PROJECT PRE-FEASIBILITY REPORT (PPR)
ON
LANDSLIDES RISK MITIGATION & MANAGEMENT IN SIKKIM
(Phase-I)

UNDER

NATIONAL LANDSLIDE RISK MITIGATION PROGRAMME
(NLRMP)

SUBMITTED BY
SIKKIM STATE DISASTER MANAGEMENT AUTHORITY
(SSDMA)

Contents

Executive Summary:

Project Overview:
The **"Landslides Risk Mitigation & Management in Sikkim (Phase-I)"** project, initiated under the **National Landslide Risk Mitigation Programme (NLRMP)**, focuses on high-risk districts of Sikkim, including Gangtok, Pakyong, Mangan, Namchi, Soreng, and Gyalshing. Its primary purpose is to mitigate landslide risks through scientific assessments, community engagement, and the implementation of structural and non-structural interventions.

Objectives:
The project aims to reduce the risks and impacts of landslides by:
- Preventing loss of life and property.
- Implementing multi-parameter sensor-based EWS (geotechnical, hydrological, and geophysical) integrated with community-driven dissemination protocols for last-mile connectivity.Enhancing technical and scientific capacities for landslide hazard mapping and mitigation.
- Empowering local communities through awareness, training, and active participation.

Key Highlights:
- **Interventions** include slope stabilization (structural measures, bio-engineering, and community-based solutions), installation of sensor-based landslide monitoring and Early Warning Systems (EWS), Multi-Hazard Risk & Vulnerability Assessments (m-HRVA), capacity-building initiatives and awareness programmes (non-structural measures).
- **Funding Mechanism**: The project is funded under the National Disaster Mitigation Fund (NDMF) and the State Disaster Mitigation Fund (SDMF) with a total estimated cost of ₹50 crore.
- **Project Duration**: Scheduled for 12–24 months
- **Milestones** include GIS-based slope information systems, landslide inventory creation, geo-technical investigations of vulnerable infrastructure, mitigation of landslide sites and training of 50 master trainers in collaboration with Sikkim Manipal Institute of Technology (SMIT).

The initiatives aims to build a landslide resilient, disaster-prepared Sikkim through community-led, technology-driven landslide risk management and mitigation.

Project Report

1. Background
Sikkim, unique land with diverse topography, climate and vegetation is a North-Eastern state of the India, its 7096 km^2 of the geographical area entirely lies in Eastern Himalaya between 27º 04' 46" and 28º 07' 45" North latitude and 88º 00' 56" and 88º 55' 25" East longitude. Sikkim's topography is predominantly rugged, with much of its land area covered by the Greater and Lesser Himalayas. This landlocked Indian state is bordered by Tibet to the north and northeast, Bhutan to the southeast, Nepal to the west, and the Darjeeling district of West Bengal to the south. The state's terrain is mostly mountainous, with elevations ranging from 284 meters at the confluence of the Teesta and Rangit rivers near Chitrey in Kalimpong district, West Bengal, to 8,598 meters at the summit of Mt. Kanchenjunga. For administrative purposes, Sikkim is divided into six districts i.e., Mangan, Gangtok, Geyzing, Namchi, Pakyong, and Soreng and further subdivided into 18 sub-districts.

Geologically, the state is relatively young, surrounded by young fold mountains, and its formation is still ongoing, with strongly folded and faulted strata in many areas. Sikkim lies in seismic zone IV on India's seismic zonation map, which is associated with seismic intensity VIII on the Modified Mercalli Intensity scale. The state receives an average annual rainfall of 2544.40 mm, with precipitation levels varying significantly throughout the year. Heavy rainfall contributes to rapid erosion and weathering of rocks, elevates groundwater levels, and weakens natural slopes, reducing their stability.

Sikkim is prone to landslides due to its geological structure, tectonic activity, slope instability, and the weak composition of its soil and rocks. Several factors contribute to this instability, including heavy rainfall, flooding, seismic events, deforestation, and construction activities. Scientific studies have shown that there is an average of two landslides per square kilometer, resulting in an annual land loss of approximately 120 meters per kilometer and a soil loss of about 2500 tons per square kilometer. Intense rainfall can trigger over 100 landslides, causing significant damage to critical road networks, public infrastructure, and agricultural crops. Therefore, landslide risk reduction and mitigation measures are required to be implemented in the State to reduce future risk and its impacts.

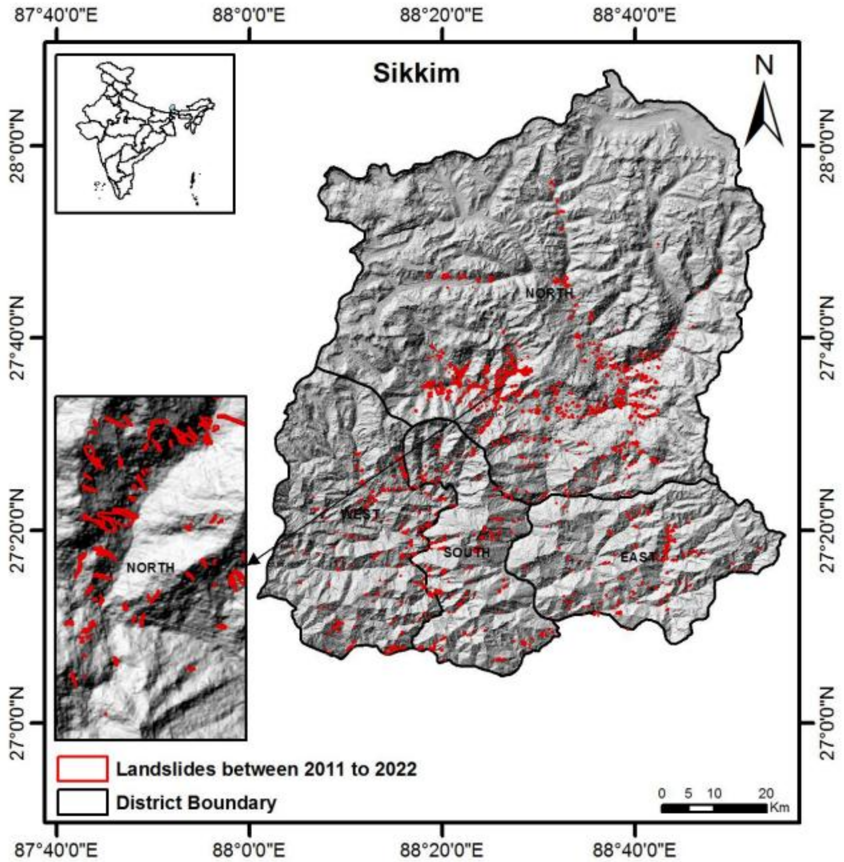


Figure 1: Landslides occurred between 2011 to 2022 are mapped by NRSC-ISRO.
Source: Landslide Atlas of India: NRSC-ISRO (Feb., 2023)

The district-wise vulnerability of landslides in Sikkim as given under:

North District (Mangan): 1.27% of the area of the district falls under very high risk zone, about 40.84% of the area falls in very medium risk zone and only 0.18% of the total area falls under very low risk zone.

East District (Gangtok & Pakyong): 2.17% of the area falls under very high risk zone, 32.97% of the total area falls under very medium risk zone, 45% of the area falls under very medium risk zone and 1.64% of the total area falls under very low risk zone.

West District (Gyalshing & Soreng): 1.97% of the total area falls under very high risk zone, 98.48% of the total area falls under medium risk zone and 0.68% of the total area falls under very low risk zone.

South District (Namchi): 4.13% of the total area falls under very high risk zone, 95.37% of the total area falls under medium risk zone.

2. Project Site (300 words)

Slope stabilization of landslides is a critical intervention aimed at preventing or mitigating the movement of soil and rock on unstable slopes prone to landslides. This process involves a combination of structural and non-structural measures, such as retaining walls, drainage corrections, soil nailing, micro pile and rock bolting etc. to enhance slope strength and stability. In addition, eco-friendly and nature-based solutions (NbS) techniques like vegetation cover and bio-engineering solutions are often integrated to reduce surface erosion and reinforce the soil naturally. Effective slope stabilization not only safeguards human lives and infrastructure but also contributes to long-term environmental sustainability by promoting safer land use and reducing the recurrence of landslide events. The mitigation or treatment of problematic landslide are site-specific in nature and depends upon the present site conditions.

Community-based slope stabilization through local interventions emphasizes the active participation of local communities in mitigating slope instability using cost-effective and nature-based solutions. These grassroots efforts often involve traditional knowledge and locally available materials, promoting ownership and long-term maintenance. Complementing these initiatives, bio-restoration and bio-engineering measures are employed to enhance slope stability by integrating vegetation and engineering practices. Bio-restoration techniques such as planting deep-rooted grasses, shrubs, and trees help bind the soil, reduce surface erosion, and improve drainage, making slopes more resilient to landslides. Locally available vegetation and native grasses, shrubs to be promoted to maintain the ecosystem. Together, these approaches not only reduce hazard risks but also support ecological sustainability and community empowerment.

Project sites are selected on the basis of high landslide vulnerability, urgency as per site conditions and geo-physical investigation carried out for mitigation of two landslide affected sites (i.e., Lumsey and Mangan) where settlements are affected.

I). Site-specific Landslide Risk Mitigation:

Site-specific landslide risk treatment and slope stabilization will be done after geo-technical investigation as per present site conditions and requirements. Following are the four sites of site-specific landslide risk mitigation as given under:-

i) Lumsey Landslide

a) Location: Geographically, the study area lies between the coordinates N 27º 19.491' latitudes E 88º 35.925' to N27º 19.579' latitudes to E 88º 35.721' longitudes and at the elevation ranging between 1149m to 1002m above mean sea level. Physically, the subsidence zone lies below Lumsey road end upto the new Adampool Highway road. Lumsey Village of Gangtok district, located within the Tadong Ward of the Gangtok Municipal Corporation, spans a total area of 124.28 hectares. According to the Census of India 2011, the ward has a population of 9,325 residents. However, the region faces significant environmental challenges, particularly due to landslides. Approximately 3.5 hectares of land within the ward are affected by landslides, posing risks to both infrastructure and residents. It is estimated that around 1,000 people are impacted by the landslides, with about 100 houses suffering varying degrees of damage. This highlights the urgent need for landslide mitigation strategies and sustainable land management in the area. The preliminary geo-technical investigation of site was done by the Directorate of Geology & Mining Department (DGM), Govt. of Sikkim.

Figure 2: Lumsey Landslide (Lat 27°19'32.48"N Long 88°35'48.20"E)

Photo Plate 1: Lumsey Subsidence Zone, Gangtok, Sikkim

Photo Plate 2: Lumsey Subsidence Zone, Gangtok, Sikkim

b) Geology: The area under consideration is a part of medium to high grade metamorphic terrain represented in the area by *gneissic rocks* with occasional bands of *garnetiferous mica-schist intermixed with or without quartz veins*. The rock exposure observed on the few locations shows the dip of foliation *plane N35ºE with angle of 100* towards NE. Three sets of joint plane is identified in the rock exposed area at the geographical location N 27º 19.608' latitude E 88º 35.845' longitude and at the elevation 1129m amsl, the orientation of the joint plane are as follows:

J1- N20ºW-S20ºE, 90ºSW, J2 – S70ºW-N70ºE, 70º NW and J3 along the foliation plane.

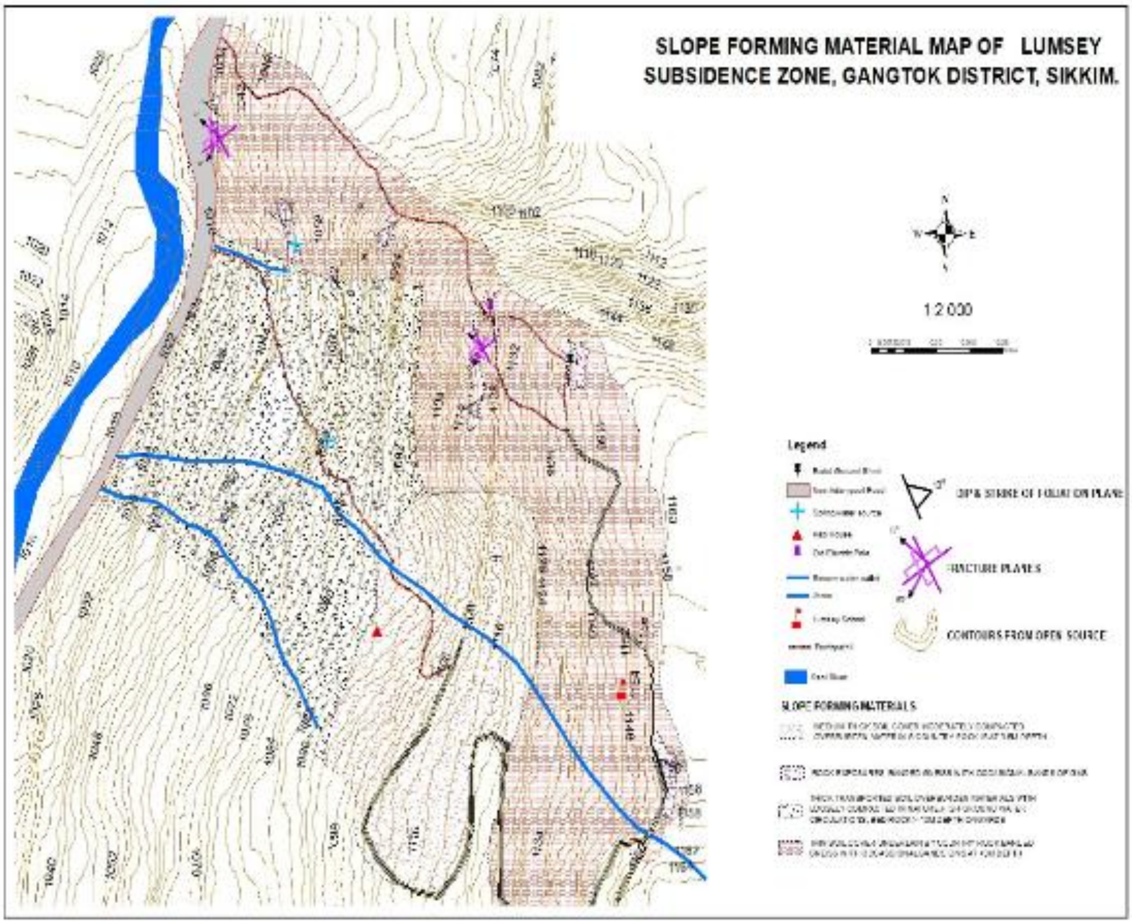
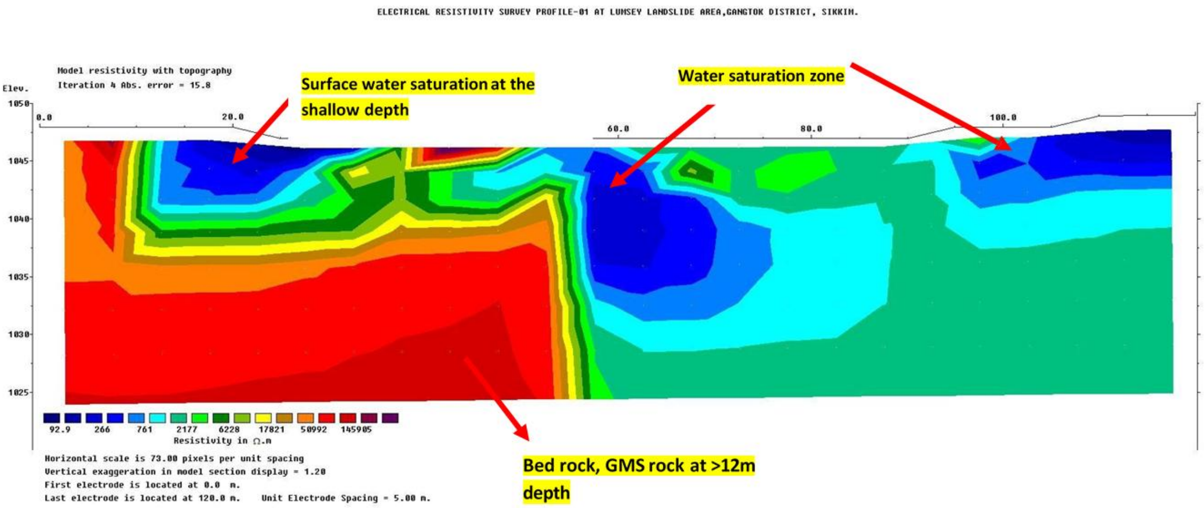


Figure 3: Slope Forming Material Map of Lumsey Subsidence Zone, Gangtok, Sikkim

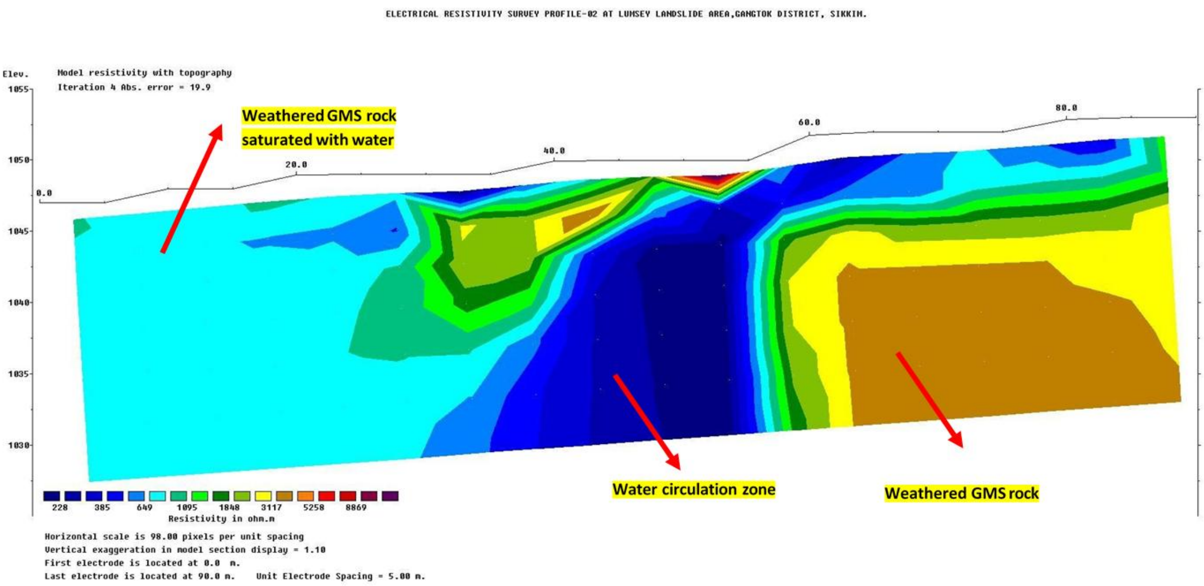
c) Geomorphology: The area has moderate slope gradient with westerly facing slope. The rock has undergone high degree of weathering due to high sub-surface water circulation. Upon detailed studies, it was observed that the slow creep movement of the entire area between two ridges was very active during rainy seasons. The considerable numbers of transported boulders were also observed in the area. Further, two springs water sources were observed within the creep zone. The discharge of the spring water is high during rainy seasons.

d) Prevailing Conditions: Upon detailed studies it was observed loosely compacted soil overburden material intermixed with boulders of the gneissic rocks exists between 8-10m average vertical depths. These materials were deposited/ transported from the upslope area and due to high water activities the compaction/settlement was noticed. However, the process of settlement in the area was observed from past many years. The geological mapping in the area was carried out in 1:2000 scales and the rock exposure were also mapped. Towards northern and eastern end of the subsidence area, the rock exposure was encountered along ridge line in many locations. However, towards the southern and western end of the subsidence zone, the bed rock is expected at greater and variable depth. Detailed slope forming material map is given at **figure 3**.

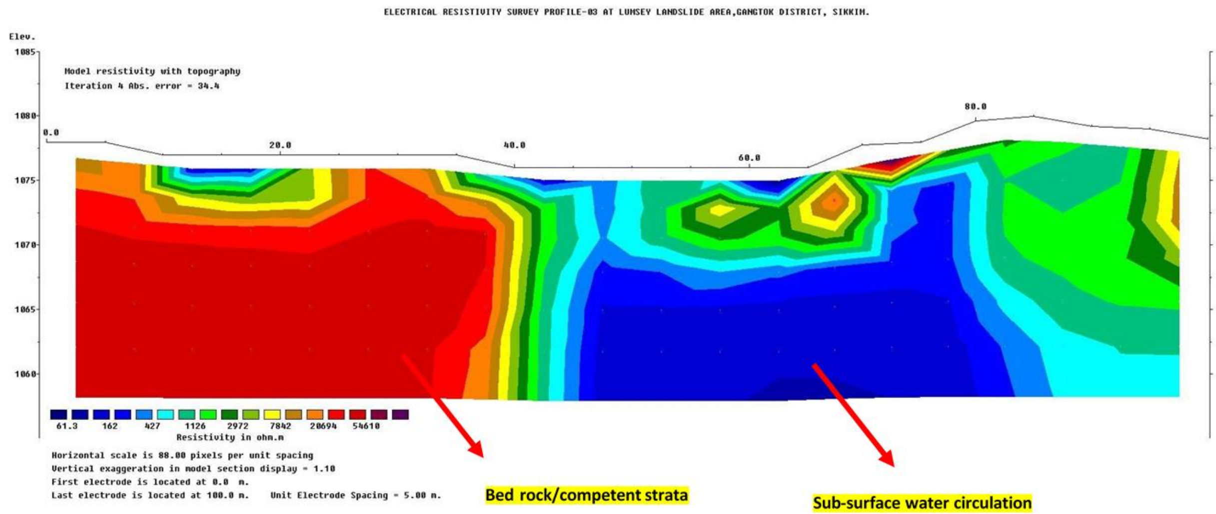
During the course of investigation number of soil samples were collected from the subsidence area especially along the cracks within the subsidence zone. Also, few pits were excavated to confirm the depth of bed rock towards the crown of the subsidence zone. Total six numbers of ERT survey profile sections were conducted in the area with wide distribution and covering not only subsidence zone but also the suspected creep area in the region. Medium thick soil overburden overlain by Garnetiferous mica schist intermixed with gnessic rock with occasional quartz veins are inferred along profile section (PS05-PS05'). The data so obtained are used in the preparation of sub-surface lithological sections along each profile and also inferred geo-hydrological regimes were carried out.



