Preliminary Site Investigation of Landslides and Associated Distress along the Hill Bypass Road around Mansa Devi, Haridwar

Uttarakhand Landslide Mitigation and Management Centre

Government of Uttarakhand

August 2023

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PROLOGUE

There were reports of landslides, cracks and ground subsidence around the Mansa Devi area, along the Hill Bypass road. Similar incidents were also reported along the Mansa Devi Paidal Marg, railway tracks and certain areas within the marketplace and township.

Hence, an initial survey was carried out by experts from ULMMC and USDMA on 26th July 2023, followed by a group of surveyors and engineers from ULMMC on 31st July 2023.

The following technical experts from ULMMC and USDMA visited the site:

1. Dr. Shantanu Sarkar, Director, ULMMC
2. Ms. Tandrila Sarkar, Geologist, USDMA
3. Dr. Rohit Kumar, GIS Expert, USDMA
4. Mr. Prem Negi, Assistant Engineer, ULMMC
5. Mr. Amit Gairola, Assistant Engineer, ULMMC
6. Mr. Deepak Bhatt, Surveyor, ULMMC

The team carried out a preliminary survey along the Hill Bypass Road (also known as Haridwar industrial Khakari road) and a few locations within Haridwar town to ascertain the cause of ongoing problems and suggest remedial measures accordingly.

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1. Introduction

The Himalaya is the youngest mountain chain among different orogenic belts of the world formed as a result of the continent-continent collision of the Indian and Eurasian plates ~ 50 million years ago. It has rugged topography, active tectonics, a highly complex nature with a variety of rocks.

Each year landslides cause massive loss of lives and infrastructures along with disruption to transport, water supply, and telecommunication (Kanungo et al. 2006; Velayudham et al. 2021). Landslides are an interplay of extrinsic and intrinsic factors and are common in the Himalayan terrain. Extrinsic factors mainly involve changes in slope geometry and land use pattern by human interference, whereas the intrinsic factors are primarily the geological conditions like weak rock types, unfavourable jointing, and the presence of shears, etc. while rainfall and seismic activity are mainly the triggering factors (Del Soldato et al. 2019).

During the monsoon season of 1998, a major landslide, hereafter called the Mansa Devi landslide, coupled with a number of small-scale isolated landslides and rock falls occurred on the slopes of the Mansa Devi hill in Haridwar (Fig. 1). The landslide was located about one km north of the Haridwar Township involving Middle Siwalik rocks consisting of an alternate sequence of mudstone and sandstone. Although no loss of human life was reported, but the landslides and rock falls along the bypass road posed risk to the settlements located at the foot of the hill.

The major portion of the road is in a dilapidated state and has become vulnerable to upslope and downslope failures which may be potentially hazardous for the population at the hill below. Considering this risk of slope failures, it is wise to maintain the road effectively so that it acts as a less potential danger to the settlements below (Fig. 2) (Tandon et al. 2020).

The requirement for the treatment of the slope failures along the Haridwar bypass is necessary since the road cut has disturbed the natural equilibrium of the hill slope and it needs constant care to maintain the new equilibrium for the stability of the hill slope. The road stretch is above the densely populated township and therefore considering the potential for any future disaster in terms of rock falls and landslides there is an imperative need for a complete investigation and implementation of suitable mitigation measures. Following this, a preliminary survey was carried out along the Hill Bypass Road (also known as Haridwar industrial Khakari road) and a few locations within Haridwar town to ascertain the cause of ongoing problems and suggest remedial measures accordingly.

