Mitigation Measures with Respect to Developmental Activities in Garhwal Himalaya

Ruchi Saraswat[1*], Shilpa Pal[2], Surya Parkash[3]

Abstract

Garhwal Himalaya is one of the most affected landslide areas in the Indian Himalayas due to steep topography, geological causes, often arising from intense precipitation events. The region has seen an increase in the frequency of landslides due to the increase in developmental activities owing to the presence of a large number of pilgrimage sites. This has led to an increased risk of landslide events, thereby making it imperative to examine the impact of such development activities to landslide occurrences in the region. Out of the various natural hazards like landslides, earthquake and flash floods, this paper focuses on the landslides occurrences have been increased due to increase in the anthropogenic activities in these areas. It is the need of hour to plan for hazard assessment for these areas to mitigate the impact of hazards like landslides so that accordingly to the assessment of these hazards developmental activities can be carried in the future. So, zonation of hazard prone areas is a must to find out the degree of influence caused by these hazards. Hazard zonation mapping has been done using 8 Landsat satellite imageries, field data, Google earth, landslide location data, toposheets by survey of India department and preparation of various thematic layers like slope, altitude, structure, geology, drainage, land use and land cover. Landslide hazard zonation has been prepared by integrating all the thematic layers in the GIS domain by weighted overlay technique. Landslide hazard susceptibility map categorises the area into different zones. Landslide hazard zonation map has been validated with the Landslide Inventory map of the study area. Hazard zonation map has also been validated mathematically as well as in the field.

[1] **Ruchi Saraswat,** Department of Civil Engineering, Gautam Buddha University & Department of Civil Engineering, JSSATE, Noida

[2] **Shilpa Pal,** Department of Civil Engineering, Delhi Technological University, Shahbad Daulatpur, Delhi 110042, India

[3] **Surya Parkash,** Geo-meteorological Risks Management Division, National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India, New Delhi

* Corresponding Author Email: rsaraswat@jssaten.ac.in

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1. Introduction

Landslides are one of the most devastating and recurring natural disasters affecting different parts of the world. Most of the landslides are triggered either due to rainfall or earthquake, of which rainfall-induced landslides are the most prominent (Froude and Petley, 2018). The Indian Himalayan region is the most affected rainfall-triggered landslide area, accounting for nearly 15% of the global landslides (Dikshit et al., 2020a). The Uttarakhand region of the Indian Himalayas is highly prone to landslides, leading to enormous amounts of financial losses and casualties. In a recent review article, by (Dikshit et al., 2020a) on landslide studies in Indian Himalayan region, more than half of the studies were dedicated to the region of Uttarakhand. This bias was due to the greater number of casualties in the region, which accounted for over 80% of fatalities during 2007-2015 (Pham et al., 2019). Apart from rainfall being a major influencing factor for landslide incidences, other key parameters include the effect of climate change (Gariano and Guzzetti, 2016) and anthropogenic activities (Dikshit et al., 2020b). The effect of climate change has led to erratic rainfall patterns, whereas the influence of anthropogenic factors is immense as the region has seen a rise in developmental activities over the past 15 years. Therefore, the present study would look towards examining these factors also and understand how these factors affect the occurrences of rainfall-induced landslides in the region.

Further, the landslide studies in the region have looked towards developing thresholds, i.e., the minimum amount of rainfall required for landslide occurrences. As an example, Kanungo and Sharma, (2014) found that a 10-day antecedent rainfall of 55mm and 20-day antecedent rainfall of 185mm are sufficient for landslides occurrences in the Chamoli district (north-eastern part of Uttarakhand). There are multiple studies which have looked towards developing a landslide susceptibility map, either regionally or locally. Landslide susceptibility assessment determines the potential of landslide event considering several predisposing factors and investigating their spatial distribution (Reichenbach et al. 2018). These studies have been conducted using either statistical or data-driven models including machine learning (Dikshit et al., 2020b). For a complete reading of the various studies and their outcomes, readers are referred to Dikshit et al., (2020a). Of the various landslide studies conducted in the region, one that has been missing, is a comprehensive understanding of the spatial and temporal changes of landslide occurrences in the region.

