CHAPTER THREE

Study Area

Pre field investigation was conducted to choose the location of the study area. The investigation was conducted along the national highway (NH - 5A) from Shimla to Rampur and along Mandi to Pathankot national highway (NH – 154) (Figure No 4). Three study areas with different types of landslides involved were chosen for the research. The first study area is located nearby Dhalli tunnel in Shimla town, Shimla Tehsil, Himachal Pradesh. The geographical location of the landslide is 31°06'10" latitude and 77°12'12" longitude. On 2nd September, 2017 massive landslide occurred near Dhalli area in Shimla town. The type of landslide involved is Rock slide with shallow translational movement. It is covered in the toposheet no. 53 E/04, assigned by Survey of India (SOI). The second landslide is located at 31°29'09" latitude and 77°41'40" in Jhakri, Rampur Tehsil, Himachal Pradesh. The type of landslide involved is Debri Slide with Shallow failure. It is covered in the toposheet no. 53 E/11, assigned by Survey of India (SOI). The third landslide is located at 31°54'48" N and 76°53'28" E, Padhar Tehsil, Himachal Pradesh. The type of landslide involved is complex slide with deep seated failure. It is covered in the toposheet no. 53 A/13, assigned by Survey of India (SOI).

The total population of Shimla as of census 2011 is 1,71,640 people. Nearly 1,69,578 of the people reside in Shimla town and the rest in Shimla Rural and Jutogh cantonment board. Three major rivers drain through Shimla namely Sutlej, Giri and Pabbar. Agriculture and Horticulture are the important economic activities in these areas. Cereals, Off season vegetables and stone fruits are most suitable to grow in the high altitude areas. Agriculture activities is mainly rainfall dependant. An average of 999.4 mm of rainfall is recorded where most of the rainfall is received during monsoon period. In valleys the soil is sandy loam and skeletal in the mountain regions. Geologically, Shimla district covers pre-Cambrian to Quaternary period.

Kotropi landslide is located at Padhar tehsil of Mandi district. The total geographical extent of the study area is 85 hectares with landslide as its epicenter. The Mandi district is situated between 31°13'0" to 32°04'01" north latitude and 76°37'45" to 77°23'21" east longitude. The total geographical area of the district is 3, 950 sq.km. As of 2011 census data the total population of Mandi is 9,99,777 people. The district

has 2 main rivers viz. the Beas and the Sutlej. Geologically the area is in a thrusted contact (Main Boundary thrust) between the Siwaliks and the Shali Group of rocks consisting mainly of dolomites, brick red shale, micaceous sandstones, purple clay and mudstones Prakasam, C., et al. (2019). The climate of the district is sub-tropical in the valleys and tends to be temperate near the hilltops. Average minimum and maximum temperature in the district varies from 3° C to 35° C. The district receives precipitation in the form of rainfall, mainly during the monsoon period from July to September. The average annual rainfall in the district is about 1331.50 mm. The landslide is located in the village of Kotropi, Mandi district, Himachal Pradesh. The landslide had caused immense destruction to human lives (47 people) and also economical loss. Nearly 300 meters of national highway (NH-154) is destroyed and buried under debris. The landslide is a 'debris flow' type. It has a long runout which clearly suggest the heavy rainfall is the main cause of its occurrence.

Physiography (Shimla District)

Shimla is located along the south western region of Himachal Pradesh with an average elevation of 2,206 meters. The district has been divided into 12 Tehsils, 6 sub- tehsils and 7 sub-divisions. The district is mostly covered by mountainous region except for the few valleys. The elevation various from 300 to 6000 mts. Shimla district has highly dissected rough and steep slopes with high altitude peaks. Most of the district is covered by dense forest and the settlement regions are located in clusters along these hilly regions. Three major flows through Shimla (Giri, Pabbar, Sutlej). A total of 414 hectares of land has been designated as green belt in the Shimla planning area. Pine, Oak, Deodar and Rhododendron are the major forest grows that are found along these areas Prakasam, C., et al. (2018).

Economy (Shimla District)

Economy is mainly supported by three major factors in this region namely Agriculture, Horticulture and Tourism. The district grows many off season vegetables, fruits and cereals. Cereals, crops and off season vegetables are grown in the valleys, while temperate and stone fruits are grown along the higher altitudes. Wheat, barleys, maize, mullets and pulses are the major crops grown along this region. Employment is largely driven by the government and tourism sectors. Education sector and horticultural produce processing comprise most of the remainder. The hotel industry is one of the major sources of income generation for the city.

Climate (Shimla District)

Shimla has four distinct climate season under the Koppen climate classification. Winter rains (Jan and Feb), Pre Monsson (Apr to May), Monsoon (Jun to Sep) and Post Monsoon (Oct to Dec). The temperature varies between 0 C in winter to 40 C in the summer. The district receives 1000 mm of rainfall annually were most of the rainfall is received during the monsoon season and some during the winter rain. Humidity varies depending upon the season. Humidity goes as high as 85 to 90% during the monsoon and as less as 36% during the summer times.

Physiography (Mandi District)

Mandi District is a hilly region with many valleys and flat areas namely Sikandar Dhar, Vairkot, Dhauladhar, Ghogardhar etc running in the north west to south east direction formed due to the course of river beas and its tributaries. Average elevation of the district varies between 203 to 4,034 meters above MSL. Based on the physiography, climate and soils the district is divided into four major regions (i) Beas basin (ii) Sutlej basin (iii) Mandi lesser Himalaya and (iv) Dhauladhar (District census Handbook, 2011).

Economy (Mandi District)

Agriculture is the main economy activity of the district. 80% of the local population engage various agricultural activities as a source of their daily and monthly wages. Major agriculture production includes Paddy, Wheat and vegetable crops such as cereals, cash crops, off season vegetables, potato and ginger. On par with agriculture tourism also plays an important aspect of the economic activity with its many historically important places and nature tourist spots (District census Handbook, 2011).

Climate (Mandi District)

The district experiences temperate climate in hilltops and sub-tropical in the valleys and experiences cold climate through the year. Most of the regions are extensively covered by forest areas. Species such as blue pine, silver fir, spruce, deodar and chil are present in abundant at 4,000 feet above msl. The district receives its rainfall during north-east monsoon with an average of 1331.5 mm. Minimum and maximum temperature varies from 40° in plains to -20° throughout the district with snowfall covering the elevation close 1300 mts above MSL. Most of the Mandi district experience a variety of climatic conditions differentiated between the geographical region and altitude variations. Lower regions of the district experience severe summer and the hilly areas experience heavy snowfall during the winter time.

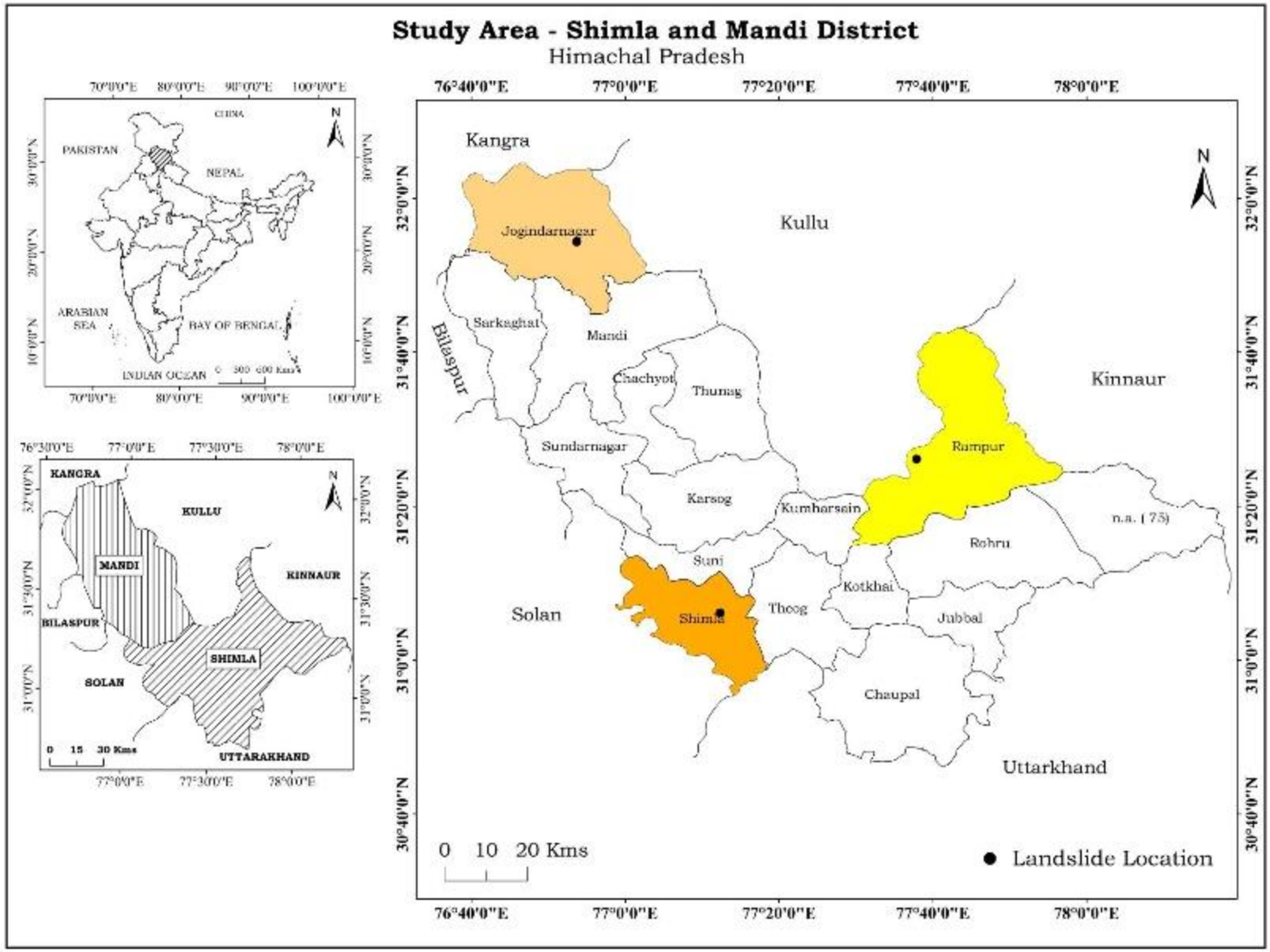

Figure No 4: Study Area

3.1 Study Area 1: Dhalli Landslide (Shimla Tehsil, Himachal Pradesh)

Dhalli landslide is located in Shimla Tehsil of Himachal Pradesh. The Rock Slided area is located along the Dhalli Tunnel in Shimla town (Figure No 5). The study area extends between 31°05'46" to 31°06'24" latitude and 77°11'55" to 77°12'40" longitude with a total geographical area of 85 ha. The study area falls under Survey of India Toposheet Number 53E/04. The total height of the landslide from crown to runout distance extends for about 76.7 m and the width of the landslide extends for about 18.6 m Prakasam, C., et al. (2020 a). Due to the Rockslide nearby Settlements along the downhill and few parked vehicles have been damaged (Figure No 6 & 7).

3.1.1 Soil

Soil datasets have been interpreted for the maps retrieved from SLUSI. Fine loamy type soil covers a larger part of the study with a total area of 78 hectares and 7 hectares constitute habitation (Figure No 8). Fine loamy soils play a huge role in landslide occurrences (Table No: 4). The soils vary in size ranging from 2 to 63 μ mts according to the soil classification system. These particles can be easily eroded and transported due to external forces. They are susceptible to landslides during rainfall season or any major earthquakes where the ground deformation is high.

Sl. No	Class	Area (hectares)	Percent (%)
1	Habitation	7	9.30
2	Fine loamy	78	90.70
	Total	85	100.00

Table No 4: Soil - Dhalli landslide, Himachal Pradesh

(Source: SLUSI)

3.1.2 Geology

Geology was interpreted from the maps retrieved form the Soil and Landuse survey of India (SLUSI). Slate forms the major portion of the study area (Figure No 9 & Table No 5). Slate ranges moderately strong rock in the Geological Strength Index. The joint sets along the landslide are highly jointed and there are gaps through soft infillings and rain waters infiltrate being one of the major factor for slope failure.

Sl.No	Class	Area (hectares)	Percent (%)
1	Habitation	45	52.94
2	Slate	40	47.06
	Total	85	100.00

Table No 5: Geology - Dhalli landslide, Himachal Pradesh

(Source: SLUSI)

3.1.3 Geomorphology

Geomorphologically the area is mostly Undifferentiated hill side (Table No: 6) and mountain side slope (Figure No 10). The first site is located at NH – 5A, near Dhalli area, Shimla Municipal corporation. Heavy monsoon rainfall triggered a massive rock slide (reactivated) on NH-5A near Dhalli area, Shimla district, Himachal Pradesh on 2nd September, 2017 which resulted complete damage of few parked vehicles, blockage and damage of National Highway and partial damage of a temple and nearby buildings. No casualties were reported due to the slide.

Sl.No	Class	Area (hectares)	Percent (%)
1	Habitation	45	52.94
2	Undifferentiated Hillside Slope	40	47.06
	Total	85	100.00

Table No 6: Geomorphology - Dhalli landslide, Himachal Pradesh

(Source: SLUSI)

3.1.4 Landuse Landcover

LULC was prepared using Worldview - 2 data in GIS environment to delineate the various feature. NRSC Level – 2 classification was used to differentiate various features. The area is covered by Shrub Forest, Shrub Land, Settlements and Barren land (Figure No 11). Shrub Forest and Shrub land cover about 38.6 ha to 24.3 ha which constitute approx. 70% of the study area (Table No: 7). The remaining area is composed of Barren land (10.6 ha), settlements (10.3 ha) and National Highway (2.0 ha).

