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Assessment of Land Subsidence and Mass Wasting around Lata-Malla and Bhatwari area, Bhagirathi valley, Garhwal Himalaya, Uttarakhand

Dr. Krishna Singh Sajwan

Geologist, Disaster Mitigation and Management Centre (DMMC), Department of Disaster Management, Government of Uttarakhand, Uttarakhand Secretariat, Rajpur Road, Dehradun 248001, Uttarakhand, India

Abstract

Almost every year a massive loss of lives, property, infrastructure, bio-diversity and agriculture have been occurred mostly due to landslides and flash floods in the Bhagirathi valley. Landslide is a complex geological process and interplay of a number of factors is known to trigger these. Geological, structural, geo-morphological and climatic factors together with anthropogenic factors are major contributing factors and details on these aspects are required not only for mitigation but also for vulnerability assessment. Lata-Malla road section in Bhagirathi valley is witnessing severe problem of mass wasting and ground subsidence in a long time. Subsidence zone mostly consist of overburden material, fractured, jointed, sheared and highly weathered rock. Bhagirathi valley has witnessed several natural calamities in the past, e.g., Kanoldiya Gad flash flood (1978), Gyansu Nala debris flow (1980), Uttarkashi Earthquake (1991), Varunavat landslide (2003) and recent flash flood of Asi Ganga (2012).The present communication aims to highlights the problem of land subsidence at Lata-Malla and Bhatwari area which is situated in the tectonically and geodynamically active Himalayan domain. Information on land subsidence in the Himalaya particularly western Himalayan region, in general, is scanty so far. Moreover, this communication gives a brief account of land subsidence in Uttarakhand Himalaya together with brief account of mass wasting, causative factors and mitigation measures.

Key words: Landslides, MCT, seismotectonics, subsidence, Uttarakhand.

1. Introduction

Rishikesh - Gangotri highway has been breached and dislocated at several locations due to slope instability problems, particularly during rainy season. Increased pore water pressure and down-slope acting forces together with reduced frictional force provide favorable conditions for the mass movement during this season. Numerous massive landslides took place on the Uttarkashi-Harsil road section, particularly on a 42 km stretch between Uttarkashi and Bhatwari, believed to be the area of intense shaking. Fissures were most prominent on the Maneri, Bhatwari stretch (Parkash 2015). Abundance of active landslide zones, alluvial/colluvial deposits, development of depositional and

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erosional terraces, ground subsidence, off-set drainage, narrow-deep gorges and formation of landslide dammed lakes witness the neotectonic activity in the area.

Steep slopes, high relief, a number of structural discontinuities and underlying geology combined with anthropogenic activities constitute a propensity towards failure affecting both massive country rock and the Quaternary cover (Gupta et al., 2015). Lata-Malla landslide is an old slide zone which is reactivated recently in 2013; however land subsidence along the road has been witnessed since a long time, according to local people and earlier field investigation (Sajwan 2010). Subsidence involves the settling or sinking of a body of rock or sediment. Subsidence is a type of mass wasting, or mass movement-transport of large volumes of earth material primarily by gravity. Subsidence may occur as the result of either natural or human caused events (science.jrank.org). Ground subsidence is of concern to geologist, geotechnical engineers and surveyors. The slow onslaught disasters do not normally catch media attention as these often do not result in human casualties. Inadequate media attention results in insufficient rehabilitation support for the victims (Rautela 2005). It is a well-known fact that there is some relationship between the tectonic forces and the processes of slope failures. Therefore, an attempt is made to define this relationship by finding how slope processes are related to the reactivation of various faults/thrusts.

2. Material and methods

The study area falls in Higher Himalayan region, along Rishikesh - Gangotri Highway (NH-108), Bhagirathi valley, Uttarakhand Himalaya (Fig. 1). Administratively, the study area located in the Bhatwari Tehsil of Uttarkashi district, Uttarakhand and falls in the Survey of India (SOI) toposheets no. 53 J/9 on a scale of 1: 50,000. The district has six Tehsil named Bhatwari, Rajgarhi, Dunda, Chinyalisaur, Mori and Purola. The district falls in the Lesser and Higher Himalayan range and contains the source of both Ganga and Yamuna rivers, which attract millions of Hindu Pilgrims. Gangotri and Yamunotri temples are situated at the highest reach of Bhagirathi and Yamuna rivers respectively, these are two Dhams amongst the 'Char Dham' of Uttarkhand.

