area is observed to be around 3.5 to 4.0 meters. Heavy rainfall is deduced to be the main triggering factor for the downslope movement of the debris. Steep slope together with the presence of thick cover of colluviums dominated with boulders on uphill side of Bastari only added to the damaging potential of the debris flow that moved past swiftly and had high erosion potential to create deep gullies in the area. The habitation is situated along seasonal drains and on steep slope. Steep slope accompanied with heavy discharge of water is deduced to have aggravated the pace of erosion along the nala.

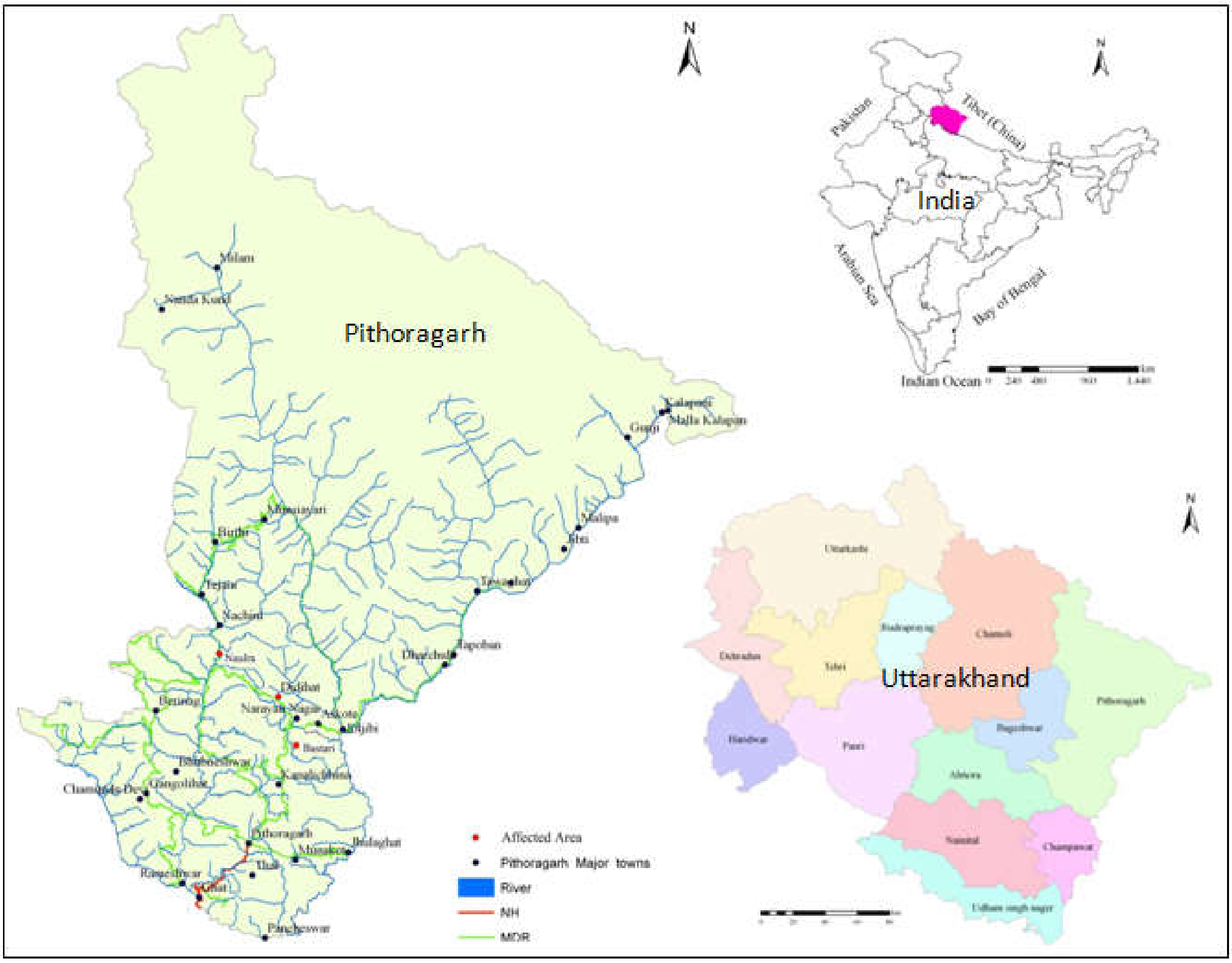

Figure 1. Location map of the study area

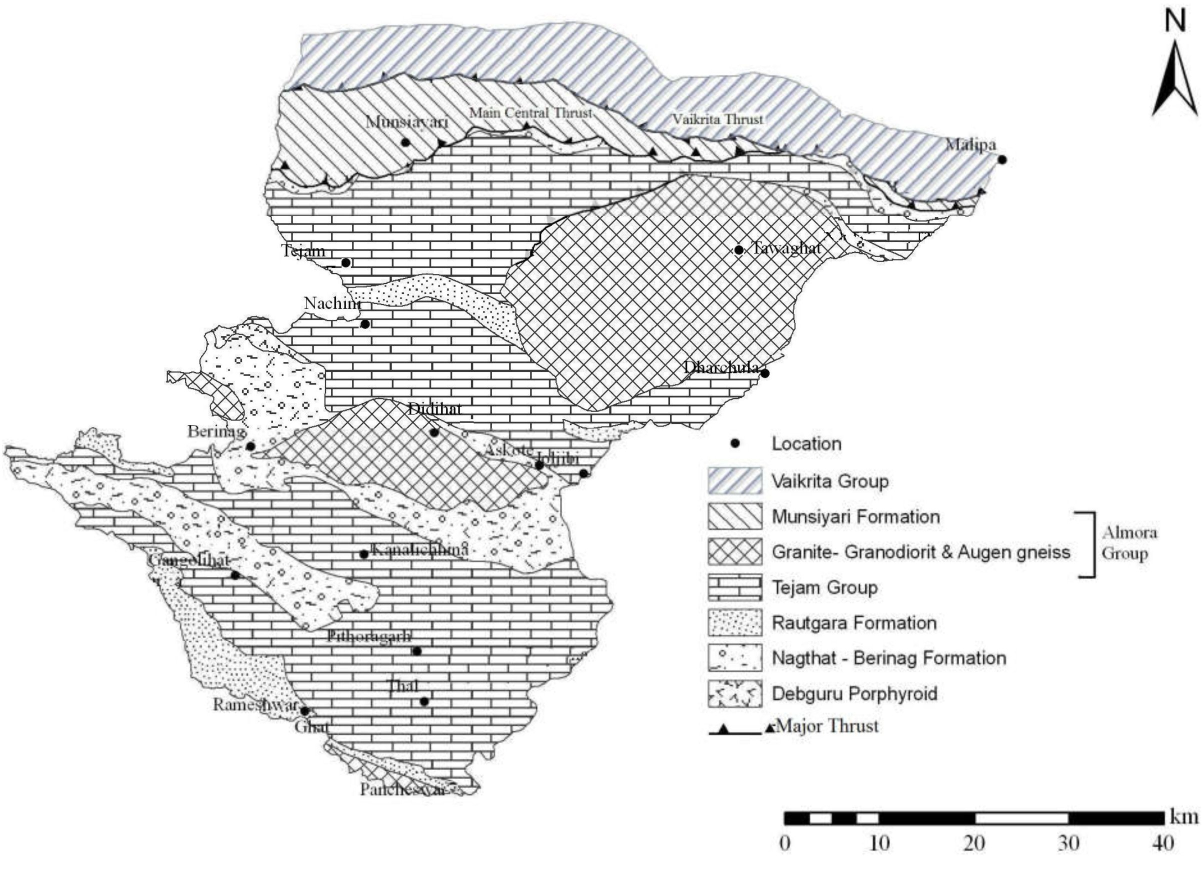

Figure 2. Generalized geological map of the area (After Valdiya, 1980)