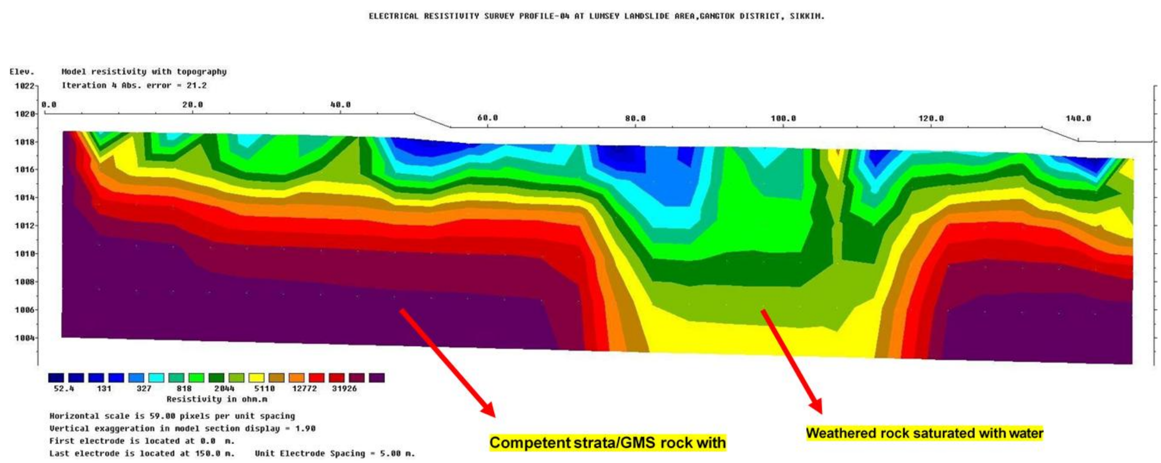
ERT Survey Profile of Site 1 (PS01-PS01') at Lumsey Landslide, Gangtok



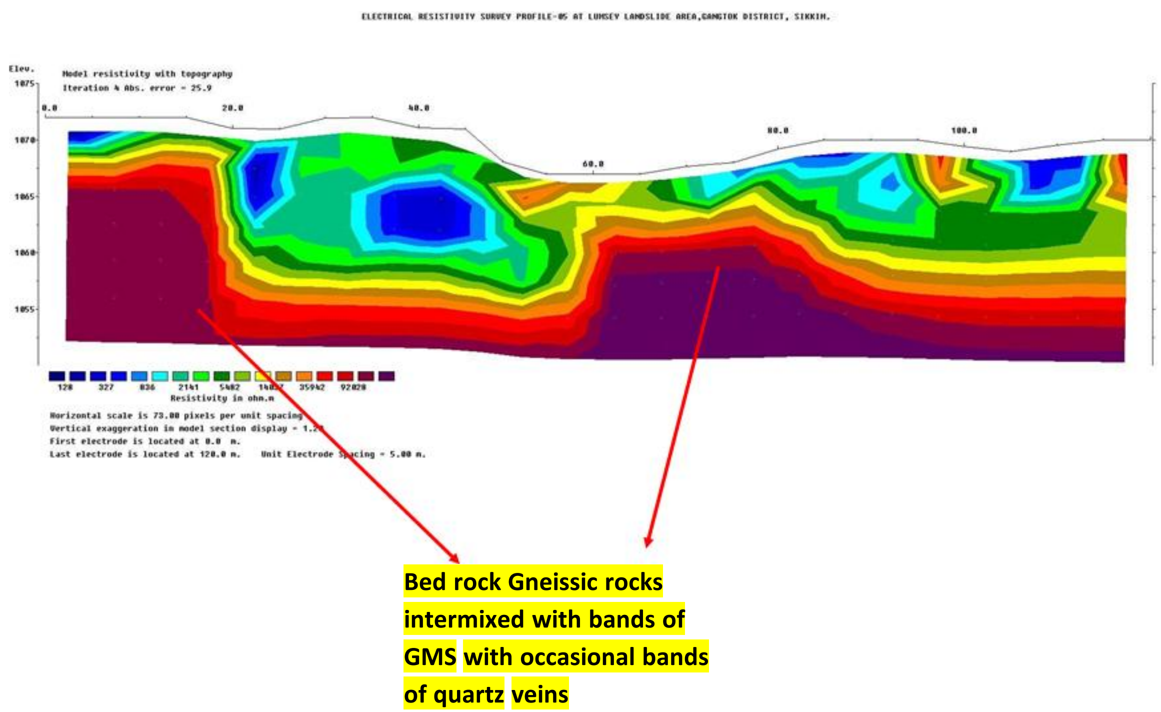
ERT Survey Profile of Site 2 (PS02-PS02') at Lumsey Landslide, Gangtok



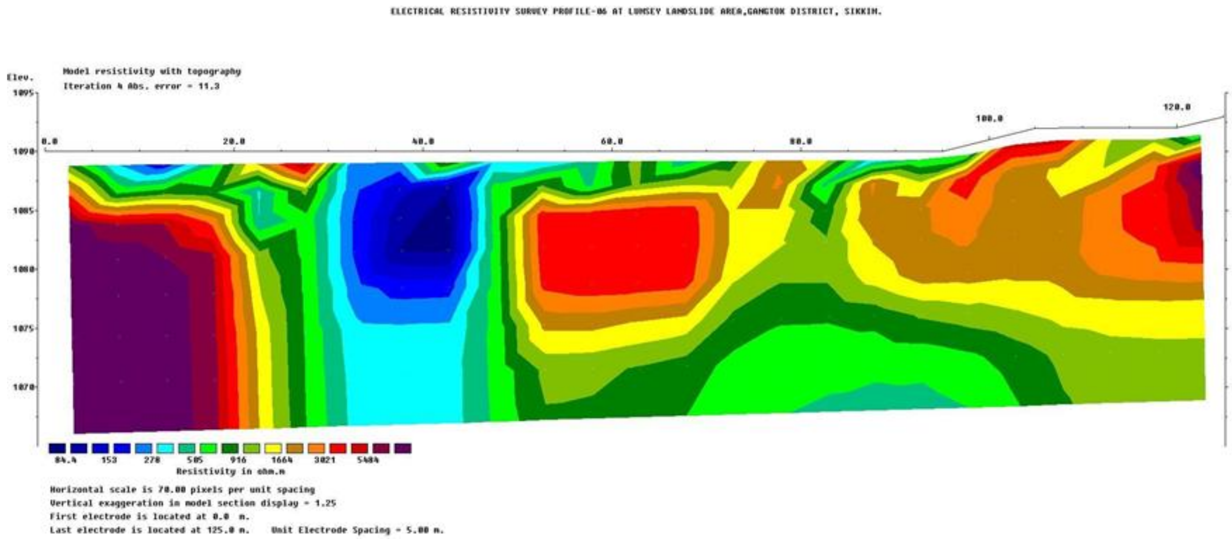
ERT Survey Profile of Site 3 (PS03-PS03') at Lumsey Landslide, Gangtok



ERT Survey Profile of Site 4 (PS04-PS04') at Lumsey Landslide, Gangtok



ERT Survey Profile of Site 5 (PS05-PS05') at Lumsey Landslide, Gangtok



ERT Survey Profile of Site 6 (PS06-PS06') at Lumsey Landslide, Gangtok

RESULTS AND ANALYSIS OF GEOPHYSICAL OBSERVATIONS:

Medium thick soil overburden overlain by Garnetiferous mica schist intermixed with gneissic rock with occasional quartz veins are inferred in profiles. Multi-electrode resistivity survey with Schlumberger-Wenner array was carried out in profile sections. Observation from 2D-inversion resistivity in the profile sections shows that the top layer consists of soil overburden intermixed with weathered/fractured rock fragments underlain by highly to moderately weathered Garnetiferous mica schist intermixed with gnessic rock with occasional quartz. Further, all the profile shows highly saturated zone of soil intermixed with rock fragments exists with variable depths ranging from 0m-15m and 0m – 20m are seen in the tomography.

DETAILS OF LABORATORY TESTING OF SOIL SAMPLES

Moisture Content

The water content of samples has been evaluated after drying each samples in an oven at 900 C-1000 C for 24 hours as per procedure laid down in the Indian standard 2720 (Part II). The natural moisture content varies from 9% to 34% in the soil samples.

Grain Size Distribution

To obtain the information concerning the soil found at various depths and to classify each strata of soil, it was necessary to conduct grain size distribution analysis. This has been done by passing dried samples over a net of sieves. The grain size distribution was evaluated and the percentage of gravel, coarse sand, medium sand, fine sand, silt and clay, fractions are calculated. These percentages are indicated in annexure and represented in graph enclosed. The overall grain size distribution in the soil gave percentage of Gravels between 2%-9% followed by all type of sands (85%- 87%), silt (3%-10%) and clay (2%-6%). The uniformity coefficient of the soil sample indicates poorly to uniformly graded in nature.

Bulk Density

Bulk density was determined by measuring the weight and dimension of the disturbed samples and the bulk density of soil samples varies from 19 to 24 Kn/m^3.

Direct Shear Test

Direct shear test of soil samples were conducted in laboratory as per IS code: 72720 and soil parameters were obtained and placed in report.

GRAIN SIZE DISTRIBUTION CHART

Location:- Lumsey, Gangtok District.

PIT NO.	Depth, (m)	Bulk Density, kN/m^3	M.C %	Grain size distribution in (%)							Uniformity Coefficient "CU"
				G	Sand				S	C	
					V.C.S	C.S	M.S	F.S			
1	1.5	19.62	11.78	0.89	5.23	5.28	41.54	39.67	5.03	2.34	2.90
1	3	19.818	12.43	1.89	2.97	4.26	43.32	39.21	5.67	2.65	1.74
2	1.5	19.62	9.43	2.12	2.16	3.33	30.85	47.62	9.68	4.22	1.5
2	3	19.62	9.29	2.87	3.05	3.97	32.01	45.76	8.21	4.1	1.51

G	GRAVEL
V.C.S	VERY COARSE SAND
C.S	COARSE SAND
M.S	MEDIUM SAND
F.S	FINE SAND
S	SILT
C	CLAY
M.C	Moisture content
Sample weight = 100g.	

Soil type-Poorly to uniformly graded soil.

Estimation Of Net Ultimate Bearing Capacity (NUBC) and Soil Bearing Capacity

The Net Ultimate Bearing Capacity of soil is calculated considering the shear failure as per IS: 6403-1981.

Location no.	Depth, (m)	Bulk Density, kN/m^3	M.C %	Grain size distribution in (%)					Uniformity Coefficient "CU"		
				G	Sand				S	C	
					V.C.S	C.S	M.S	F.S			
1	0.9	24.525	13.26	4	3.02	4.75	28.88	44.33	9.66	5.32	2.88
2	0.9	23.082	14.09	3.91	3.11	4.68	28.1	44.76	9.85	5.56	1.61
3	0.9	15.328	34.41	2.82	4.28	7.75	46.61	30.04	4.73	3.72	1.96
4	0.9	19.62	23.62	3.87	5.48	7.29	32.82	35.26	8.7	6.52	2.30
5	0.9	22.813	13.8	4.12	3.25	5.04	30.79	42.35	8.62	5.78	2.36
6	0.9	20.02	17.61	5.41	4.54	5.28	35.67	42.07	4.53	2.45	1.59
7	0.9	20.234	17.96	5.34	4.8	5.61	36.02	40.83	4.71	2.66	3.33
8	0.9	21.326	16.27	8.91	6.25	10.69	47.61	21.66	2.84	2.01	1.65

G	GRAVEL
V.C.S	VERY COARSE SAND
C.S	COARSE SAND
M.S	MEDIUM SAND
F.S	FINE SAND
S	SILT
C	CLAY

Soil type-Poorly to uniformly graded soil.

M.C	Moisture content
	Sample weight = 100g.

PIT NO.	Depth (m)	Shear stress (kg/cm^2)			Normal stress (kg/cm^2)			Shear strength (T/m^2)	Angle of frictional resistance (Phi)	Type of Shear failure
		Ss1	Ss2	Ss3	Ns1	Ns2	Ns3			
1	1.50	2.47	2.90	3.16	1.00	1.50	2.00	1.35	29^o	Local/General shear failure
1	3.00	2.09	2.35	3.01	1.00	1.50	2.00	1.67	30^o	General shear failure
2	1.50	2.44	2.76	3.25	1.00	1.50	2.00	2.23	28^o	Local/General shear failure
2	3.00	2.29	2.78	3.34	1.00	1.50	2.00	1.80	31^o	General shear failure
Location 01	0.90	3.29	3.74	4.01	1.00	1.50	2.00	3.15	29^o	Local/General shear failure
Location 02	0.90	2.29	2.40	3.11	1.00	1.50	2.00	1.96	25^o	Local/General shear failure
Location 03	0.90	2.24	2.31	2.85	1.00	1.50	2.00	2.06	20^o	Local shear failure
Location 04	0.90	2.18	3.02	3.03	1.00	1.50	2.00	2.23	28^o	Local/General shear failure
Location 05	0.90	1.93	2.54	3.12	1.00	1.50	2.00	2.32	32^o	Local/General shear failure
Location 06	0.90	2.58	2.62	2.91	1.00	1.50	2.00	1.51	12^o	Local shear failure
Location 07	0.90	1.82	2.01	2.54	1.00	1.50	2.00	1.40	22^o	Local shear failure
Location 08	0.90	2.06	2.43	2.87	1.00	1.50	2.00	1.98	26^o	Local/General shear failure

Table: Safe bearing capacity of soil at 1.50m & 3.00m depth below ground level as per IS Code:-6403-1981

Location	Depth,(m)	Surcharge q,(kN/m^2)	Bulk Density (kN/m^3)	Width of the foundation(m)/bottom of the footing	Factor of safety	SBC(T/m^2)
PIT-01	**1.50**	**29.43**	**19.620**	**1.5 X 1.5**	**4**	**22.051**
				3 X 3		**24.379**
PIT-01	**3.00**	**59.454**	**19.818**	**1.5 X 1.5**	**4**	**44.327**
				3 X 3		**46.259**
PIT-02	**1.50**	**29.727**	**19.620**	**1.5 X 1.5**	**4**	**21.00**
				3 X 3		**23.080**
PIT-02	**3.00**	**58.86**	**19.620**	**1.5 X 1.5**	**4**	**51.216**
				3 X 3		**53.647**
Loc-01	**0.90**	**22.072**	**24.525**	**1.5 X 1.5**	**4**	**19.726**
				3 X 3		**22.950**
Loc-02	**0.90**	**20.773**	**23.082**	**1.5 X 1.5**	**4**	**11.559**
				3 X 3		**13.171**
Loc-03	**0.90**	**13.795**	**15.328**	**1.5 X 1.5**	**4**	**5.193**
				3 X 3		**5.712**
Loc-04	**0.90**	**17.658**	**19.620**	**1.5 X 1.5**	**4**	**14.129**
				3 X 3		**16.406**

Loc-05	**0.90**	**20.531**	**22.813**	**1.5 X 1.5**	**4**	**26.450**
				3 X 3		**31.389**
Loc-06	**0.90**	**18.018**	**20.020**	**1.5 X 1.5**	**4**	**3.643**
				3 X 3		**3.862**
Loc-07	**0.90**	**18.210**	**20.234**	**1.5 X 1.5**	**4**	**7.785**
				3 X 3		**8.672**
Loc-08	**0.90**	**19.193**	**21.326**	**1.5 X 1.5**	**4**	**12.197**
				3 X 3		**14.061**

Based on the parameters obtained from geo-technical and geophysical survey, a subsidence susceptibility map is prepared in 1:2000 scale and area has been categorized as high, moderate and low subsidence susceptible Zone Map is given at **figure 4.**

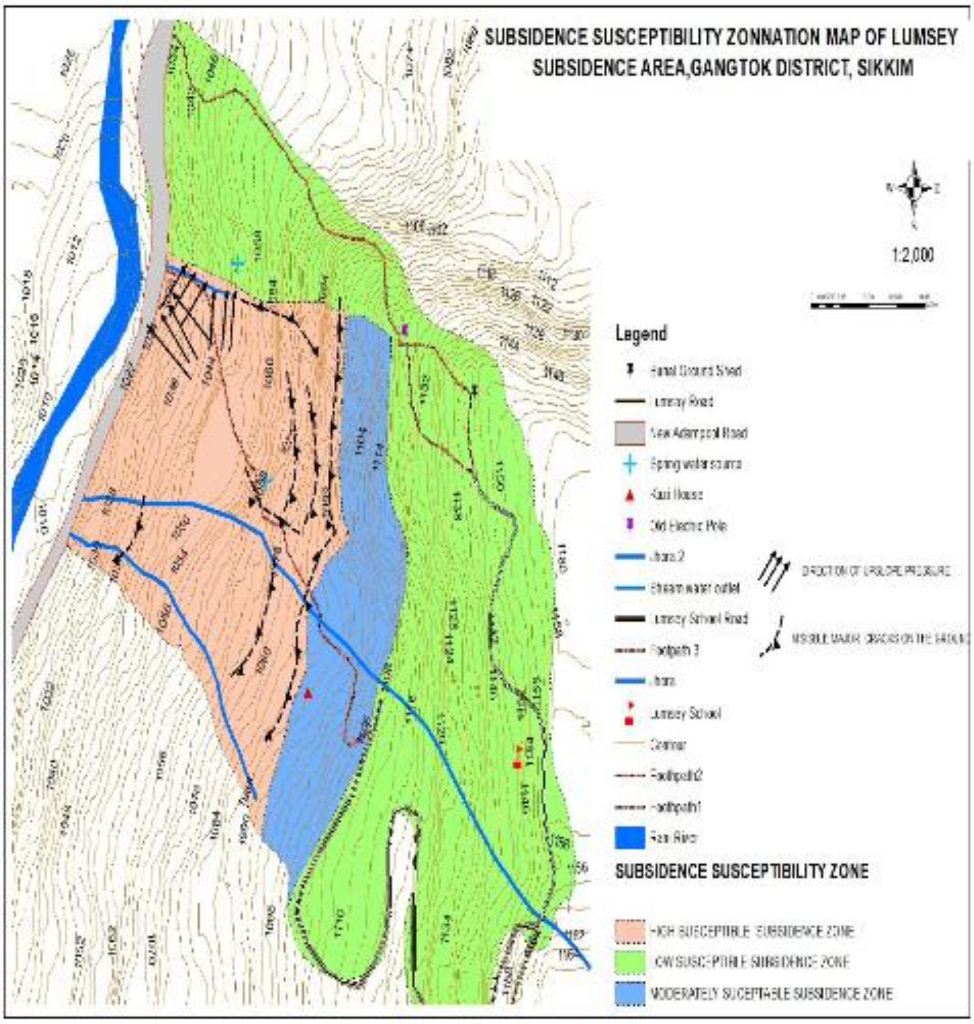


Figure 4: Subsidence Susceptibility Zonation Map of Lumsey Subsidence Zone, Gangtok, Sikkim.

The area is characterized by gentle slope at the base and high slope towards the upslope of the crown of the subsidence zone and accordingly the thickness of overburden materials and water activities impacted the area variably. Therefore probable mitigation measures required in the area were also different. Hence, probable Mitigation Measure Map of the Area was prepared in 1:2000 scale given at **figure 5**.

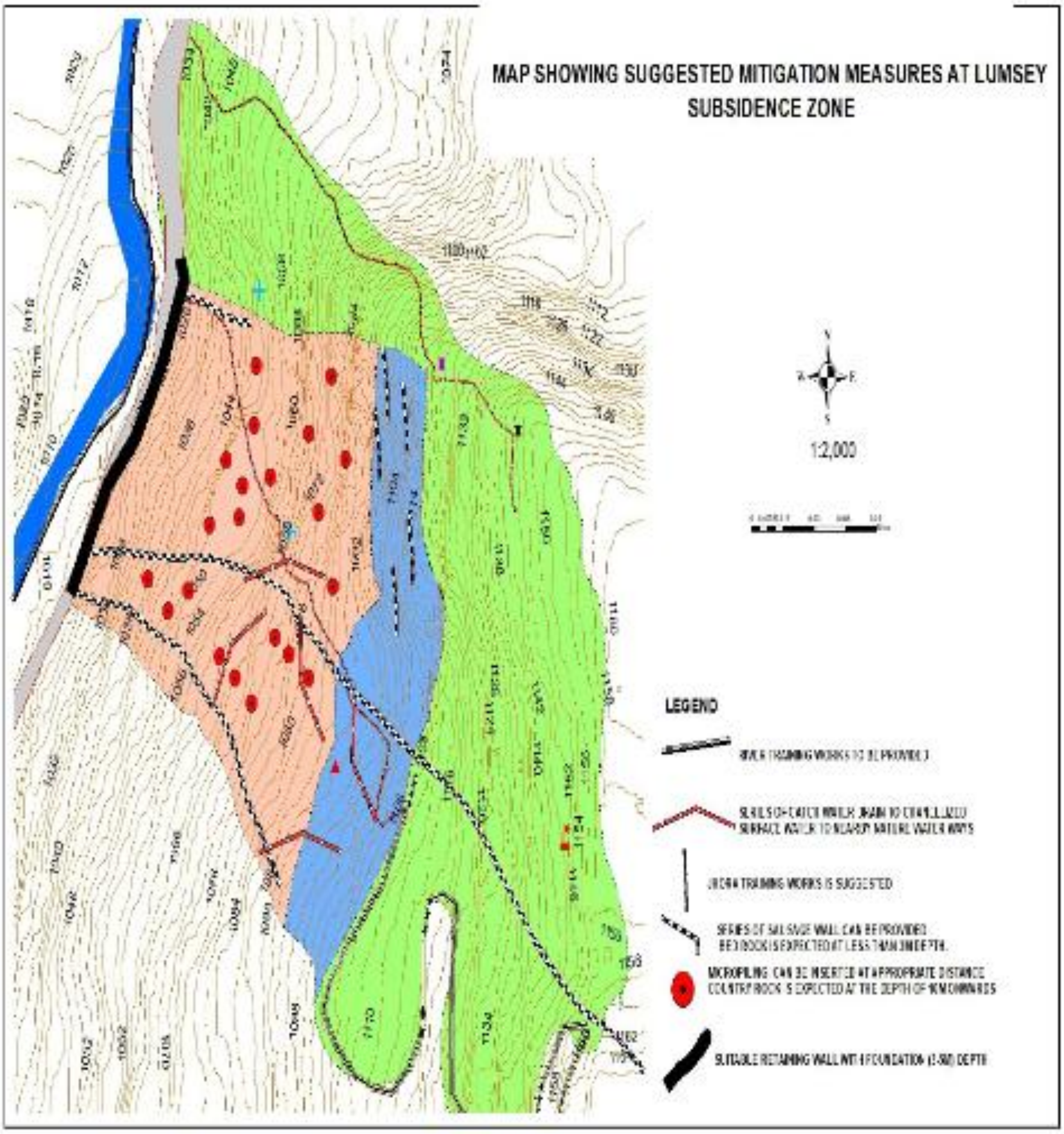


Figure 5: Suggested Mitigation Measures at Lumsey Subsidence Zone, Gangtok, Sikkim.

Results and Analysis of Geophysical Observations:

Multi-electrode resistivity survey with Schlumberger-Wenner array was carried out in profile section, the first electrode is placed at location 0.00 meter of section. Geographically, it is located at N27º 19.615' latitude E88º 35.814' at an elevation of 1074m amsl. The direction of the profile section runs N-S from the first electrode. The last electrode was placed at a distance at 120 meters, it is located at N27º 19.615' latitude E88º 35.814' at an elevation of 1060m amsl, (profile section 05-05'), to delineate probable sub-surface geology. Observation from 2D-inversion resistivity in the profile section 05-05' shows that the top layer consists of soil overburden intermixed with weathered/fractured rock fragments underlain by highly to moderately weathered Garnetiferous mica schist intermixed with gnessic rock with occasional quartz. Further, PS05-PS05' shows highly and moderately saturated zone of soil intermixed with rock fragments exists between 3m-4m, 16m-23m, 30m-33m, 33m-40m and 102m-107m horizontally with variable depths ranging from 0m-11m as seen in the tomography.