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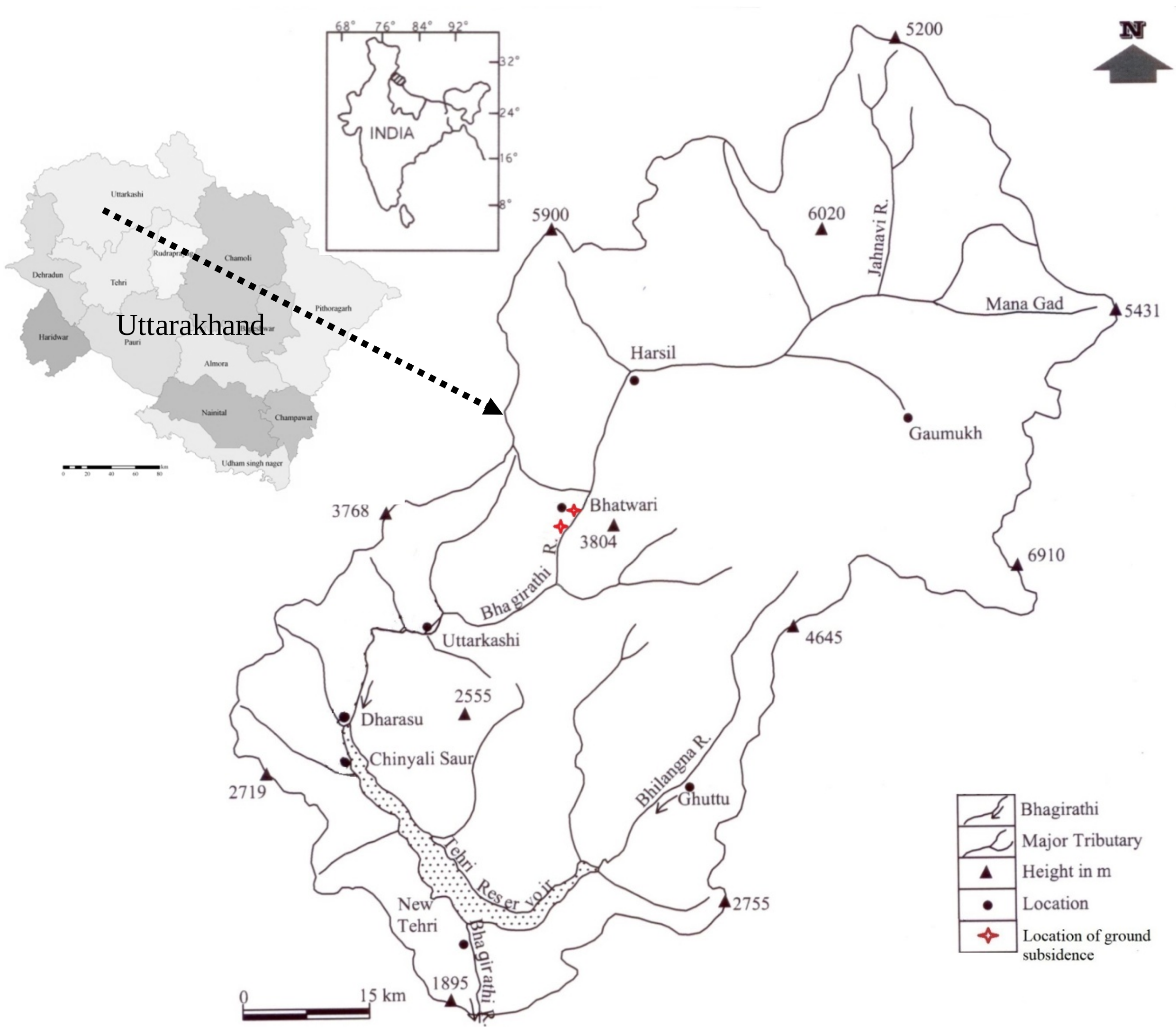
Fig. 1. Location map of the study area.



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3. Regional tectonics

The Uttarkashi district comprises the rocks of Lesser and Higher Himalayan Formations. The district is seismically active, North Almora Thrust (NAT) and Main Central Thrust (MCT) are two major dislocations present in the district. MCT is trending NW-SE and situated near Sainj south of Bhatwari in Bhagirathi valley and going through Wazri in Yamuna valley and Naitwar in Tons valley where it separates the gneisses / schists of Central Crystallines from quartzites of Garhwal Group. MCT in the north, Main Boundary Thrust (MBT) in the south and active transverse faults are geodynamically sensitive zones in the Himalaya. Severe mass movements and erosion are mainly concentrated along these zones (Valdiya 1981). The predominant rock types in Central Crystalline Group are gneisses, schists, amphibolites and migmatites while Garhwal Group comprises quartzite, phyllite and basic intrusive (Fig. 2). The rock sequences are traversed by major faults and thrusts which have deformed these rocks to a great extent. Detailed geological and structural set-up of the study area and surrounding region have been discussed by few workers (Jain 1971; Agarwal and Kumar 1973; Purohit 1990).