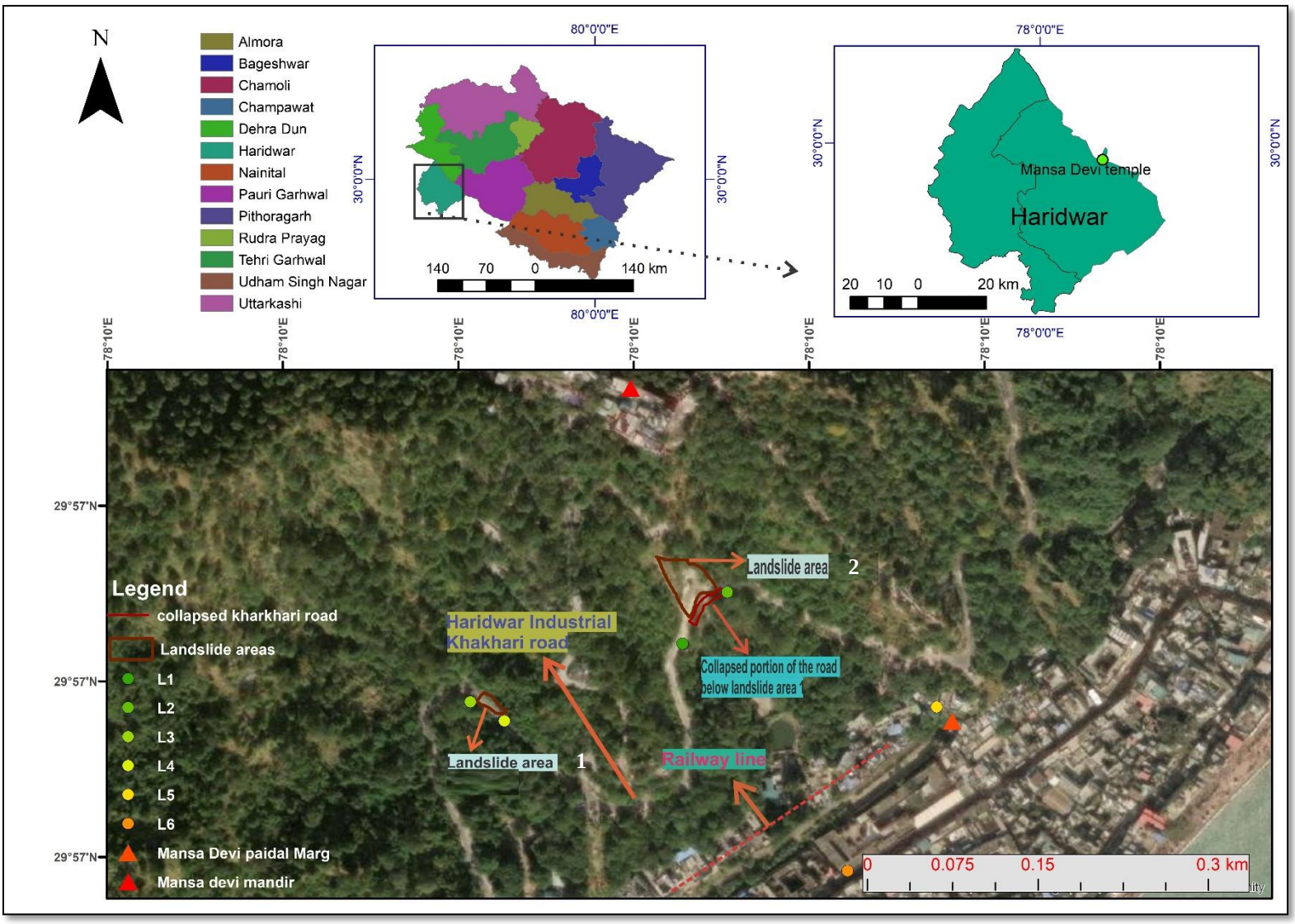

Fig 1: Location map of Haridwar on Google image highlighting the areas of the preliminary survey. The survey locations are marked as L1, L2, L3, L4, L5 and L6 which are discussed as; L1 and L2 mark the start and end point of the extent of Landslide area 2, L3 and L4 mark the start & end point of the extent of Landslide area 1, L5 marks the area around railway track which is seen from Mansa Devi Paidal Marg, L6 marks the area within Haridwar market and just below the railway track.