Conclusion & Recommendations:

a) The subsidence area at lower Lumsey is characterized by gentle slope at the base followed by moderate slope and steep slope towards crown of the subsidence zone. The thickness of the overburden material/transported loosely compacted overburden materials is greater at the base (10m to 12m in average) followed by 5 to 10m on the middle of the slope and towards the crown of the subsidence area country rock is expected at 3-5m depth.

b) The cause of the subsidence in the area is due to deposition of transported material (loosely compacted) over a moderated slope gradient and charged by high water activities seepage from untrained jhora, spring water, water seepage from sewerage tank and torrential monsoon rain resulted into accelerate the process of subsidence. However, the process of subsidence in the area is observed from the past many years.

c) Geologically, the area is a part of high-grade metamorphic rock sequence represented in the area by gneissic rocks with bands of garnetiferous mica schist with or without quartz veins. The general dip of foliation of bed rock is N35ºE with dip amount 100NE. However, the direction of slope is towards westerly, therefore, geometry of the country rock and slope direction in the area makes the area favourable on stability point of view at the base of the country rock.

d) After analysing the various technical aspects and soil parameter of the area it was observed that the subsidence is due to thickness of overburden material rested over moderate slope gradient and high activities of water in the area. Therefore, proper channelization of water by catch water drains, jhora training works, channelization of spring water, sewerage connectivity is required to stabilize the area followed by soil nailing/compaction by micro piling techniques and some simple retaining structures (sausages wall) can be provided on the area where country rock is at very shallow depth. Area where micro piling is suggested, the strength of the country rock needs to be confirmed by Drilling at two (02) locations prior to the execution of the work.

e) Below subsidence zone, along Adampool Highway, high upslope pressure were observed during the investigation and country rock along the stretch is expected at shallow to 5m depth at maximum. Hence, appropriate retaining structure needs to be provided to cope the upslope pressure with sufficient provision for weep holes for safe passage of water during the rainy seasons so that impact of pore water pressure be minimized to a greater extent. Further, Rani Khola is directly hitting the base of the concerned slope hence; proper river training work is suggested.

f) The thickness of overburden material, depth of rock, subsurface water circulation etc. is given in the individual ERT profile sections tomography. Further, all soil parameters and geological data were provided at the Annexure.

g) The chances of migration of the subsidence area beyond the rock exposure are negligible as the dragging force of the slope will break/ discontinue on the point of bed rock exposures. However area where loosely compacted material exists have greater chances of further damage to settlements, therefore the area demarcated as high subsidence susceptibility zone is not advisable for any kind of construction other than required mitigation measures for slope stabilisation till the area attain fully compaction or ultimate settlement. The area demarcated as medium susceptible subsidence zone can be used for construction activities subject to foundation of the structures to be footed at bed rock only or after detailed geo-technical investigation.

h) Possibility of community based slope stabilization interventions/ measures with bio-restoration will be explored and done.

i) Efficacy of implemented mitigation measures will be measured with the help of sensors and instrumentation for monitoring of slope movement in future.

j) Activities for community level awareness generation and capacity building of line departments will be organized by the SSDMA in collaboration with district authorities (i.e., DDMA's).

ii). Mangan Landslide

a) Location: Lower and upper area of Mangan has experienced a number of landslides in the past The situation becomes bad to worse after jolt of 18th September 2011 earthquake, specially the area along jhoras and old slide zones. The affected area was further devastated by landslide during cloud burst / heavy rainfall between September 19th to 23rd 2012. Protection works provided along Raffong Khola & Rimit Khola was completely washaway and heavy scouring of slopes took place. As a result, slope lying above jhora section got badly damaged and the building along North Sikkim highway is at high risk. The culvert constructed over Raffong Khola was washed away by slush & debris carried by heavy discharge during the year 2016.The area above Mangan remained cut-off almost for few weeks. Mangan town is the district headquarter of North Sikkim, located at 27.52°N 88.53°E, on the left bank of the Teesta river valley. As of 2011 India census, Mangan had a population of 4644. Males constitute 55% of the population and females 45%.

b) Area & Past Incidences: Lower and upper area of Mangan has experienced a number of landslides in the past. The situation becomes bad to worse after jolt of 18th September 2011 earthquake, specially the area along jhoras and old slide zones. The affected area was devastated by landslides during cloud burst / heavy rainfall between 19th to 23rd September, 2012. Mangan town in north Sikkim is particularly affected by several major slides. Some of the site-specific causative factors responsible for this phenomenon are given below:

- Mangan Town area is bounded by Raffong Khola in North & Ramet Kyong khola in south, which is delineated as high & very high hazard zone. It is a very unstable zone.
- The MCT is passing by close vicinity of the Mangan Town; hence entire area is under high stress and seismic activities.
- Present landslides represent reactivation of the older landslides and their shape/size is gradually increasing after monsoon rains.
- Soil of Mangan Town area has moderate absorbing capacity and bed rock in this area shows low compressive strength and normal moisture absorption capacity.
- Landslide and sinking zones are more prominent on either side of the Raffong Khola and Ramet Kyong khola.
- During the site visit it has been observed that continuous water ingress through joint plane, removal of soft strata and presence of structural discontinuity.
- Physical factors Like heavy rainfall, Debris torrential, massive infiltrated rainwater in the upper slope of the slide areas will seep downwards and accumulate to raise the ground water level and it alternatively increase the pore-water pressure on the potential sliding body.
- Anthropogenic activities such as mining, deforestation and excavation makes the area vulnerable for sinking and landslides.
- Human Activities construction of high-rise buildings houses, movement of heavy vehicles/loading on the week hill slopes etc.
- Inadequate, lack of proper drainage system and choking of existing drains.
- The worst affected area is towards South East of the SNT complex adjacent to Raffong Khola.

c) Geology and Geomorphology: Geological factors - Weak zones, Sensitive and sheared materials, presence of fissures, joints, contact in permeability or stiffness of the slope forming material.

d) Geomorphology: Morphological factors - Such as tectonic uplift, glacial rebound & erosion of the hill slope or toe etc.

e). Past Initiatives & Prevailing Conditions: Under Landslide Risk Mitigation Scheme (LRMS) project, mitigation of landslide of Mangan was initiated as per DPR submitted but the protection works of micro piles provided at toe of landslide was damaged during heavy rainfall of **13th July, 2023**. As a result, mitigation work completed under LRMS project is vulnerable. The most immediate measures is to provide treatment of jhoras training works to reduce risk of toe cutting due to heavy rainfall. The total cost of previous mitigation work done at Mangan landslide under LRMS was Rs. 18,75,92,412 with the support of funding support provided by the NDMA and the Sikkim Government.

Works done previously under LRMS project:

- Scaling and dressing of loose material in soft rock and hard rock.
- Micro pile with cashing driving method i/c supply of ERW MS casing 273 mm (OD) × 8mm thickness.
- Supply, binding and installation of reinforced into the pile and RCC pile cap. RCC pile Caps M25 grade.
- 25R 25 N self drilling anchors 6M long 3M c/c complete in all respects.
- 38 MM dia 6M long pressure relief holes i/c installation of PVC perforated pipe with membrane.
- Shotcrete M25 with wire mesh.
- Consolidation grouting and SDA grouting.

- Catch drain/ drainage system, pits, box culverts, RR stone masonry and concrete drains.

f) Following works to be completed as recommended by NDMA team visited Sikkim on 16th Feb., 2023:

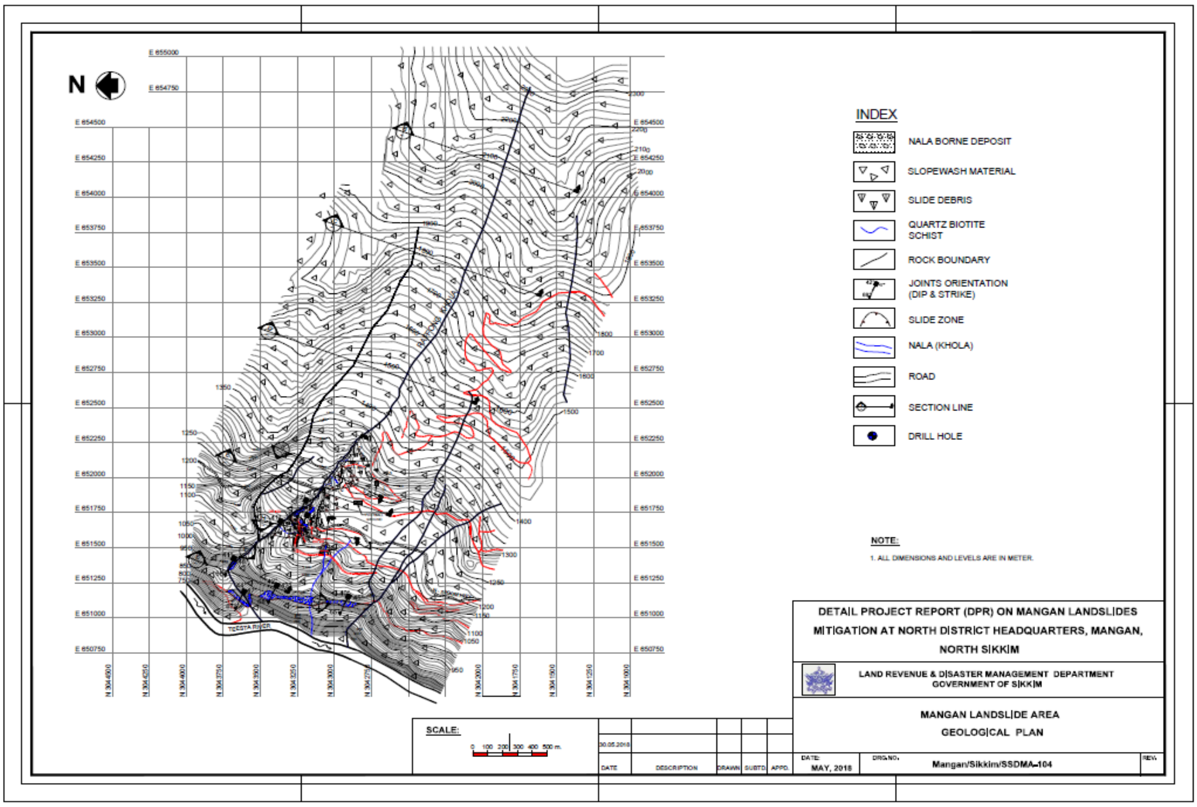
- "In place instrumentation" rather than conventional probes and sounders used in this project is more practical, especially if instrumentation is planned in multiple landslides.
- The instrumentation being placed should be augmented by reflectors which can be monitored by total station. Reflectors and total stations can be used to augment the monitoring system already in place.
- It was observed that putting cement plaster on the coir matting on the area above top row was redundant as coir mat was sufficient protection against erosion.
- Members suggested bio-remediation rather than shotcreting for 30m × 30m unprotected area between second and third row.
- It was also suggested that cropping be started in the private land between third and fourth row for erosion protection.
- Various forms of bio-remediation were suggested for the 30m × 30m patch as a cheap and effective alternative to shotcreting.
- Piles can be used along the river banks to provide a stable foundation for gabion walls. Alternatively, gabion walls can be founded/anchored to rocks if available at a shallow depth.
- Jhoras training works will be done as per site condition and feasibility of mitigation measures. Provision of community based intervention for Jhoras training works will also be explored.

Figure 7: Mangan Landslide (Lat 27°30'11.86"N, Long 88°32'7.39"E)

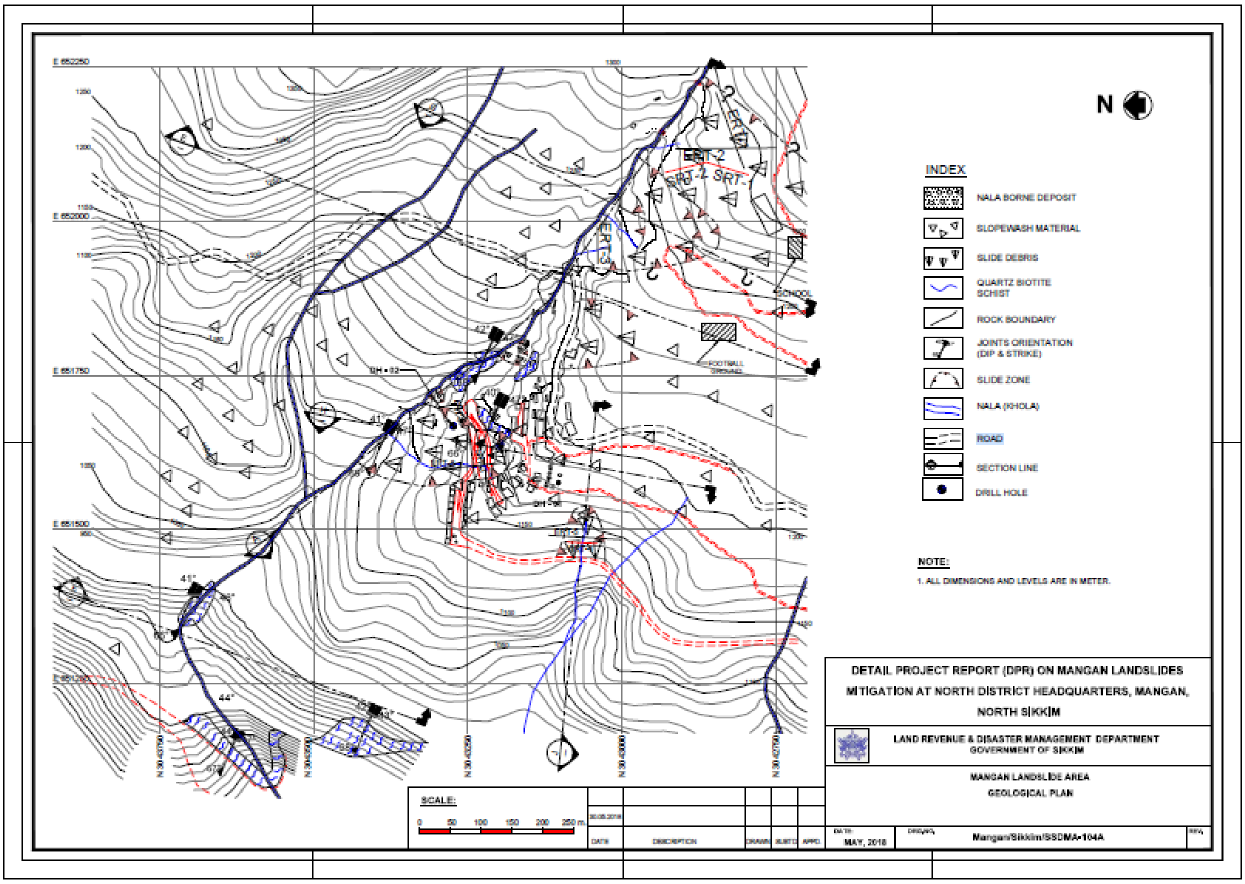
Photo Plate 6: Raffong Khola along Mangan Landslide

Photo Plate 7: Treatment of Mangan landslide completed under LRMS project of NDMA & SSDMA.

Photo Plate 8: Visit of NDMA Team at Mangan, Sikkim on 16th Feb., 2023

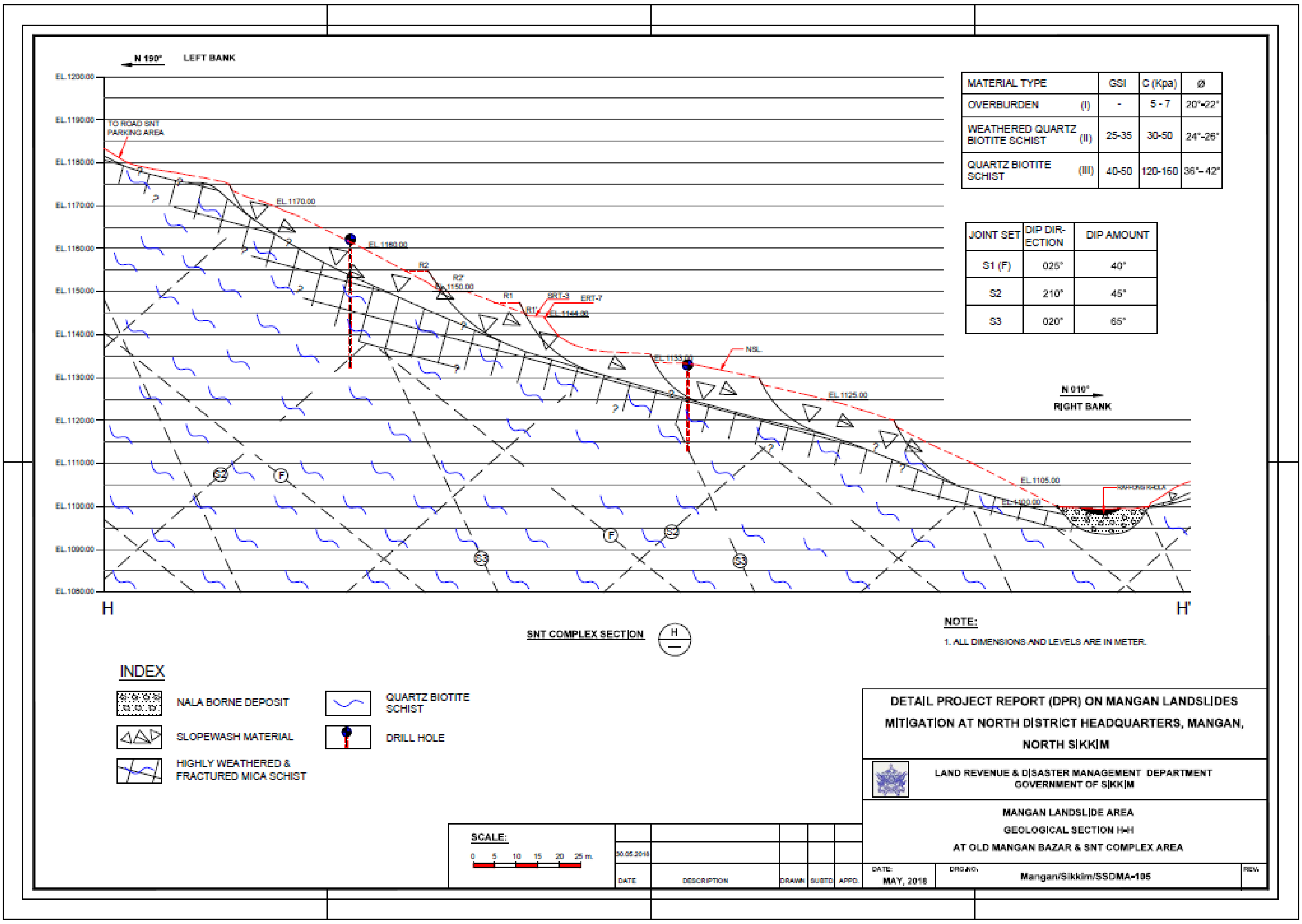


(a)

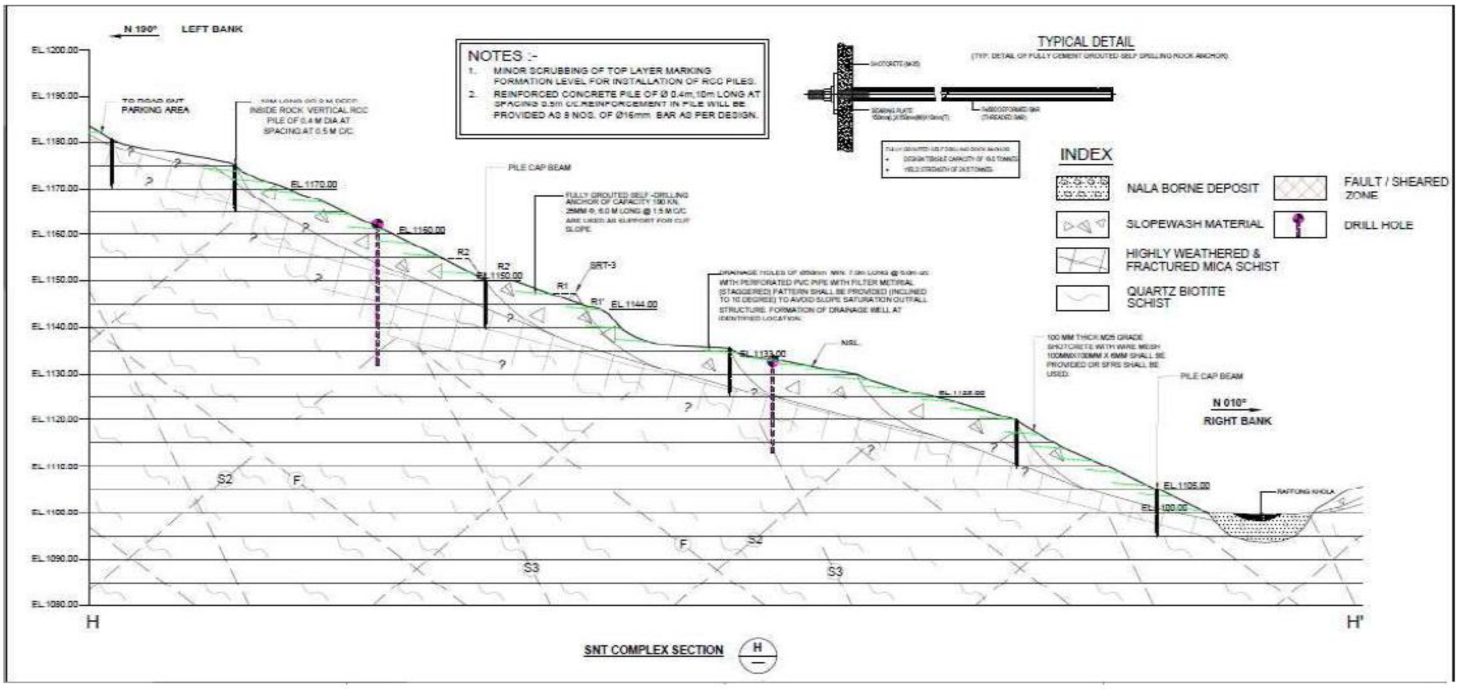


(b)

Geological Plan (a) & (b) of Mangan Landslide



Geological Section at Old Mangan Bazar & SNT Complex Area



Profile of landslide area

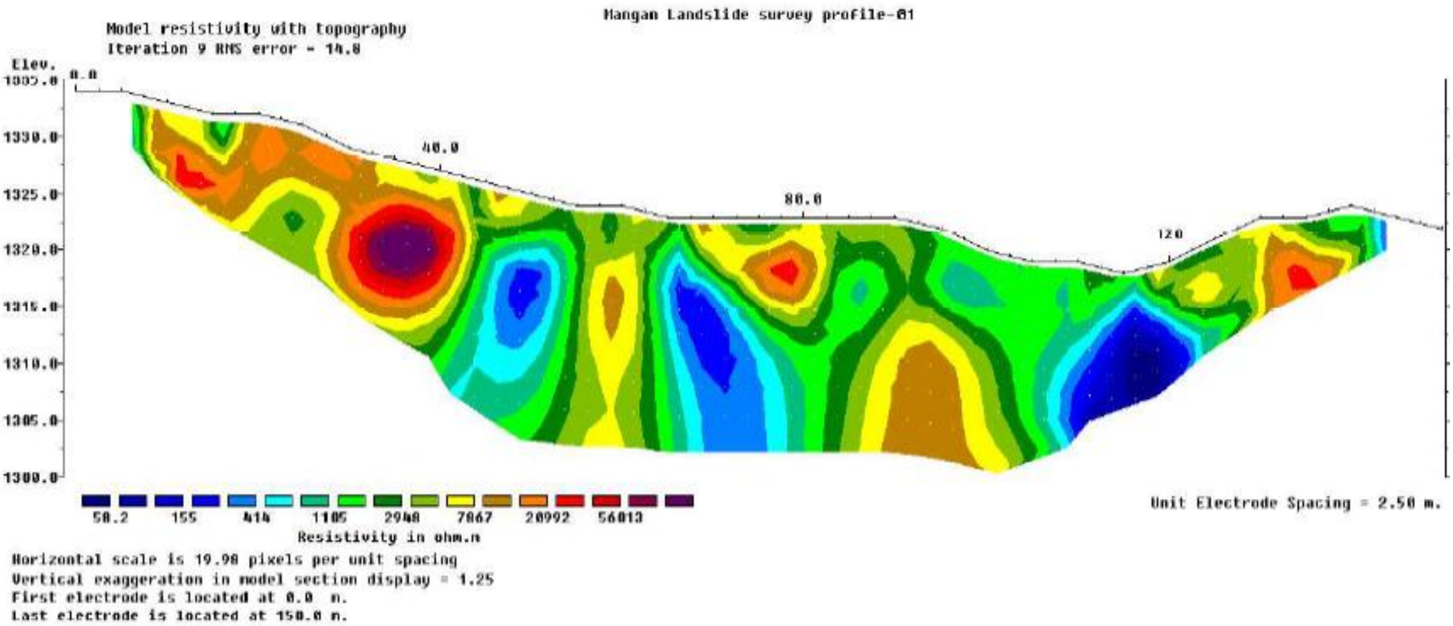


Fig: Electrical resistivity Tomography of Profile section–01 near Mangan Sr. Sec. School, North Sikkim