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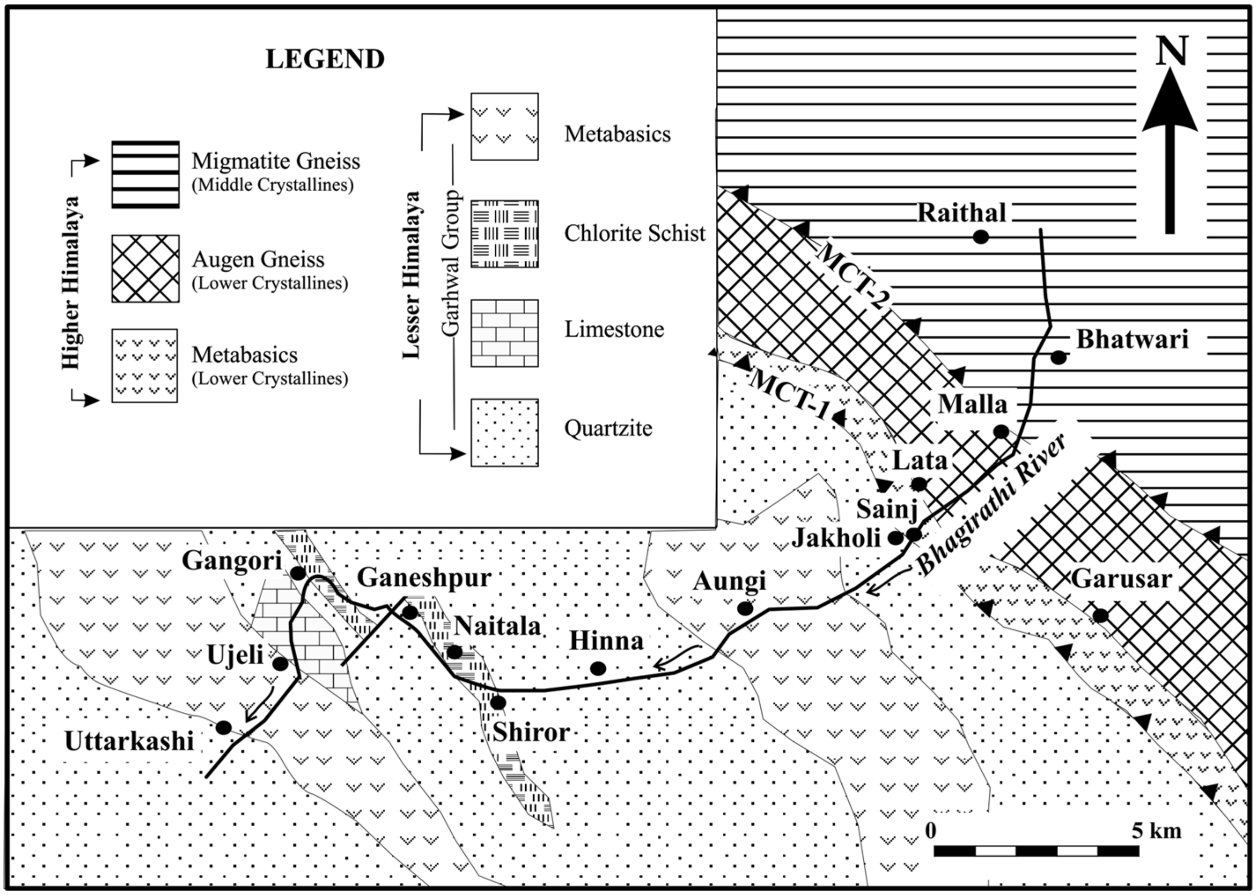
Fig. 2. Geological and structural map of the study area.



(Gupta et al., 2015)

4. Geomorphology

The area represents dissected topography characterized by high peaks, cliffs, moderate to steep slopes, elongated ridges, deep and narrow valleys. Bhagirathi river is the main river in the study area, originates from Gangotri glacier. Major tributaries of Bhagirathi present in the area are Kedar Ganga, Jad Ganga, Jalandri Gad, Ganwan Gad, Asi Ganga etc. The river and stream course of the area appears to be controlled by lithological and structural factors as well as climatic fluctuation. Bhagirathi river originates from Gangotri glacier at Gaumukh is considered to be the source of the Ganga river. In upper reaches of the area, Bhagirathi has a narrow, "V " shaped valley forming deep