The present study is focused on the Dunda region which is situated in the northern part of the state. The study area was chosen as the region has been suffering from frequent and recurring landslides every year. The three main objectives of the paper are: i) Examining the decadal variation (2008-2018) of the spatial and temporal changes in landslide occurrences; ii) Analysing the effect of rainfall patterns and various developmental activities, and iii) Possible mitigation measures which could be adopted to prevent landslide casualties.

2. Study Area

The study area (119 km^2) is between Dunda to Bhatwari which is located in the Uttarkashi district situated in the northern Indian state of Uttarakhand. The area is located along the banks of River Bhagirathi with an average elevation of 1680m (Figure 1). The study area is selected as it covers one of the most pilgrimage routes and the frequent landslides in the region causes severe casualties and economic loss.

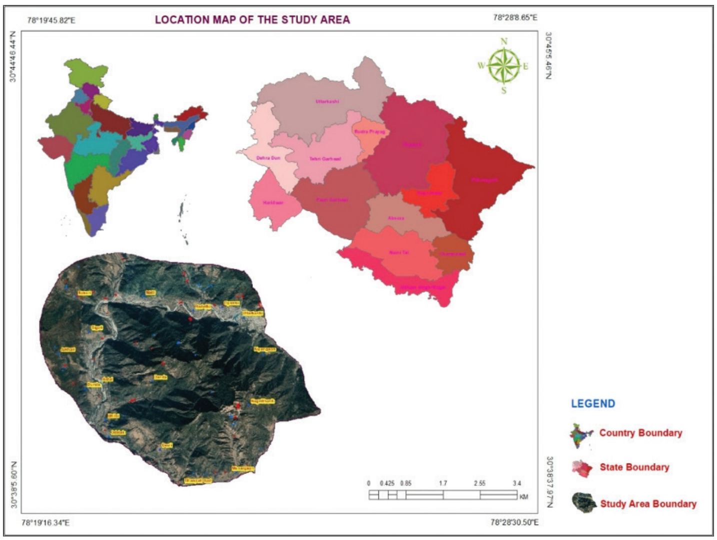

Figure 1: Location of the study area

Geologically, the study area is mainly composed of major rock formations like quartzite, metavolcanics, Pujaragon limestone etc. Dunda quartzite, augen mylonite and epidiorites are the main rock formations which occurred in the study area. Due to repeated tectonic activities in the rock formations, geology of the area is very much complicated. Dunda formation consists of thick limestone, slate and quartzite. The Garhwal Himalaya forms the most extensive group of rocks in Uttarkashi district. Garhwal group is limited by the main central thrust in the north and main boundary fault in the south. The main rock types are dolomite, limestone, slate, phyllite. These rocks are disrupted by acid and basic igneous rocks. Geology plays an important role in shaping the groundwater scenario of an area. Therefore, it becomes necessary to understand the geology of Uttarkashi district. The geology of the area is highly complex as the rock formations have undergone tectonic activities as shown in Figure 2.