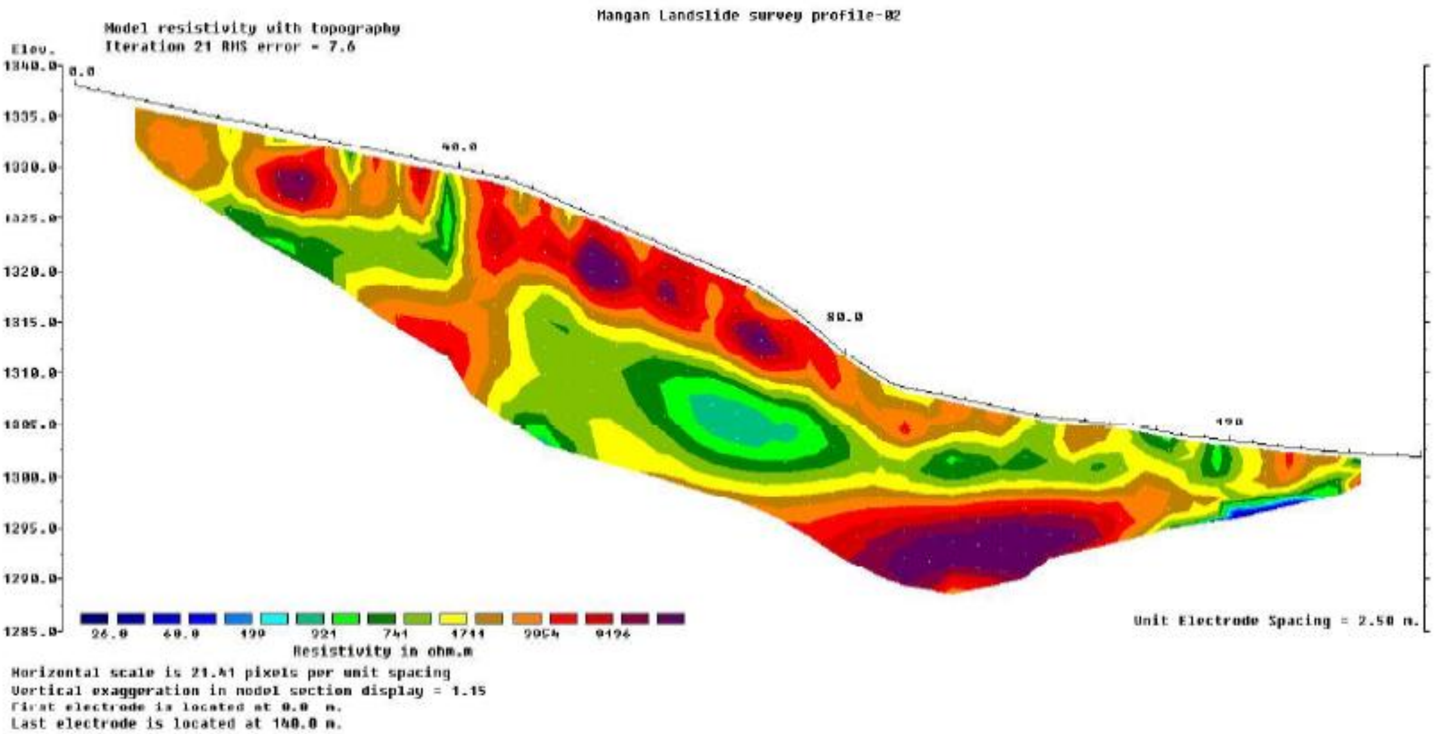


Fig: Electrical resistivity Tomography of Profile section–01 near Mangan Sr. Sec. School, North Sikkim

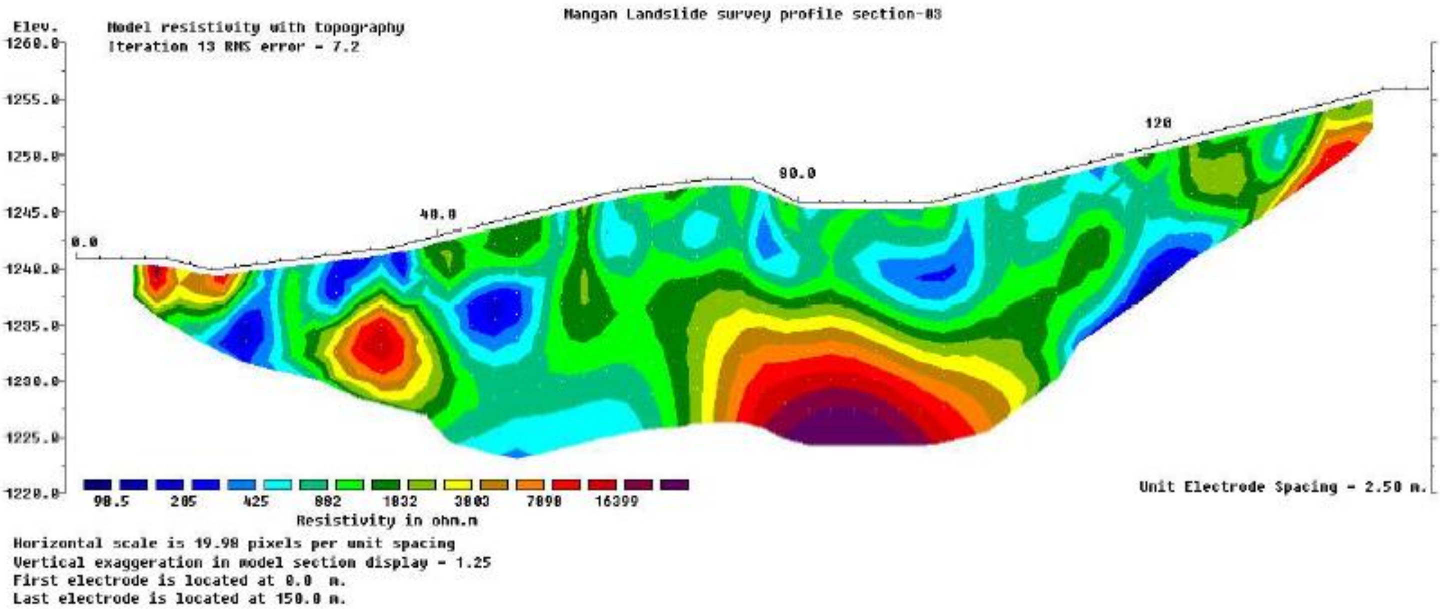
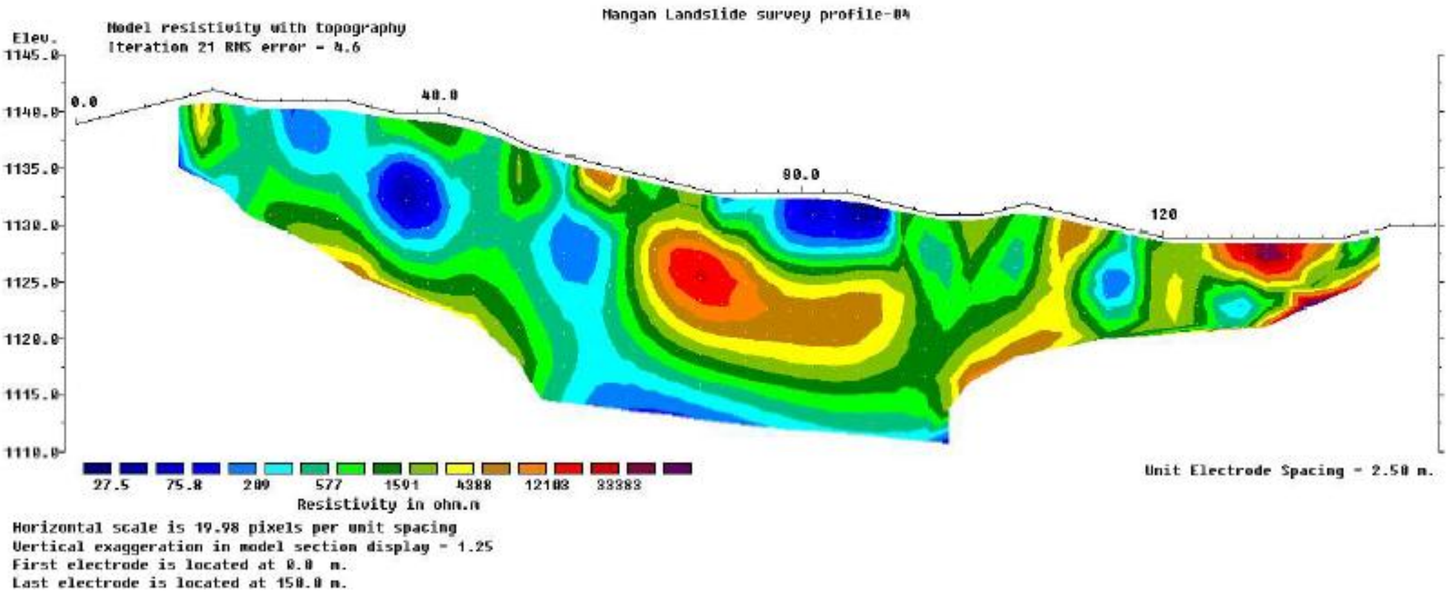
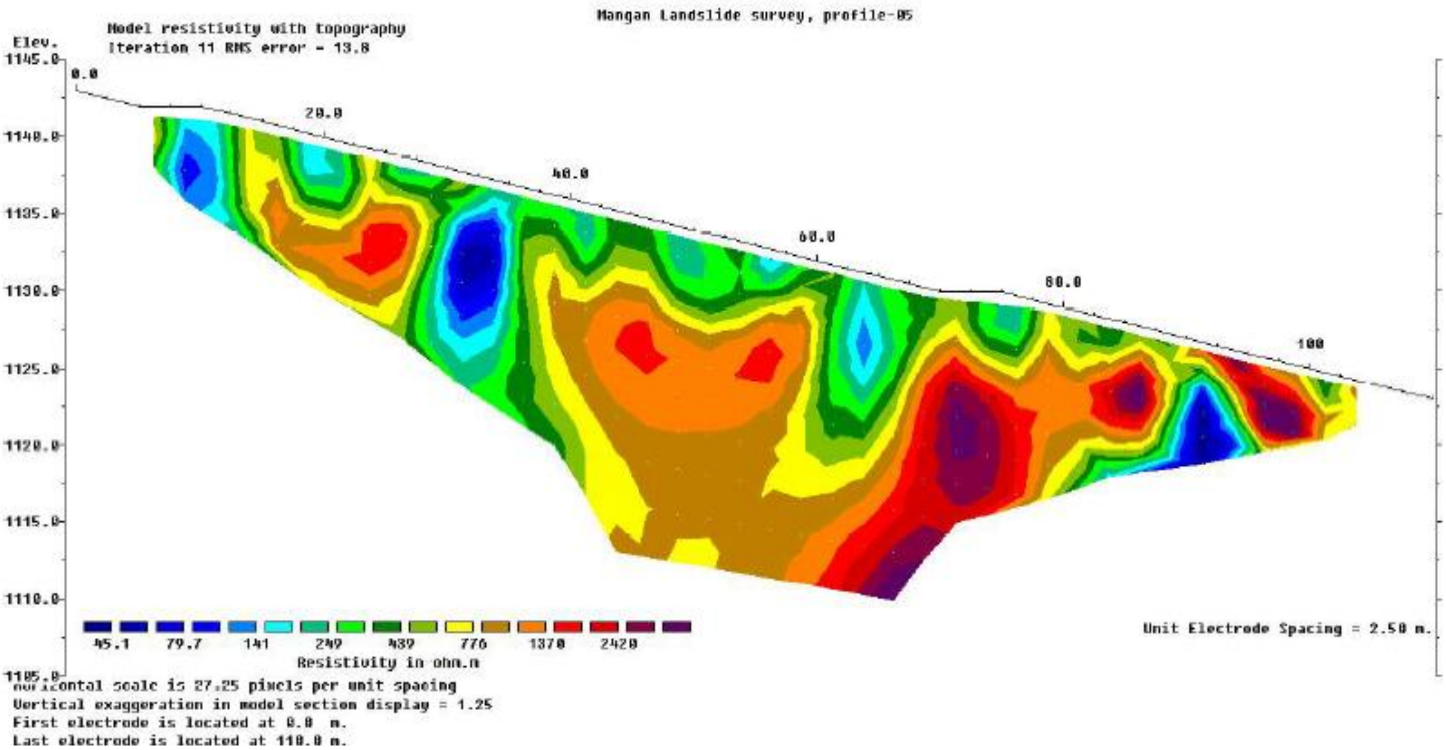


Fig: Electrical resistivity Tomography of profile section-03 near proposed administrative block



(a)



(b)

Fig: Electrical resistivity Tomography (a) & (b) of profile section-04 & 05 near SNT colony

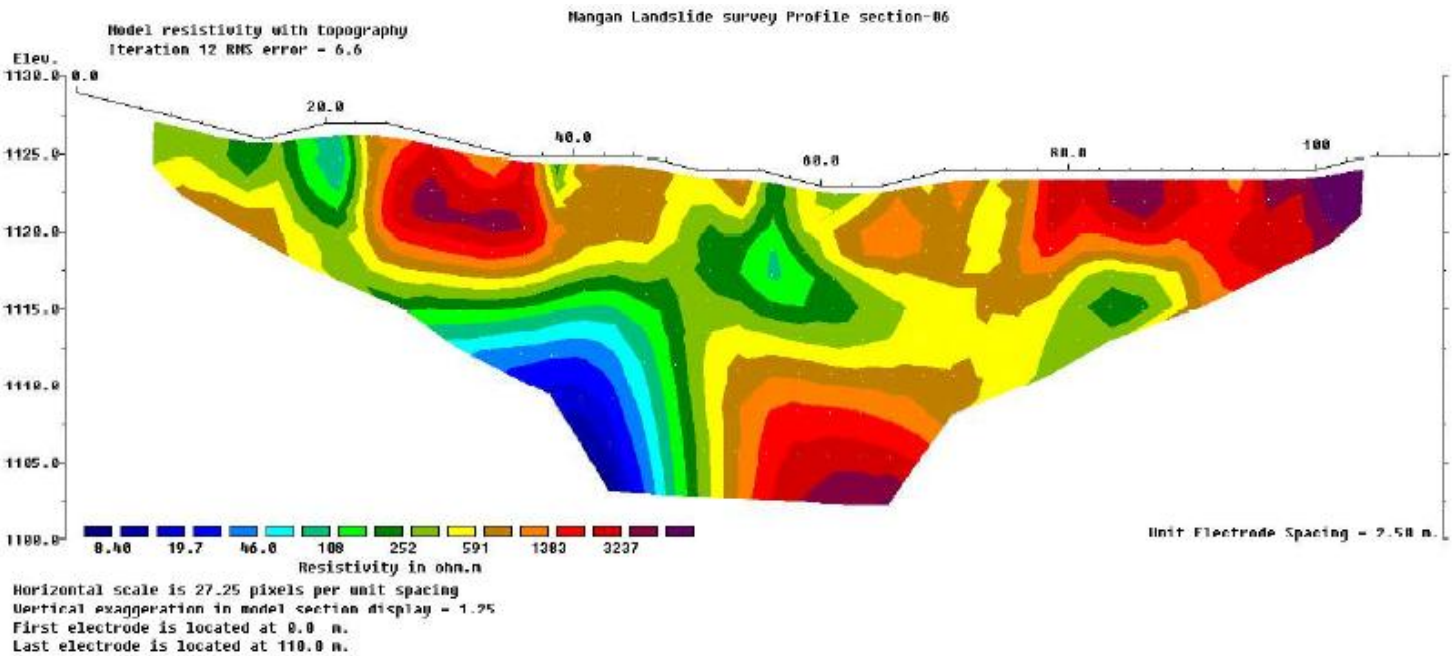


Fig: Electrical resistivity Tomography of profile section-06 below Parking Stand, Mangan Bazar

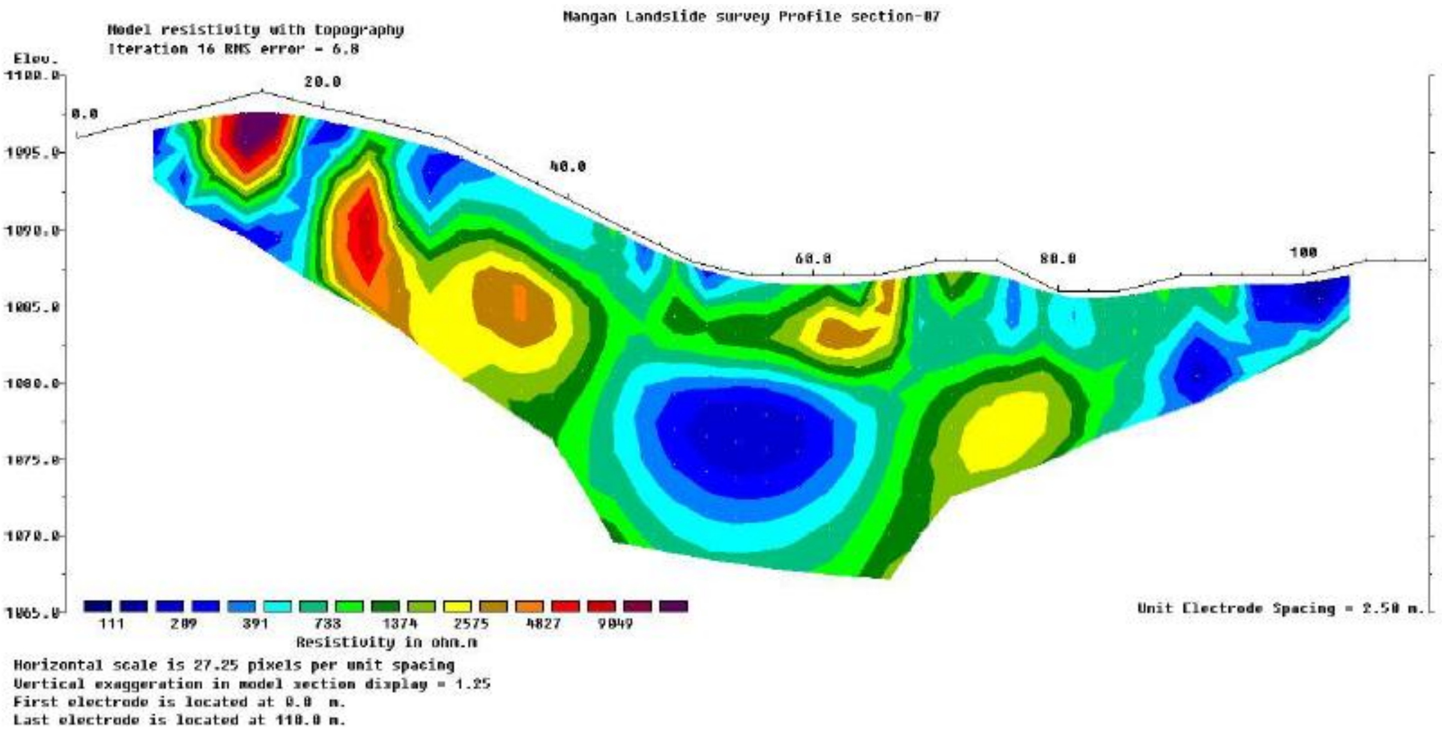
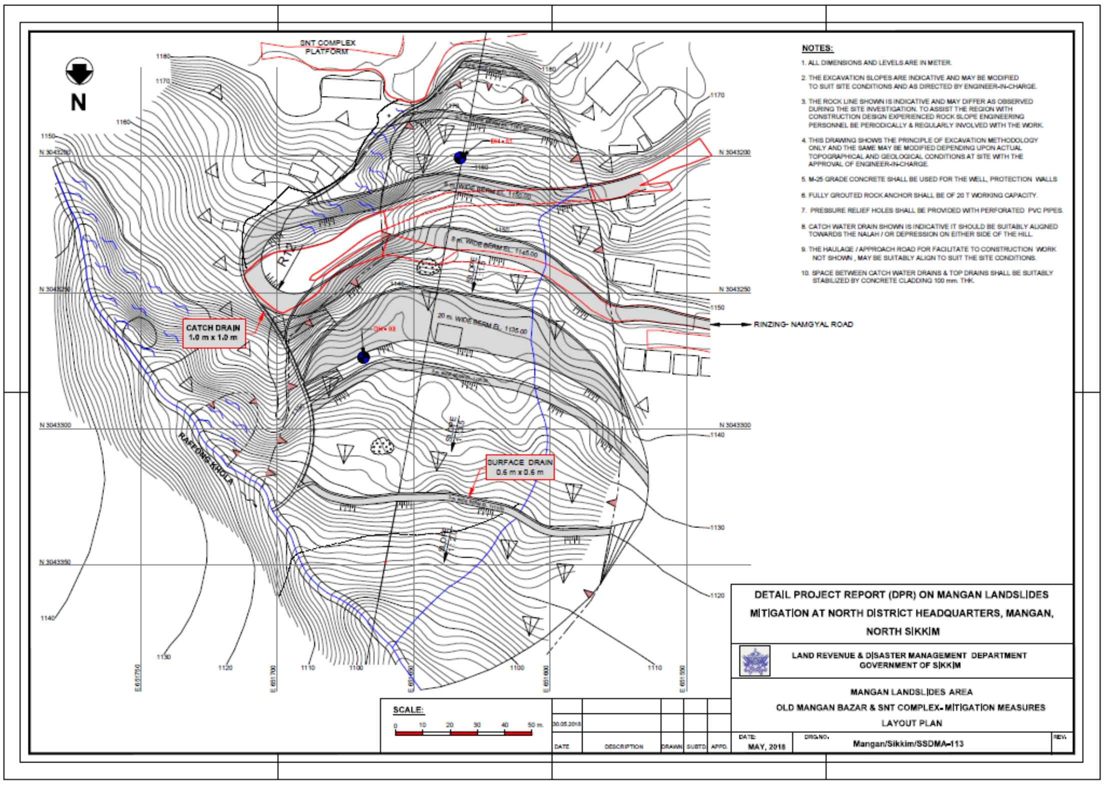