Sl. No	Class	Area (hectares)	Percent (%)
1	Barren Land	10.61	12.38
2	Built-up Land	13.03	15.21
3	Roadways (NH -5A)	3.01	3.52
4	Shrub Forest	32.67	38.12
5	Shrub Land	26.36	30.77
	Total	85	100.00

Table No 7: LULC - Dhalli landslide, Himachal Pradesh

(Source: Worldview - 2)

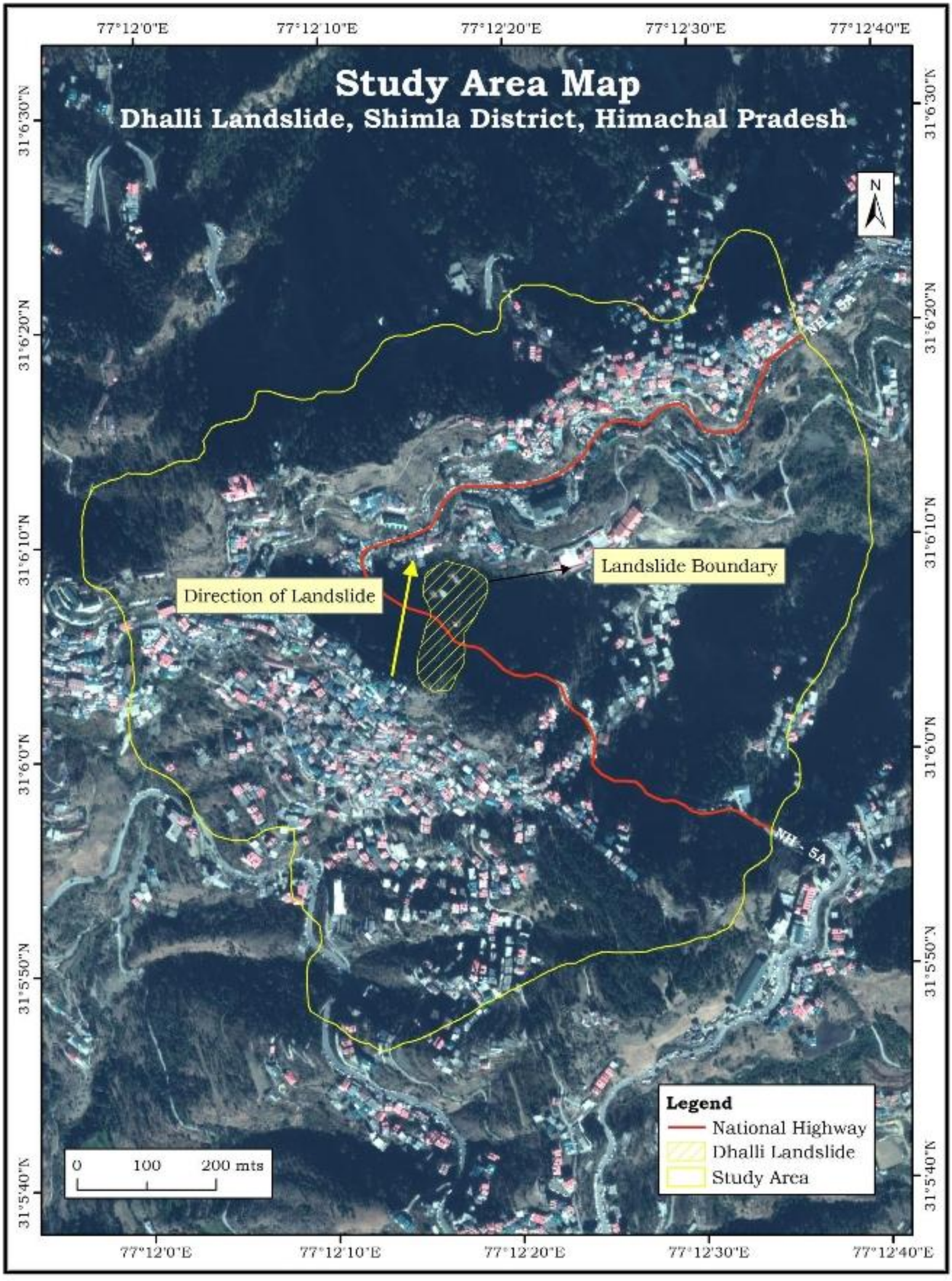

Figure No 5: Study area (Dhalli Landslide)

Figure No 6: Settlements damaged along the landslide (Dhalli Landslide)

(Source: Field Photographs)

Figure No 7: Damaged Vehicles and Buildings due to landslide (Dhalli Landslide)

(Source: Field Photographs)