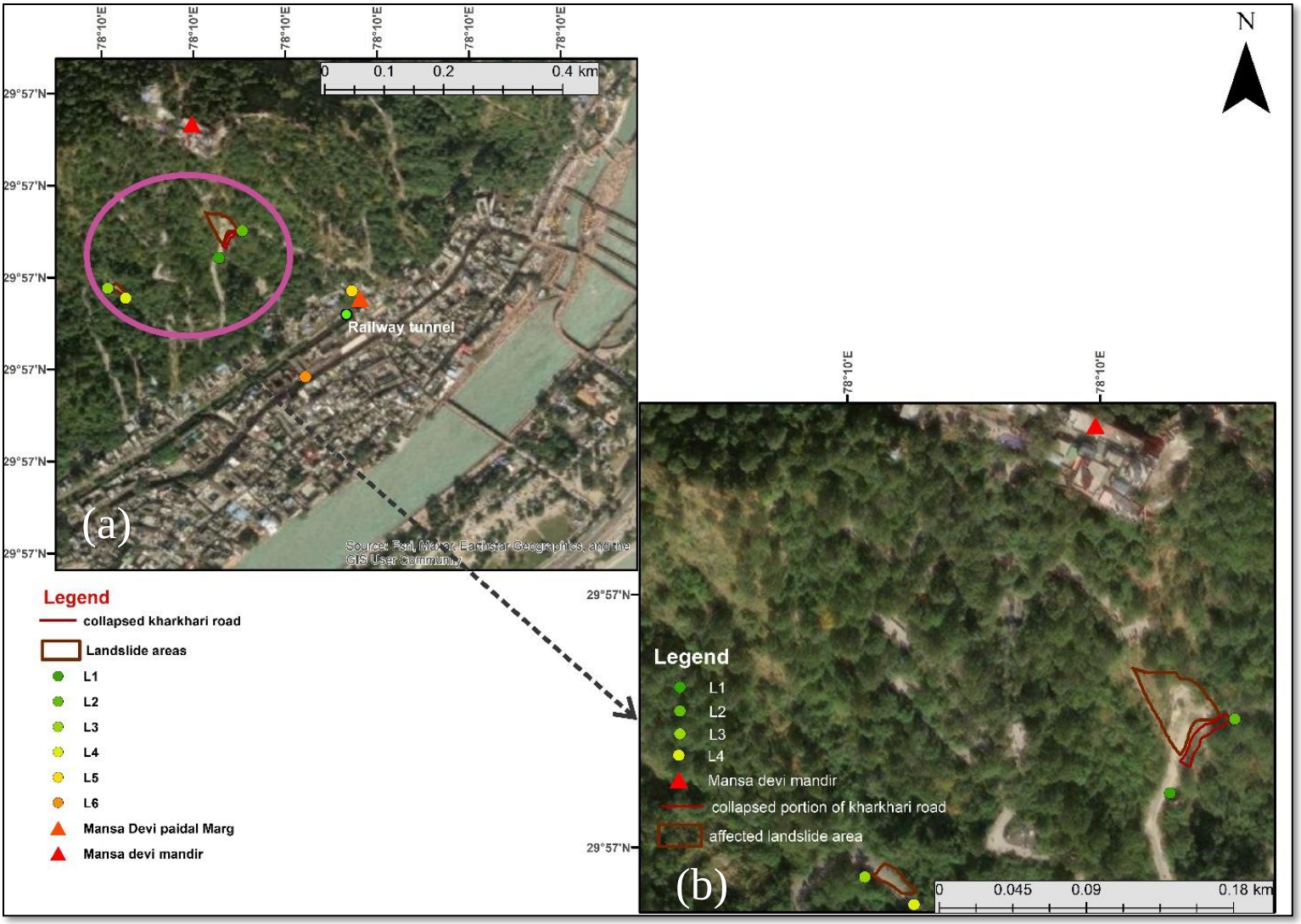

Fig. 2: (a) Location map showing the points where preliminary survey is carried out **(b)** The pink circle marked in (a) is extended further which highlights two major landslide areas along the Hill Bypass road

2. Study Area

a) Geology

Geologically the Mansa Devi hill where the slope instability has occurred consists of alternating beds of medium-grained greyish massive sandstone and brick red and green mudstone of the Middle Siwalik Formation (Fig. 3). The thickness of the mudstone varies between 1 to 3 m. The bedrock in the slide area generally trends in the ESE-WNW direction with a dip of 22° to 35° SSW. The dip of the bed rock is generally gentle in comparison to the angle of the hill slope. Three sets of joints dipping at moderate to steep angle towards NE, SE and WSW are observed. Of these, NE dipping

joints are the most prominent. All the joints are close and tight and the spacing between the joints varies between 30 and 150 cm.

b) Geomorphology

Geomorphologically, Mansa Devi hill is an extension of the Outer Himalayan Siwalik range that gets terminated abruptly at the Ganga River due to the effect of the Ganga Tear Fault. The entire hill slope of the Mansa Devi hill depicts a rugged topography mainly because of its high relief and active deundational processes. The relief along the valley slope is 182 m with Mansa Devi peak at 470 m asl and the river Ganga flows at the base at 288 m asl.

c) Hydrogeology

The drainage in the area is dendritic type with second and third order streams joining the river Ganga. A number of new first-order drainages have been observed originating from the middle of the slope, mainly because of the concentrated overland flow, particularly during the rainy season. Most of the earth's surface processes get reactivated during high-intensity rainfall and the great variation in the seasonal and diurnal temperature. The valley slope evolution is in evidence through a number of processes like landslides, most of which are anthropogenic in nature, slope wash, boulder fall and regular channel flow.