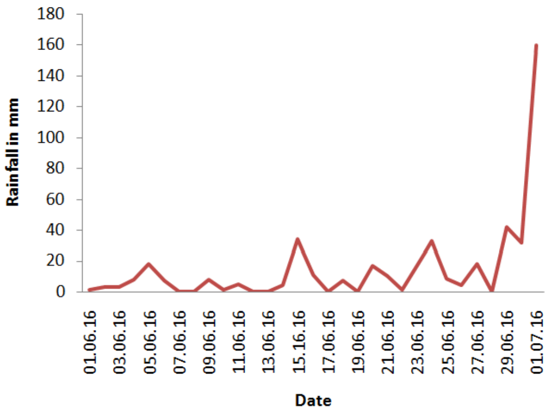

Figure 3. Rainfall data of Didihat tehsil, before devastating landslide at Bastari (Source: DEOC, Pithoragarh)

down slope at fast pace. A well exposed contact zone of phyllite and granitic gneisses is situated below Bastari. Presence of stable hard rocks thus protected Urma village that is located just below Bastari (Figure 4, a and b). In case of Naulra landslide, presence of river born material (RBM) is observed behind the habitation. Slope at this location is observed to dip towards east at an angle of around 40°. Indications of heavy rainfall induced gulley erosion and debris flow are observed during field investigation. RBM is always vulnerable for the slope failure due to the roundness of its constituents and poor cohesion. The debris slide is observed to have occurred on the eastern slope of N-S trending ridge. The landslide debris that descended down from the area upslope of the Naulra was observed to have overrun both agricultural fields and houses.

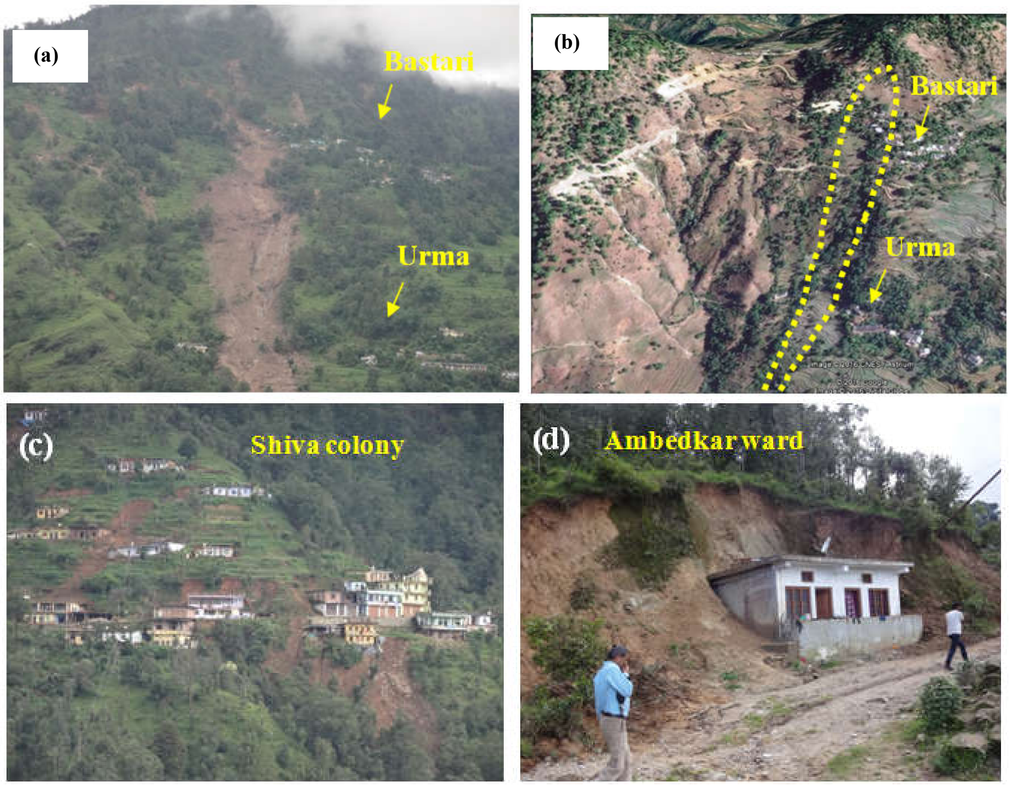

Figure 4. (a) View of Bastari debris flow (b) Google image of Bastari area shows recent changes in landuse / landcover by newly constructed road, yellow dotted line shows damaged area by the recent landslide. Image also depicts cultivated land on downhill side