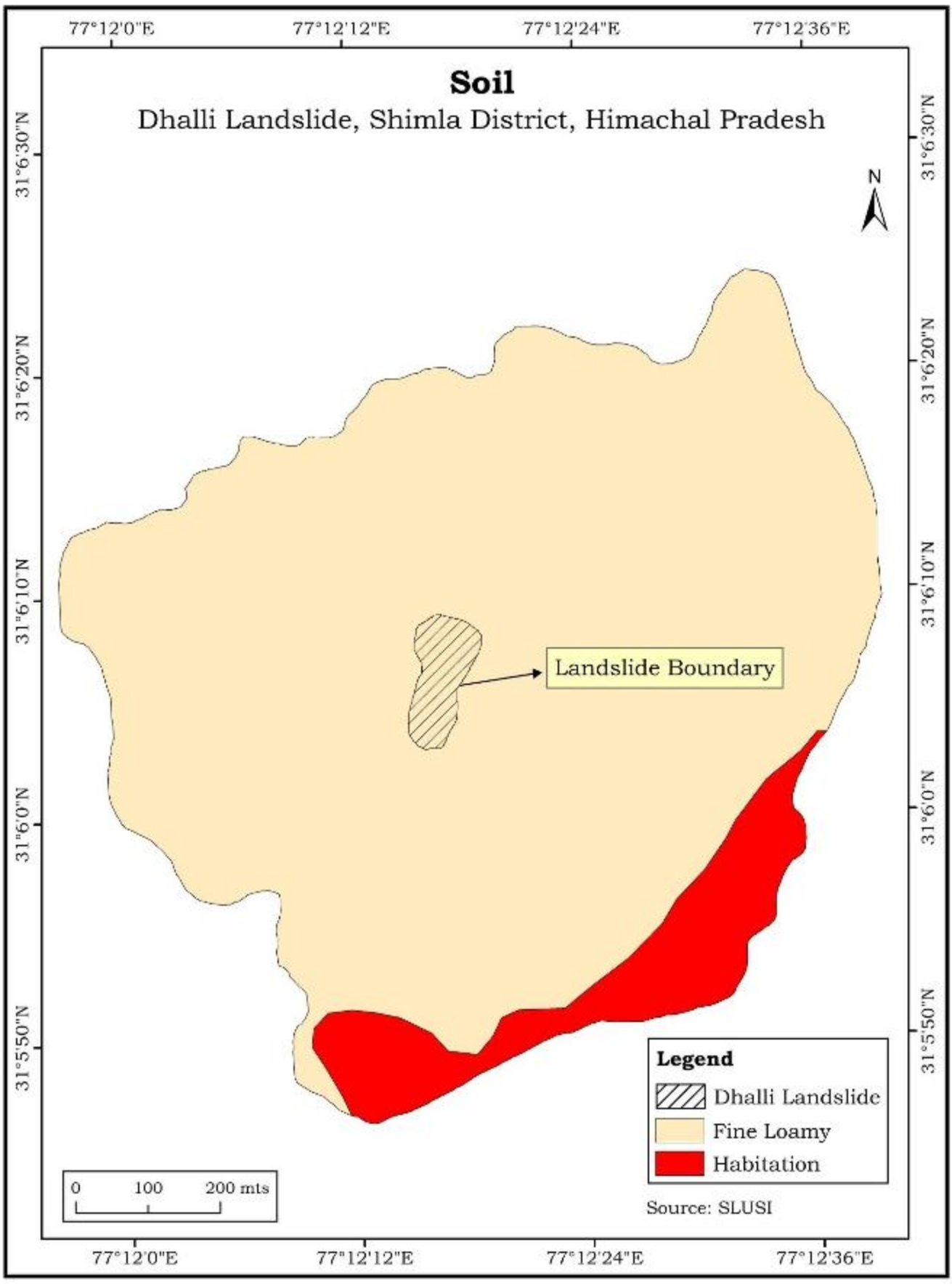

Figure No 8: Soil – Dhalli landslide

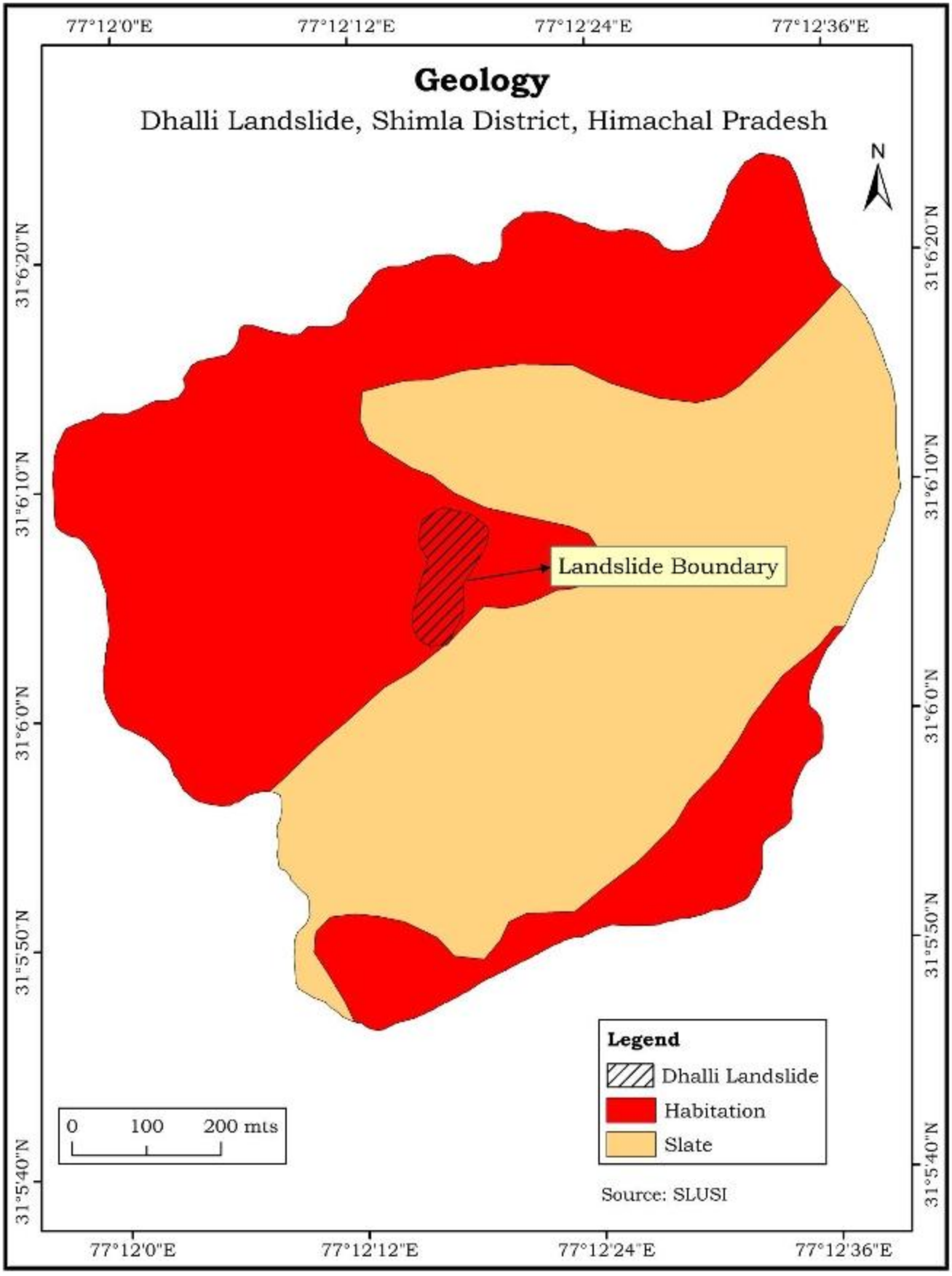

Figure No 9: Geology – Dhalli landslide

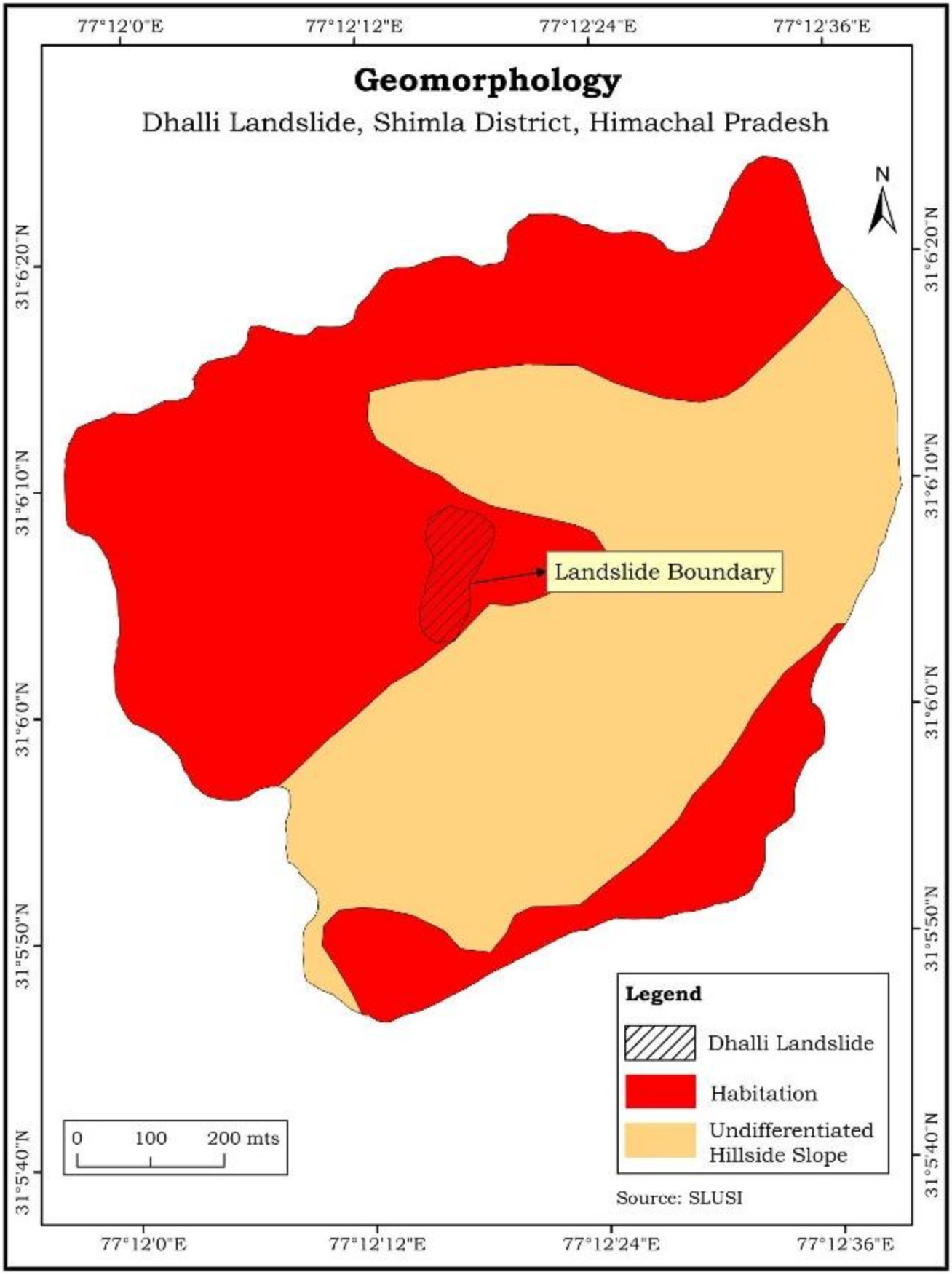

Figure No 10: Geomorphology – Dhalli landslide

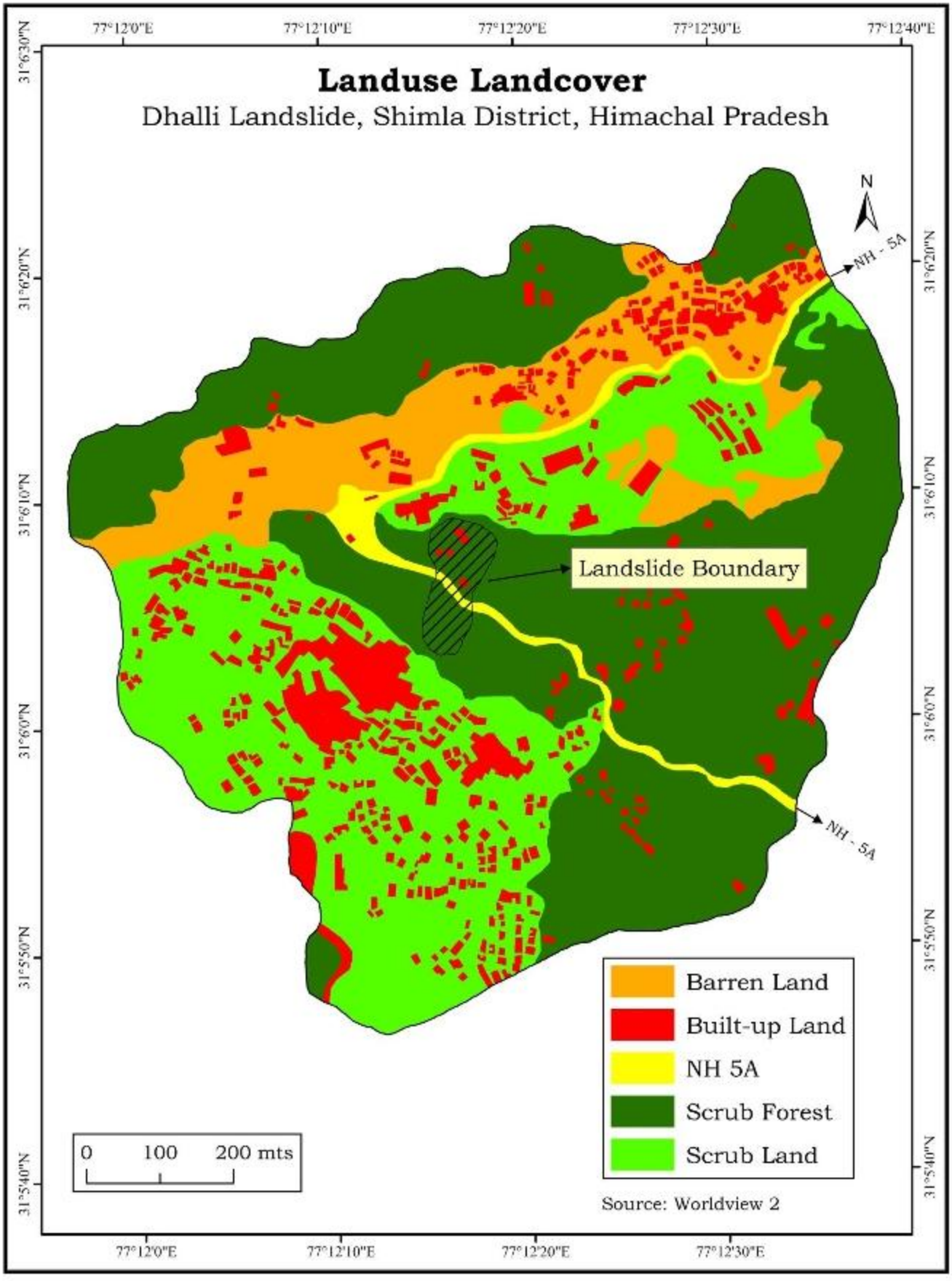

Figure No 11: Landuse Landcover – Dhalli landslide

3.1.5 Land Susceptibility – Dhalli (Rock slide)

Landslide susceptibility map (LSM) was developed for the Dhalli area using various physical and anthropogenic factors such as Geology, Soil, Geomorphology and LULC. The factors were rated using numerical modelling in scale of 1 to 5 ranging from very low to very high (Figure No 12). The final landslide susceptibility map was analyzed and processed in the GIS environment using weighted overlay method. The results reveal that 42.15% of the total area was covered in moderately vulnerable zone and 57.85% of the area is covered in high and very high vulnerable area (Table No: 8). The crown, main scarp and body of the landslide falls under high and very high vulnerable area Prakasam, C., et al. (2020 b).

Sl.No	Susceptibility	Area (hectares)	Percent (%)
1	Moderate	0.51	42.15%
2	High	0.5	41.32%
3	Very High	0.2	16.53%
	Total	1.21	100.00%

Table No 8: Landslide Susceptibility - Dhalli landslide, Himachal Pradesh

(Source: Authors Calculation)

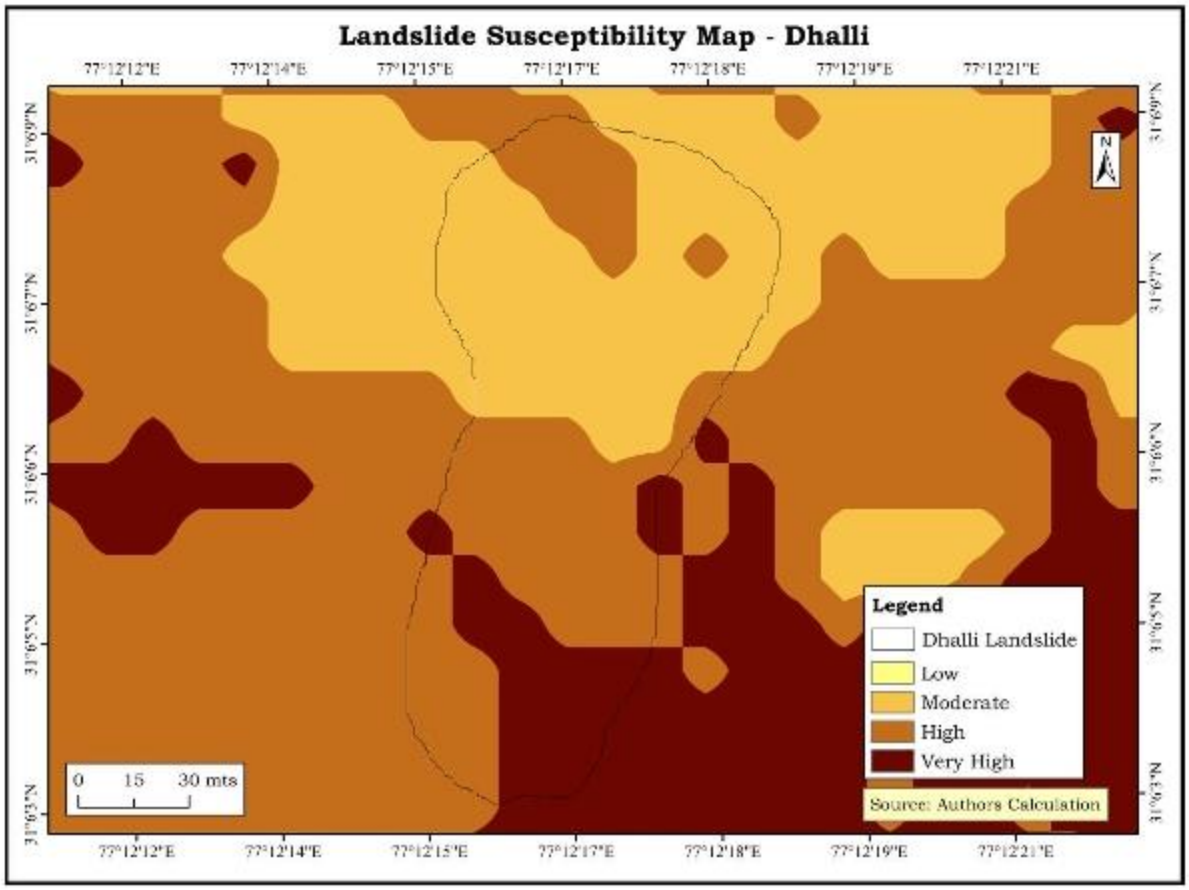

Figure No 12: Landslide Susceptibility Map - Dhalli

3.2 Study Area 2: Jhakri Landslide (Rampur Tehsil, Himachal Pradesh)

The landslide in research is located along the National Highway (NH – 22) along the edge of Jhakri town (Figure No 13). The study area extends from 77°41'30" to 77°42'15" N and 31°28'45" to 31°29'30" E (Figure No 14). The total extent of the study area is of 74.7 ha. The study area falls under Survey of India Toposheet Number 53E/11. Rampur Tehsil has 218 villages and a population of 77,542. Sutlej is the only source of river that drains through Rampur Tehsil. While the northern part of the Tehsil is covered by glaciers coarse and fine loam are the two major types soil attributes present in this area. The area has variety of rock types namely Schist, Slate and Alluvium. Agriculture and Horticulture are the important trademarks of Rampur. Beside agriculture few medicinal herbs, grass and bamboo also provides economic stability in these areas. Agriculture and Horticulture other forest produces are mainly dependant on the monsoonal rainfall. Along with Agriculture the Tehsil also thrives on tourism and other small scale industrial jobs. Rampur experiences Sub – tropical climate in the valleys and temperate in the hill tops. An average of 999.4 mm of rainfall is recorded where most of the rainfall is received during monsoon period. Average temperature ranges from minus 0° in the winter to about 40 in the summer. Jhakri has two major hydroelectric projects of 1500 MW and 343 MW capacity Prakasam, C., et al. (2020 c).

Figure No 13: Field photographs of Jhakri landslide

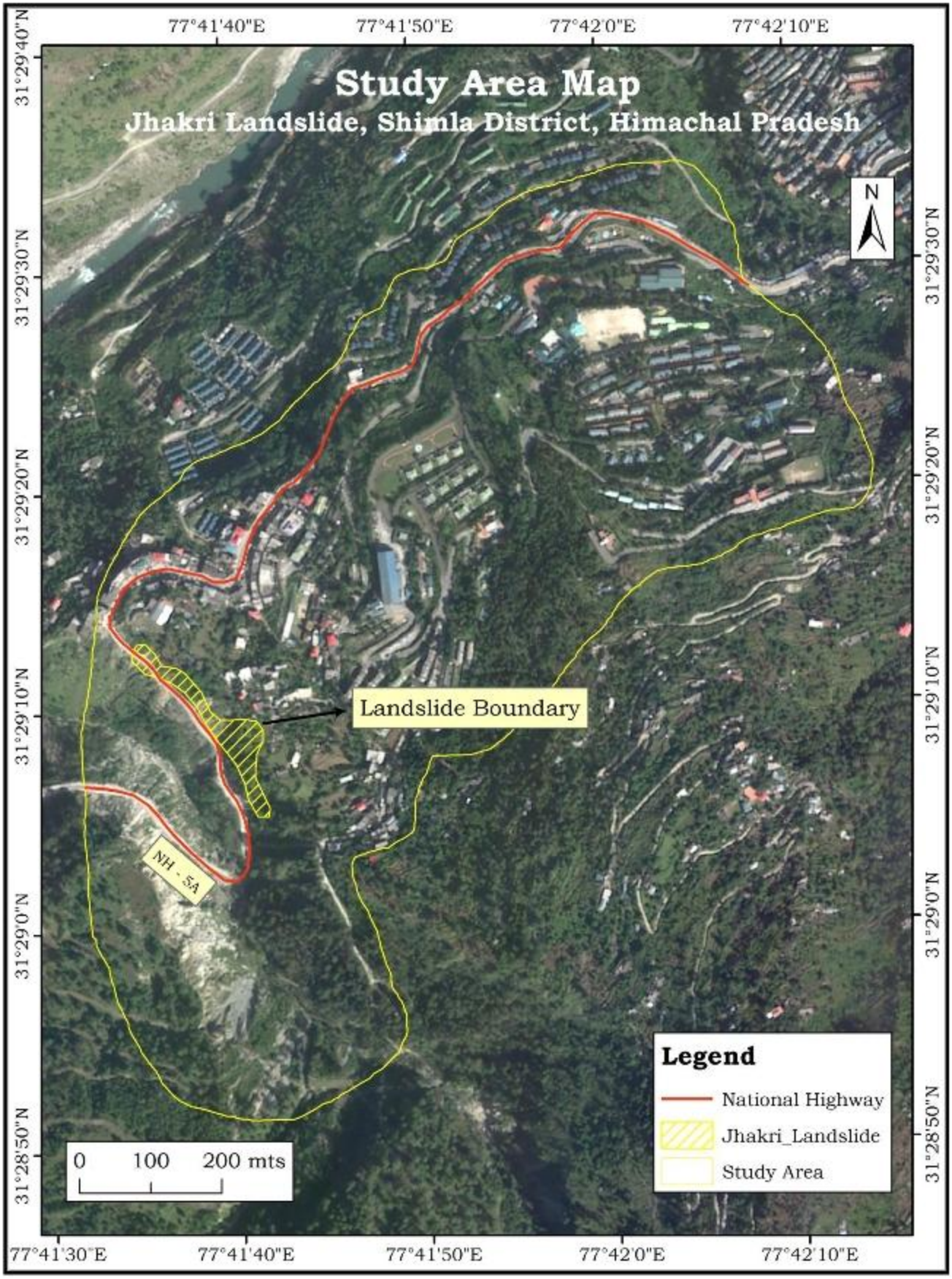

Figure No 14: Study area (Jhakri Landslide)

3.2.1 Soil

The soil class in the study area is diversified into two classes namely Coarse Loam and Fine Loamy (Figure No: 15). Fine loamy covers most of the study area with 43.85%. Coarse loamy covers about 56.15% (Table No: 9). Coarse loamy and Fine loamy soils play a huge role in landslide occurrences. The soils vary in size ranging from 2 to 63 μ meters according to the soil classification system Prakasam, C., et al. (2020 d). These particles can be easily eroded and transported due to external forces. They are susceptible to landslides during rainfall season or any major earthquakes where the ground deformation is high.