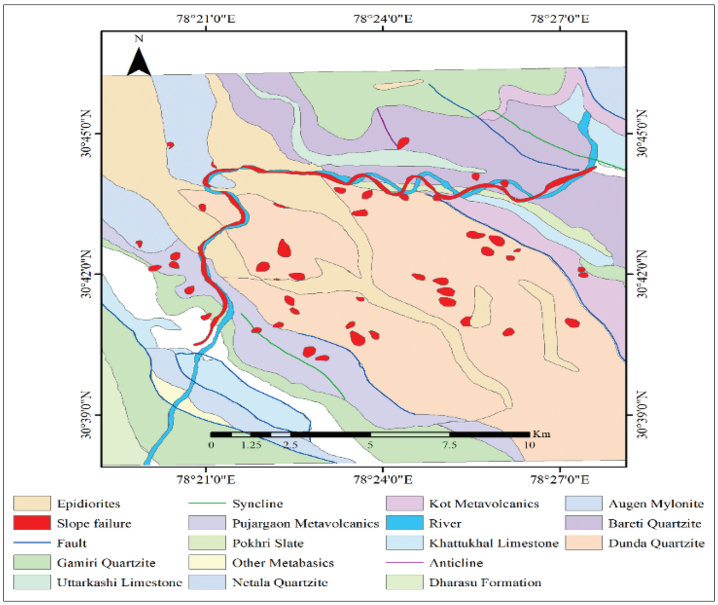

Figure 2: Geology of the study area

The region receives an annual rainfall of more than 1400mm, with more than 75% of the rainfall during the monsoon season (June-September). The contribution of pre-monsoon (March-May) and post-monsoon (October-December) are 14% and 3% respectively. Figure 3 illustrates the monthly and cumulative rainfall for the region from 2013-2017, collected from Indian Meteorological Station, Pune.Whereas Figure 4 shows the damages observed during the field study.

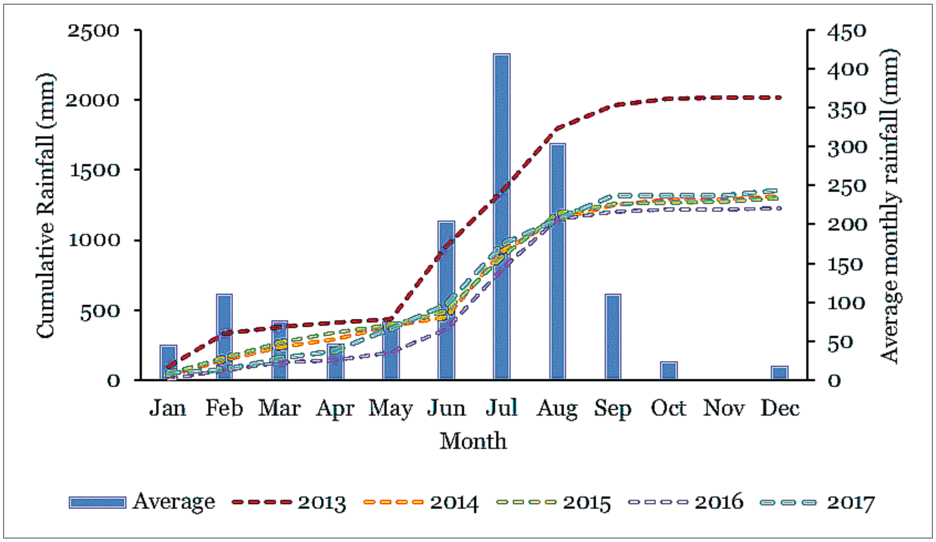

Figure 3: Average monthly and cumulative rainfall in the study region (2013-2017)

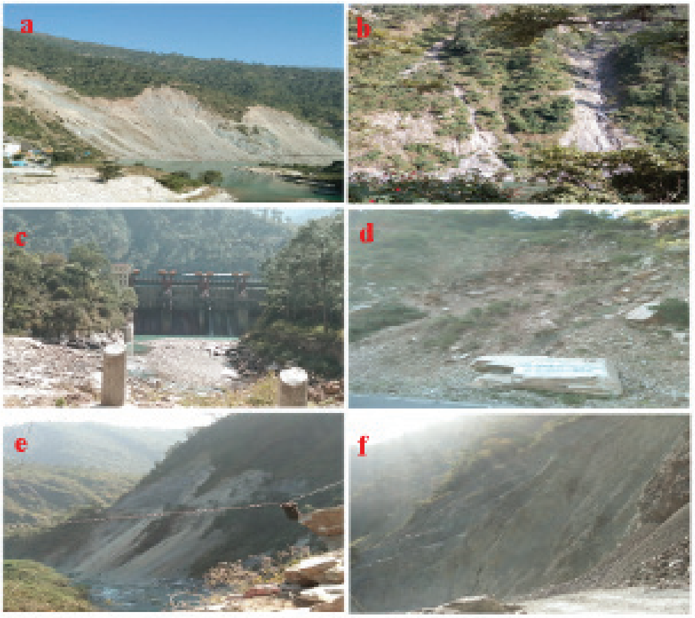

Figure 4: Observed damages during the field study

3. Data Collected

Different types of data have been used in this study, which can be categorized as remote sensing data, google earth, field data, ancillary data and relevant literature. In the present study, the remote sensing data consist of both optical and microwave sensing images. Optical image-based data have been utilised in the preparation of various thematic layers and satellite-based data have been used in finding out the vulnerability studies in the study area.