Mansa Devi Hill is composed of a series of interbedded claystone, mudstone and sandstone sequence (Table 1) (CGWB, 2016). This interbedding of the strong and the weak rock sequences is highly prone to landslide given the discontinuity pattern that is parallel or sub-parallel to the surface topography. Slope instability of various forms has occurred at many places along the Haridwar By-pass road on the slope of Mansa Devi Hill. Most of the instabilities involved are breaking off, toppling and/or sliding of mudstone or sandstone, which collects over time as debris at the foot of the slope.

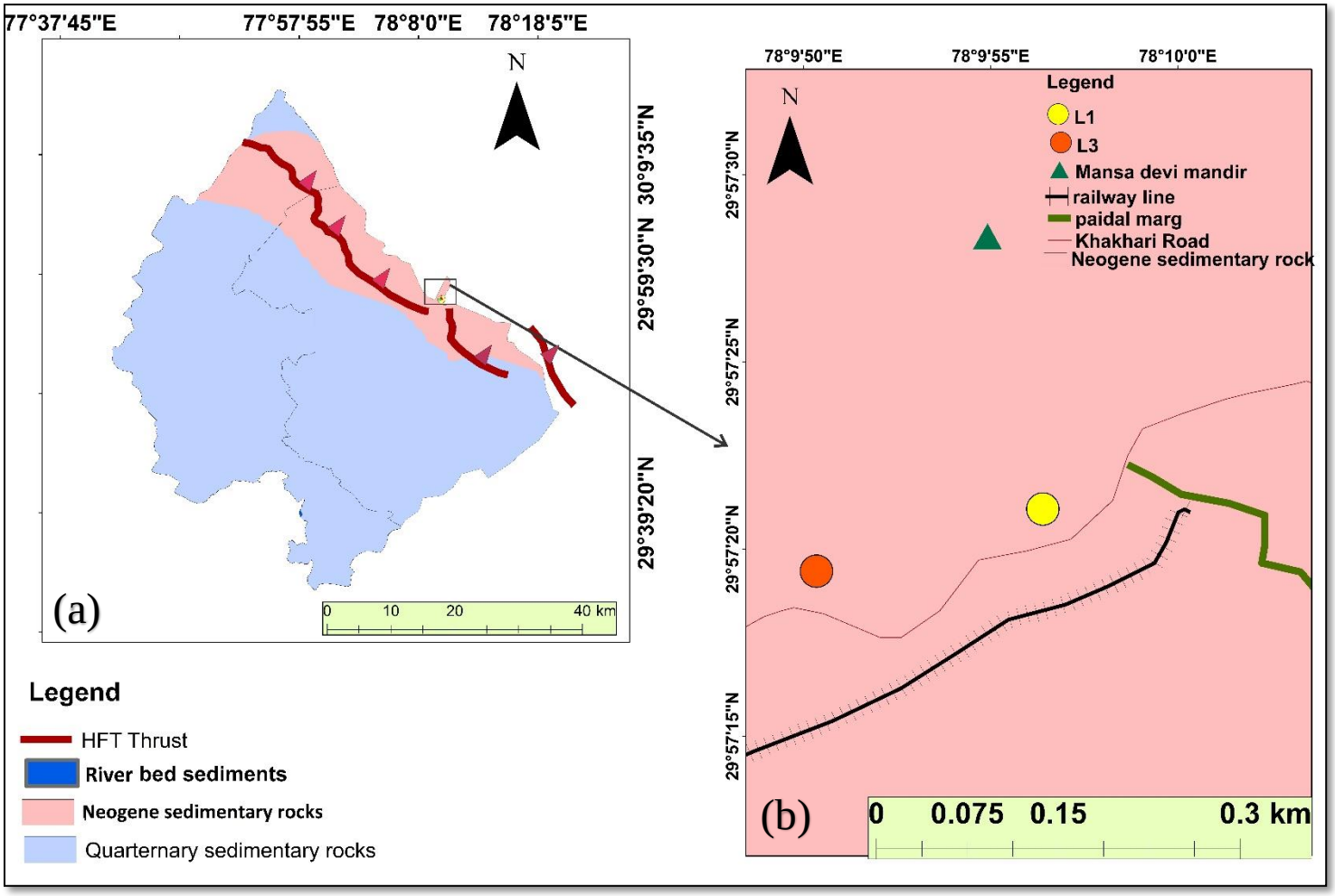

Fig 4: (a) Geology map of Haridwar, composed of Neogene and Quaternery sedimentary rocks. The brown colour line demarcates the HFT or Himalayan Frontal thrust **(b)** The black square in (a) is extended further, which shows the lithology of the preliminary survey area and important location points.