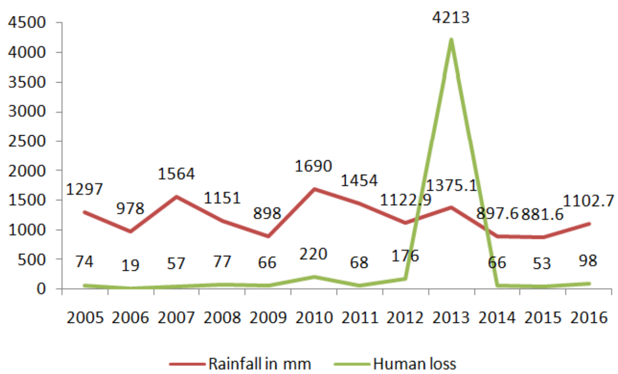

Figure 5. Monsoon rainfall (mm) in relation to human loss in Uttarakhand (Source: IMD)

Rapidly running water and gravity driven movement induced by lubricating action of ground water thus derived the debris

Figure 4, c and d are from different locations of Didihat town but scenario is almost same in all the region, though the area was devastated by heavy rainfall of 1st July 2016, but most of the region common things responsible for the slope failure are construction on moderate to steep slope made up off overburden material or old landslide debris, excavation of slope, absence of proper drainage network. Besides, encroachment along the drain is observed at several locations and most of the places buildings have been constructed close vicinity to hill slope even 2 meter minimal gap is avoided between hill slope and buildings. Due to this reason most of the places debris laden water either entered into the rooms or flowing through the roof.

Extreme precipitation events

Incidences of extreme precipitation have increased in previous some years, causing enormous loss of lives and damage to property, infrastructure and natural resources. Uttarakhand Himalaya is severely affected by recurrence of rainfall induced disaster, particularly in 2010, 2012 and 2013 (Table 2). In 2016 besides Bastari village, cloudburst and subsequent landslides damaged several roads and houses in the villages of Tehri district on 28th may 2016. Budhakedar - Ghansali motor road was blocked and a large number of houses and cattle were buried in mud due to heavy rainfall. On 30st June 2016, six (06) people killed and many houses in the Ghat area of Chamoli had also been reportedly washed away by flash floods caused due to torrential rains in the area. Meanwhile, water level was reportedly continuing to rise in the Nandaprayag town. Whereas, on 21st August 2016, cloudburst kills 5, injures 2 in Markhola (Pauri). Figure 5, illustrates relationship between human loss and monsoon rainfall in Uttarakhand, except extreme event of June 2013 average human loss during 2005 to 2016 is 89 persons per year. However, scenario would be drastically changed if 2013 is included. A Global Flood Inventory (GFI) which suggests that the majority of flood events (64%) are associated with short duration heavy rains, followed by events due to torrential rains (11%) during the monsoon period. These latter heavy rain events are particularly associated with localized causes, such as cloudbursts, lake bursts, landslides and orographic forcings, etc. These events are distinctly different from the large scale monsoonal flow (Adhikari *et al*., 2010). The study on extreme events in Nepal from 1971 to 1990 indicates that the incidents of such events are increasing (Chalise and Khanal, 2001). An analysis of last 71 years climate data of Pakistan have indicated that the storm precipitation intensity has increased in recent years (1991 ~ 2001) in the northern part of the country (Siddiqui, 2002). Analysis of long term data is necessary for clear understanding of such phenomenon in the Himalaya. In most of the years extreme rainfall events and cloudburst disaster were reported in August during the later part of the monsoon season (Joshi and Kumar, 2006). Geographical distribution of these exhibits them to be concentrated in the proximity of the Main Central Thrust (MCT) and along the northern extremity of Lesser Himalaya. If bed rocks present debris flow would be less, on the other hand unconsolidated material, old landslide debris, structurally weak area (traversed by fault/thrust and composed by highly weathered and jointed rocks) has been destroyed and damaged in a large scale (Sajwan and Khanduri, 2016).