Sl.No	Class	Area (ha)	Percent
1	Coarse Loamy	41.9	56.15
2	Fine loamy	32.7	43.85
	Total	74.6	100.00%

Table No 9: Soil – Jhakri landslide, Himachal Pradesh

Source: SLUSI

3.2.2 Geology

Geology is study of physical characteristics of rocks such as size, texture, core samples etc. Geology was digitized from Soil and Landuse Survey of India maps at 1:50,000 scales**.** The Geology of the study area mainly covers two distinct types namely Schist and Slate (Figure No: 16). Both Schist and Slate accounts for 63.61% and 36.39% (Table No: 10). Schist and Slate ranks weak to moderately strong rock in the Geological Strength Index. However, slope surface along the area are more prone landslides due to its high monsoon activity and also ground tremor induced by the traffic along the National Highways.

Sl.No	Class	Area (hectares)	Percent (%)
1	Schist	47.45	63.61
2	Slate	27.15	36.39
	Total	74.6	100.00%

Table No 10: Geology Class – Jhakri landslide, Himachal Pradesh

Source: SLUSI

3.2.3 Geomorphology

The geomorphology of the study area is classified into two types namely, Undifferentiated hillside slopes and Undifferentiated mountainside slopes (Figure No 17). Nearly 89.42% of the study area falls under undifferentiated mountainside slopes. Undifferentiated hillside slopes cover about 10.58% (Table No: 11).

Sl.No	Class	Area (hectares)	Percent (%)
1	Undifferentiated Mountainside Slope	66.7	89.42
2	Undifferentiated Hillside Slope	7.9	10.58
	Total	74.6	100.0

Table No 11: Geomorphology Class – Jhakri landslide, Himachal Pradesh

Source: SLUSI

3.2.4 Landuse Landcover

LULC was digitized using the CARTOSAT – 2A data. NRSC level 2 classification was used for feature classification. Most of the Landuse category fall under forest and Shrub lands contributing about 30.84% and 34.99% (Table No: 12) of the area. Barren land and Built-up land together contributes about 40.4% and agriculture contributes only 1.74%. Few off season plantation were grown nearby settlements as agriculture practices. The town is mostly residential area with most of the population depend on the Agriculture practices Prakasam, C., et al. (2020 e). The landslide is located along the Slope region coursing through National Highway- 22 connecting Rampur to Jhakri town (Figure No 18)

Sl.No	Class	Area (hectares)	Percent (%)
1	Barren Land	16.36	21.90
2	Built-up Land	7.87	10.53
3	Agriculture	1.3	1.74
4	Forest	23.04	30.84
5	Shrub Land	26.14	34.99
	Total	74.6	100.00