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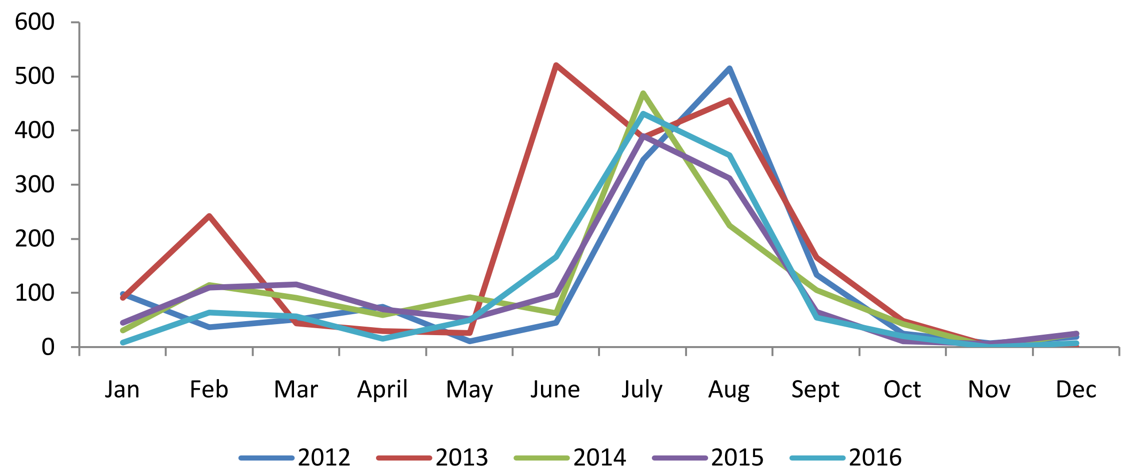
gorges while downstream to Netala, at Uttarkashi, Matli and Dunda it is wide, sinuous and sometimes braided also. It indicates that the nature of the bedrocks and bank material that play important role in the enlargement of the channel and in the widening of the valley. Furthermore, the erosivity of channel, litho-structural conditions of bed rocks and gradient govern the shape of the channel. Well preserved sequences of erosional and depositional terraces of the area are representing different cycle of erosion and deposition in the Quaternary period. Fossil valleys and epigenetic gorges observed near Maneri, Dunda and Dharasu in Bhagirathi valley (Pant 1975).

Fig. 3. Average monthly rainfall data for last five years of Uttarkashi district



(Source: IMD)

5. Climate and rainfall

The climate of the area is moderate and tropical characterized by hot and dry summer from March to middle of June. Due to southwest monsoon precipitation mainly arises during June to September. A cool winter spanning between December and February, its severity increases in the higher reaches and high peaks of the area are covered by snow in the winter season. The scattered rains and snowfall arise during winter months. The heavy seasonal downpour on the deformed rocks and Quaternary deposits creates a variety of slope failures.

Fig. 3 illustrates average monthly rainfall (mm) in Uttarkashi district for last five years. Exceptionally high rainfall in June 2013 followed by August 2012 can be observed. In August 2012 Asi Ganga flash flood and several other slope failure incidences were experienced by the district. Subsequently,

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unprecedented and unusual rainfall was also experienced not only by the region but also all over the state in June 2013. Five district viz., Rudraprayag, Chamoli, Uttarkashi, Pithoragarh and Bageswer were severely affected and damaged district in the state by landslides and flash floods.

6. Seismotectonics

Uttarkashi district has a long and devastating history of disasters, particularly landslides and earthquakes. The district falls in Zone V and IV of the Seismic Zoning Map of India. The study area falls in the high seismotectonically active zone, because of the tectonic movement several faults and weak planes have developed in the region. The investigation depicted that these structural features directly confined the river course of the area rather than topography at several places (Sajwan 2010). The frequent occurrences of micro-seismic events in the region suggest that the valley is under stress and tectonic adjustments are going on in the region. Earthquake of 1803 had devastated the old township of Uttarkashi, then known as Barahat. Major earthquake in this region during the previous centaury include 16th June 1902, east of Gangotri. Another major earthquake took place on 13th June 1906. The epicenter of this earthquake was to the east of Gangotri. Then on 20th October 1991 there was Uttarkashi Earthquake (6.6 magnitude) that had its epicenter around Agora in Asi Ganga valley (Miral et al., 1992). Official information indicates that population of about 3,07,000 in 1,294 villages were affected by this earthquake and 768 persons lost their lives while 5,066 were injured. In addition to this the earthquake claimed 3,096 cattle and as many as 42,400 houses were damaged (GSI 1992; Jain et al., 1992). Besides causing massive loss of infrastructure and property this earthquake triggered a number of rock slides. Large number of ground fissures were reported in the area. The earthquake also brought forth changes in spring discharge besides the chemistry of the hot springs in the region (GSI 1992).