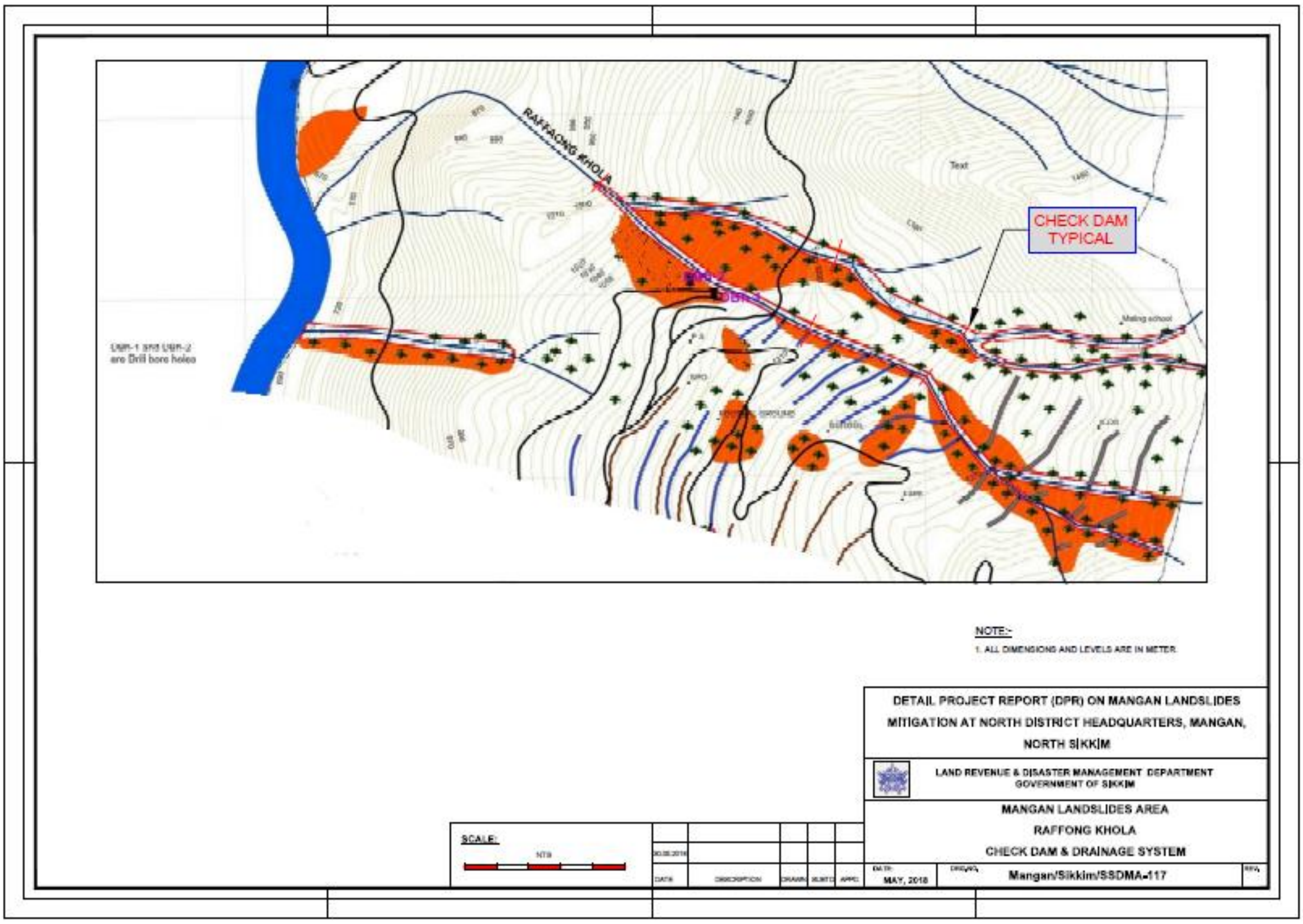
Fig: Electrical resistivity Tomography of profile section-07 adjacent to construction Himgiri quarters at Adarsh Gaon

RESULTS AND ANALYSIS OF GEOPHYSICAL OBSERVATIONS:

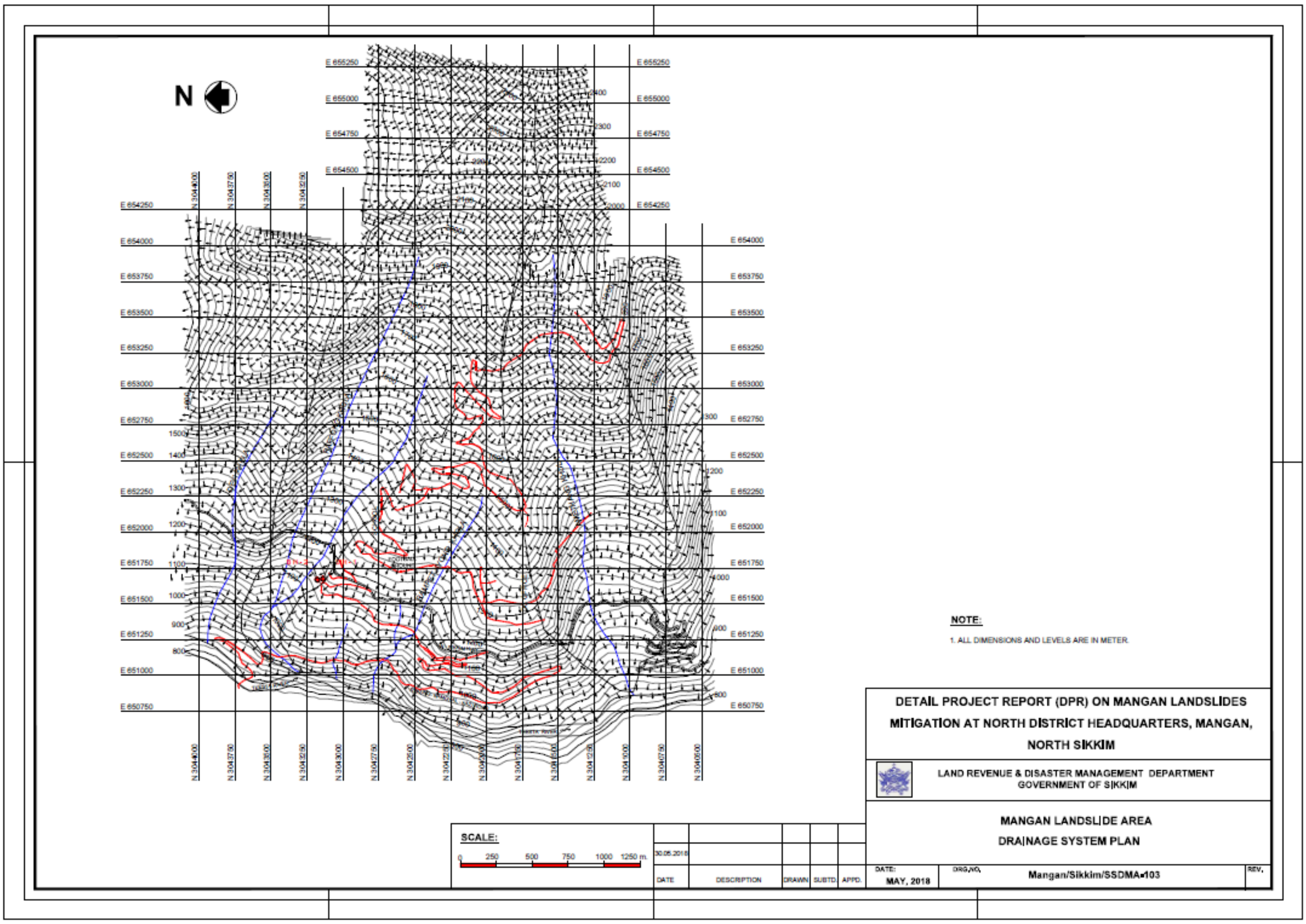
The study area is geologically characterized by three primary rock types: Quartz-biotite schist, Biotite schist, and Garnetiferous mica schist. These formations are prominently exposed along nala sections, road cuttings, and ridges, with a general NW–SE strike and dips ranging from 30° to 50° towards the northeast. Two major joint sets, in addition to the foliation planes, have been identified. Mica schist units, due to their susceptibility to surface and subsurface water infiltration, are highly prone to weathering. This has led to the development of gentle slopes and gullies, especially in areas such as Mangan School, Raffong Khola nala section, the Goskhan playground, and lower Mangan, where intense weathering and ground activity are prevalent. The region is predominantly underlain by a medium-thick, matured or transported soil cover mixed with rock fragments, overlying a low-grade metamorphic sequence comprising quartz-chloritic-sericitic phyllites and mica schist. High groundwater movement is evident, as indicated by numerous streams, Jhoras, tilted trees, and road subsidence. Additionally, the presence of Raffong Khola to the north contributes to toe erosion. As a result, the area is classified as a slow-moving landslide zone, driven primarily by groundwater dynamics and slope instability exacerbated by erosional processes.



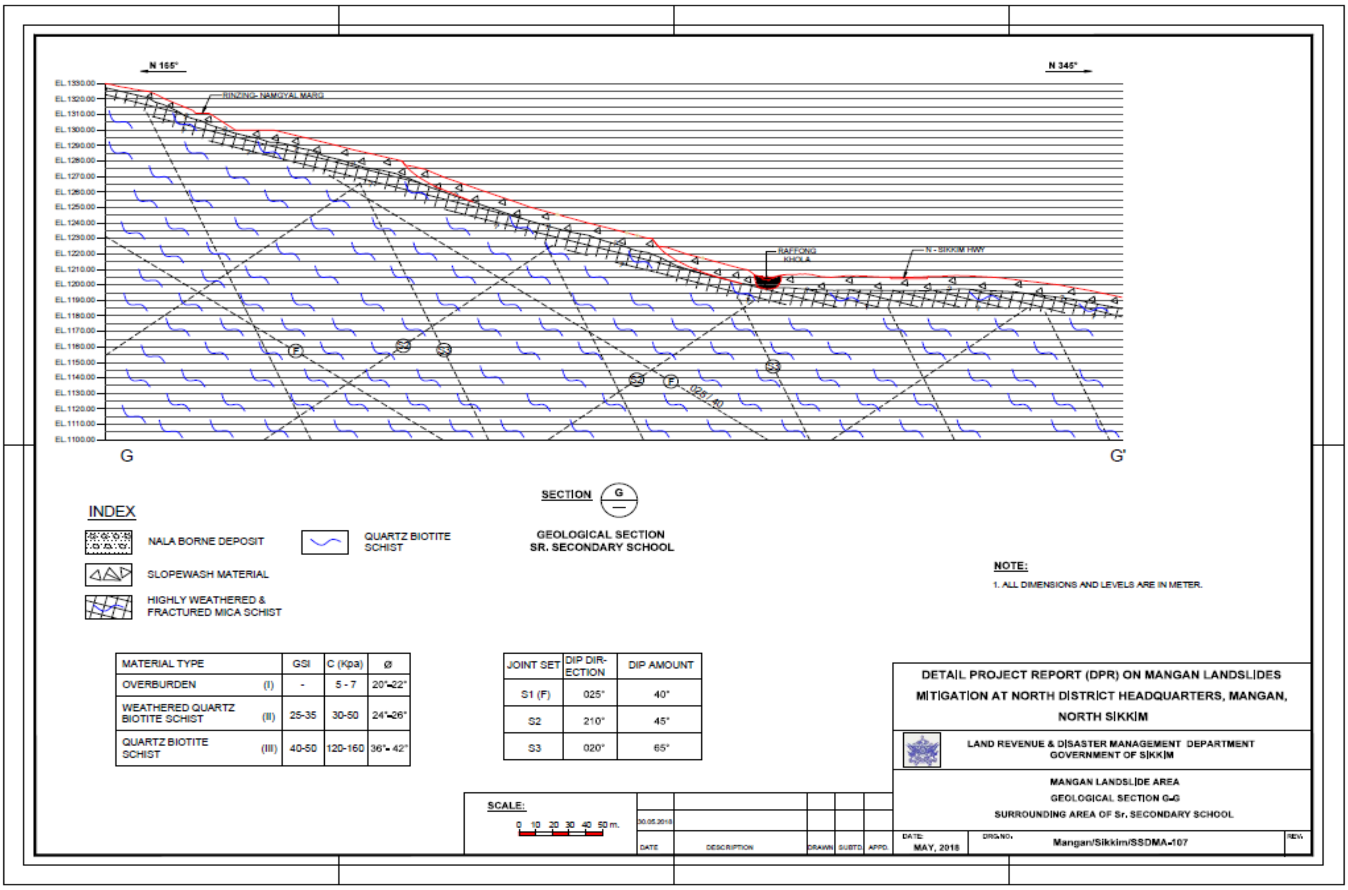
Mitigation measures implemented under LRMS project of NDMA



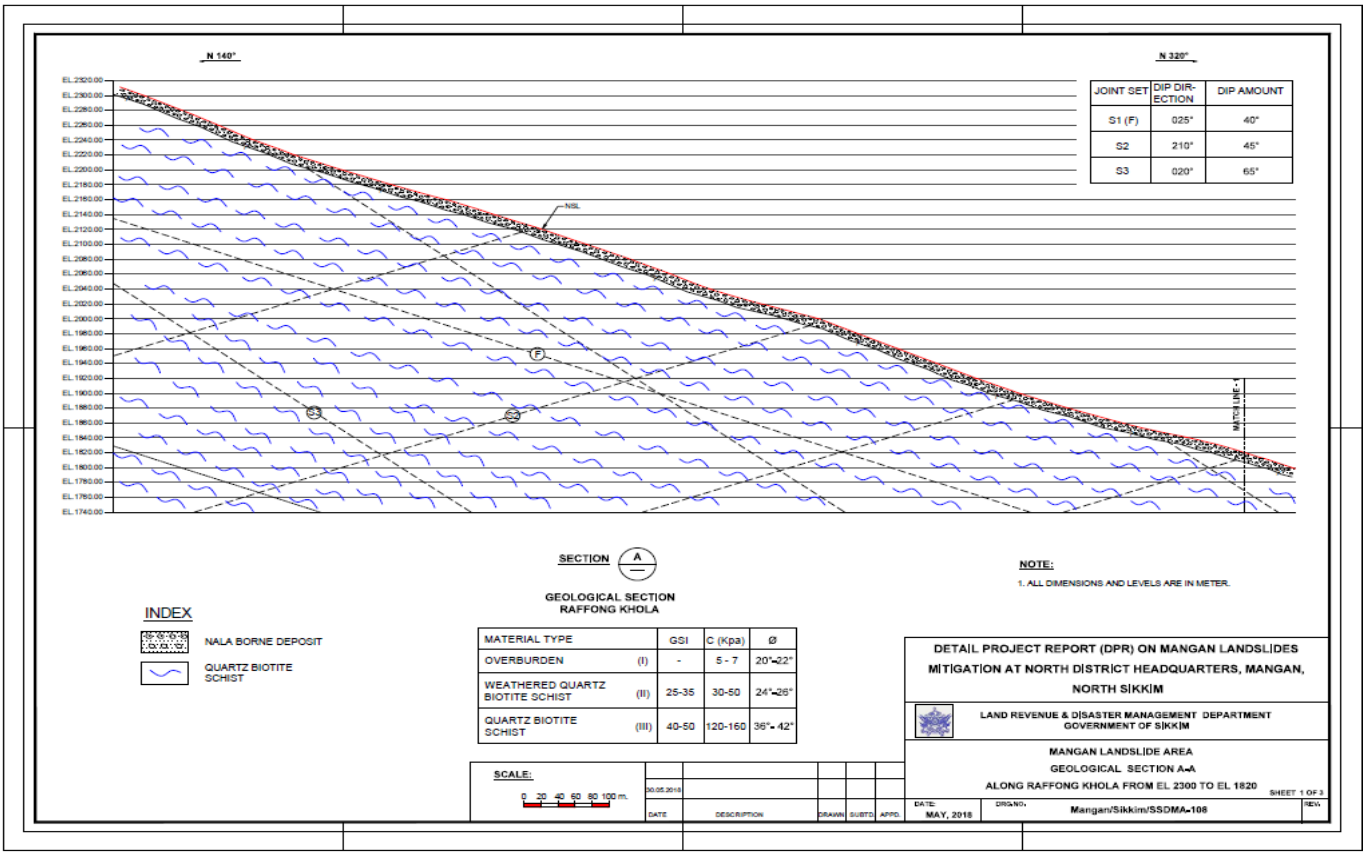
Raffong Khola Check Dam & Drainage System



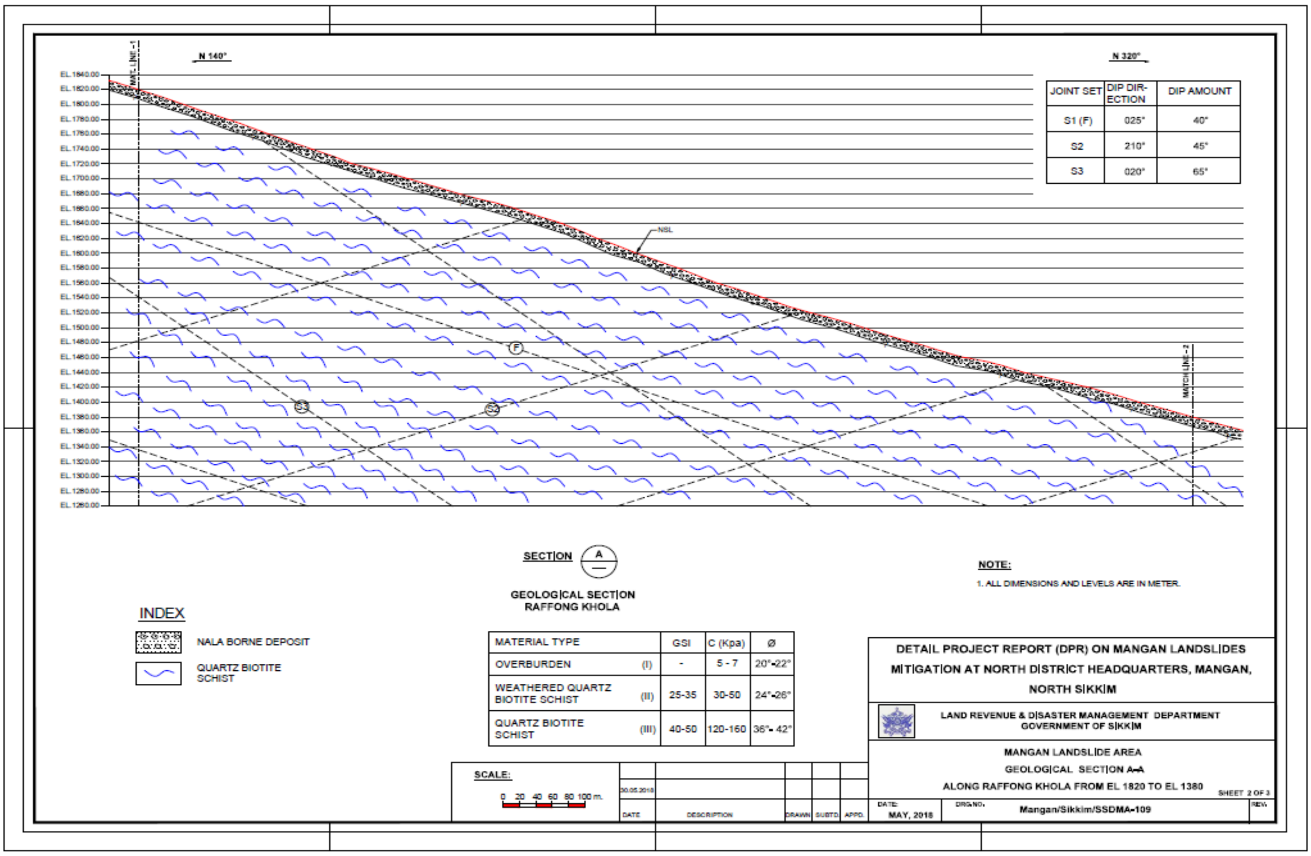
Drainage System Plan of Mangan Landslide Area



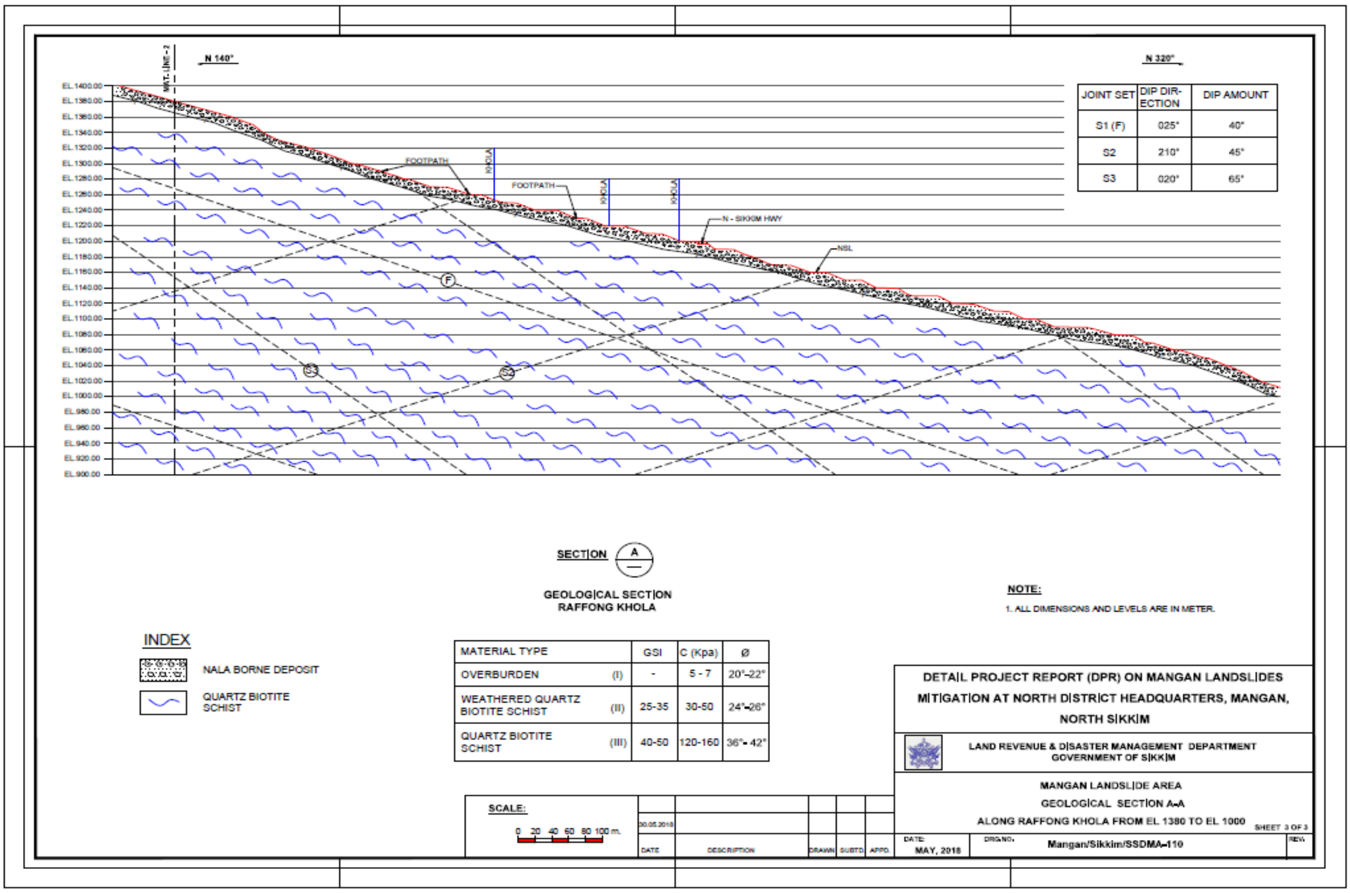
Geological Section of Surrounding Area of Sr. Secondary School