Table No 12: LULC – Jhakri landslide, Himachal Pradesh

Source: SLUSI

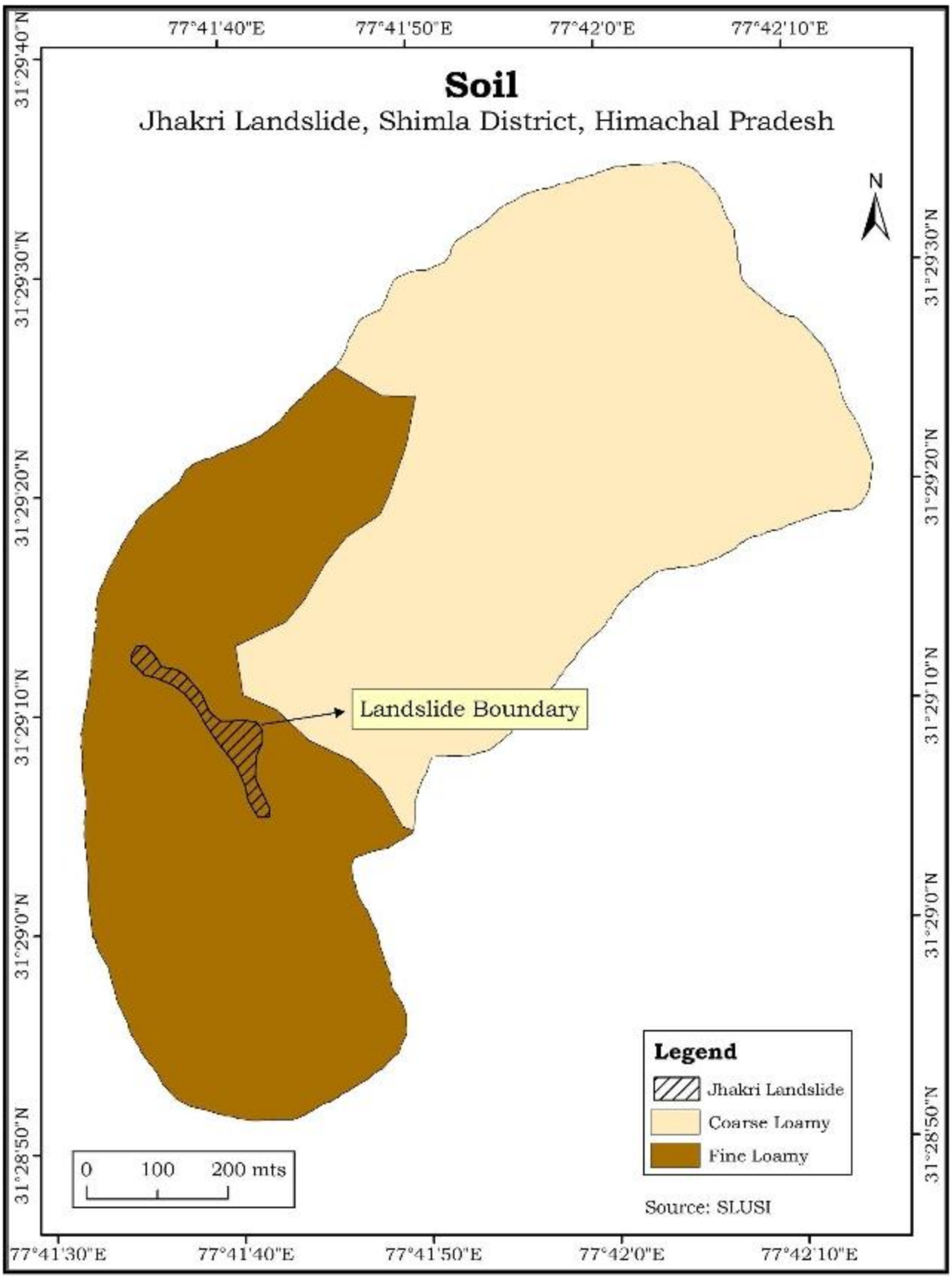

Figure No 15: Soil – Jhakri Landslide

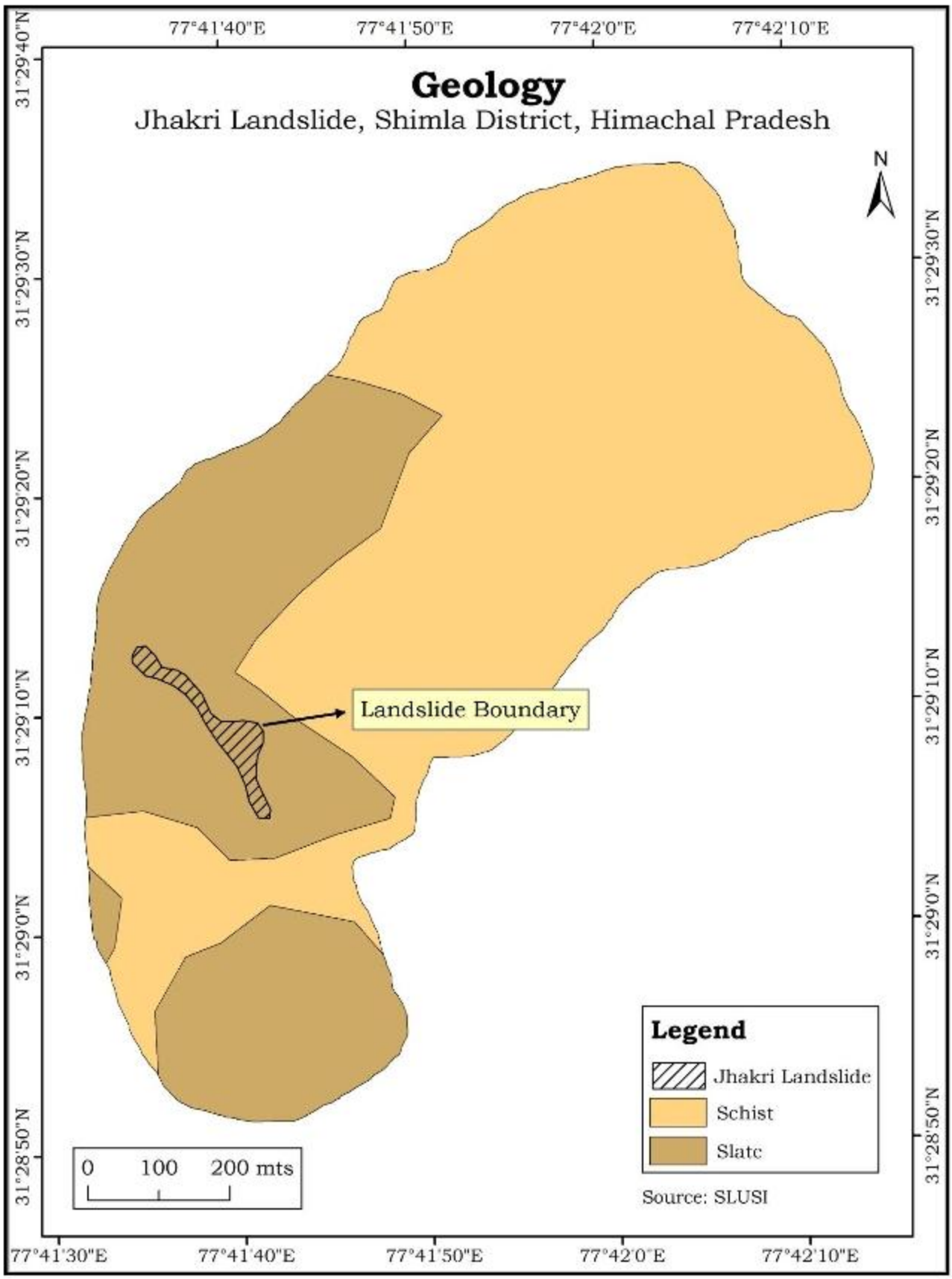

Figure No 16: Geology – Jhakri Landslide

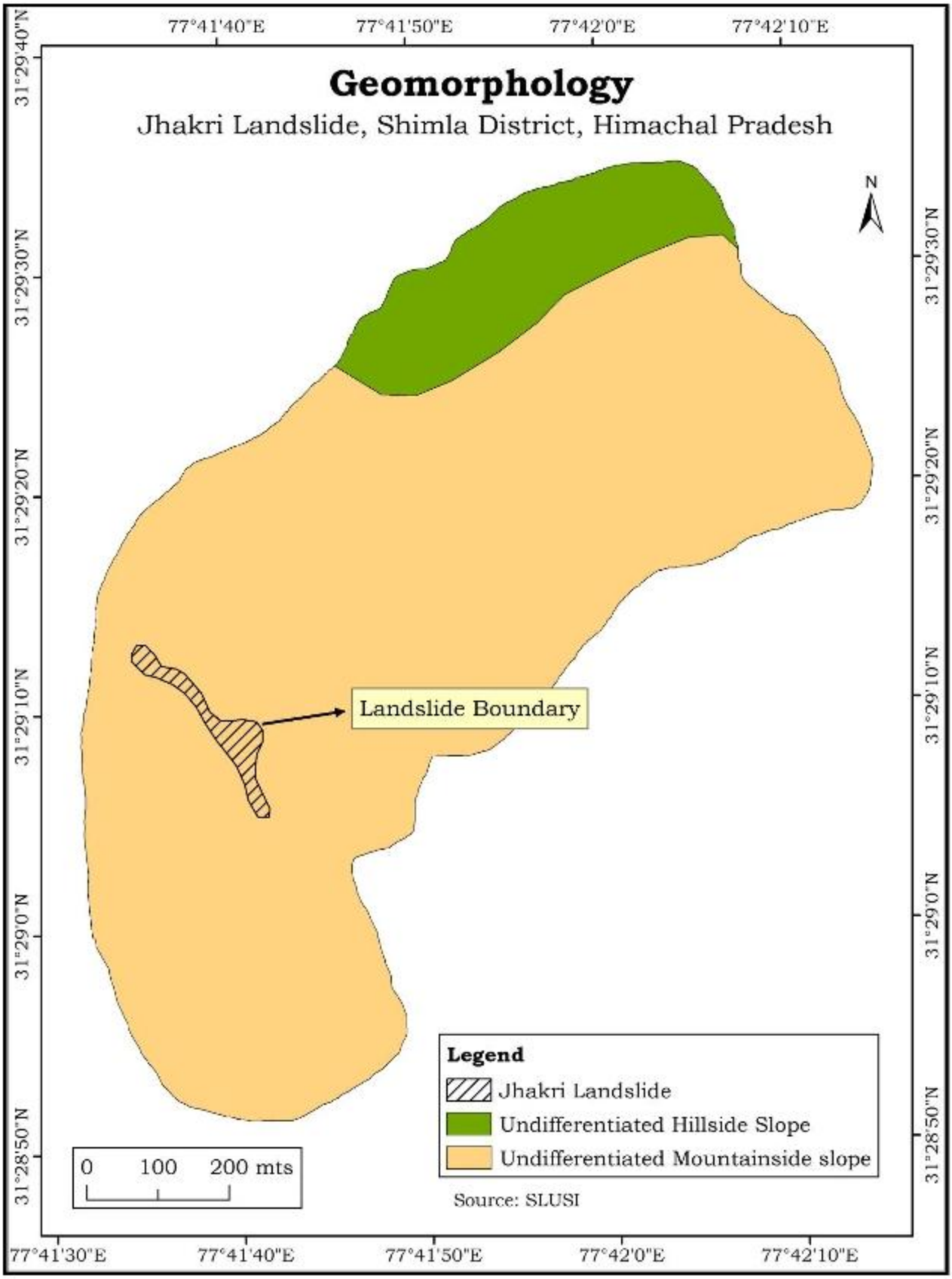

Figure No 17: Geomorphology – Jhakri Landslide

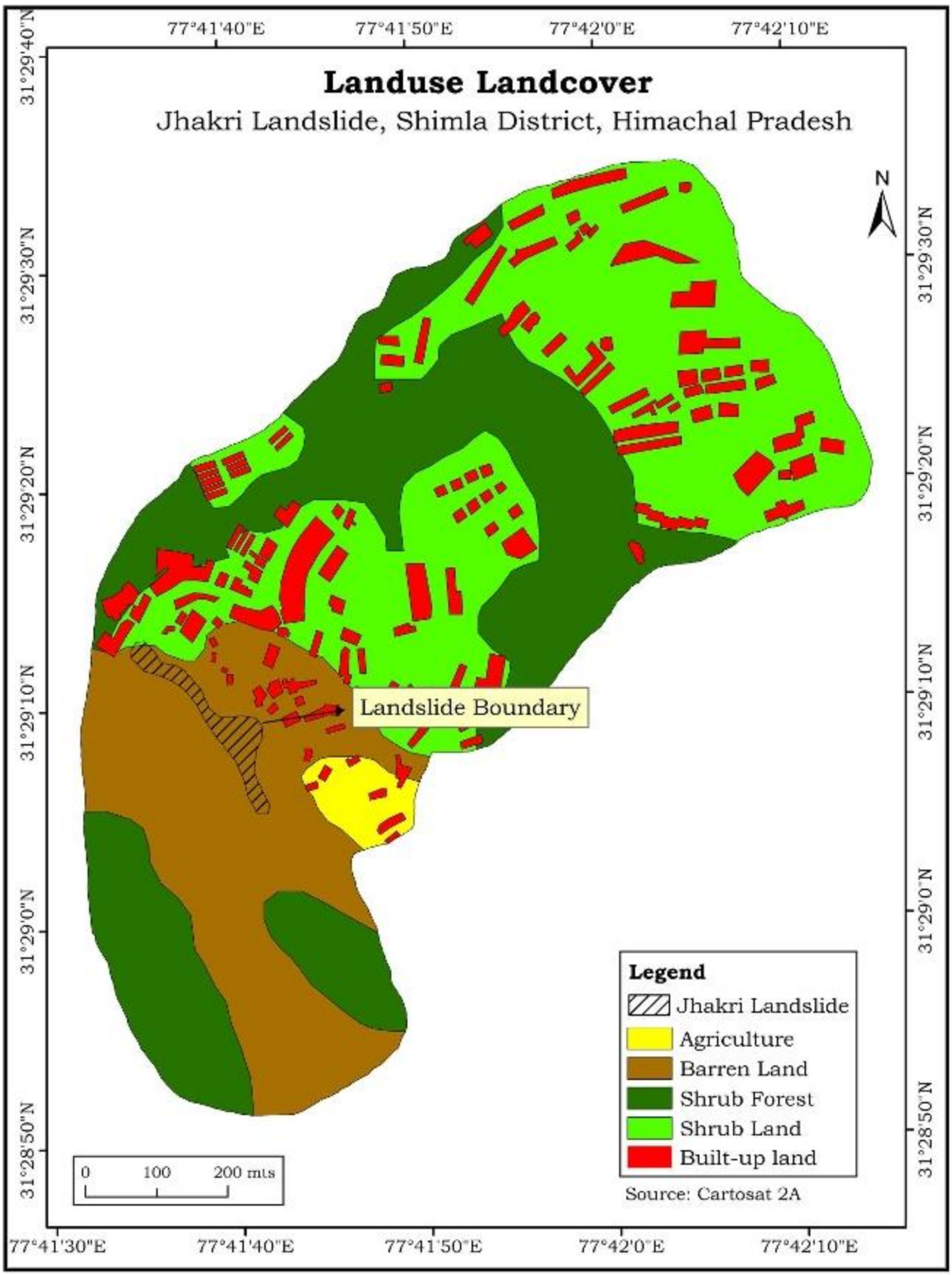

Figure No 18: Landuse and Landcover – Jhakri Landslide

3.2.5 Land Susceptibility – Jhakri (Debri Slide)

Landslide susceptibility map have been developed for the Dhalli area using various physical and anthropogenic factors such as Geology, Soil, Geomorphology and LULC. The factors were rated using numerical modelling in scale of 1 to 5 ranging from very low to very high. The final Landslide susceptibility map has been analyzed and processed in the GIS environment using weighted overlay method. The results reveal that 100% of the total area was covered in Very High vulnerable zone (Figure No 19). The crown, main scarp and toe of the landslide falls under very high vulnerable area. The Dhalli landslide is located along the steep slopes of NH-22. The Debri soil nature of the landslide region, Overburden due to settlements along the crown pat of the landslide coupled with pore water pressure during the monsoon season makes highly vulnerable for the reinitiation of landslides.

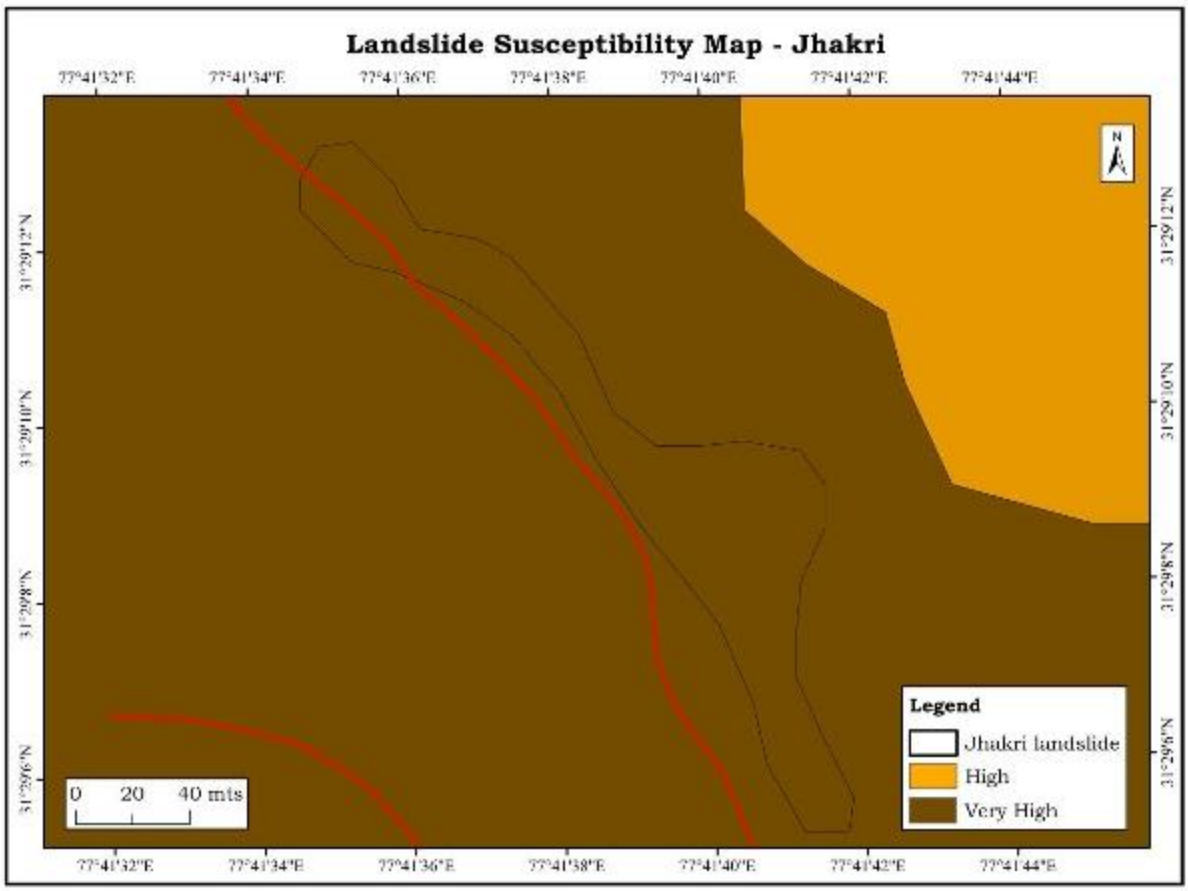

Figure No 19: Landslide Susceptibility Map – Jhakri Landslide

3.3 Study area 3 Kotropi landslide: (Padhar Tehsil, Himachal Pradesh)

Kotropi landslide is located at Padhar tehsil of Mandi district, Himachal Pradesh (Figure No 16b). The Mandi district is situated between 31˚13'0" to 32˚04'01" north latitude and 76˚37'45" to 77˚23'21" east longitude (Figure No 20). The landslide site falls under Survey of India Toposheet Number 53A/13. Kotropi landslides is of deep

seated type with point of failure more than 30 mts below the surface. Post landslide analysis of Kotropi landslide revealed that the entire stretch of the landslides extends for 1155 mts. The landslide has completely destroyed the step cultivation, settlements and national highways located along the upslope as well as downslope of the study area (Figure No 21). The total geographical area of the district is 3, 950 sq.km. As of 2011 census data the total population of Mandi is 9,99,777 people. The district has 2 main rivers viz. the Beas and the Sutlej. The climate of the district is sub-tropical in the valleys and tends to be temperate near the hilltops. Average minimum and maximum temperature in the district varies from 3° C to 35° C. The district receives precipitation in the form of rainfall, mainly during the monsoon period from July to September. The average annual rainfall in the district is about 1331.50 mm. The landslide is located in the village of Kotropi, Mandi district, Himachal Pradesh. The landslide had caused immense destruction to human lives (47 people) and also economical loss (Figure No 22). Nearly 300 m of National highway 154 is destroyed and buried under debris. The landslide is a 'debris flow' type. It has a long runout which clearly suggest the heavy rainfall is the main cause of its occurrence. The width of the landslide is 190 m and the run out length is 1155 m.

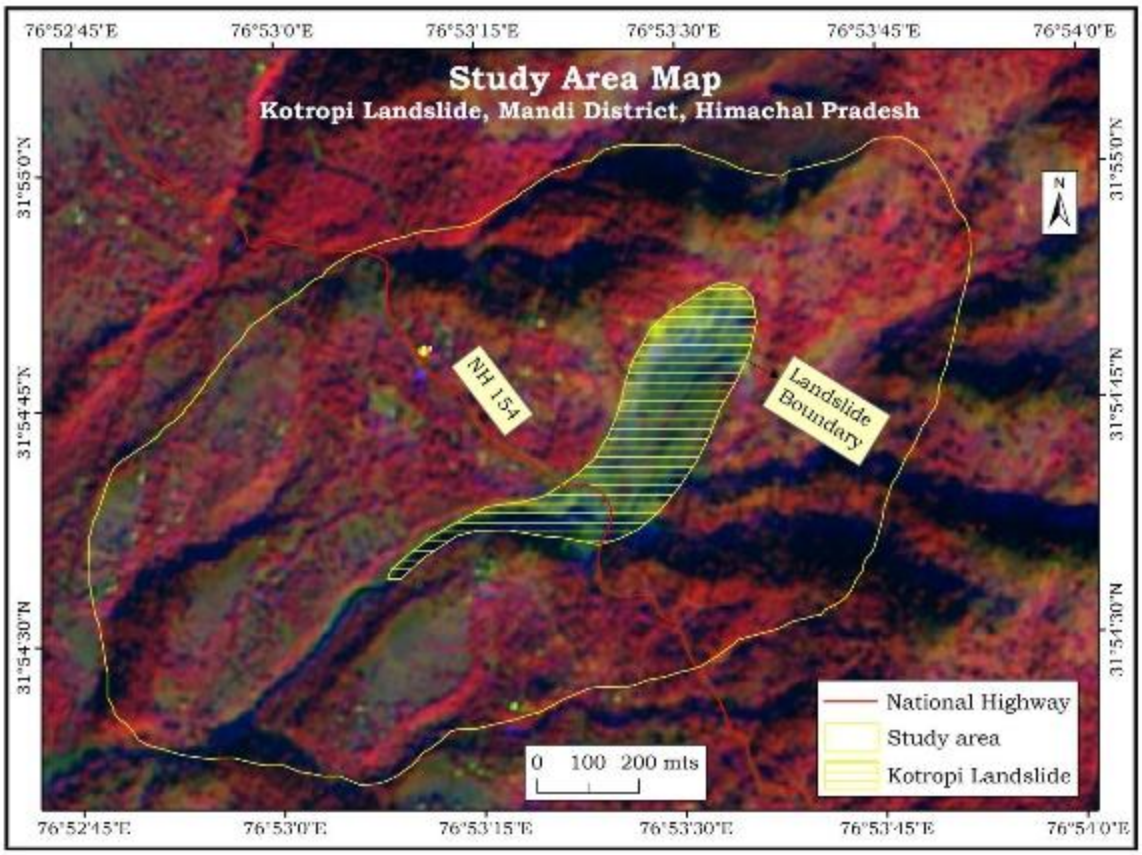

Figure No 20: Study area (Kotropi Landslide)