Earthquakes are commonly associated with subsidence. When two blocks of the earth's crust slide against each other, causing an earthquake, ground movement may occur, raising or lowering the ground surface. During Alaska's 1964 Good Friday earthquake, an area of at least 180,000 sq km, much of it coastline, subsided 3 ft (1 m) or more (http://science.jrank.org). It has opined that the Uttarkashi earthquake was related to movements along the MCT (Khattri 1999). However, it was judged that the reactivation of some tear faults associated with MCT might have been responsible for the above event (Prasad and Verma 1993). Some seismically induced landslide occurrences are well known from Bhagirathi valley as Varunavrat landslide in Uttarkashi (Sai et al., 2008). Investigations carried out along the rivers Kali, Darma (Eastern Dhauli), Gori, Western Dhauli, Alaknanda, Mandakini and Bhagirathi demonstrate that practically all thrusts of the MCT zone, and quite many of the Lesser Himalayan terrain are neotectonically active. These have been active in the Late Quaternary times, including the Holocene (Valdiya 2014). Moreover, tremors less than five magnitudes is a common phenomenon in the area (Fig. 4). Further, landslides, ground subsidence

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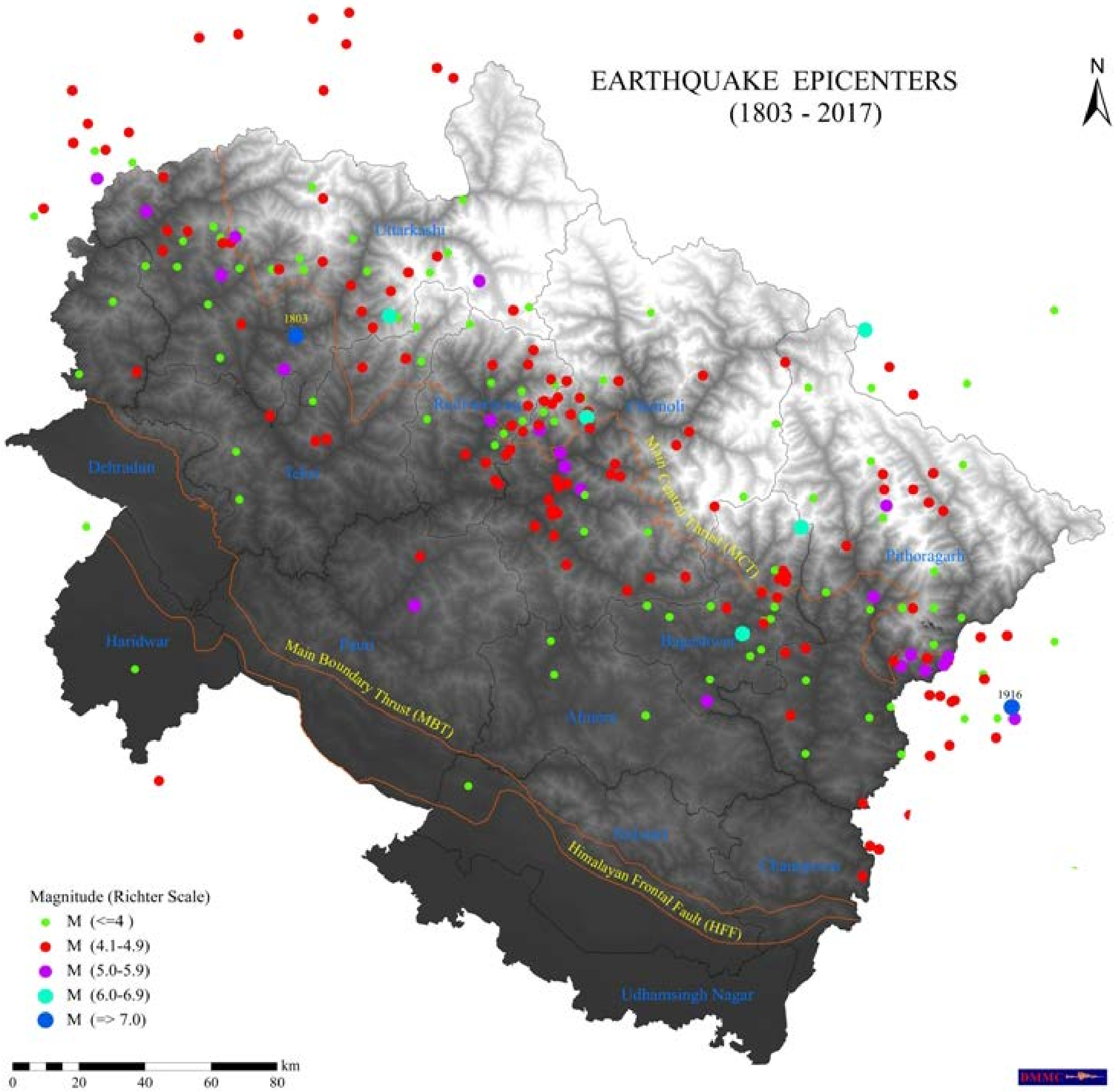
and flash floods are very common in the area. All these processes are relatively more confined to the vicinity of the MCT, thus suggesting it to be neotectonically very active.