Orographic and tectonic control on cloudburst

In Uttarakhand Himalaya due to its orographic and tectonic setup rainfall in the region is highly variable even over short distances. Dissected topography and tectonically active nature of the region further promotes mass movement and slope instability. Even though most portion of the state has mountainous topography heavy rainfall related losses are not evenly distributed; some regions suffer more due to these events (Figure 5). Often these events seem to be orographically and tectonically controlled. More importantly, the terrain provides an orographic barrier which facilitates torrential rain. There is a significant variation in the rainfall intensity as a function of vertical height. During Ukhimath cloudburst (2012), the most intense rainfall was recorded in the nearby Byung area, which however remained unaffected. This indicates the temporal variability in rainfall pattern even at the local level (Rana *et al*, 2012). However, it is well known fact that the Higher Himalaya is comparatively more tectonically active than Lesser Himalaya due to its proximity to the Suture Zone; with concentration of most earthquake epicentres in its proximity MCT being considered highly active. Geological investigation of the cloudburst affected areas reveals that major events are more in Almora Crystallines of Lesser Himalaya and Munsiyari Formation of Higher Himalaya (Table 2).

Table 1. Rainfall trend of prominent locations in Uttarakhand (Source: IMD and soil conservation Dept. Gairsain)

Location	Month	Period	No. of years	Mean rainfall in mm
Joshimath	June	1958-1987	29	132.30
	July	1958-1987	29	247.40
	August	1958-1987	29	222.40
	September	1958-1987	29	104.80
Mukteswar	June	1901-2000	100	157.20
	July	1901-2000	100	307.40
	August	1901-2000	100	299.40
	September	1901-2000	100	202.30
Nainital	June	1953-1979	27	327.50
	July	1953-1979	27	725.00
	August	1953-1979	27	553.40
	September	1953-1979	27	385.00
Gairsain	June	1980-2004	25	160.93
	July	1980-2004	25	372.90
	August	1980-2004	25	382.74
	September	1980-2004	25	196.68
Dehradun	June	1901-2000	84	201.80
	July	1901-2000	84	672.60
	August	1901-2000	84	728.20
	September	1901-2000	84	296.50

Garhwal - Kumaon region is highly comprises with micaceous Pinjor sediments (Chaudhri and Sing, 2012) such as gneiss, mica schist and garnet schist, biotite etc. So, there are plenty numbers of freezing nuclei (mainly Illite, keolinite) presence in atmosphere due to excessive weathering and erosion process of these micaceous elements. This freezing nuclei rapidly freezes small water droplet into ice crystal within 0°C to -40° C temperature and cloud become more dense and heavy. In such a way large wide based cumulonimbus cloud formed (Das, 2015). Altitude greater than 2200 meters seems to create a strong barrier for the movement of clouds. Due to narrow valley and steep sloping mountains most of the clouds thus precipitate much before crossing the Central Crystallines. Whenever these clouds enter and precipitate to the north of MCT major cloudburst and flash flood events are experienced as was the case of Malpa (1998) and Kedarnath (2013). Brief account of major cloudburst events is given in Table 2, which exhibits intensification of events in previous some years. The analysis shows that there has been a constant rise in cloudburst occurrence during the last 2 decades; however last half decades (during 2010-2016) number of events have been increased (Table 2). In Uttarakhand maximum cloudbursts incidences have occurred in three districts namely Pithoragarh, Rudraprayag and Chamoli. Certain peculiar geo-morphic features that include cirque, saddle, cliff, ridge and funnel shaped valleys with high relative relief, cultivated land on downhill side and dense forest cover on uphill side, and average altitude exceeding 1,200 m. are considered to provide favourable conditions for cloudburst incidences (Figure 6). It is coincident that most of the settlements in the Garhwal Himalaya exist on the Quaternary deposit that provide good soil cover for the human activity, are most vulnerable during cloudburst events (Asthana and Sah, 2007). The alluvial terraces are highly productive and account for most agricultural production of the region. Despite this the people do not traditionally have habitations over terraces and invariably settled down at a respectable distance from the streams over hard rock on the uphill side (Rautela, 2015).