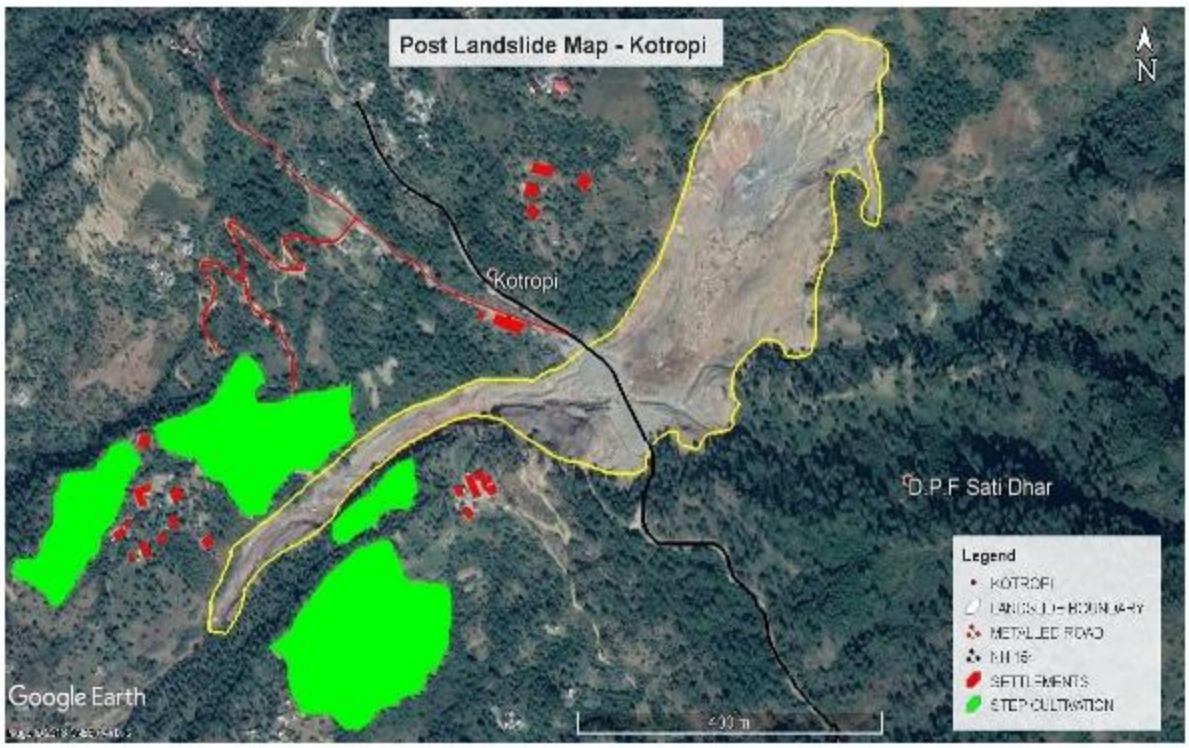

Figure 21: Kotropi Landslide (Post slope failure)

Source: Authors Calculation

Figure 22: Field Photographs (Post slope failure)

3.3.1 Soil

Two types of soils are mainly observed in the Mandi district viz. Sub-Mountainous Soil occurring in Seraj and Karsog blocks and Mountainous Soil occurring in remaining eight blocks of the district. The Lithic Udorthents is present in 52.16% and 47.8% constitutes about Dystrictic Fluventric Eutrochrepts soil (Table No 13) is high in organic carbon, low in available phosphorous and medium in potash, whereas the mountainous soil is brown in colour, medium in available nitrogen & potash and deficient in available phosphorous. The soil reaction is slightly acidic to neutral and texture in general varies from loam to sandy loam, except in low valley areas being heavy textured (Figure No 23).

Sl.No	Soil Class	Area (hectares)	Percent (%)
1	Lithic Udorthents	77.87	52.19%
2	Dystrictic Fluventric Eutrochrepts	71.26	47.81%
	Total	149.08	100.00

Table No 13: Soil – Kotropi landslide, Himachal Pradesh

Source: SLUSI

3.3.2 Geology

Geologically the area is in a thrusted contact (Main Boundary thrust) between the Siwaliks and major rocks groups constitutes about Mandi Darla Volcanics (31.75), Katpul memer (39.9%) and Lower Siwalik constitutes about (28.2%) (Table No 14). The landslides area mainly constitutes both rock and soil particles combined where fine soil particles major contribution (Figure No 24).

Sl.No	Class	Area (hectares)	Percent (%)
1	Mandi Darla Volcanics	47.36	31.76%
2	Katpul memer	59.6	39.97%
3	Lower Siwalik	42.14	28.26%
	Total	149.08	100.00

Table No 14: Geology – Kotropi landslide, Himachal Pradesh

Source: SLUSI

3.3.3 Geomorphology

Mandi district presents an intricate mosaic of mountain ranges, hills and valleys. Slopes are mainly found dipping towards southwest. The south western part consists of Siwalik ranges having scarped slopes. There are few small intermountain valleys;

prominent among them is the Balh valley, located in the lesser Himalayan ranges, having an average altitude of about 790 m above MSL and have a general slope towards NNE (Table No 15). The valley floor is undulating and is marked by low hillocks and terraces fringing the hills and intervening low alluvial plain (Figure No 25).

Sl.No	Class	Area (hectares)	Percent (%)
1	Undifferentiated mountainside slope	81.9	54.9%
2	Alluvial plains	67.18	45.0%
	Total	149.08	100.00

Table No 15: Geomorphology – Kotropi landslide, Himachal Pradesh

Source: SLUSI

3.3.4 Landuse Landcover

LULC changes are calculated along the study area for the year 2019 (Figure No 26). The change in Landuse is estimated using supervised classification using maximum likelihood method. Training sites are derived from the FCC and Pan merged LANDSAT data to achieve a greater accuracy. Google earth imageries are used in conjunction with the Pan merged LANDSAT data for classifying training sets. The analysis revealed that a greater portion of the study area falls under Plantation and Shrub lands. Both plantation and Shrub land accounts for about 10% and 75% of the total land surfaces. The post landslide satellite imageries reveal that 10% of the study area is covered under landslides. The landslide area mostly affects the natural slopes and agricultural areas that are present along the downslope of the landslide. Barren land and Built-up land accounts for about 3.1% of the area (Table No 16).

Sl.No	Class	Area (hectares)	Percent (%)
1	Barren Land	3.91	2.62%
2	Built-up Land	0.83	0.56%
3	Plantation	16.34	10.96%
4	Landslide Area	15.60	10.46%
5	Shrub Land	112.4	75.40%
	Total	149.08	100.00