Fig. 4. Earthquake epicenters in Uttarakhand



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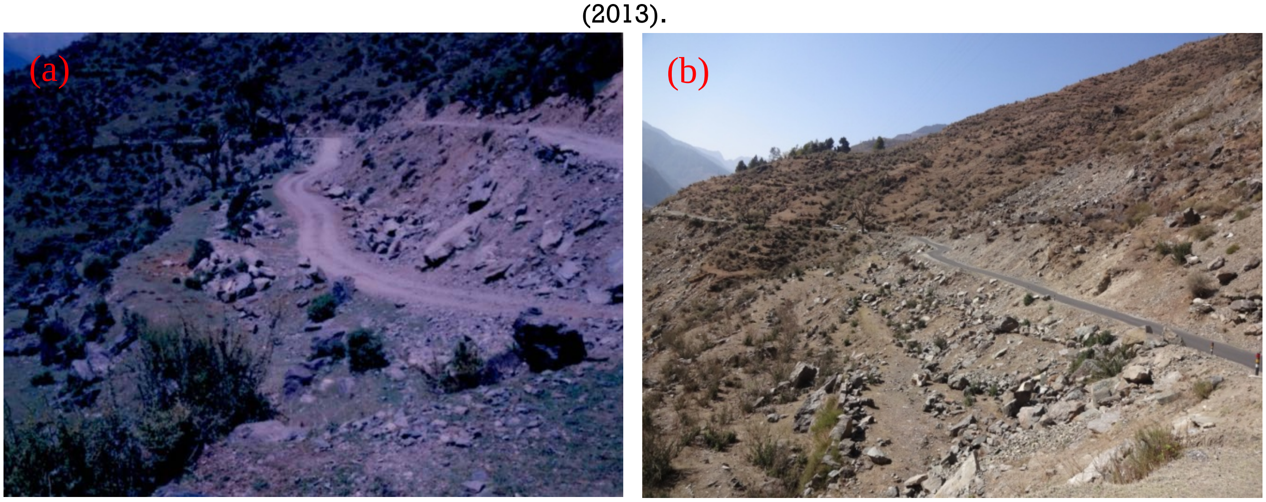
7. Lata - Malla and Bhatwari Subsidence Zone

The Lata-Malla subsidence zone is located just downstream to Bhatwari town and covers a stretch of about 1.5 - 2.0 km. The zone actually represents a subsidence area which perhaps started after 1978 Bhagirathi floods or Uttarkashi earthquake of 1991. The field observation indicated different levels of road at different times in the past (Figs. 5 a and b). The landslide area is observed to be occupied by well exposed rocks of metavolcanics and gneiss, boulders and fragments of rocks together with overburden material. Landslide and subsidence zone consists of dominantly slope wash material and angular to sub-angular clasts of gneiss/schists embedded in silty, sandy and clayey matrix. Slope of the landslide zone on uphill side is observed to have very steep gradient (>55°), whereas downhill side 35° - 40° with affected face towards SE.

Fig. 5 (a) View of land subsidence along NH-108 near Lata (2007) (b) Landscape changes along the road at Lata-Malla subsidence zone (2015), (c) Damaged building of Tahsildar office and (d) Severely damaged building of Tahsil office Bhatwari due to land subsidence by flooding in Bhagirathi river (2013).



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The ground subsidence at Lata - Malla and Bhatwari area is caused by toe erosion by Bhagirathi river and subsequent down slope movement. The mass is moving under the influence of gravity along the preexisting tectonogenic weak planes. Toe erosion by river is accelerating the pace of movement and land subsidence (Fig. 5). The area is observed to be less vegetated in addition, high degree of fracturing, jointing and weathering of rocks and loose unconsolidated material permit greater amount of water to pass through the bed rocks and subsurface. During monsoon season Bhagirathi river swollen with rains and associate deluge has caused severe toe erosion of the colluvial deposit. As a result, the angle of repose of colluvial material has been changed and this in turn has caused the subsidence at Lata-Malla and Bhatwari area.

In the recent years (2010, 2012 and 2013) high intensity rainfall and subsequent flash floods have generated series of landslides in the mountainous terrain of Uttarakhand especially entire Bhagirathi Valley (Sati et al., 2011; Gupta 2013 and 2015). Lata-Malla to Bhatwari road section has severely damaged and affected by landslides and flash floods (Dangwal et al., 2013; Gupta et al., 2015). Some major landslides, their slope aspect, lineaments which have been triggered the slide from Lata-Malla to Bhatwari road section is described in Table 1. Total five landslide zones were observed to be located along this section.