Table 1: General Stratigraphic sequence of Haridwar District

Era	Period	Age	Formation	Group	Lithology
Cenozoic	Neogene	Holocene	Younger alluvium Terraces, channels, flood plains, fans, paleochannels	Newer/Younger Alluvium	Sands of various grade, silt and clays
		Middle to Upper Pleistocene	Older Alluvium (Bhabber and Terai)	Ramnagar/ Varanasi/ Ambala	Boulders, Cobbles, Pebbles, Gravels, Sand, Silt & Clay
		Pleistocene to Early Pleistocene	Sedimentaries	Middle Siwaliks	Sandstone with boulders,cobbles, Pebbles, Conglomerate and associated Clay
				Upper Siwaliks	Conglomerates, Sandstones, Siltstones, Shales with boulders,Pebbles, Sands and Clay

3. Recommendations from the previous survey

3.1. Year 2007

Mansa Devi hillside area is a rock-fragile zone, which is receding every time with the onset of heavy rains. So a committee comprising experts from different organizations was constituted to assess the Mansa Devi landslide area and take necessary mitigation measures accordingly. The committee members carried out a geological/geotechnical survey on 28 September 2007, and recommended the following:

- All the drainage channels located on Mansa Devi Hill should be cleaned at regular intervals so that there is free water flow. It is advised that water shouldn't be allowed to seep through the slopes and for this proper lined drainage, particularly along the road should be built for the next monsoon.
- Dumping of garbage leading to the clogging of the drainage channel needs to be banned in the area.
- Wherever there are small rock falls like at the intersection of the footpath and the bypass road, short-term mitigation measures like a support wall should be constructed at the base of the slope with proper weep holes for free flow of water.

- Geotechnical investigations of soil and rock need to be undertaken to provide desired input for engineering treatment for slope stabilization.

3.2.Year 2008

The committee members followed up with one day survey on 23/01/2008 in Mansa Devi landslide area. A comprehensive report was prepared on the Stabilization of Mansa Devi Hill Slope, Haridwar. The recommended outputs are discussed as follows:

- Proper and lined drain needs to be provided along the road section to flush out the surface runoff.
- Drainage channels and the culverts are to be cleaned at regular intervals so that there is free flow of water and the fine sediment.
- In the lower valley slope, tipping of garbage is avoided at any cost to obviate the problem of overflow of water and sediment.
- No new construction along the path of the drainage descending from hill.
- River borne materials used in retaining walls need to be cut into square blocks to provide maximum contact between the blocks for stability of structure.
- Scaling of cliff sections (acting as natural retaining wall), so to remove the hanging rock blocks.
- Rocks exposed critically along the road section should be strengthened by rock bolting and wire meshes.

3.3.Year 2011

In 2011, Maccaferri Environmental Solutions Pvt. Ltd. proposed to conduct a geotechnical survey in the landslide area and prepared a report after reviewing the findings from previous fieldwork carried out by the constituted committee.

In this regard, Maccaferri Environmental Solutions Pvt. Ltd. presented a technical proposal along with financial requirements. The solution discussed in the report is to install Green Terramesh systems/ Terramesh system and Gabion walls, which form part of flexible retaining structures and Macmat can be used effectively for erosion control and assisting vegetation growth.

3.4. Year 2016-2017

GSI carried out a geological field survey at the Mansa Devi landslide area during 2016-17 in which they also studied in and around landslide-prone zones of Mansa Devi Hill. The recommendations by GSI are as follows:

The entire Mansa Devi hill section rises from elevation 300m to 565m and generally slope in an easterly direction. The causative factors which seem to be a contribution to the slope stability problem are:

- **Nature of litho units**: The rocks exposed on the hill are alternate bands of sandstone and silt/claystone, at places sand rock is also present. The rock mass particularly the sandstone and the claystone are very weak and fragile leading to slope failure. The impervious nature of soil resists the flow of water whereas the soluble nature of rock mass weakens the slope-forming material.
- **Rockmass**: In general, the rockmass on the hill slopes are of fair to poor quality, making the slopes unstable in places.
- **Improper drainage**: The provisions for draining the slope water particularly during monsoon seems to be ineffective as most of the drainage hole in the retaining structures are choked and the drains provided are filled with garbage which resist water to flow. The accumulated and astray flow of water may add to the slope stability problem.
- **Unplanned retaining structures**: The retaining structures should be properly designed. They should be founded on the rock or firm surface. The structures founded on the loose overburden material negatively affect the slopes instead of providing stability to the slope.
- **Toe cutting**: The toe cutting of the slope by the local nala (Mansa Devi Nala) causes slope failure on the left bank at the crossing of the bye pass road and the Mansa Devi Nala.
- **Road Cutting**: The road cutting in the section where incompetent litho units like sand rock or claystone are present cause slope stability problem and settlement of the road.