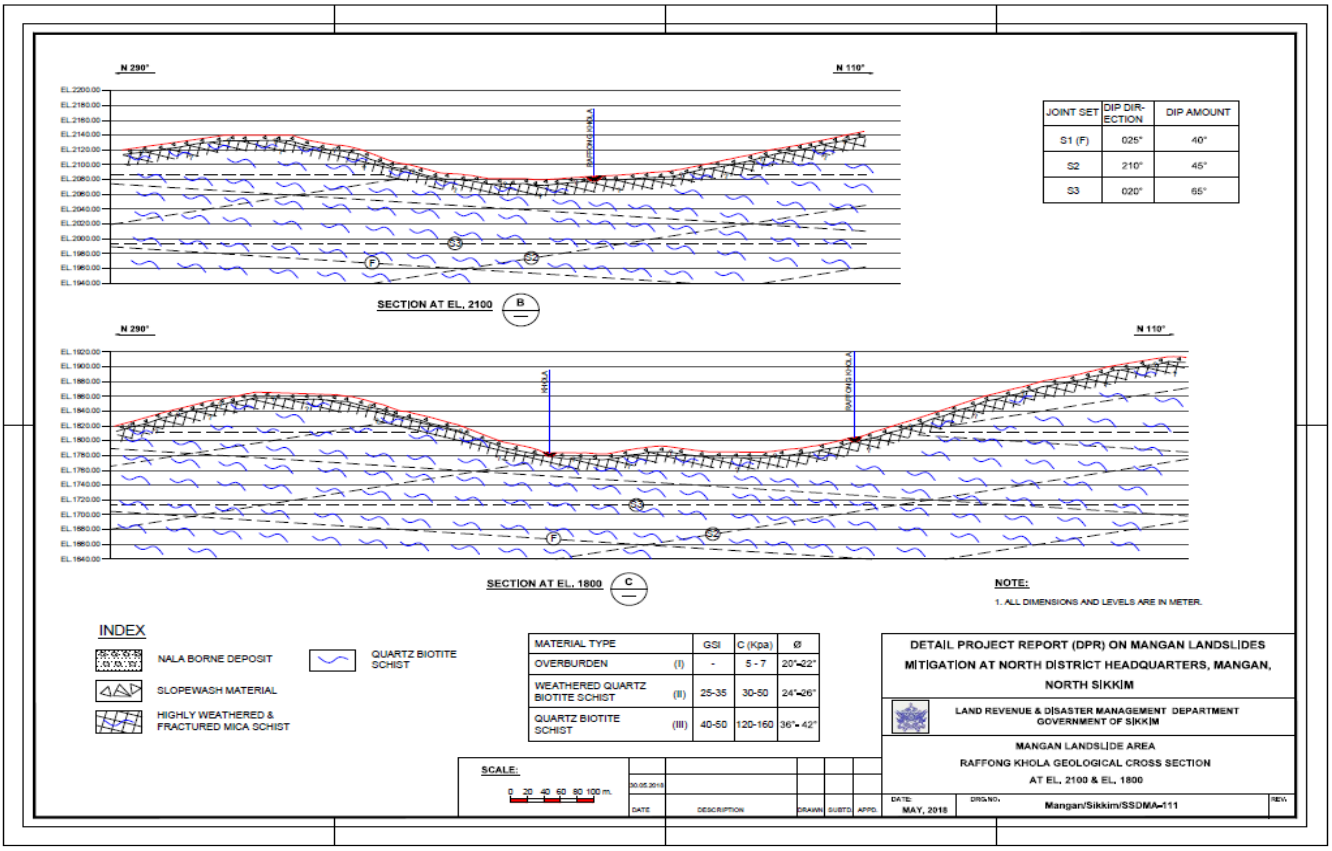
Geological Section of Raffong Khola from EL. 2300 to EL. 1820



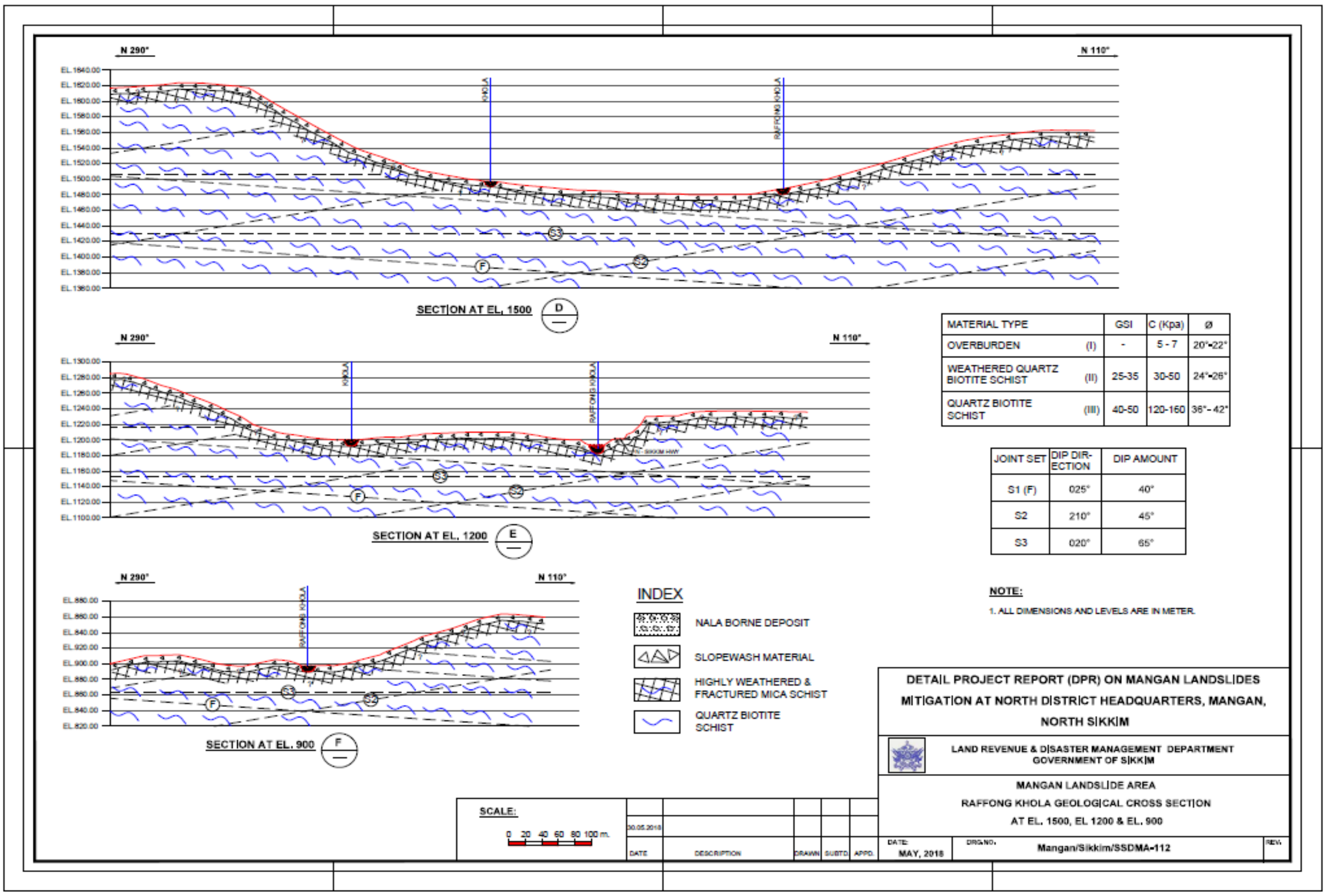
Geological Section of Raffong Khola from EL. 1820 to EL. 1380



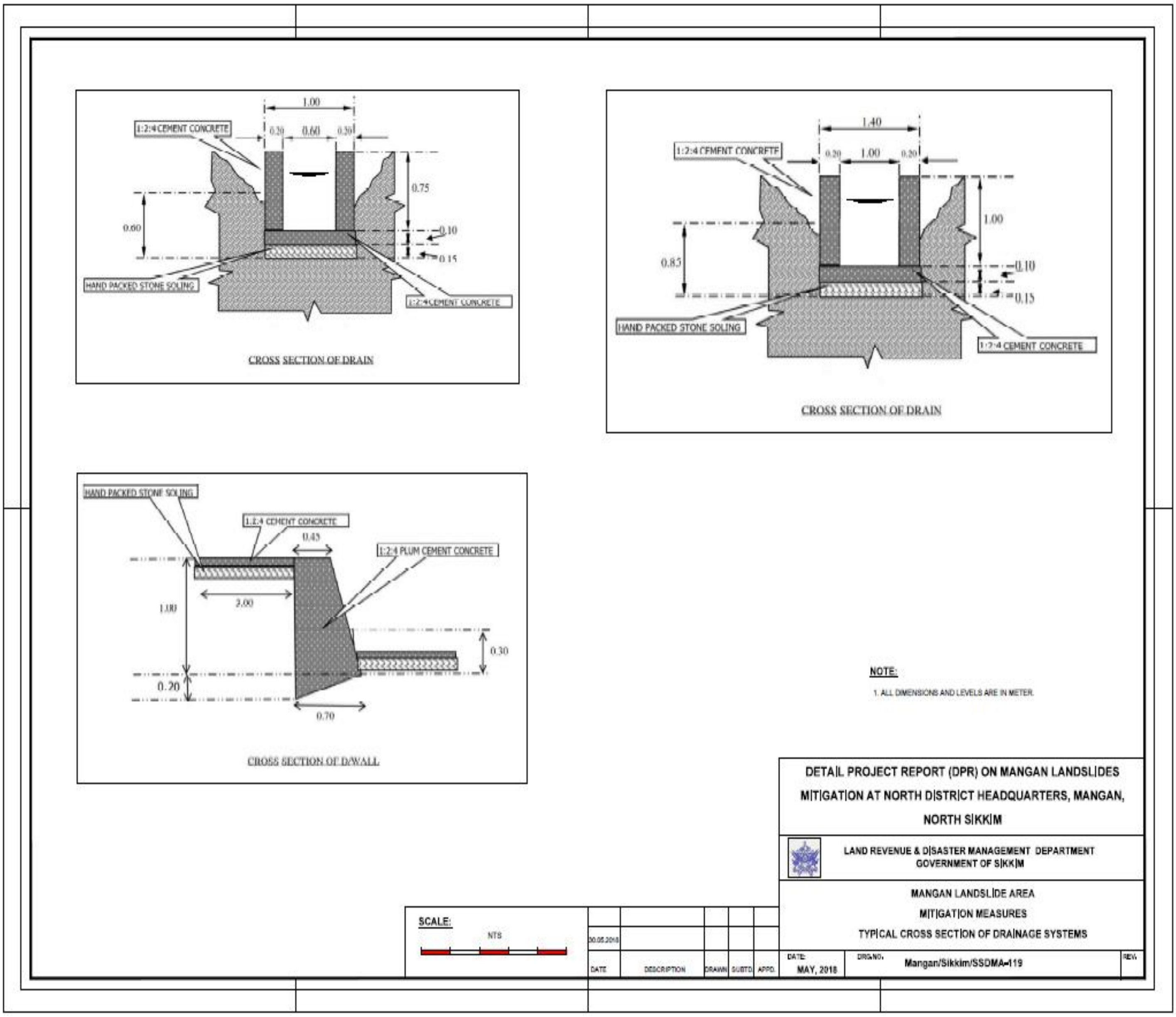
Geological Section of Raffong Khola from EL. 1380 to EL 1000



Geological Cross Section of Raffong Khola at EL. 2100 & EL. 1800



Geological Cross Section of Raffong Khola at EL. 1500, EL. 1200 & EL. 900



Cross Section of Drainage Systems at Mangan Landslide

Tentative Mitigation Measures Proposed for the Two Sites as Listed Below				
Site Name	**Retaining Structure**	**Drainage Corrections/ Jhora Training**	**Slope Reinforcement**	**Bio-Engineering Measures**
Lumsey, Gangtok	√	√	√	√
Mangan	√	√	√	√

Following are the project sites and components to be covered in this project are given in the Table 1 as under:-

Table 1: Proposed project sites.

SN	District Name	Name of Site	Type of work/ components	Number of sites/ programmes
1	Gangtok & Mangan	1.Gangtok GMC Area 2. Mangan District	**Risk Assessment** **i)** Multi-Hazard Risk Vulnerability Assessment (m-HRVA) on meso-scale (1:10,000 or 1:5,000) **ii)** GIS based slope information system and landslides inventory is to be carried out for Gangtok, and Mangan. **iii)** Geo-technical investigation of vulnerable existing lifeline buildings (school & PHCs)	2
2.	Gangtok & Mangan		**Landslide monitoring and EWS** **i)** Sensor Based landslide monitoring and Early Warning System **ii)** Community based early warning and dissemination system	Vulnerable sites
3.	Gangtok District	Lumsey Landslide	**A) Slope Stabilization** **i)** Site-Specific Mitigation of Lumsey Subsidence Zone, Gangtok District, Sikkim **ii)** Community Based Slope Stabilization by Local Interventions **iii)** Bio Restoration and Bio-engineering Measures **B) Landslide instrumentation and monitoring –** Efficacy of landslide mitigation will be monitored by installation of sensors	District Level 1 site
	Mangan District	Mangan Landslide	**A) Slope Stabilization** **i)** Site specific structural measures in the toe-portion of landslide with Jhora training and treatment works. **ii)** Community Based Slope Stabilization along Jhoras by Local Interventions **iii)** Bio Restoration and Bio-engineering Measures **B) Landslide instrumentation and monitoring –** Efficacy of landslide mitigation will be monitored by installation of sensors	1 site
4.	All districts		**A) Awareness Generation & Capacity Building** **i)** Awareness generation and sensitization programme **ii)** Training of Engineers and geologist as master Trainers 50 Nos. by 10 training programmes in collaboration with Sikkim Manipal Institute of Technology (SMIT) **iii)** Training to local community at vulnerable landslide prone areas of 6 districts of Sikkim by DDMAs	6 districts (6 programmes) 10 programmes 6 sites (6 programmes)

5.	All Districts/ Expert Institutions	All districts/ Expert Institutions (National / State Level)	**e) Research & Development (Small Grant Window)** 1. Project proposal with local knowledge and best practices will be funded	-

3. Risk Assessment:

Sikkim is affected by multi-hazards such as landslide, earthquake, GLOF, flood/ flash floods, snow avalanches, drought, fire etc. therefore, it is important to carried out a Multi-Hazard Risk Vulnerability Assessment (m-HRVA) of highly vulnerable areas of Gangtok and Mangan districts. The Sikkim SDMA has previously carried out the m-HRVA in small scale (**i.e.,** 1:50,000), whereas now it is proposed to carry out the m-HRVA in meso-scale (i.e., 1:10,000 or 1:5000).

The Multi-Hazards Risk and Vulnerability Assessment (m-HRVA) plays a critical role in identifying and evaluating the potential risks posed by various hazards, particularly in regions like Sikkim, which are prone to landslides, seismicity, flash floods, extreme weather events etc. As part of this, a GIS-based slope information system platform will be developed to analyze terrain stability and support better land-use planning. In addition, a detailed landslide inventory of Sikkim has been prepared, providing spatial documentation of past landslide events to aid in hazard zoning and early warning systems. Complementing these efforts, geo-technical investigations are being conducted on vulnerable lifeline buildings to assess their structural integrity from a slope instability perspective, ensuring the safety and resilience of essential infrastructure against future landslides threats.

Objectives of Multi Hazard Risk and Vulnerability Assessment (m-HRVA)

The objective of m-HRVA is to help a community and make risk-based choices to address vulnerabilities, mitigate hazards and prepare for mitigation, response and recovery from hazard events. The objective of the mHRVA is to:
1. Investigate prominent natural and human-caused events.
2. Identify the various hazards affecting the area and hazards likely to occur in Sikkim.
3. Identify any threats that may require a timely and coordinated response to protect lives, property, and to reduce economic losses.
4. Evaluation of the effectiveness of the mitigation and emergency plans and implementation of training activities such as simulation, seminars and workshops.

mHRVA will be designed to provide an assessment of the hazards that may present risks in the district of Gangtok and Mangan. However, the following hazards are most likely to occur and may result in significant consequences. Each hazard is examined to assess the relative risks to the community and to highlight opportunities for mitigation and coordinated response. In this analysis, extensive background and historical research was compiled and considered in the context of severity and likelihood to assess the hazard risk.

Components for Assessment of Multi Hazards Risk Vulnerability Assessment (mHRVA)

mHRVA are being undertaken where the following hazards are considered in the district of Gangtok and Mangan as per IS codes and other requisite data from the field, which is required for Multi Hazards Risk Vulnerability Assessment Study as below:
a) Landslide hazards
b) Earthquake hazards
c) Fire hazards
d) Flood/ flash floods hazards
e) Snow Avalanches hazards
f) Drought hazards

Following activities will be covered under this study are given as below:

- **i)** Creation of Multi-Hazards Risk & Vulnerability Assessment (mHRVA) on meso-scale (1:10,000 or 1:5,000) will be done at Gangtok and Mangan Districts.
- **ii)** Development of GIS based slope information system and landslides inventory are to be carried out for Gangtok, and Mangan districts.
- **iii)** Geo-technical investigation of vulnerable existing lifeline buildings of all schools and Primary Health Centres (PHCs) will be done by the Sikkim Manipal Institute of Technology (SMIT).

The risk assessment will be carried out by evaluating both the direct and indirect impacts of mountain hazards on communities, livelihoods, and critical infrastructure. This study aims to provide a scientific basis for disaster risk mitigation, early warning, awareness and preparedness planning. The implementation methodology is designed to be comprehensive, leveraging modern technology and local participation to ensure accuracy and inclusiveness.

- **Creation of GIS-Based Information System:**

  A web-based GIS platform will be developed by the Sikkim State Disaster Management Authority (SSDMA), enabling the public to contribute real-time information about landslide incidents. This system will feature cloud-based storage for secure and scalable data management. By integrating spatial data and crowd-sourced inputs, this platform will enhance monitoring and response capabilities.

- **Landslide Inventory and Data Integration:**

  The methodology involves consolidating all existing landslide hazard maps of Sikkim and establishing a comprehensive, dynamic landslide inventory within a GIS platform. This inventory will be enriched with high-resolution satellite imagery for detailed spatial analysis and identification of vulnerable areas. Crucially, the GIS platform will integrate real-time data streams from the sensor-based EWS network enabling continuous updates to hazard assessments. This integrated data framework will support Multi-Hazard Risk Vulnerability Assessment (m-HRVA) studies by providing near-real-time monitoring of slope instability triggers and predictive analytics through machine learning algorithms applied to the historical and live data. The resulting dynamic hazard models will allow for proactive risk management and can be scaled to other regions following validation of the methodology and resource availability.

- **Community Involvement:**

  A mechanism will be established to collect real-time data on landslide occurrences from local residents, either directly or through the tracking of posts on social media platforms. This participatory approach will be supported by extensive awareness generation programmes to sensitize the public on how to identify and report landslide incidents. Such efforts will not only improve data collection but also strengthen community-level disaster preparedness and resilience.

Landslide monitoring and EWS:

Previously, Sikkim SDMA had supported the project of Amrita University funded by the Department of Science & Technology (DST) for the development of landslide EWS at Chandmari landslide in Gangtok, Sikkim. This project remained a R&D effort without proper transfer of knowledge or support for adoption by the state institution. Given this gap, there is now a clear need to develop a conventional, community-based EWS for Sikkim, focusing on rainfall threshold-based alerts, supplemented by seismic motion sensors such as geophones.

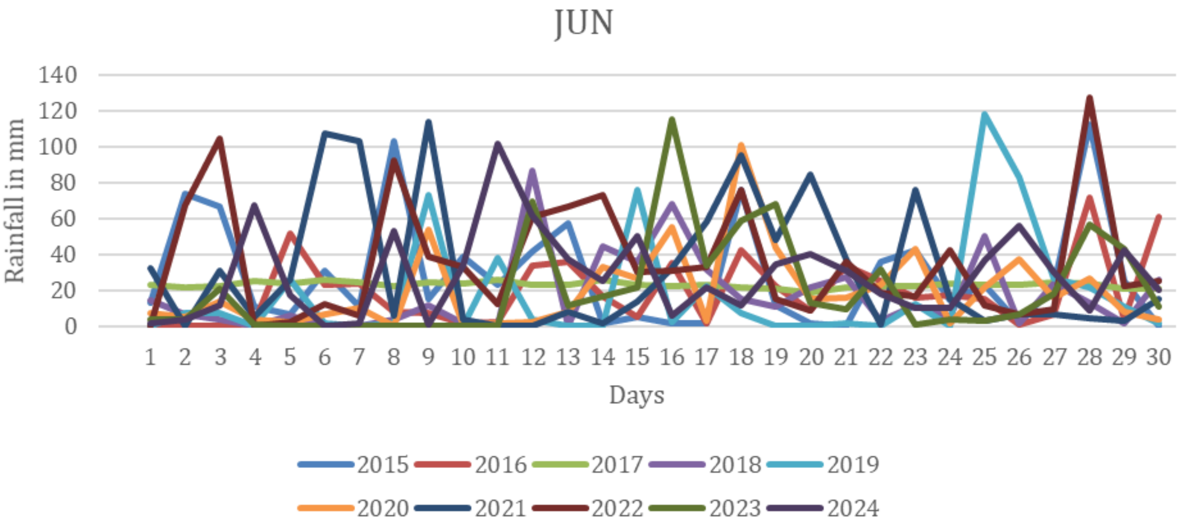
This initiative aims to implement a fully operational, multi-parameter EWS across high-risk zones. The system will integrate geotechnical sensors, including piezometers to measure pore water pressure and inclinometers to track slope movement, along with hydrological sensors like tipping-bucket rain gauges and geophysical instruments such as geophones to detect seismic activity. These instruments will be deployed at critical locations identified through risk assessments, such as Lumsey and Mangan. Real-time data will be transmitted via GSM networks to a central processing server, where region-specific thresholds will trigger automated alerts - including rainfall intensity, validated against IMD historical data and slope displacement rates, calibrated through initial monitoring.

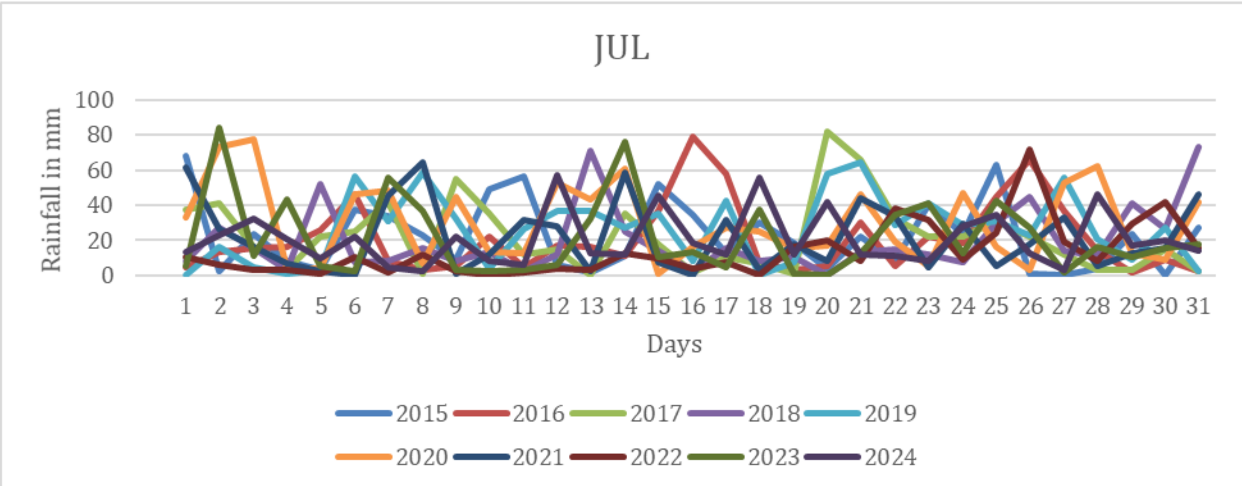
For community-level dissemination, the system will include multiple channels to ensure redundancy and reliability. Programmable hooters will sound automated warnings, while SMS alerts will be sent to registered residents. In addition, dedicated WhatsApp groups moderated by trained Aapda Mitra volunteers will provide real-time updates and safety instructions. These volunteers will participate in quarterly field drills focusing on sensor maintenance, evacuation route planning, and response protocols to minimize false alarms. The effectiveness of these drills will be evaluated through timed response measures to ensure continuous improvement.