The use of satellite remote sensing images has increased rapidly for landslide studies as it provides synoptic view of the area and provides continuous data at high spectral resolutions. Table 1 shows the details of the satellite data used in the study.

Table 1: Satellite data used in the study area

S. No.	Name of Thematic Layers	Scale of Map	Data Source
1.	Slope Map	1:25000	Bhuvan
2.	Land use and Land Cover Map	1:25000	Bhuvan
3.	Geological map	1:50000	Parkash 1998
4.	Road map	1:1000	Google Earth
5.	Soil map	1:50000	Open Source World Soil Map
6.	Drainage map	1:50000	H44G06 and H44G05
7.	Structure Map	1:50000	Parkash 1998
8.	Toposheets	1:50000	H44G06 and H44G05
9.	LISS III Satellite image	1:25000	Bhavan / NRSC Open Source
10.	Landslides Inventory Map	1:1000	Google Earth

3.1 Road Infrastructure map

Owing to the cutting of steep slopes on hilly terrain, road construction often leads to slope instability. In addition to this, road building also requires rock blasting, which destabilises rock masses and also disturbs the slopes and makes it more vulnerable to failure due to heavy traffic movement and rock blasting. The road buffer map was then prepared around the main road that was plotted from the satellite images. Developmental activities which affect the landslides are discussed below buildings and roads.

3.2 Building Infrastructure

Man-made structures are also affected by the landslides whether they are near to landslides or not. As the landslides destroy foundations, transportation network, transmission lines, damages of the residential buildings occur. Commercial buildings can also experience the same after effects as residential buildings, but due to disruption to access roads, impacts may be greater in the case of commercial structure due to business interference. Figure 5 represents the building map of the field of study which has been prepared from the building footprint map using the data of high resolution. Satellite images of the study area have been procured. About 7000 numbers of buildings were digitized within the study area. Table 2 indicates number of types of buildings falling in the field of study. Figure 6 indicates different types of buildings in the study area whereas Figure 7 shows the decadal change of buildings in the study area.

Table 2: Types and numbers of buildings in the study area

Building types	No. of Buildings (2018)	No. of Buildings (2008)
Industrial Building	30	1
Government building	30	11
Hydropower plant	1	1
Educational Building	22	22
Religious Building	33	16
Commercial Building	1023	600
Residential Building	1366	900