Table 2. Some major cloudburst events in Uttarakhand Himalaya

S. No.	Place	Year	Height	Geology
1.	Belakuchi, Birhi River, Chamoli	July 1970	2150 m	Deoban (Gangolihat) Fms
2.	Kandauliya Gad, Uttarkashi	August 1978	1950 m	Munsiari Fms (Almora Group)
3.	Kaunth, Chamoli	17th August 1979	1800 m	Granitic gneisses and schists (Almora Group)
4.	Thalisain, Pauri	August 1989	2150 m	Granite - Granodiorite and Augen gneiss (Almora Group)
5.	Neelkanth, Pauri	July 1990	1800 m	Limestone, shale & quartzite (Tal Fms)
6.	Mandal, Chamoli	August 1991	1800 m	Granite - Granodiorite and Augen gneiss (Almora Group)
7.	Bhenti (Ukhimath), Rudraprayag	August 1998	1800 m	Munsiari Fms (Almora Group)
8.	Malpa, Pithoragarh	17th August 1998	2275 m	Higher Himalayan Crystallines of Vaikrita Group
9.	Phata, Rudraprayag	August 2001	1650 m	Munsiari Fms (Almora Group)
10.	Burakedar-Agunda, Balganga valley, Tehri	August 2002	1650 m	Munsiari Fms (Almora Group)
11.	Baram, Pithoragarh	September 2007	1850 m	Granite - Granodiorite and Augen gneiss (Almora Group)
12.	Lah- Jhekla, Pithoragarh	8th August, 2009	1600 m	Deoban (Gangolihat) Fm.
13.	Asiganga, Uttarkashi	3rd August 2012	2000 m	Munsiari Fms (Almora Group)
14.	Ukhimath, Rudraprayag	14th September 2012	1311 m	Munsiari Fms (Almora Group)
15.	Kedarnath, Rudraprayag	June 2013	3562 m	Higher Himalayan Crysatllines of Vaikrita Group
16.	Khiro Ganga, Chamoli	June 2013	3250 m	Higher Himalayan Crysatllines of Vaikrita Group
17.	Bhuindar Ganga, Chamoli	June 2013	3400 m	Higher Himalayan Crysatllines of Vaikrita Group
18.	Ghat, Chamoli	30th June, 2016	1335 m	Granitic gneisses and schists (Almora Group)
19.	Ghansali, Tehri	28th May, 2016	1150 m	Nagthat - Berinag Fms
20.	Bastari, Pithoragarh	1st July 2016	1600 m	Granite - Granodiorite and Augen gneiss (Almora Group)

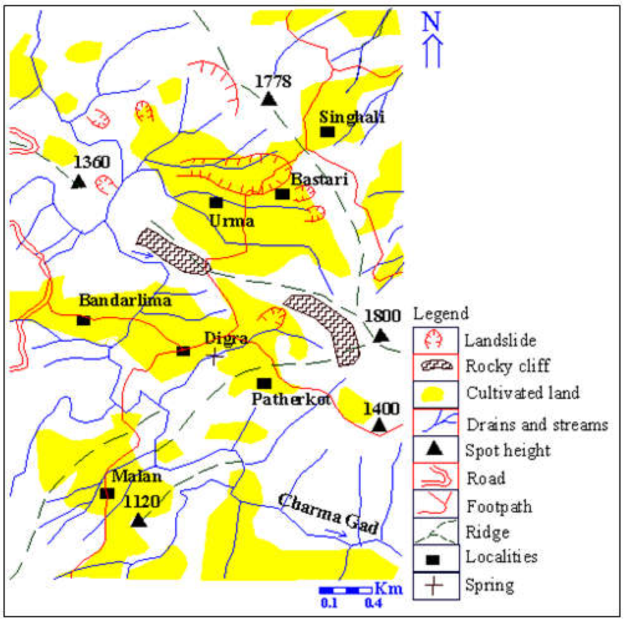

Figure 6. Geo-morphological map of Bastari area

The Lesser Himalaya and Higher Himalayan Crystallines (Munsiyari Formation), that houses good population of the region, are deduced to be more vulnerable to heavy rainfall/cloudburst events. Rainfall trend of different location in Uttarakhand shows variations in rainfall. It is obvious from Table 1, that Siwalik (Dehradun) and Lesser Himalaya (Nainital, Mukteswer and Gairsain) have been experienced more rainfall with respect to Higher Himalaya (Joshimath). According to the locals, the Higher Himalaya used to experience intermittent drizzling and snowfall until 10-15 years back. The scenario has however changed, may be due to climate change.