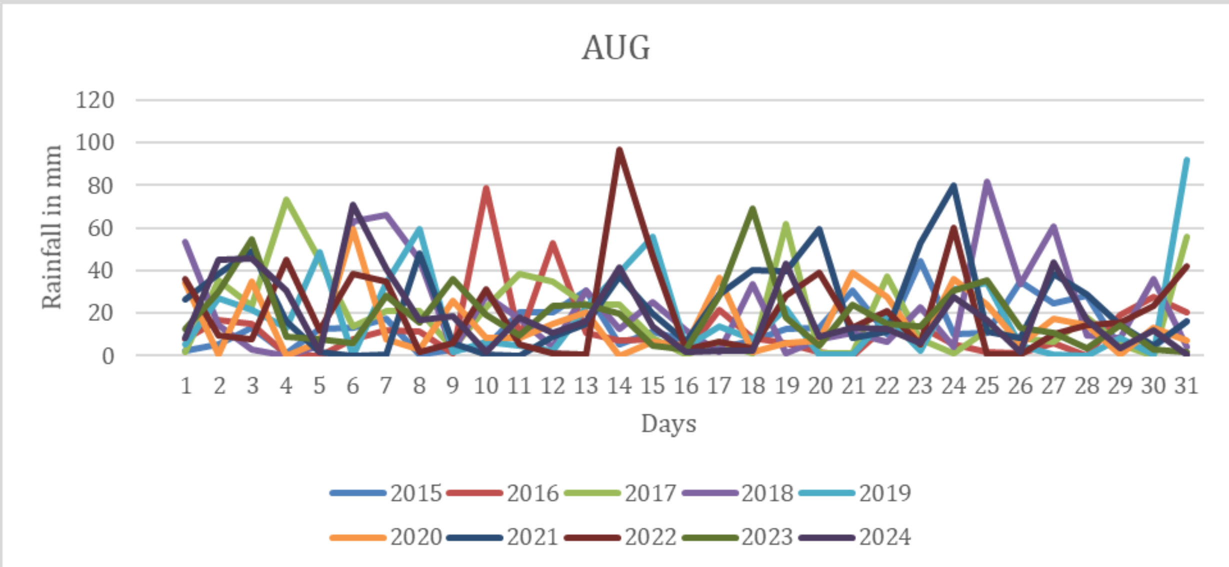
All collected sensor data will be integrated into GIS-based slope information system of the project, which will enable real-time hazard mapping and predictive analysis. Machine learning algorithms will be applied to the existing landslide inventory to improve the accuracy of risk forecasts and identify emerging patterns. Unlike earlier approaches that tested commercial sensors against in-house prototypes, this project will focus solely on deploying a unified, maintainable system with clearly defined institutional ownership by SSDMA and technical oversight by the Project Monitoring Committee. This approach ensures a practical, community-driven, and scalable EWS that can be sustained over the long term.

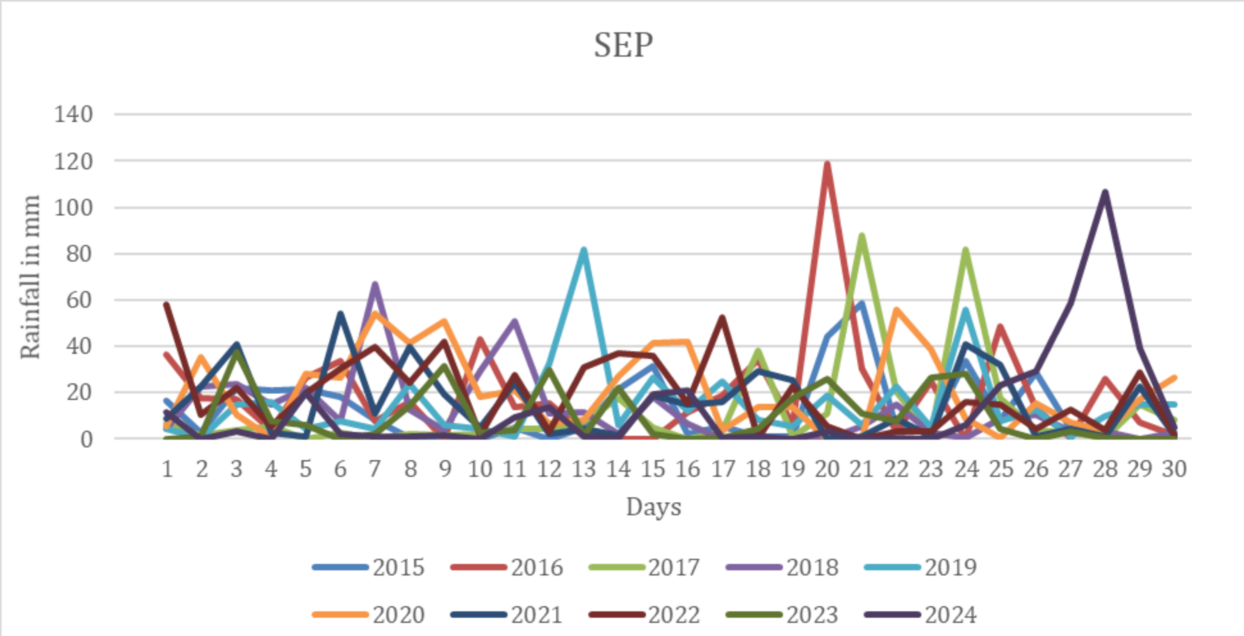
Rainfall data from the past 10 years recorded at three IMD stations (Gangtok, Mangan and Tadong clearly indicate that Sikkim receive the highest rainfall between June to September the period during which most landslides are generally occurred.

i) IMD Gangtok Station Rainfall Records from June to September (2015-2024):

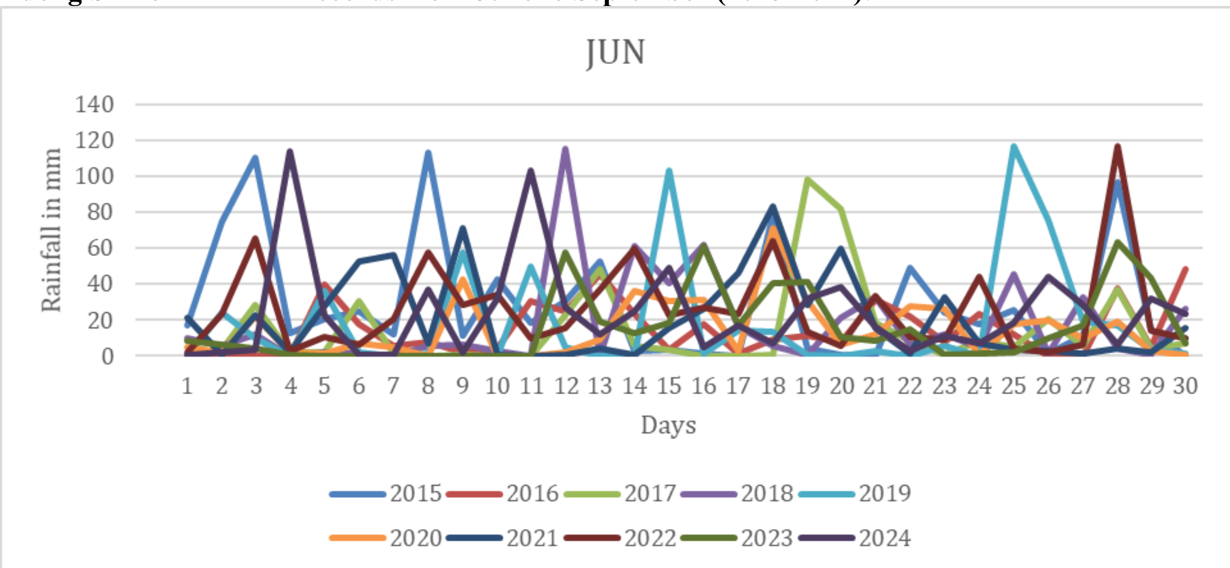


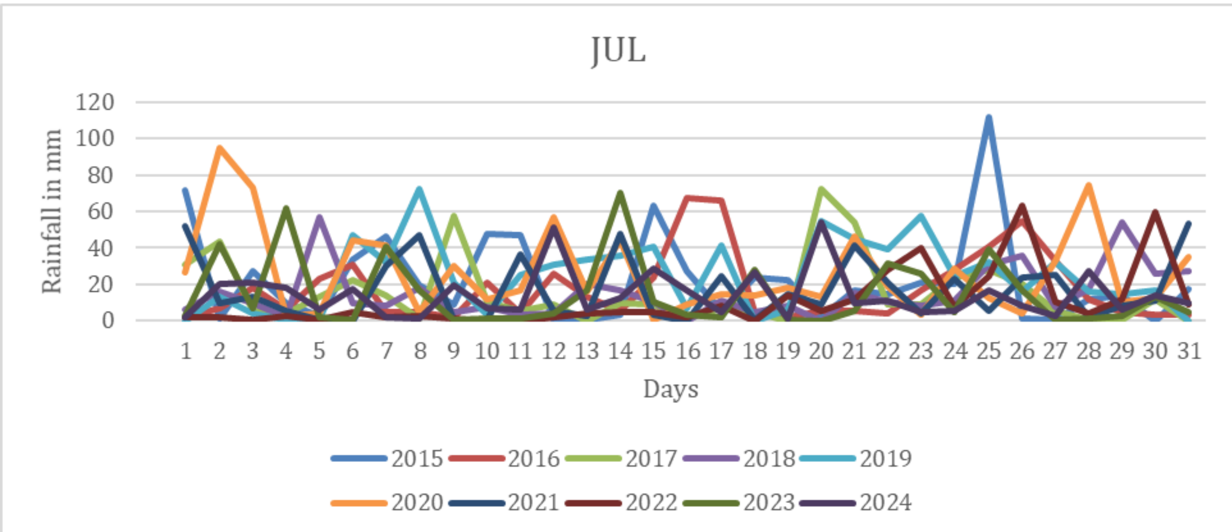


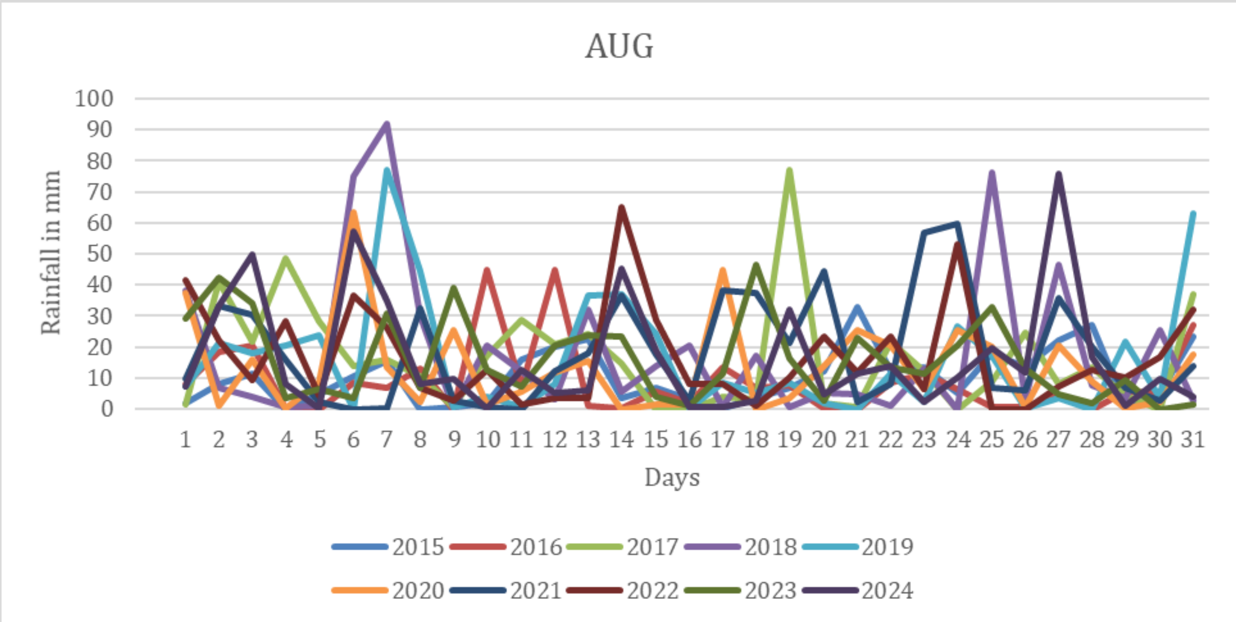


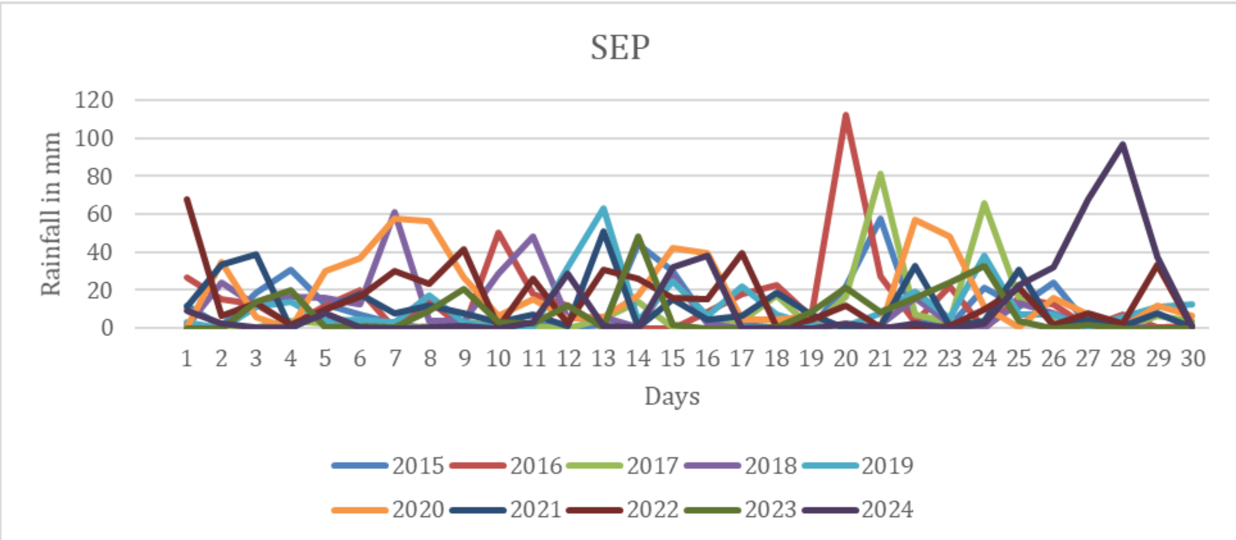


ii) IMD Tadong Station Rainfall Records from June to September (2015-2024):

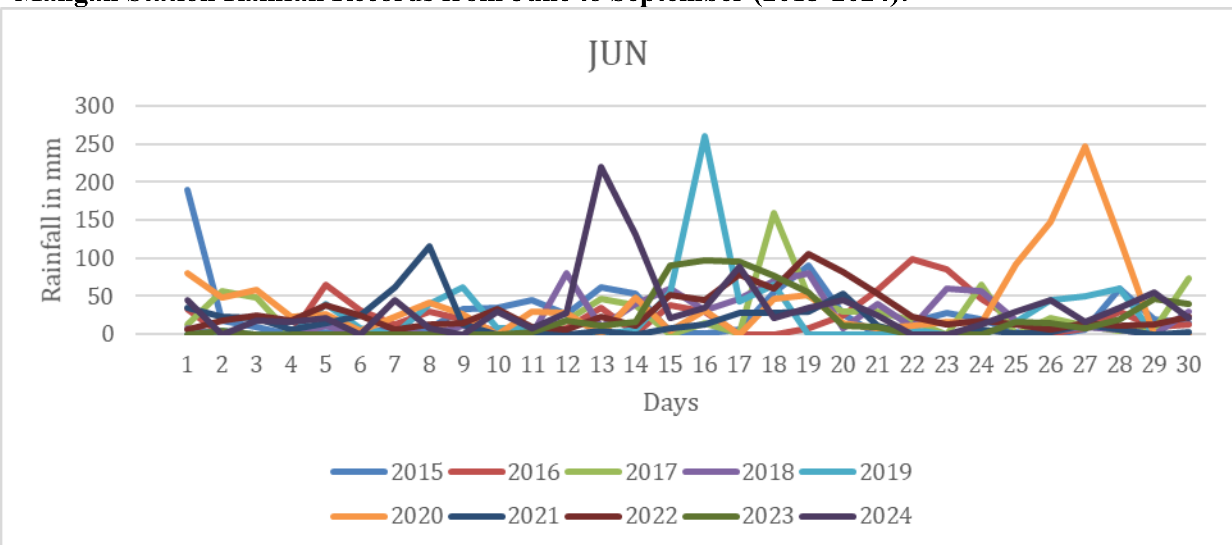


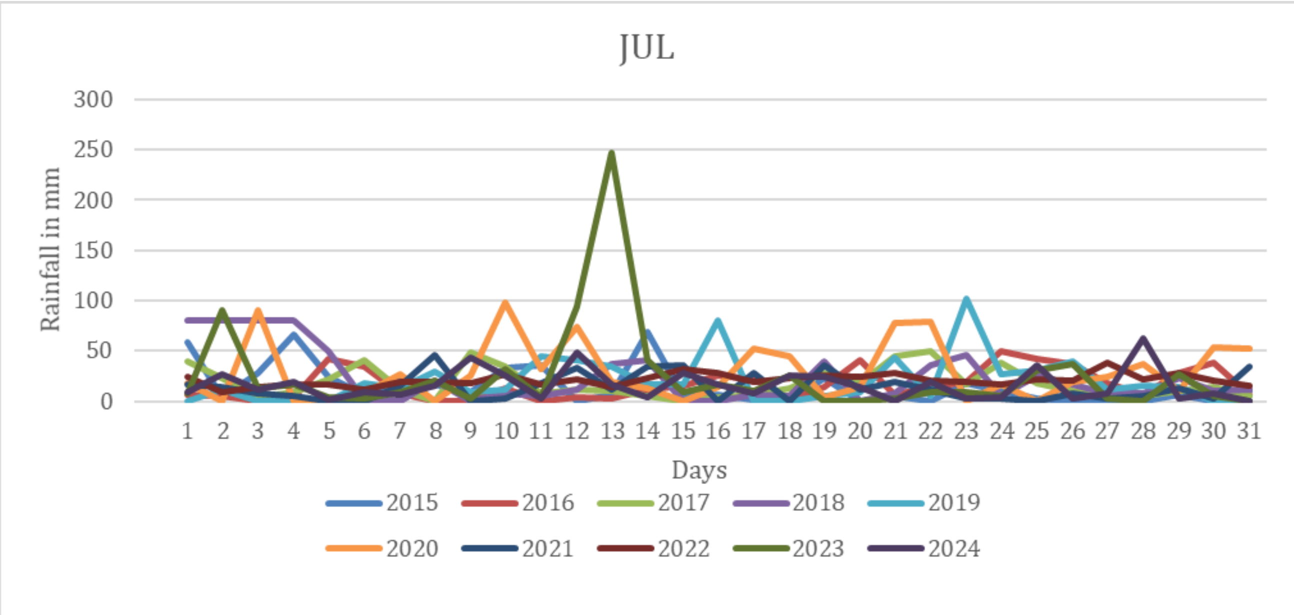






iii) IMD Mangan Station Rainfall Records from June to September (2015-2024):




JUL
Rainfall in mm
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days
2015 2016 2017 2018 2019
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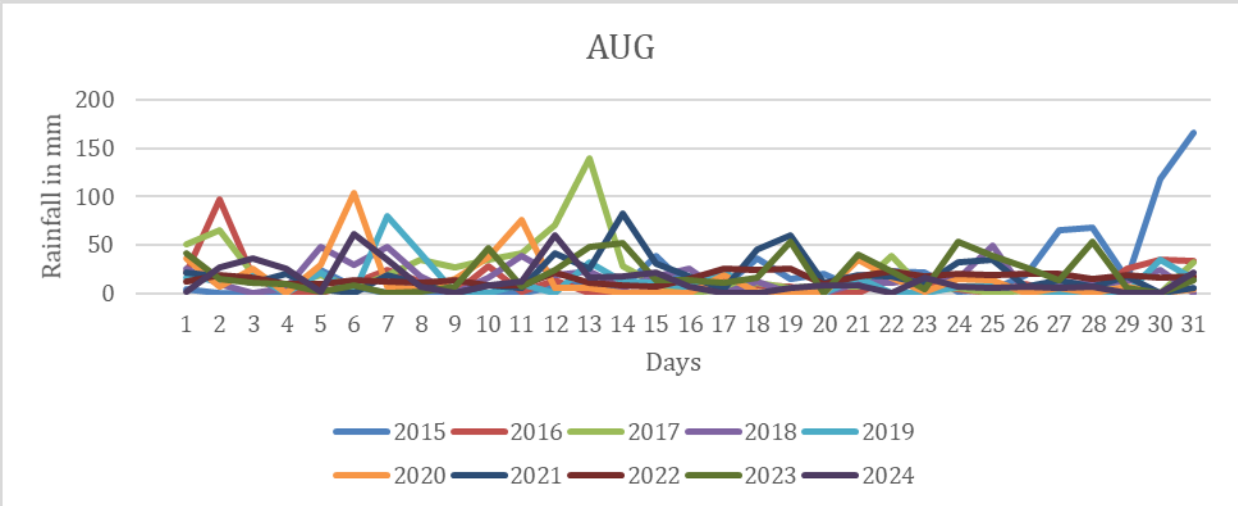
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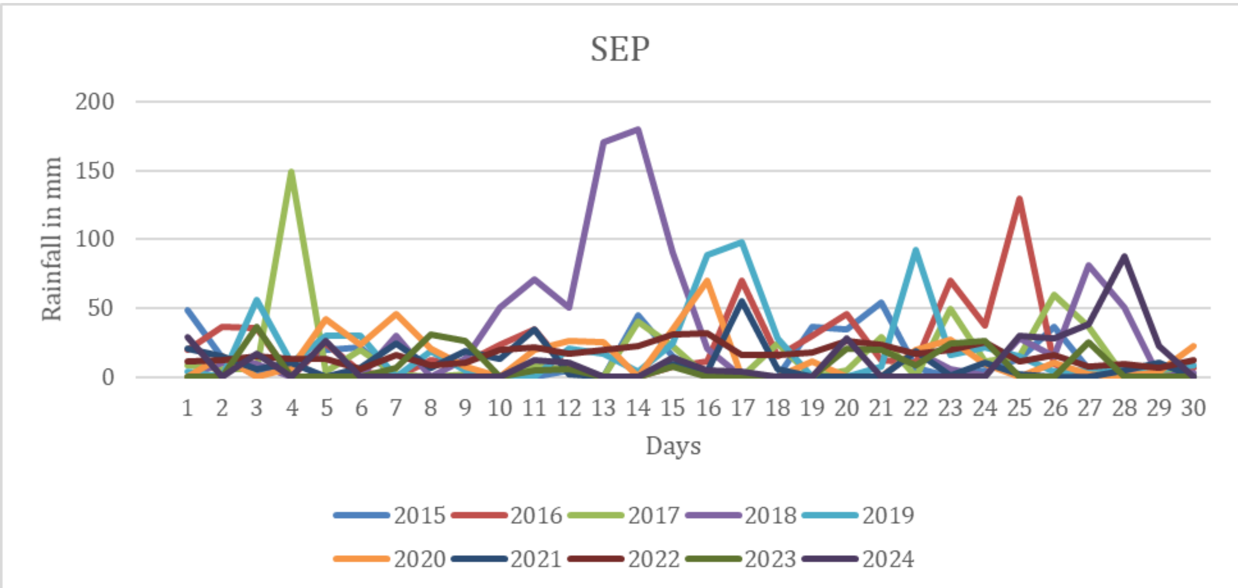
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Awareness Generation & Capacity Building

Awareness generation and capacity building are most important components of disaster risk reduction and mitigation, especially in a landslide-prone state like Sikkim. To foster a culture of preparedness, awareness generation and sensitization programmes have been conducted to educate communities about landslide risks, safety, and mitigation measures.

In a strategic move to strengthen technical expertise, 50 engineers and geologists have been trained as Master Trainers through 10 specialized training programmes conducted in collaboration with Sikkim Manipal Institute of Technology (SMIT). These Master Trainers serve as key resource persons for further knowledge dissemination. Additionally, targeted training sessions have been organized by District Disaster Management Authorities (DDMAs) across all six districts of Sikkim to empower local communities in vulnerable areas, enhancing their ability to respond effectively to landslide hazards and contribute to local resilience.