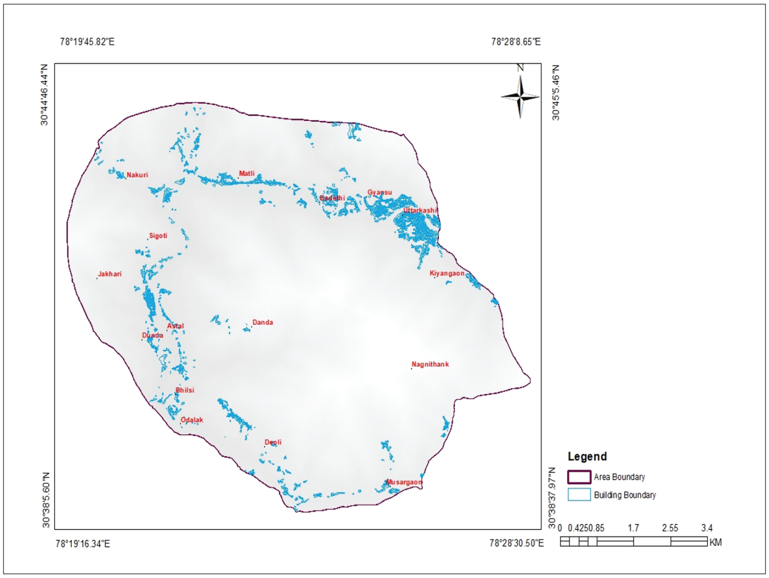

Figure 5: Building Map of the Field of Study

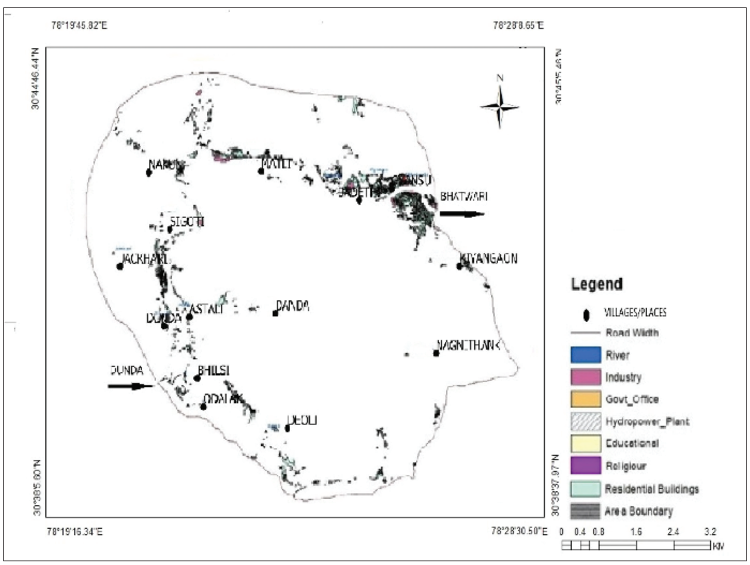

Figure 6: Types of Buildings in the Study Area

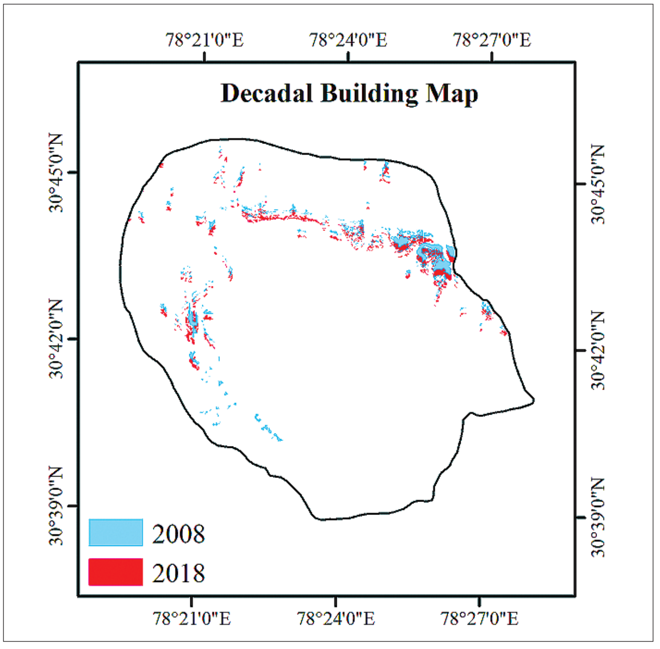

Figure 7: Decadal Change of Buildings in the Study Area

3.3 Road Infrastructure

Landslides have one of the biggest impacts on highways, impacting the highest number of people in any area. Connecting roads whether it may be national highways or state highways are also very vulnerable to the effect of landslides. Figure 8 represents road map of study showing availability regarding different types of roads. Table 3 shows the increase in the length of the roads from 2008 to 2018.

Table 3: Types of roads with their lengths in the field of study

Road Type	Road Length (in km) (2018)	Road Length (in km) (2008)
National Highway	21	17
State Highway	30	29
Other Major Roads	40	38
Village Road	75	70