DISCUSSION

Heavy rainfall is assessed to have triggered the landslides in the area but it is noteworthy that the sites that were damaged and destroyed in these incidences have some striking similarities. It is noticed that most cloudburst events occur on cultivated land as was the case in Bastari. Similar observation was experienced during previous cloudburst as in the case of Okhimath cloudburst, 2012. According to DMMC report (2012 and 2014) most of the habitations were observed to be situated amid agricultural lands with thick cover of overburden material. This added to the devastation and a number of houses were completely swept away by the landslide debris. Other observation is that these events mostly occur along first and second order drainages (seasonal streams). Majority of the incidences have at the same time been encountered on the rocks of Munsiyari Fm. and Almora Crystallines (Table 2). The villages affected by disaster of July 2016 are traditional habitations where people had been living happily for ages. Even though mass movement is a function of a number of factors of which presence of water plays a decisive role, none can really claim that the area has never in the past received this kind of heavy rainfall. So it can be deduced that despite spells of heavy and prolonged rainfall these habitations were not affected by mass movement in the past. One therefore needs to investigate if the area has witnessed some physical changes in the recent past (5 to 7 years) and if there has been increase in the frequency of such incidences after these changes. These changes could be related to landuse, construction, drainage, road, forest, agriculture and the like. Newly constructed road around Bastari in which there would have been use of explosives and ground excavation for the construction around Naulra are such changes observed during the field investigation (Figure 4, b). Didihat town, like any other urban area in the hills of Uttarakhand, is faced with the dilemma of striking a balance between fast growing population and limited availability of land for fulfilling their housing and other related needs. Earlier (before 10 to 15 years ago) people living there were not so much vulnerable to landslide hazard and had the option of choosing a better site for settling down. The scenario has changed dramatically in the present times largely due to fast landuse / landcover changes. Rampant excavation of toe portion of slope for building and road construction is observed to be common place around Didihat. Indiscriminate construction, overloading of debris slope, encroachment along drain / streams and absence of drainage network for safe disposal of rainwater are some other factors responsible for slope failure. Excavation of slope often introduces changes in slope characteristics and in the hills it mostly transforms moderately sloping land into steep sloping land. Tendency of leaving the excavated slopes untreated is dangerous, especially during spells of heavy rainfall. Change in angle of repose due to road construction is responsible for the slope failure particularly at Patherkot Malla, Nonpapon and Kandai villages.

Conclusion

Considering recent extreme rainfall events in Uttarakhand Himalaya, it is suggested that instead of valleys and along abandoned channel of drains people should inhabit on the hard rock or firm ground of slopes for safety reasons. At locations where ground fissures have developed and subsidence has taken place appropriate measures are required for checking infiltration of rainwater as well as surface water. This should precede implementation of permanent treatment measures. People living around these slopes should remain vigilant, particularly during the monsoon period and any physical change in the slope should immediately brought into the notice of authorities. On the basis of information collected from the local people, strong wind and lightning are very common during cloudburst. Even though locals consider it to be a cloudburst event it is hard either to accept or reject their assertion in absence of authentic meteorological data from the proximity of slope failure incidences. Indiscriminate and unscientific construction should be banned especially in landslide affected areas. Besides this safe disposal of rainwater needs to be given due importance. Both surface and subsurface drainage measures should therefore be planned and executed. For this drain pipes could be provided on debris slope. The planned drainage network should be stepped and wide enough to accommodate heavy downpour events. Increasing anthropogenic activities, venturing in unsafe areas due to limited land availability and heavy localized precipitation, these are continuously increasing the landslide vulnerability in Didihat town as well as hilly terrain of Uttarakhand. In case indiscriminate and unscientific construction could not be regulated all mitigation and treatment measures would remain a mere formality and would be of little use. The bioengineering technology can be successfully implemented by using specific and local vegetation along with engineering measures to reduce instability and soil erosion. Although it is difficult to forecast cloudburst events, dense network of rain gauges particularly in the areas identified as being vulnerable to cloudburst is required for better understanding of this phenomenon. Accurate measurement of such events and studies based on different aspects of geology, geomorphology and climatology could help in developing a cloudburst forecasting model. Such studies would at the same time result in efficient landslide risk mitigation. At the same time the awareness about the extreme precipitation events and associated disasters among the dwellers of the area is needed.

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