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Table 1. Landslides and related discontinuity/lineament present in the area

S. No.	Landslide name	Geographical Location	Elevation	Landslide type	Slope direction	Major discontinuity
01.	Lata	N 30°46'35.5" E 78°36'21.5"	1500 m	Debris	SSE	MCT-1
02	Malla-01	N 30°46'43.4" E 78°36'29.4"	1510 m	Debris slide	SE	MCT-1
03	Malla-02	N 30°46'59.2" E 78°36'48.8"	1530 m	Rock cum debris	SE	MCT-1
04	Malla-03	N 30°47'16.9" E 78°36'56.6"	1560 m	Debris slide	E	MCT-2
05.	Bhatwari	N 30°48' 44.3" E 78°37'12.7"	1600 m	Rock cum debris	SE	MCT-2

Being located in tectonically active zone, instability of the rocks in the area is largely controlled by structural elements that include thrust/fault and lineaments. These are held responsible for slope failure. The landslide zone is marked by the presence of major structural discontinuity/dislocation (MCT) at Sainj (Figs. 2 and 6). Even small seismic tremors that are frequent in the region create disturbance in these tectonic features and eventually causes landslide in their vicinity. The seismic tremors at the same time widen the joints of the rock and thus adversely affect the rock mass strength. Heavy and prolonged rainfall during monsoon season reduces shear strength of the slope mass and enhances pore water pressure, thus induces slope instability. Moreover, removal of slope material particularly for the road cutting and widening interventions also induce slope instability.

8. Land subsidence and associated chronic landslide zones in Uttarakhand

The possible causative factors of slope instability may be categorized as inherent, acquired and external. The inherent factors are lithological and structural state of bed rocks and hydrological condition including the toe erosion, whereas the acquired factors are indiscriminate road cuttings, increase in head load and deforestation. The external factors include seismicity, cloudburst and heavy rainfall. Extensive anthropogenic interference particularly in the form of road cutting is a significant factor that increases landslide hazard by manifold, especially in the areas witnessing active toe erosion by rivers and streams. It is noteworthy that most of the chronic landslide and land subsidence zones present in Uttarakhand are located in close proximity of MCT which is a prominent tectonic discontinuity of Himalayan tectogen (Fig. 6). The three important thrusts of the MCT zone are

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the Munsiari Thrust (MCT - I) at the bottom, the Vaikrita Thrust (MCT - II) in the middle and the Pindari Thrust (MCT - III) at the top (Valdiya 1980 and 2014). Such sites are very critical for the slope instability and these three factors i.e., toe erosion, vicinity of structural dislocation (MCT) and road cutting are dominant triggering factors behind most notorious landslides in Uttarakhand (Fig. 6).

Table 2. Some significant examples of land subsidence and associated chronic landslide zones in Uttarakhand Himalaya

S. No.	Location	Valley	Geographical Location	Major dislocation	Risk elements
01.	Lata-Malla	Bhagirathi	N 30°46’45", E 78°36’27"	Munsiyari Thrust	NH-108
02.	Bhatwari	Bhagirathi	N 30°48’ 44”, E 78°37’12”	Vaikrita Thrust	Habitation and NH-108
03.	Semi	Mandakini	N30°30’45”, E 79°05’08”	Munsiyari Thrust	Habitation and NH-109
04.	Helang	Alaknanda	N 30°31’48", E 79°30’37"	Munsiyari Thrust	Habitation and NH-58
05.	Joshimath	Alaknanda	N 30°33’04", E 79°33’57"	Vaikrita Thrust	Habitation and NH-58
06.	Wariya	Yamuna	N 30°55’51", E 78°23’55"	Vaikrita Thrust	Habitation and NH-134
07.	Naitwar	Tons	N 31°03’55", E 78°06’08"	Munsiyari Thrust	Habitation and road
08.	Garbyang	Kali	N 30°07’29", E 80°51’29"	Tethyan Fault	Habitation and road

Lata-Malla landslide in Bhagirathi valley, Semi landslide in Mandakini valley, Wariya landslide in Yamuna valley, Garbyang landslide in Kali valley and Naitwar landslide in Tons valley are few examples of chronic landslides witnessing incessant land subsidence in Uttarakhand Himalaya (Table 2 and Fig. 6). Semi village is situated just opposite to Okhimath town; it has witnessed worst condition of slope instability. National Highway (NH-109) going through the village, it was damaged and subsided at several portions after June 2013 disaster (Sajwan and Khanduri 2016).