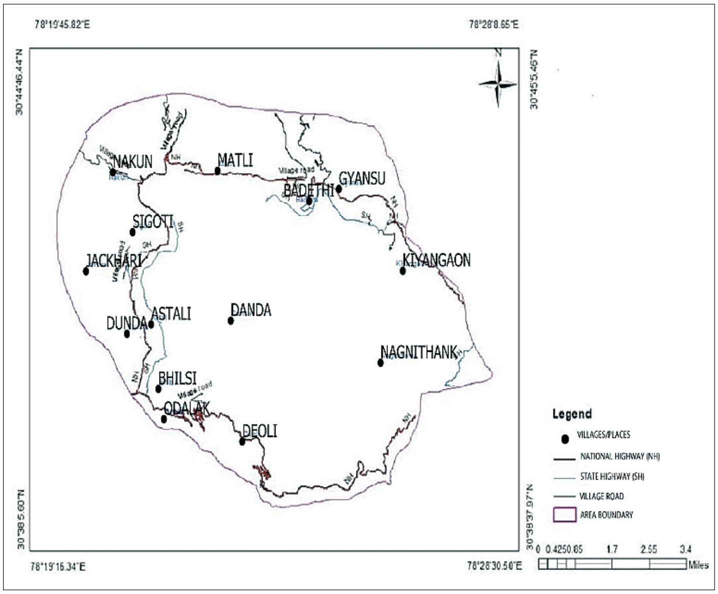

Figure 8: Road Map of the Study Area

In this study, change detection of developmental activities with respect to land use for two (2) periods of ten years (10) was conducted. This was done using satellite images of different dates (2008 and 2018) which were interpreted and analysed to extract the required information for finding out the changes in the study area. The results showed significant increase in built up areas whereas vegetation was annually decreasing. Also, there is no appreciable change in the water bodies. This study can help the urban planners in managing the land use development of the region. Table 4 gives the change detection of developmental activities with respect to land use of 2018 and 2008. Whereas Table 5 gives the change detection with respect to land use and land cover class of 2018 and 2008. Figure 9 shows the change detection map on the basis of number of buildings.

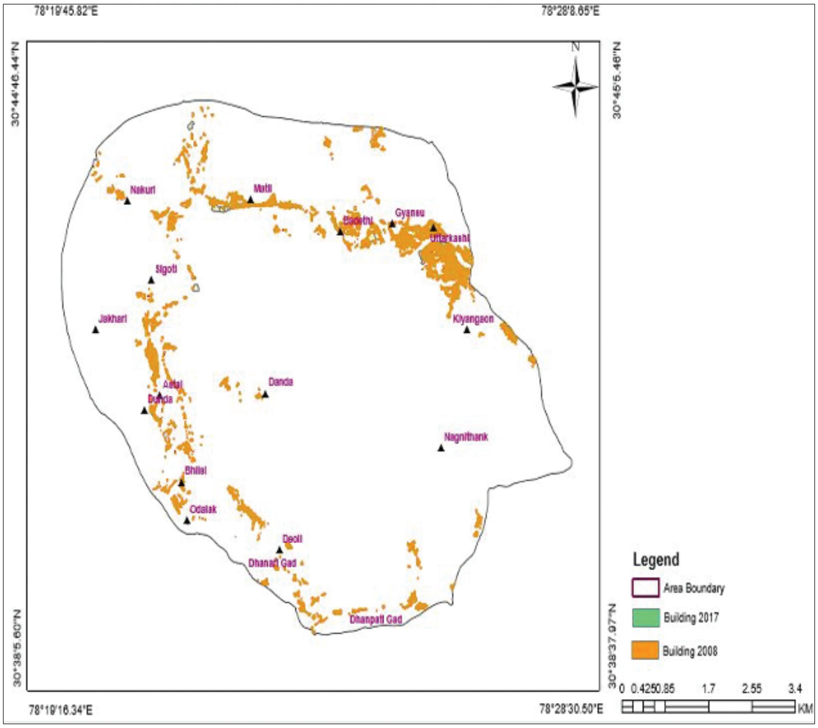

Figure 9: Change detection map on the basis of number of buildings

Table 4: Change detection of developmental activities with respect to land use

Sl. No	Class Name	Land use 2018	Land use 2008	Change Detection
1	Residential Building	3665	2711	954
2	Industrial Building	3	1	2
3	Educational Building	29	22	7
4	Commercial Building	3252	2711	541
5	Government Building	18	11	7
6	Religious Building	33	16	17
7	Hydro Power Plant	1	1	0
8	Major Roads	41	21	20