Table No 16: LULC – Kotropi landslide, Himachal Pradesh

Source: SLUSI

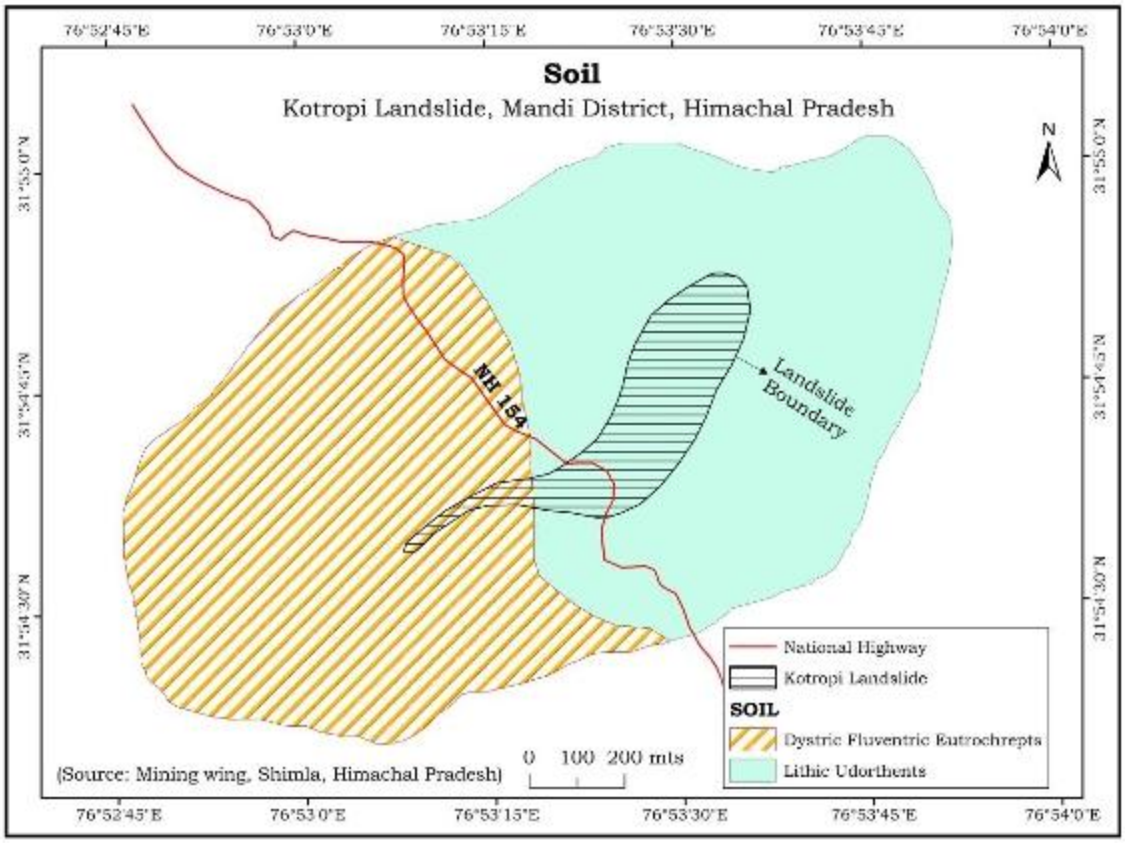

Figure No 23: Soil – Kotropi Landslide

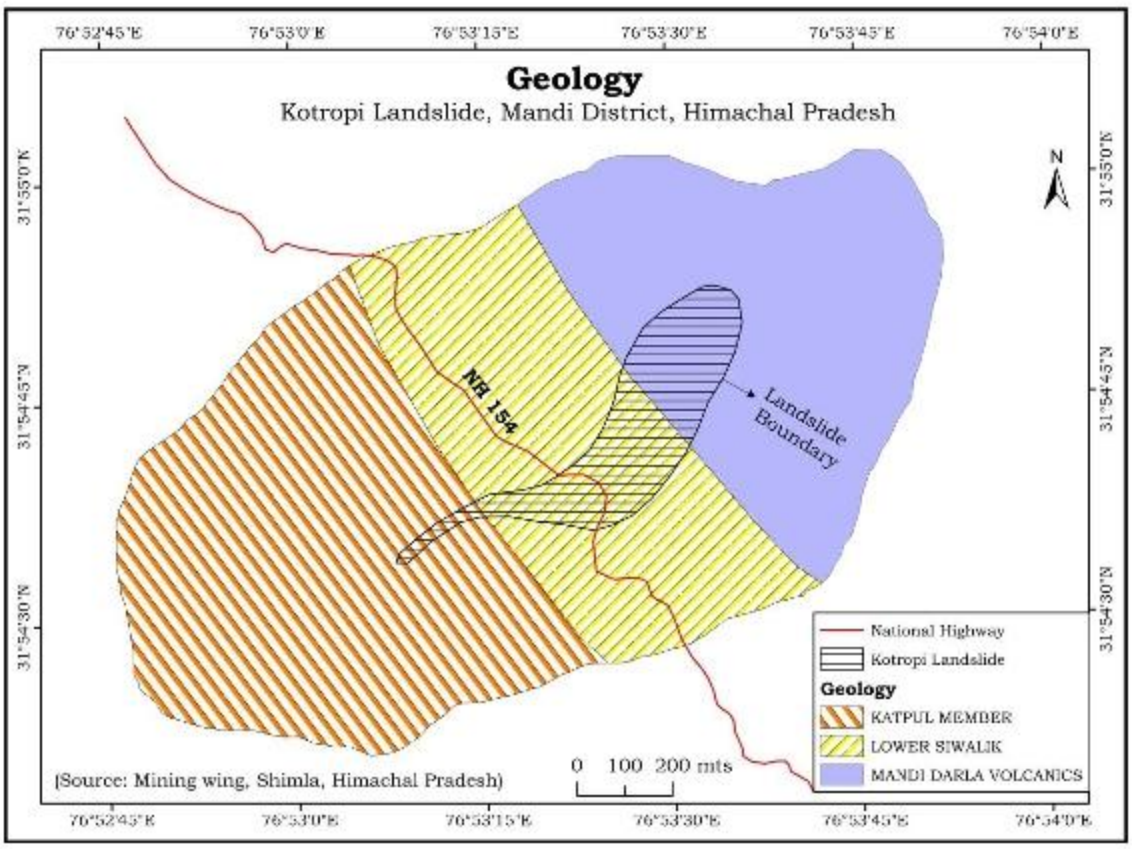

Figure No 24: Geology – Kotropi Landslide

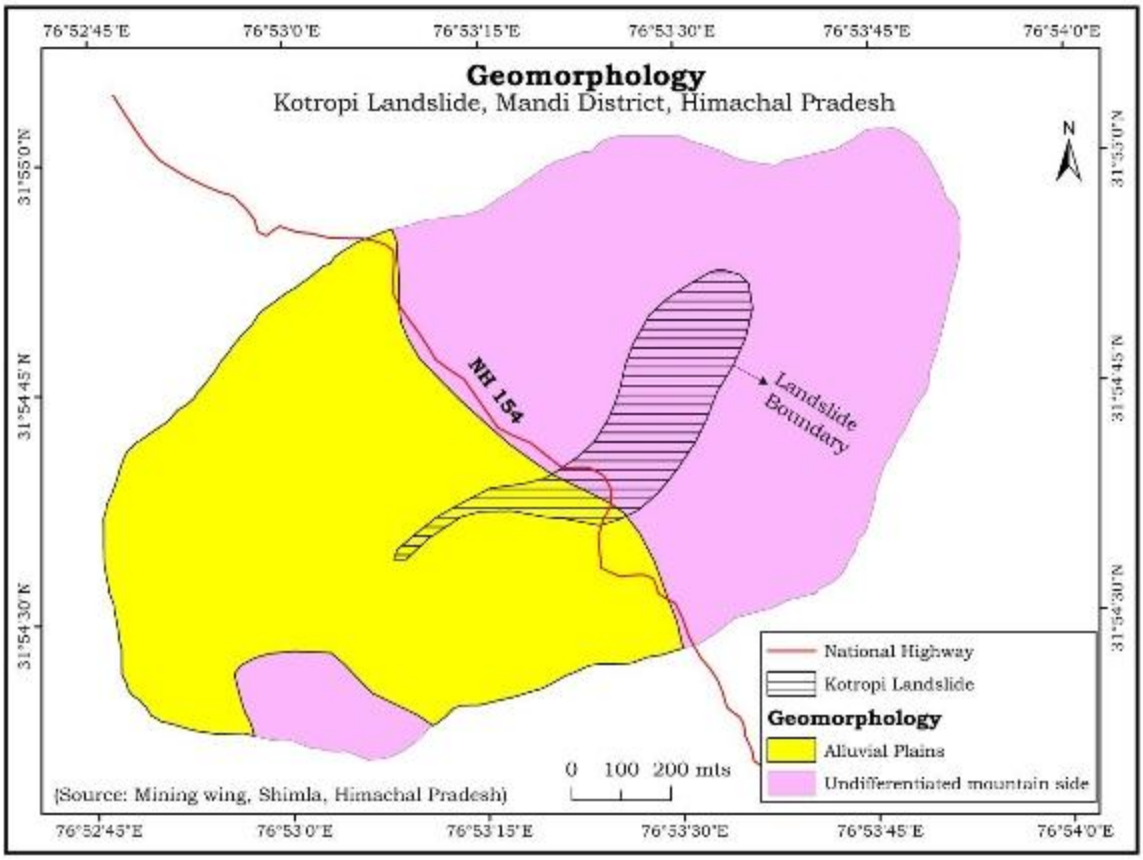

Figure No 25: Geomorphology – Kotropi Landslide

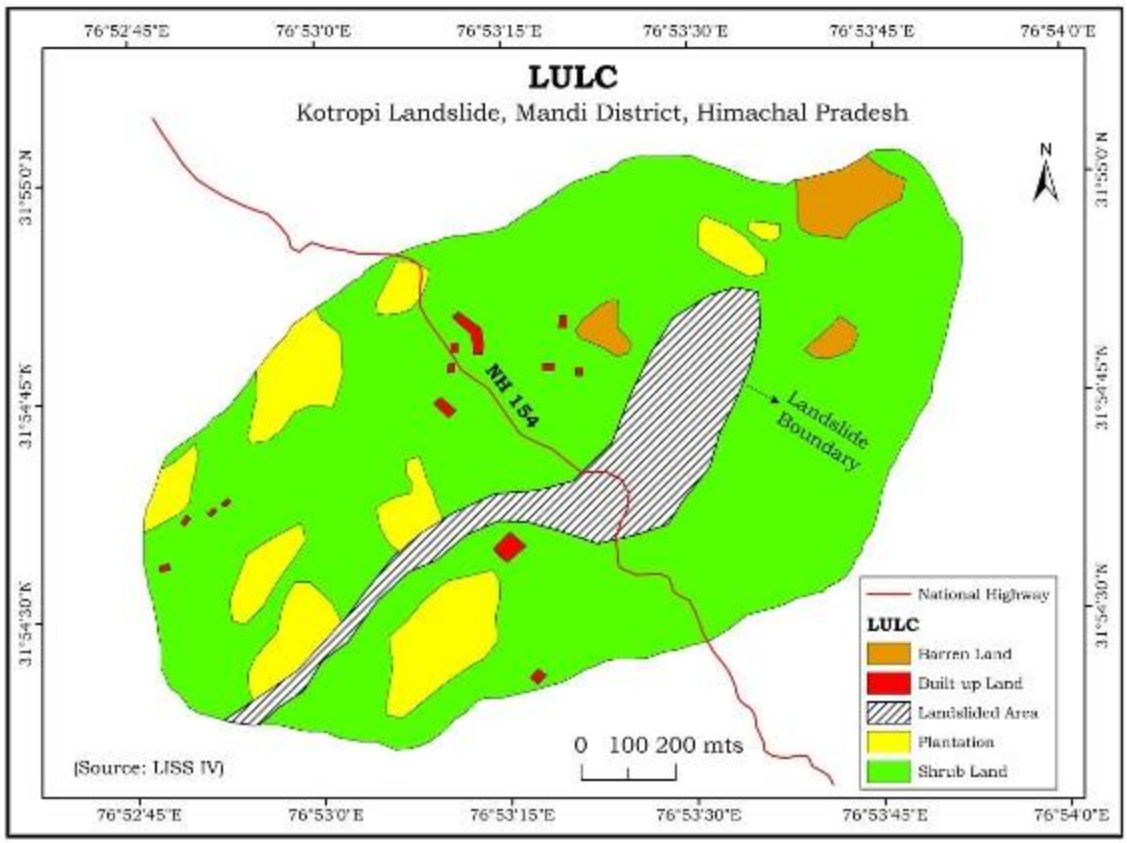

Figure No 26: Landuse Landcover – Kotropi Landslide

3.3.5 Land Susceptibility – Kotropi (Complex slide)

Landslide susceptibility map have been developed for the Kotropi area using various physical and anthropogenic factors such as Geology, Soil, Geomorphology and LULC. The factors were rated using numerical modelling in scale of 1 to 5 ranging from very low to very high. The final Landslide susceptibility map has been analyzed and processed in the GIS environment using weighted overlay method. The results reveal that 43.5% of the total area was covered in moderate vulnerable zone, 42.5% falls under high vulnerable zone and 14% falls under very high vulnerable zone. The crown, main scarp and toe of the landslide falls under very high vulnerable area (Figure No 27).

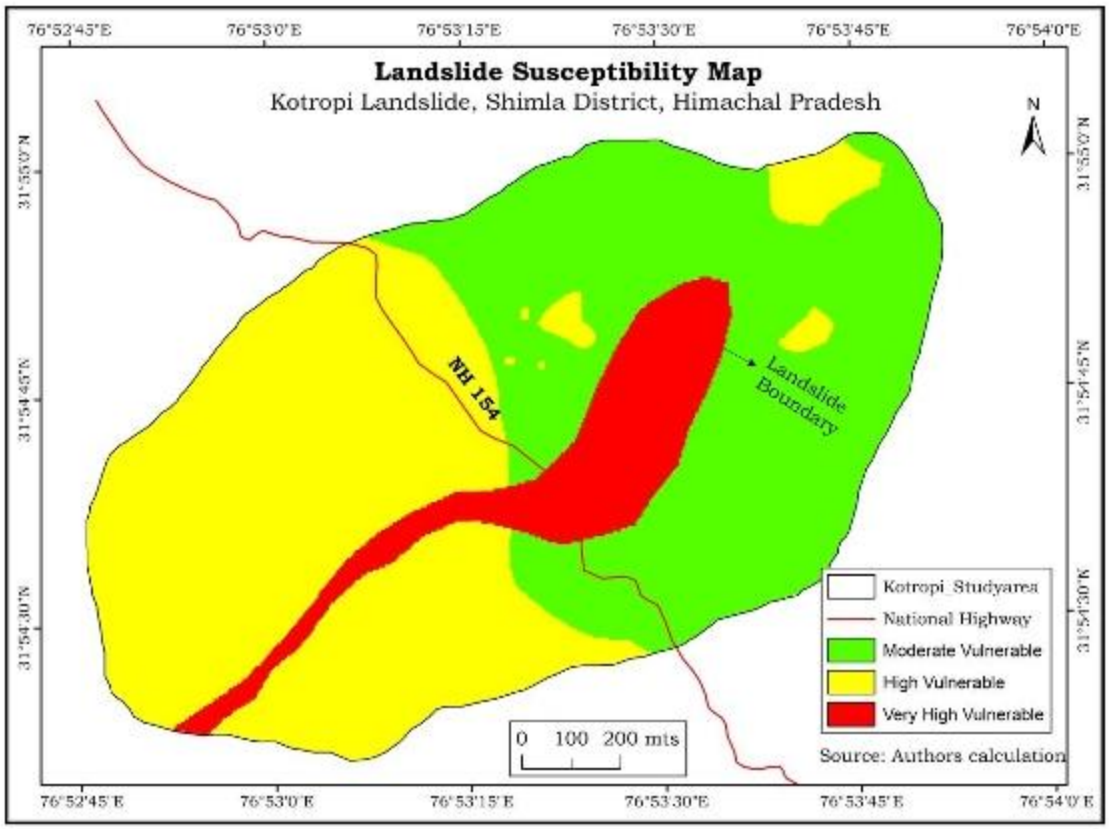

Figure No 27: Landslide Susceptibility Map - Kotropi landslide

S.no	Vulnerable category	Percent (%)
1	Moderate	43.5
2	High	42.5
3	Very High	14

Table No 17: Landslide Susceptibility – Kotropi landslide, Himachal Pradesh

(Source: Authors Calculation)

3.4 Rainfall Characteristics of the Study area:

Shimla district mainly receives its rainfall from the South-West Monsoon due the western disturbances that move along the north-west part of the country. The monsoon season exists from the Mid-June to September along these regions where Jhakri receives its peak rainfall during the month of July and August. The region also receives rainfall during the winter season (January and February), the rainfall occurrences are frequent and inconsistence during the winter season that causes more landslides compared to the post – monsoon rainfall.

3.4.1 Dhalli Study area:

Dhalli study area has four major seasons, The winter Rain, Pre Monsoon, Monsoon and Post Monsoon. The study area receives most of its rainfall from the month of June to September and also during the winter rain.

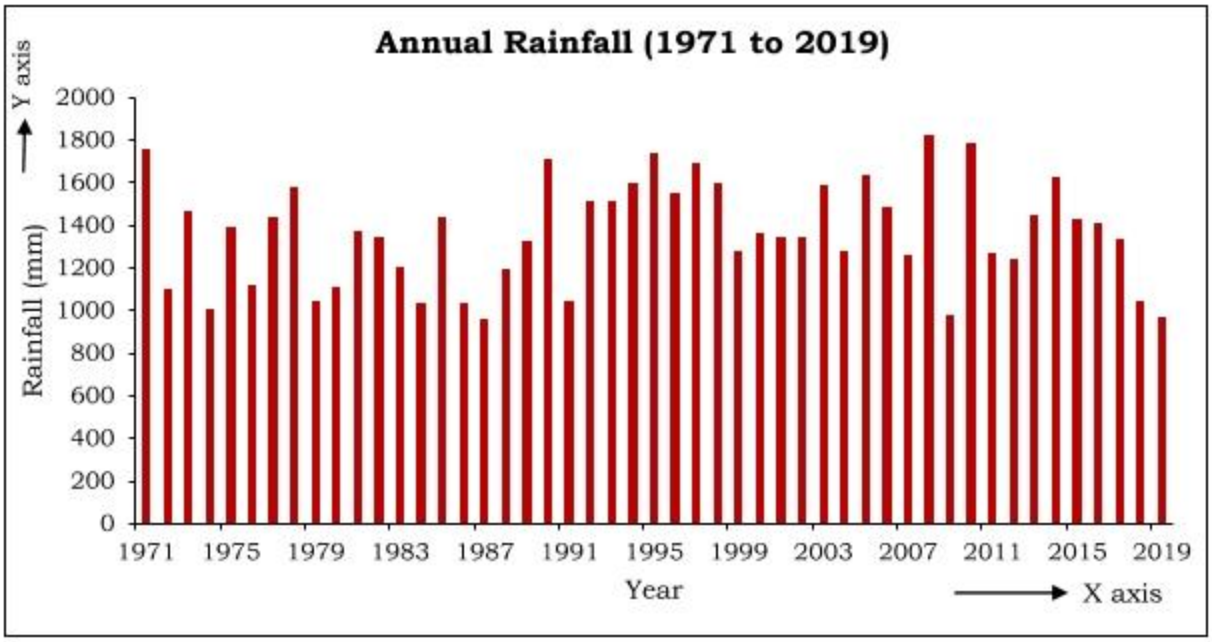

Figure No 28: Annual rainfall precipitation - Dhalli (1971 to 2019)

(Source: Author's Calculation)

In the recent years the Dhalli area has been receiving rainfall of 1250 mm to 1630 mm along the region between 1971 to 2019 and most of the rainfall has been received during the Monsoon season and Winter Rain (Figure No 28 and 29). The severe rainfall intensity causes high infiltration rate along the soil surface leading to the increased pore water pressure and soil burden leading to the instability of slopes. Water infiltration along the fractured rock surface and joint beds and the repeated freeze & thawing of the rocks leads to rupturing of rock slopes leading to mass movements.