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Fig. 6. Land subsidence along with chronic landslide zones located close vicinity to major structural dislocation (MCT) in Uttarakhand

Naitwar Bazar with a floating population of about 300 or even more is witnessing mass wasting in the form of slide, subsidence and debris flow (Uniyal 2006). The village of Garbyang which has witnessed

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the problem of ground subsidence for a long time, is situated on the Indo-Nepal border at Dharchula on the right bank of Kali river in Pithoragarh district of Uttaranchal (Rautela 2005).

9. Mitigation and management

Avoidance is the best strategy of mitigation in case of chronic landslides and subsidence zone. Options of either realigning the road along the other bank of the river or bypassing the landslide through a tunnel therefore need to be explored. It is well recognized fact that unchecked road construction in the hills is adding to the menace of landslides in the hills. During the road construction, the removal of base support destabilized the slope and promotes extensive landslides (Nainwal 1999). Road construction along the river bed as also in close proximity of it should be invariably avoided and uphill side should be preferred, especially in case of overburden material and the presence of fractured / jointed rocks as well as in case of valley side dipping strata. Roads aligned along the ridges and over topographically higher ground have proved to be relatively free of landslides. Ghansali - Vasukedar – Guptkshi (Rudraprayag) and Ukhimath - Chopta – Gopeswer (Chamoli) roads are examples of such roads. These have remained open for vehicular traffic and proved their utility even when the state of hit by major disaster incidences. More of such alternative roads should be developed and existing ones maintained and repaired, especially before the monsoon season. Chardham Yatra, Hemkund Sahib Yatra and Kanwar Yatra; all take place in the rainy season. In this season in case of landslides and flooding traffic can thus be diverted to these alternative routes.

As toe erosion is one of the major triggering factor for the slope failure. Thus slope should be protected from toe cutting by river. It is recommended that appropriately designed flood protection walls of suitable height along with steps are required to be erected from river for checking slope failure in such areas if possible. Appropriate measures are required for checking infiltration of rainwater and surface runoff needs to be channelized by constructing contour drains, catch drains and linned toe drains. It is suggested that bio-engineering slope stabilization practices be promoted as these are cost effective and sustainable. For long term stabilization measures of such chronic landslide zones detailed geological as well as geotechnical investigation needs to be carried out.

Alerts or warnings have been disseminated by the government time to time through print media, electronic media and SMS, mostly these are based on weather forecast coming from Indian Metrological Department (IMD). People need to be vigilant during such forecast. Community awareness programmes needs to be organized so that disaster signs and events can be identified and reported timely. Such programmes are useful for the better cooperation and coordination between stakeholders and communities. Communities should be trained to elicit early warning signs of disaster and should be prepared to inform district headquarter or district / state emergency operation centre. On account of prediction and timely information instant relief can be provided and

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consequences be minimized if efficient management, mitigation and preparedness are adopted. For better landslide risk reduction people should be aware and learn, do not construct houses, buildings and agriculture practices near steep sloping areas and vicinity of river and tributary.

10. Discussion and conclusion

Every landslide however has its distinctive characteristics and several factors work in unison for causing slope failure. Single causative factor can never be held responsible for the failure. Initiation of every landslide however requires some triggering factor. Toe erosion, structural influence and road cutting are dominant triggering factors responsible for the chronic landslides present in Uttarakhand Himalaya (Table 2). These landslides get reactivated from time to time, especially during heavy and prolonged rainfall as well as subsequent flash floods in monsoon season. Semi and Kunjethi landslides in Mandakini valley triggered by flash floods of June 2013 and witnessed ground subsidence. Similarly, Lata-Malla and Wariya landslides also triggered by high intensity rainfall and flash floods in 2012 and 2013. Similarities with respect to causes in these landslides include toe erosion, road cutting and structural influence as vicinity of MCT (Fig. 6). So far there has been no effort for undertaking effective and permanent treatment of these slides.

The study area is seismically and neotectonically active. Due to seismotectonic activity, the rocks of the area are highly shattered, fractured, fragmented and thinly jointed. The MCT zone witnessed two major earthquakes since 1991 (Uttarkashi, 1991 and Chamoli, 1999). Any seismic activity such as Uttarkashi earthquake (1991) will lead to movement along such dislocations, causing several types of slides. Therefore, Faults and Thrusts zones must be categorized as potential hazardous zones.

It is recommended that bio-engineering slope stabilization measures needs to be given to all problematic sites discussed in the present communication. Stabilization measures can be suggested only after detailed geological and geotechnical investigations of the particular site. In view of the risk posed to the settlement special care needs to be taken while excavating the hill slope for construction and infrastructure development. In view of the landslide threat local population, pilgrims and tourists are advised to keep vigilant and if necessary stay away from subsidence and landslide affected region during heavy and prolonged rainfall. The lesson learned from earlier events should not be ignored. Complete prevention and mitigation of natural disaster cannot be possible but damage and destruction can be minimized moreover life can be saved if such events can be predicted and reported timely.

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