Table 5: Change detection in land use between 2008 and 2018

Land use	2018	2008	Change Detection
Class Name	**Area in Ha.**	**Area in Ha.**	**Area in Ha.**
River	246.62	227.21	19.41
Waterbody	1.39	1.53	-0.14
Dense Forest	4781.95	4688.37	93.58
Medium Dense Forest	1811.78	2637.91	-826.13
Low Dense Forest	1378.31	1528.7	-150.39
Agriculture Land	1319.97	1080.54	239.43
Open Land	2098.98	1503.84	595.14
Village Settlement	110.72	87.55	23.17
Urban Settlement	141.71	138.02	3.69
Dense Urban Settlement	75.71	73.58	2.13
Industry	8.52	8.41	0.11
Total Area	11975.66	11975.66	

4. Landslide Mitigation and Remedial Measures

Systematic approaches related to the preparation and implementation of principles and interventions are needed for a comprehensive risk management strategy. It includes risk control. Pre-disaster and post-disaster reduction techniques. Pre-disaster methods include hazard identification, risk analysis by tracking current incidents, hazard zoning mapping and the implementation of new techniques to avoid the activation of hazardous processes. The purpose of Comprehensive Hazard Zoning is to avoid settlements, to identify infrastructural components in vulnerable areas and, to some degree, to administer adequate treatment measures needed at vulnerable locations.

Various Mitigation measures which include correction in case of slope geometry, protection of the slope toe by retaining structures, water management of surface and subsurface water which includes pore pressure growth, bolting, nailing, anchoring, micro-piling, geo-textile application and afforestation, are powerful components employed in case of geotechnical packages being used to improve stabilisation.

4.1 Mitigation Methods for Various types of Landslide Hazards

Avoiding construction on steep slopes and current landslides is the best way of dealing with landslides. This is not always realistic, however. Another solution is to control the usage and development of land to ensure that construction does not minimize slope stability. Physical measures should be used in situations in which landslides impact existing structures or cannot be stopped. In some of the cases, monitoring systems are helpful for the residents to evacuate when there are chances of landslide activity. Fig 10 (a) and Fig10 (b) gives the slope stitching techniques for surficial failures. Fig 10 (c) shows the block masonry wall with weep holes whereas Fig 10 (d) shows the remedial measures taken for stabilizing landslide site. Fig 10(e) shows the empty bitumen drums acting as retaining wall whereas Fig 10 (f) shows the random boulder gabion wall as wire crates

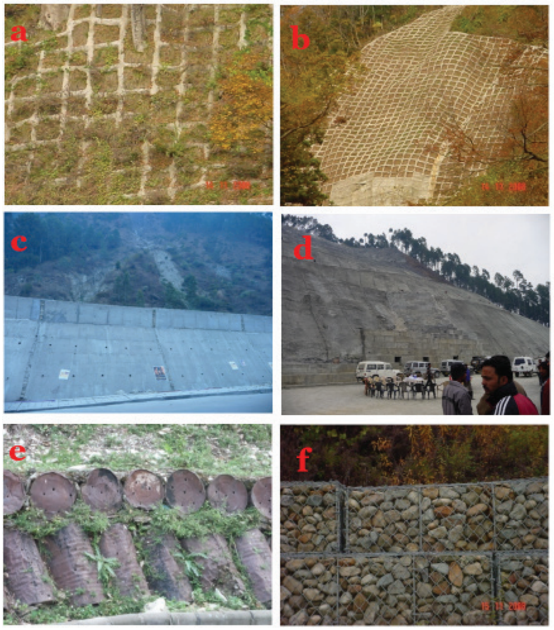

Figure 10: (a, b) Slope stitching technique for preventing surficial failures, (c) Block masonry retaining wall with weep holes, (d) Multiple remedial measures for stabilizing landslide site, (e) Empty bitumen drums filled act as retaining wall, (f) Random Boulder Gabion Wall debris with wire crates (Prakash, 2019)

4.1.1 Mitigation Measures for Buildings:

The following impact-reducing, non-structural mitigation steps are:

- Early warning systems
- Restricting building activities
- Growing resistance by accommodation, evacuation methods, etc.
- Relocation of the building or not using it for essential facilities

Non-structural mitigation measures for reducing the effects, such as the warning system, building restrictions, and structural mitigation measures for the reduction of the impact on operating operations during hazards should be given priority for critical infrastructure.