4. Present Study in July 2023

The study area is located in the vicinity of Haridwar township (29°56′ 42″ N and 78° 10′ 30″ E) in the state of Uttarakhand. It is bounded by NNW-SSE fault running along low relief hills. Small-scale isolated landslides and rock fall activities have been often reported every year during monsoon on the western hills, also known as Mansa Devi hills and threaten the urban settlements and railway track situated at the base of the hills. The team visited the site on 26 July 2023 and observed the problem of slope instability along the road. The observation during the survey is described below.

a. Site 1: Hill Bypass Road or Haridwar Industrial Khakhari road

i. **<u>Landside Area 1</u>:** This location is situated between the coordinates points L3 (29.955391°N, 78.163984°E) and L4 (29.955241°N, 78.164254°E) along the Hill Bypass Road, and is characterized by debris slide comprising mainly mud particles. The slope is estimated at ~> 80° and of height ~30 m. This landslide has affected the road and caused disruption in the commute of the pilgrims. The

saturated materials borne by this landslide are entering the locations situated downhill which has flustered the daily routine of Haridwar township locals. Due to such invasion, problems like water logging, cracks and subsidence have aroused at certain locations (Fig. 4).

Fig. 4: Google Earth image showing the location of the first landslide, situated along the Hill Bypass road, points L3 and L4 mark the start and end point of the landslide stretch. It is also observed that landslide materials accompanied by water are flowing downhill in S (continuing straight by the road into an existing Nala) and SW (down the road into the township) direction. Each point marked in the Google Earth image is explained with respect to field photographs.

ii. **Landslide area 2**: This location is situated between the coordinates points L1 (29.955853˚N, 78.165664˚E) and L2 (29.956259˚N, 78.166019˚E) along the Hill Bypass road, and is characterized by debris slide comprising mainly mud particles. The scarp of the landslide is ~ 120 m with a vertical height of around ~3 m, and a slope ~ 65- 70 ˚.

Due to its influence a considerate length (~80 m) P1 (29.956016°N, 78.165698°E) to P2 (29.956268°N, 78.166006°E) of the Hill bypass road (lying below this landslide area) collapsed. In accordance with the geology of this region, the mudstone formation under the trigger of rainfall has gushed down the hillock. This landslide hill lies adjacent to the hilltop where Mansa Devi Temple is located and the distance between the scarp and the step of the temple is ~ 3.0-4.0 m (Fig. 5).