4. Project Rationale & Objectives:

The primary aim of this landslide risk reduction and mitigation project is to effectively address landslide risk and vulnerability by implementing local-level interventions that enhance landslide resilience and reducing risks. In order to implement the project main objectives are:

i). Preventing loss of life and property due to landslides: Preventing loss of life during landslides requires community-based awareness, preparedness, and timely response. Local communities must be trained to recognize early signs of slope instability and follow safe evacuation protocols. Regular sensitization and inclusion of local knowledge can significantly improve safety and reduce casualties.

ii). Reducing economic loss due to the landslide risk: Landslides can cause severe economic disruption by damaging homes, farmland, and infrastructure. Community-led planning and land-use management, such as avoiding construction in high-risk zones and reinforcing vulnerable structures, can reduce such losses. Supporting livelihood diversification also helps communities recover faster from disaster impacts.

iii). Strengthen the early warning system (EWS) based on last-mile connectivity: An effective early warning system must reach every individual, especially in remote areas. Involving local communities in the design and operation of EWS ensures that alerts are understandable, trusted, and acted upon. Using local communication channels—like community radio, sirens, or mobile alerts - can bridge the last-mile gap and enable timely evacuations.

iv). Strengthening scientific and technical capabilities in landslide risk reduction and mitigation at various levels: Empowering local authorities and communities with scientific tools and technical knowledge is crucial. Training in hazard mapping, risk assessment, and the use of monitoring equipment enables locals to take proactive measures. Collaboration between researchers, scientists, governments, and communities ensures that risk reduction strategies are both technically sound and locally applicable.

v). Empower local communities as partners to reduce and mitigate landslide risk: Communities are the first responders to any disaster and should be seen as key partners in risk reduction. Empowering them through education, resources, and involvement in decision-making builds resilience. When communities take ownership of landslide mitigation efforts, solutions become more sustainable and culturally appropriate.

5. Project details

Name of the Project (specific name by the State, if any)	**Landslides Risk Mitigation & Management in Sikkim (Phase-1)**
Type of Project (Structural/ Non-Structural/ Both)	Both (Structural & Non-structural)
Total Budgeted Expenditure (Rs. cr)	**₹ 50.0 Crores**
Duration Of the Project (FY and Quarter-wise)	**12 - 24 months**

6. Mitigation Interventions

Following are the structural and non-structural mitigation measures are proposed under the project as given in the Table 2:

Table 2: Proposed Components

SN	Components	Name of Site	Type of Activities	Component Ratio	Budgeted Amount (Rs. Cr)	Collaborative Partners
1	**Landslide Risk and Vulnerability Assessment**	1.Gangtok GMC Area 2. Mangan District	**i)** Multi-Hazard Risk Vulnerability Assessment (m-HRVA) on meso-scale (1:10,000 or 1:5,000) **ii)** GIS based slope information system and landslides inventory is to be carried out for Gangtok, and Mangan. **iii)** Geo-technical investigation of vulnerable existing lifeline buildings (school & PHCs)	9 %	4.5	GSI, DGM-Sikkim, SMIT, Municipal Corporations / Local Authorities, other stakeholders
2.	**Landslide Monitoring and Early Warning System**		**Landslide monitoring and EWS** **i)** Sensor Based landslide monitoring and Early Warning System **ii)** Community based early warning and dissemination system	6%	3.0	IITs, CBRI, GSI, DGM-Sikkim, DST-Sikkim, other stakeholders
3.	**Slope Stabilization**	Lumsey Landslide	**A) Slope Stabilization** **i)** Site-Specific Mitigation of Lumsey Subsidence Zone, Gangtok District, Sikkim along with operation and maintenance cost. **ii)** Community Based Slope Stabilization by Local Interventions **iii)** Bio Restoration and Bio-engineering Measures **B) Landslide instrumentation and monitoring** – Efficacy of landslide mitigation will be monitored by installation of sensors	80%	40.00	SSDMA, DDMA, Local Authorities, NIRM, GSI, DGM-Sikkim, other stakeholders
		Mangan Landslide	**A) Slope Stabilization** **i)** Site specific structural measures in the toe-portion of landslide with Jhora training and treatment works along with operation and maintenance cost. **ii)** Community Based Slope Stabilization along Jhoras by Local Interventions **iii)** Bio Restoration and Bio-engineering Measures **B) Landslide instrumentation and monitoring** – Efficacy of landslide mitigation will be monitored by installation of sensors			
4.	**Awareness**	All districts	**i)** Awareness generation and	5%	2.5	SSDMA,

	Generation & Capacity Building		sensitization programme **ii)** Training of Engineers and geologist as master Trainers 50 Nos. by 10 training programmes in collaboration with Sikkim Manipal Institute of Technology (SMIT) **iii)** Training to local community at vulnerable landslide prone areas of 6 districts of Sikkim by DDMAs			DDMA, SMIT, Other Stakeholders
		All districts/ Expert Institutions (National / State Level)	**Research & Development (Small Grant Window)** i). Project proposal with local knowledge and best practices will be funded			SSDMA, Sikkim University, SMIT, other stakeholders

**Note:* *It is important to mentionsed here that design of mitigation measures (structural and non-structural) will be as per site conditions thus, costs of implementation measures may vary from the table above)*

MITIGATION MEASURES: Mitigation Measures will be designed as per landslide affected site-conditions and geo-physical parameters. Following are the types of civil engineering and bio-engineering measures are given as below:

A) Civil Engineering Measures: These involve engineering structures designed to improve slope stability, reduce water infiltration, and restrain debris movement.

Measure	Description
Retaining Walls	Reinforced concrete, gravity, or gabion walls to resist lateral earth pressure.
Rock Bolting and Anchoring	Steel bolts/anchors drilled into bedrock to stabilize rock masses.
Drainage Systems	Surface and subsurface drains (e.g., horizontal drains, weep holes) reduce pore water pressure.
Check Dams and Debris Flow Barriers	Small masonry or concrete structures across gullies to trap debris flow.
Slope Reinforcement (Shotcrete, Mesh)	Steel wire mesh or concrete sprayed (shotcrete) over unstable rock surfaces.
Terracing and Bench Cutting	Reduces slope angle by creating stepped surfaces.

B) Bio-engineering Measures: These use vegetation and natural materials to stabilize slopes and reduce erosion.

Measure	Description
Vetiver Grass Plantation	Deep-rooted grass planted to bind soil and reduce surface runoff.
Brush Layering and Fascines	Layered vegetation or bundles of live branches placed in trenches across the slope.
Coir Geotextiles	Biodegradable mats placed on slopes to reduce erosion and support plant growth.
Live Crib Walls	Timber crates filled with soil and live plants used as retaining structures.
Revegetation and Afforestation	Planting native shrubs, trees, and grasses to bind topsoil and improve infiltration.

7. Expected Outcomes (300-500 words):

SN	Activity	Output	Outcome
1	Multi-Hazards Risk & Vulnerability Assessment (m-HRVA)	● Generation of large scale Multi-Hazard Risk Assessment maps. ● Development of methodology for m-HRVA.	▪ Prioritization of areas for geo-technical investigation based on m-HRVA. ▪ It is helpful in site-specific landslide risk mitigation. ▪ Future projects/ programmes will be based on this study.
2	Development of GIS based slope information system	● Collating all information of vulnerable slope at one platform.	▪ Establishment of system for collection of database related to vulnerable slope and landslide sites.
3	Preparation of landslide inventory atlas of Gangtok and Mangan.	Database of landslide events and sites compiled.	Database will be helpful in landslide risk assessment in future projects.
4	Geo-technical investigation of vulnerable existing lifeline buildings	● Promote geo-technical investigation of lifeline building and its surrounding vulnerable slope before its treatment. ● Reducing risk of landslide at problematic site.	Results of geo-technical investigation will be utilized in slope treatment and building retrofitting.
5	Sensor Based landslide monitoring and Early Warning System	Promote research and operationalize an integrated sensor-to-community EWS reducing evacuation time by 80% during high-risk events.	Provide database and solution for generation of reliable landslide EWS.
6	Site-Specific Structural Mitigation of landslides	Treatment of problematic landslide site and	Reducing loss of life and property.
7	Community Based Slope Stabilization by Local Interventions	Mainstreaming of community driven landslide stabilization and treatment.	Promotion of Nature based solutions in landslide treatment.
8	Bio Restoration and Bio-engineering Measures	Treatment of landslide site with bio-engineering interventions as per site condition.	Aesthetic look to problematic site with greenery in place of concretization of slope.
9	Community level awareness generation and sensitization programme	Enhancement of community awareness level.	Reduction in loss of life and property.
10	Capacity building of line departments – Training of Engineers and geologist as master trainers	Approximately 500 number of engineers and geologist will be train as master trainers	Capacity building of line departments and officials to deal with landslide risk and provide expertise in landslide reduction and mitigation.
11	Training to local community at vulnerable landslide prone areas	Capacity building of local community to reduce landslide risk.	▪ Mainstreaming and strengthening landslide disaster risk reduction. ▪ Mitigation of landslide vulnerable areas through community driven approach.
12	Research and Development (Small Grant Window)	Collection of local knowledge and best practices in landslide risk mitigation at one place.	▪ Promote local knowledge and best practices in landslide risk reduction and mitigation in future projects. ▪ Promote research and development in landslide risk reduction and mitigation.

8. Budget

The component wise budget share of centre and state under NDMF and SDMF are given in the table 3 as under:-

Table 3: Proposed Budget Structure (Sub-Component Wise Budgeting)

Component	Proposed Activities	Component Ratio in %	Centre Share of NDMF (₹ Cr)	State Share of SDMF (₹ Cr)	Total Budget (₹ Cr)
1. Landslide Risk and Vulnerability Assessment*	**i)** Multi-Hazards Risk & Vulnerability Assessment (m-HRVA) **ii)** GIS based slope information system and landslides inventory is to be carried out for Gangtok, and Mangan. **iii)** Geo-technical investigation of vulnerable existing lifeline buildings (school & PHCs)	**9%**	4.0	0.5	**4.5**
2. Landslide Monitoring and Early Warning System*	**i)** Sensor Based landslide monitoring and Early Warning System **ii)** Community based early warning and dissemination system	**6%**	1.0	2.0	**3.0**
3. Slope Stabilization*	**i)** Site-Specific Mitigation of Lumsey Subsidence Zone, Gangtok District and Mangan landslide site, Mangan District along with operation and maintenance cost. **ii)** Community Based Slope Stabilization by Local Interventions **iii)** Bio Restoration and Bio-engineering Measures	**80%**	38.0	2.0	**40.0**
4. Awareness Generation and Capacity Building*	**Awareness Generation & Capacity Building** i) Awareness generation and sensitization programme ii) Training of Engineers and geologist as master Trainers 50 Nos. by 10 training programmes in collaboration with Sikkim Manipal Institute of Technology (SMIT)	**5.0 %**	2.0	0.50	**2.5**

	iii) Training to local community at vulnerable landslide prone areas of 6 districts of Sikkim by DDMAs **Research & Development (Small Grant Window)** i). Project proposal with local knowledge and best practices will be funded				
Grand Total		**100%**	**45.00**	**5.00**	**50.0**

****Note:*** *It is important to mentionsed here that design of mitigation measures (structural and non-structural) will be as per site conditions thus, costs of implementation measures may vary from the table above)*

9. Technical Assistance

Following institutions will be engaged to offer technical guidance throughout the project lifecycle:

- IITs
- CSIR-CBRI, Roorkee
- Sikkim University
- Sikkim Manipal Institute of Technology (SMIT)
- Geological Survey of India (GSI)
- National Institute of Rock Mechanics (NIRM)
- Department of Science & Technology (DST), Sikkim
- Department of Mines & Geology (DGM), Sikkim
- Gangtok and other Municipal Corporations / Local Authorities

Roles:

- **Pre-Project Phase: Support risk assessments and technical design preparation.**
  In the pre-project phase, the Department of Mines & Geology (DGM), Government of Sikkim and DST, Government of Sikkim, will support risk assessments and technical design of detailed project report preparation for mitigation measures in collaboration with hired expert agencies or institutions. This will involve identifying vulnerable slopes, analyzing potential landslide triggers, and assessing risks to communities and infrastructure using tools like remote sensing, GIS mapping, and satellite imagery etc. The findings will facilitate further site-specific, cost-effective, and sustainable mitigation designs, ensuring a strong scientific and technical foundation for effective project implementation.

- **Implementation Phase: Ensure technical oversight and adherence to standards.**
  During the implementation phase, the Sikkim State Disaster Management Authority (SDMA) will ensure strict technical oversight and adherence to prescribed standards and guidelines. This will be achieved through the Project Monitoring Committee (PMC), constituted under the Landslide Risk Mitigation Scheme of the National Disaster Management Authority (NDMA). The PMC will supervise and guide the implementing agencies, providing technical support, reviewing progress, and ensuring that all construction and mitigation activities are carried out in accordance with approved designs, safety norms, and quality benchmarks. This structured oversight will help maintain the integrity, effectiveness, and sustainability of the project interventions.

- **Post-Completion Phase: Conduct performance reviews and recommend upgrades.**
  In the post-completion phase, the Project Monitoring Committee (PMC), constituted under the Landslide Risk Mitigation Scheme of NDMA, will play a key role in evaluating the overall performance and impact of the implemented project interventions. The PMC will conduct systematic performance reviews to assess the effectiveness of the landslide mitigation measures, the reliability of landslide monitoring systems, and the level of community preparedness. These evaluations will help identify any gaps, operational challenges, or areas requiring improvement. Based on the findings, the PMC will recommend necessary upgrades or modifications to ensure the long-term sustainability and continued effectiveness of the project outcomes. This phase will also contribute to building institutional learning and enhancing future disaster risk reduction initiatives.

10. Implementation Framework

Stakeholder Roles: Define the responsibilities of SDMAs, DDMAs, technical agencies, and local governments.

- IITs
- CSIR-CBRI, Roorkee
- Sikkim University
- Sikkim Manipal Institute of Technology (SMIT)
- Geological Survey of India (GSI)

- National Institute of Rock Mechanics (NIRM)
- Department of Science & Technology (DST), Sikkim
- Project Monitoring Committee (PMC)

- **SSDMA and PMC** – Overall project execution with collection of data and submission of progress report to NDMA. Facilitate collaboration among State departments, and technical agencies etc.
- **Project Monitoring Cell (PMC)**: Project Monitoring and Evaluation (M&E) and approval of mid-term course correction, if required.
- **CBRI, GSI, NIRM, DGM-Sikkim, SMIT, DST-Sikkim IITs, other stakeholders:**
  - Technical guidance for geo-technical investigation and implementation of project.
  - Suggestions and evaluation of DPRs and slope stability analysis with designing of mitigation measures.
  - Technical guidance for implementation of project as required by the SDMA and PMC.
- **Sikkim University, SSDMA, other stakeholders:**
  - Expert advice on the R&D project proposals calls and advertisements.
  - Selection of R&D project proposals with evaluation of outcomes and deliverables.
- **DDMA (Gangtok, Mangan) and other Municipal Corporation / Local Authorities:**
  - Project implementation at sites with collection of data and submission of project report to Sikkim SDMA. Facilitate collaboration among line departments, Municipal Corporation/ local authorities, communities and other stakeholders.
  - Assist in proper implementation of project at site in collaboration with local community.

Phased Timeline including O&M Phase:

The project will be implemented within 12 - 24 months as per the approval of project and allocation of funds. Although, site-specific mitigation of landslides will depend upon the Detailed Project Reports (DPRs) preparation and award of work to the implementing agency.

SN	District Name	Name of Sites	Type of work/ components	1st Year	2nd Year
1	Gangtok & Mangan Districts	1.Gangtok District 2. Mangan District	**Risk Assessment** **i)** Multi-Hazards Risk & Vulnerability Assessment (m-HRVA) **ii)** GIS based slope information system and landslides inventory is to be carried out for Gangtok, and Mangan. **iii)** Geo-technical investigation of vulnerable existing lifeline buildings (school & PHCs)	√	√
2.	Gangtok, Mangan and other districts		**Landslide monitoring and EWS** **i)** Sensor Based landslide monitoring and Early Warning System **ii)** Community based early warning and dissemination system	√	√

3.	Gangtok District	Lumsey Landslide	**A) Slope Stabilization** **i)** Site-Specific Mitigation of Lumsey Subsidence Zone, Gangtok District, Sikkim along with operation and maintenance cost. **ii)** Community Based Slope Stabilization by Local Interventions **iii)** Bio Restoration and Bio-engineering Measures **B) Landslide instrumentation and monitoring –** Efficacy of landslide mitigation will be monitored by installation of sensors	√	√
	Mangan District	Mangan Landslide	**A) Slope Stabilization** **i)** Site specific structural measures in the toe-portion of landslide with Jhora training and treatment works along with operation and maintenance cost. **ii)** Community Based Slope Stabilization along Jhoras by Local Interventions **iii)** Bio Restoration and Bio-engineering Measures **B) Landslide instrumentation and monitoring –** Efficacy of landslide mitigation will be monitored by installation of sensors	√	√
4.	All districts		**Awareness Generation & Capacity Building** i) Awareness generation and sensitization programme. ii) Training of Engineers and geologist as master Trainers 50 Nos. by 10 training programmes in collaboration with Sikkim Manipal Institute of Technology (SMIT) iii) Training to local community at vulnerable landslide prone areas of 6 districts of Sikkim by	√	√

			DDMAs		
5.	All Districts/ Expert Institutions	All districts/ Expert Institutions (National / State Level)	**Research & Development (Small Grant Window)** 1. Project proposal with local knowledge and best practices will be funded	√	√

Monitoring Mechanisms: Metrics for assessing and evaluation of progress, such as the number of interventions completed, and community training sessions.

Activities as per Components	Monitoring Indicators	Means of Verification	Frequency
Risk Assessment and Mapping	- No. of hazards maps prepared - No. of risk assessments conducted - Area covered (sq.km)	- GIS database - Assessment reports - Maps	Quarterly
Landslide Monitoring and EWS	- No. of monitoring stations installed - Functionality rate of sensors - Alerts generated and disseminated	- System logs - Alert records - Maintenance reports	Quarterly
Slope Stabilization	- No. of sites stabilized - Type of stabilization method/ measures implemented - Reduction in slope failure or slope movement	- Site reports - Photographic evidences - Field inspections	Bi-monthly
Community Based Landslide Mitigation	- No. of local interventions implemented - Community participation rate - Feedback from community	- Implementation records - Community engaged at no. of sites - Photographic evidences	Quarterly
Research and Development	- No. of studies conducted - Technical papers published - Innovations introduced with local knowledge and best practices	- Research reports - Publications - Project records	Half-yearly
Awareness Generation & Capacity Building	- No. of training/awareness programs held - No. of participants trained - No. of master trainers developed	- Attendance records - Training reports - Feedback forms	Monthly / Per event
Documentation	- No. of reports generated - Data entries in information systems - Accessibility of documents	- Document archives - Digital repository - Audit reports	Quarterly / Ongoing
Monitoring and Evaluation	- No. of sub-components in progress or completed - No. of sites in progress or completed	- Utilization Certificate as per GFR - Progress report - Photography/ videography	Fortnightly/ monthly basis

11. Quality Assurance and Documentation

To ensure the effective execution and high-quality outcomes of the project, a dedicated Project Monitoring Cell (PMC) will be utilized. This cell will be responsible for overseeing all stages of implementation, ensuring that the project activities adhere to the planned objectives, timelines, and quality standards. The PMC will also play a key role in identifying potential challenges during execution and suggesting timely corrective measures. By maintaining regular communication with implementing agencies, the PMC will help in streamlining processes and ensuring accountability at every level. If required, mid-term corrections to the mitigation measures will be approved by the PMC on case-by-case basis.

In addition to quality assurance, comprehensive documentation of the project will be carried out by the Sikkim State Disaster Management Authority (SSDMA) in collaboration with the implementing partners. This will include detailed records of methodologies, interventions, community engagement activities, monitoring data, and progress reports. Proper documentation will not only ensure transparency but also serve as a valuable resource for knowledge sharing and future reference in similar projects across other vulnerable regions.

To further strengthen the integrity and credibility of the project, a third-party technical audit will be conducted by the State. This independent evaluation will assess the technical soundness, effectiveness, and efficiency of the implementation process. The audit will provide an objective review of the project's outcomes, ensuring that all interventions are scientifically valid, cost-effective, and aligned with the desired output and outcomes.

12. Compliance with NDMF Guidelines:

The implementation of this project is envisioned to significantly enhance the overall understanding of risk assessment, improve landslide monitoring techniques, and support the development of an effective early warning system. By combining scientific research, advanced technology, and localized knowledge, the project will enable better identification of high-risk zones and help design targeted mitigation strategies. Furthermore, it will promote innovation and foster knowledge sharing in the field of landslide studies, creating a robust framework for disaster preparedness and mitigation in mountainous regions like Sikkim.

A key focus of the project is on localized interventions and strong community participation. Site-specific landslide risk mitigation measures will be implemented based on the unique geological and site conditions. Community-based approaches will be emphasized, ensuring that local residents are actively involved in both planning and execution. To strengthen the technological aspect, sensor-based landslide monitoring stations will be installed in selected vulnerable areas. These stations will not only aid in real-time data collection but also facilitate the development of community-driven early warning systems, empowering local populations to respond swiftly and effectively in the event of a landslide.

The project will be implemented in alignment with the guidelines provided by the National Disaster Mitigation Fund (NDMF), ensuring compliance with national standards and best practices. These guidelines will serve as a framework for planning, execution, monitoring, and evaluation of various components of the project. Capacity building and awareness programmes will further reinforce the project’s impact by equipping stakeholders including community members, engineers, and local authorities with the skills and knowledge necessary to manage landslide risks sustainably and effectively.

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Compliance Note in response to the comments by the 2nd TAC Meeting

SSDMA is thankful to valuable suggestions and comments of all the TAC members.

Shri Krishna Vatsa, Member, NDMA
Reply: As per suggestions, budget allocation for mitigation interventions is revised.

Dr. Saibal Ghosh, GSI
Reply: As per suggestion, GSI is incorporated as important collaborative partner in the project and DPR is revised as per suggestions.

Prof. Prashanth Vangla, IIT Delhi
Reply: The suggestions are well taken and same will be incorporated while implementation of project.

Prof. Arun Kumar
Reply: Suggestions are well taken to consider GSI report during preparation of DPRs for landslide mitigations.

Prof Sajin, University of Kerala
Reply: The suggestions are well taken and same will be incorporated while implementation of project.

Prof Neelima, IIT Indore
Reply: As per suggestions, project will be implemented at ground level.

Dr. Ajay Naithani, NIRM
Reply: Suggestions are well taken and will be taken forward while preparation of DPRs for landslide mitigations.

Prof. Surya Parkash
Reply: Suggestion are to be considered during implementation of capacity building exercises to include NIDM in the project.

Compliance Note in response to the comments by the 1st TAC Meeting

SSDMA is thankful to valuable suggestions and comments of all the TAC members.

Dr. Saibal Ghosh, GSI
Reply: As per suggestion, only two landslide affected sites are selected. All the details discussed during the presentation are now incorporated in the revised PPR.
Prof. Vikarm Gupta
Reply: As per valuable suggestion rainfall data is incorporated in the document. It is clearly mentioned here that Mangan landslide mitigation is pilot project which was successful, although toe portion of treatment was damage during heavy rainfall event and same is proposed for mitigation as per NDMA team visit.

Prof Neelima, IIT Indore
Reply: As per recommendations of the 15th Finance Commission, the proposal submitted under NDMF could not duplicate the efforts of ongoing central government planning. The proposed sites are highly vulnerable towards landslides and settlements / houses are affecting here.

Prof Vikram Gupta, Sikkim University

Reply: As per suggestion, revised PPR included cross-sections of proposed landslides sites mitigation and IMD rainfall data of 3 stations as per availability.

Dr. Ajay Naithani, NIRM
Reply: Suggestions are included and revised PPR is prepared.

Prof Sajin, University of Kerala
Reply: Revised PPR is prepared as per suggestions.

Prof. Arun Kumar
Reply: IMD Monthly rainfall records of proposed sites are included in the revised PPR.

Prof. Surya Parkash
Reply: Suggestion are included in the revised PPR.

Dr. Tisanu Banik
Reply: Suggestions are incorporated in the revised proposal. The multi-hazard risk and vulnerability maps will be created by combining each hazards and creation of composite map.

Member, NDMA
Reply: As per suggestions, revised PPR is prepared and incorporated local community led interventions and capacity building.