4.1.2 Mitigation Measures for Roads Planning for Existing Highways

Primary concern for the highway slopes is the stability of the slopes. Scope of planning for existing highways can vary widely, ranging from a road upgrade to local changes to the alignment of a road including widening of roads. The planning of road improvement is usually more limited by existing systems compared to a new highway, services and utilities and the surrounding topography. A significant constraint also is the need to maintain traffic flow during construction. These restrictions should be taken into consideration in choosing suitable route alignment and/or design choices.

If a network has a large number of failures, an inventory may help to determine a target for earthworks that are most likely to fail or pose the greatest risk. Once a database of relevant slope data has been developed and analysed, it is possible to focus on those datasets that are both important to the slope condition and are likely to change during engineering time to update the database. The inventory can provide a tool to:

- layout the location of earthwork.
- Description and classification of slope failure
- Cost of repair calculation

The major drawback of a slope inventory is that the data only provides data on the calculated slopes. If the landscape is large, there is no data about the slopes. The two together form a powerful tool for planning, design and management when used within the context of a terrain classification. A wide variety of hazard management methods are available and these methods may have very different applications:

a) **New Roads construction:** The key task is to determine an alignment that minimizes the hazards that are likely to impact the route. This includes broadly examining a wide area of landscape. This suggests a terrain assessment approach to the evaluation.

b) **Existing Roads:** Specific design details for particular slope hazards may be needed by the engineer for an existing alignment or network. In this case, a numerical method is more likely to be acceptable.

c) **Geomorphological mapping and geotechnical mapping:** It is based on the assumption that there are strong indicators of past instability in the landscape, which can be expected for future operations. It also includes that how the land has been developed in its present state and how it can be used in future.

d) **Techniques for Hazard Reduction on existing roads:** The risk mitigation challenge is to classify areas with a sufficiently high-risk rating to justify investing large amounts of money on engineering work. In economic terms, it is difficult to justify the costs associated with the construction of remedial works over long road distances and may be unaffordable. As part of any developmental activity, a significant study of the alignment of culverts and other conduits close to the road should be done.

Three extensive methods are being used in case of hazard reduction works:

- Path protection: Acquire the presence of debris flows and take steps to safeguard the path. Debris basins, lined debris channels, debris flow shelters, overshooting and obstacles (including ditches, walls and fences) are possible solutions.
- Preventive measures for debris flow: engineering activities are carried out to minimize the chances of a debris flow happening
- Realignment of the Road: Realign the road. In order to improve the road in terms of alignment and junction setting, road re-alignment may be taken as route improvement practises, in particular to minimise accidents and to ensure competition with existing design requirements.

5. Conclusions

1) Landslide Hazard Susceptible zonation map of the study area shows that around 11.2% of the area lies in very low hazard zone,10% of the area falls in low hazard zone,13.3% of the area falls in low moderate zone,21.7% of the area falls in moderate

zone, 35.5% of the area falls in high hazard zone and 9.45% of the area falls in very high hazard zone where the probability of landslides is high due to weathered rock and soil debris covering steep slopes which when disturbed are prone to landslides.

2) Main developmental activities are road construction and urban development in terms of construction of buildings which have been calculated as 7000 buildings. Out of which, maximum are the number of residential and commercial buildings which are 4496 in number.

3) In calculating the building susceptibility with reference to LSZ it has been noticed that 29.63% of buildings are there in the high hazard zone and 32.48% n of buildings are there in the very high hazard zone which again indicates that construction activities are one of the reasons which account for the increase in hazards and accordingly planning should be done to mitigate the hazard to some extent.

4) In finding out the road susceptibility with respect to LSZ, it has been concluded that out of 166km length of the road in the study area,39 km of road is lying in the high and 65km of road is in the very high hazard zone. It also signifies that 23.49% of the roads lies in high hazard zone and 39.16% roads lies in very high hazard zone.

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