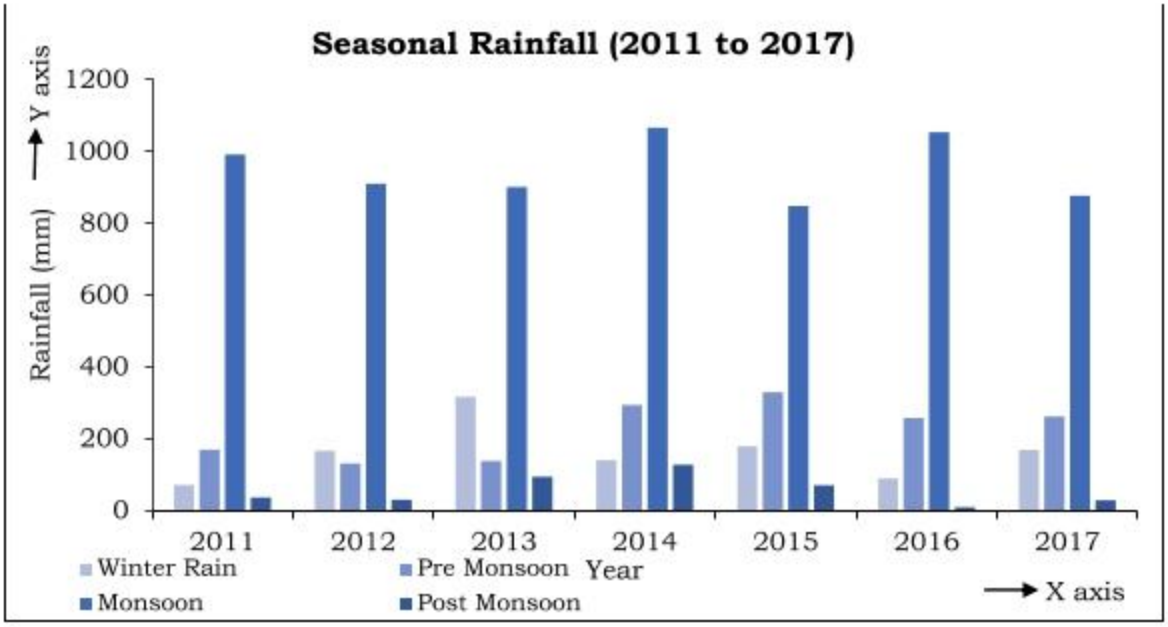

Figure No 29: Seasonal rainfall precipitation - Dhalli (2011 to 2017)

(Source: Author's Calculation)

3.4.2 Jhakri Study Area:

Rainfall data has been collected from Regional Meteorological Centre, Shimla for Rampur station and analysis were performed during peak rainfall months (July and August) for the year 1971 to 2017 (Figure No 30). The result suggest that the study area receives an average of 153 mm (July) and 136 mm (August) during monsoon season. During the month of July, 2014 Jhakri registered an amount of 263 mm of rainfall. The trend pattern of both months suggest an increased rainfall amount along the study area.

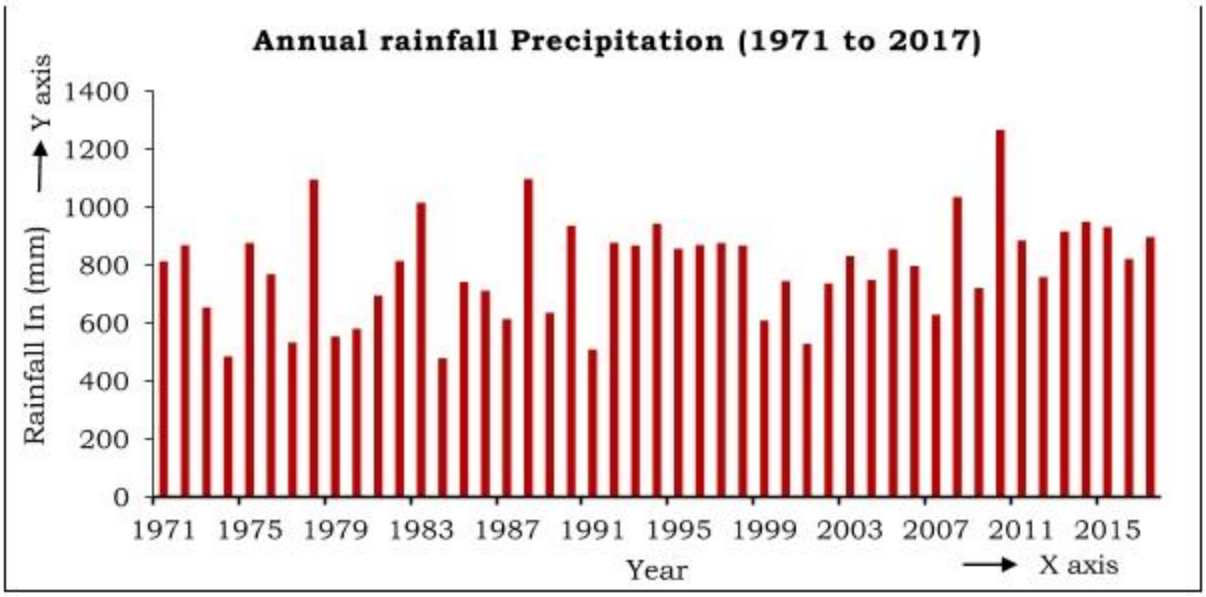

Figure No 30: Annual rainfall precipitation - Jhakri (1971 to 2017)

(Source: Author's Calculation)

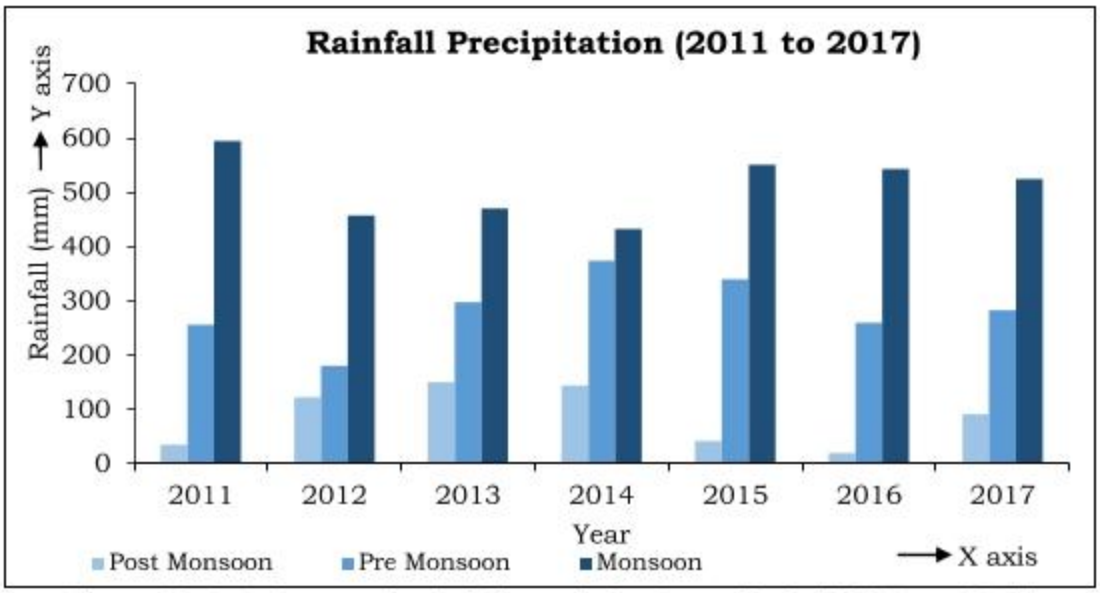

Figure No 31: Seasonal rainfall precipitation – Jhakri (2011 to 2017)

(Source: Author's Calculation)

Based on the rainfall data it is conclude that an average of 500 mm of rainfall occurs during the monsoon season that contributes to the higher saturation rate of the soil. Compared to the post monsoon trend pre monsoon rainfall contributes more in terms of precipitation with an average of 284 mm (Figure No 31).

3.4.3 Kotropi Study Area

Rainfall data has been purchased from Indian Meteorological department, Pune, Govt of India. The data has been purchase for Mandi rain gauge station on daily basis from 1981 to 2018. The results show on an average the region receives 867 mm of rainfall throughout the year (Figure No 32).

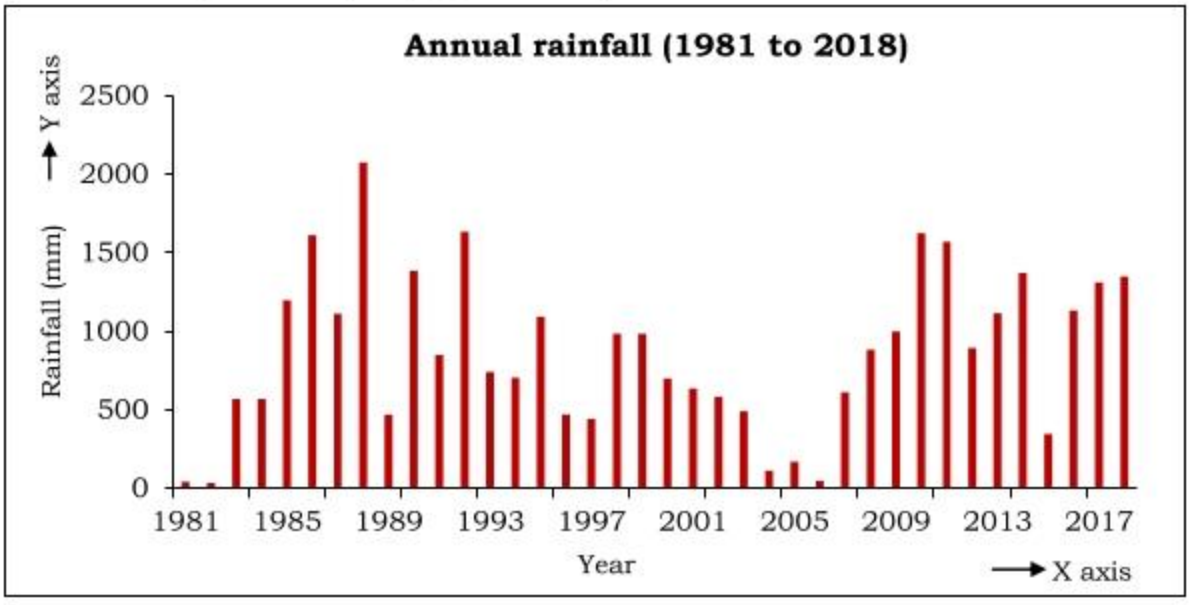

Figure No 32: Annual rainfall precipitation - Kotropi (1971 to 2018)

(Source: Author's Calculation)

In the last eight years (2011 to 2018) the region has received an average of 1137.47 mm of monsoon rainfall (Figure No 33). The high intensity of rainfall during the monsoon season causes an increased water infiltration capacity especially in areas with unstable slopes. The water infiltration coupled with no or poor drainage networks increases the soil burden causing slope failure.

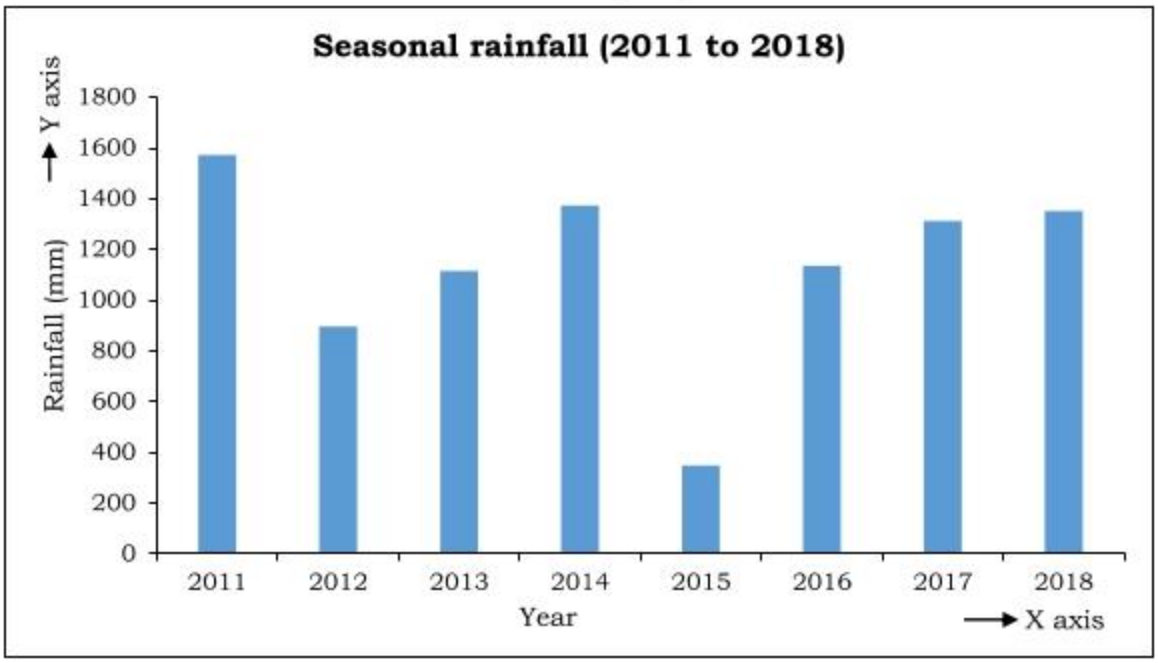

Figure No 33: Seasonal rainfall precipitation – Kotropi (2011 to 2018)

(Source: Author's Calculation)

Conclusion

Chapter three concludes on the selection of study area. Three different sites were selected Dhalli (Rock Slide), Jhakri (Debri Slide) from Shimla district, Himachal Pradesh and Kotropi (Mudslide). Introduction to Physiography, Economy and Climate were given followed by LULC, soil, Geology, Geomorphology etc. Annual and Monsoon rainfall analysis was also given for the Dhalli and Jhakri area. The landslide regions are located high to very high vulnerable regions based on the Landslide susceptibility maps. Moreover, all three landslides are located along the major national highways of the Himalayan region which requires stability assessment and stabilization measures. The regions also receive high amount of rainfall especially during the monsoon reason coupled with the soil nature of these areas increases chances of landslide failure and mass slope movements.