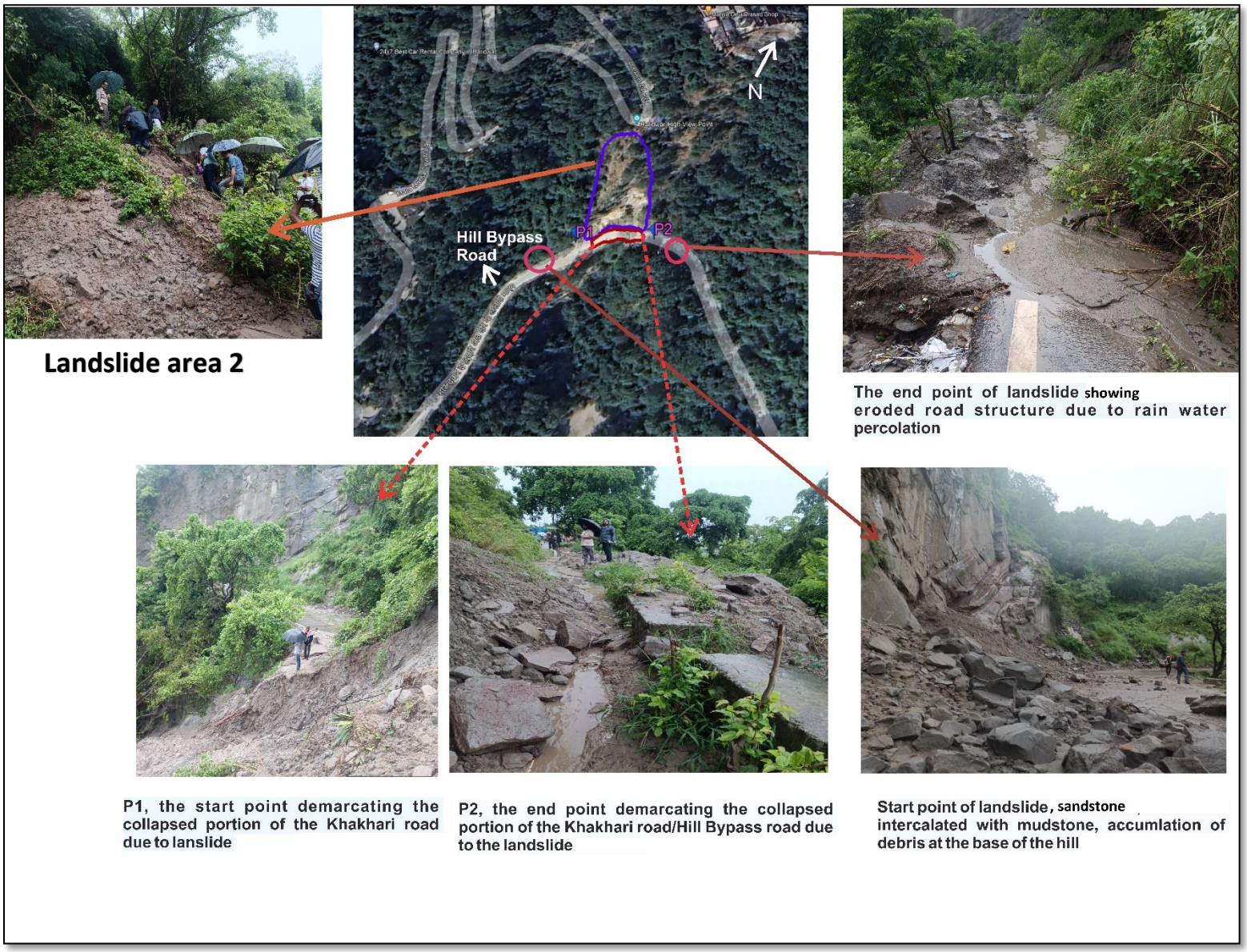

Fig. 5: Google Earth image showing location of the second landslide, along the Hill Bypass Road, the points L1 and L2 mark the start and end point of the landslide stretch. It is observed that due to influence of this landslide a significant portion of Hill Bypass road has collapsed demarcated within P1 and P2 points. Each point marked in the Google image is explained in respect to field photographs.

b. Site 2: Inside the Haridwar township and market

i. **Mansa Devi paidal marg:** This location L5, is situated at coordinate points 29.955352°N, 78.167678° E adjacent to the Mansa Devi Paidal Marg road. At this location, we saw prevailing problems like erosion in the areas around railway tracks, visible cracks along the steps of the marg. Such a situation might be the result of entry of the debris fragments and improper drainage planning in the township (Fig. 6).

Fig 6: Google Earth image shows location L5 situated along the railway track, which is visible from the Mansa Devi Paidal Marg. It is observed that around L5, there is an accumulation of moist rock and mud fragments which is apparently adding an erosion effect to the surrounding. Likewise, the steps of Mansa Devi Paidal marg are also eroded and cracks appear in places. Each point marked in the Google image is explained with respect to the field photograph.

ii. **Haridwar market area:** This location L6 is located at the coordinate points 29.954055°N, 78.166972°E below the Haridwar railway track. At this location, problems like water logging and erosion can be seen, which has also sparsely flooded the market areas too. Such a situation might be the result of the dumping of garbage and improper drainage planning in the township (Fig.7).

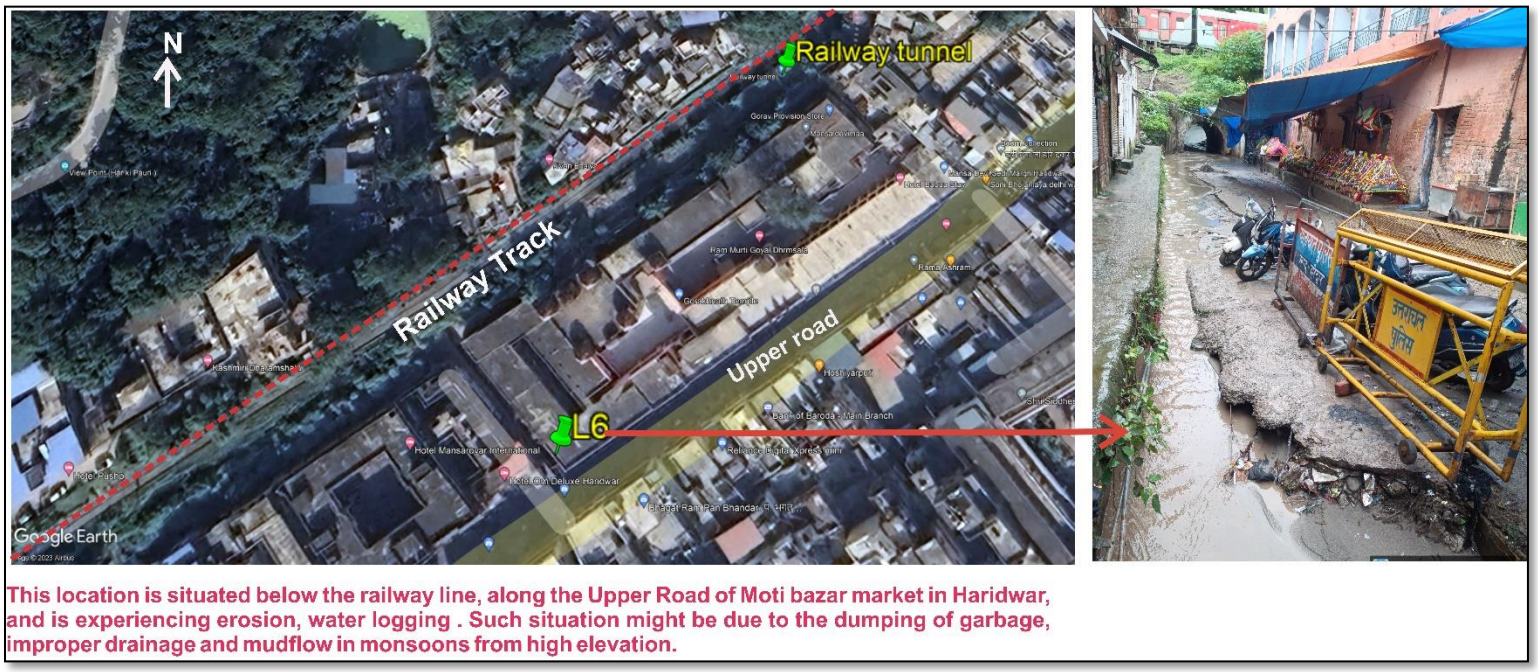

Fig 7: Google Earth image shows the location L6, situated just below the Haridwar railway track. It is observed that the area around L6 experiences a water logging situation that has led to an erosive effect on the surroundings and adjacent to the market area. The location point on the Google Earth image is explained with respect to field photographs.

5. Recommendation

The primary causes of the slope instability problems along the Hill bye-pass road appears to be very weak rocks, highly weathered mudstone, steep slope and poor drainage system for surface runoff water. Similar problems exist in other hill towns of Uttarakhand as well. Based on the field observations made during the field visit, the following recommendations are suggested:

a) Construction of retaining walls, proper drainage of water and surface treatment are the important measures to be adopted for the stabilisation of the unstable slopes along the Hill bypass road. Since, ingress of water is identified as a major problem in the affected areas, the site should be studied for proper water discharge. Accordingly, proper surface drainage should be provided in the area.

b) Proper drainage system with stepwise check dams should be adopted along the channels which are carrying the debris and mud along the slope to the township.

c) The old drainages which are damaged and filled up with debris and muck should be repaired.

d) The check dams along the drainage should be reconstructed.

e) Retaining structure should be implemented on the hill side as well as on the valley side in all the unstable slopes from which debris are sliding mainly from the mudstone of Middle Siwalik.

f) The loose soil mass on the slope should be reinforced with soil nailing and wire mesh which may be followed by suitable bio-measures.

g) Laying of Erosion Control Mat on the soil slope may be a better option to prevent further erosion and sliding.

h) RCC retaining wall is suggested at the unstable slope near the railway track to prevent the possibility of loose debris reaching the track.

i) There is need of topographic mapping of the whole area for generating large scale contour map. Drone survey is suggested for 3D topographic mapping of the Mansa Devi hill which may provide large scale contour map and high-resolution images for proper investigation plan and mitigation measures.

j) Complete detailed investigation further needs to be done comprising geological, topographical, geophysical and geotechnical survey alongwith mitigation measures. The investigation must be initiated immediately after the monsoon season so that proper mitigation measures can be designed and implemented.

6. Concluding remarks

Appropriate mitigation measures should be planned, designed and implemented after a detailed topographical, geological, geotechnical and geophysical investigation of the area. These studies are essential for recommending suitable mitigation measures. These data are of upmost importance for slope stability assessment through which the global safety of the moving slope can be studied and appropriate measures can be designed. The area has been inspected by several organisations and state departments but so far, no detailed investigation has been carried out to arrive at a proper solution.

7. References

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