

Landslide Susceptibility Assessment of NH 1D from Sonamarg to Kargil, J&K, India using Frequency Ratio Method

Aadil Manzoor Nanda¹, Zahoor ul Hassan², Pervez Ahmed³, T.A.Kanth⁴

Department of Geography & Regional Development, University of Kashmir-190006, Srinagar

This Study is an attempt to carry landslide susceptibility assessment along NH 1D a lifeline to Ladakh region using Frequency Ratio Method in GIS environment. The landslide influencing factors which have been investigated to form the FR matrix are a slope, lithology, rainfall, landuse, distance to road, distance to fault, distance to river, altitude, soil and slope aspect. The study identified and mapped a total of 317 landslides along NH 1D through rigorous multiple field surveys and secondary sources. The smallest landslide that was identified in the field had an area of 77 m² at Hardas, while the largest one was 107 m², at Zojila Pass. The results show that the area of 696 Km² is covered by very high and high landslide susceptibility zones constituting 42 percent of the study area. The villages which fall under these zones are Sonamarg, Gumri, Pandras, and, Matayan and thus are highly prone to landslide activity. There certainly arises a need to take concrete measures to minimize human and economic losses along the highly susceptible areas.

Keywords: -Landslide; Susceptibility; GIS Environment; NH 1D; Frequency Ratio (FR).

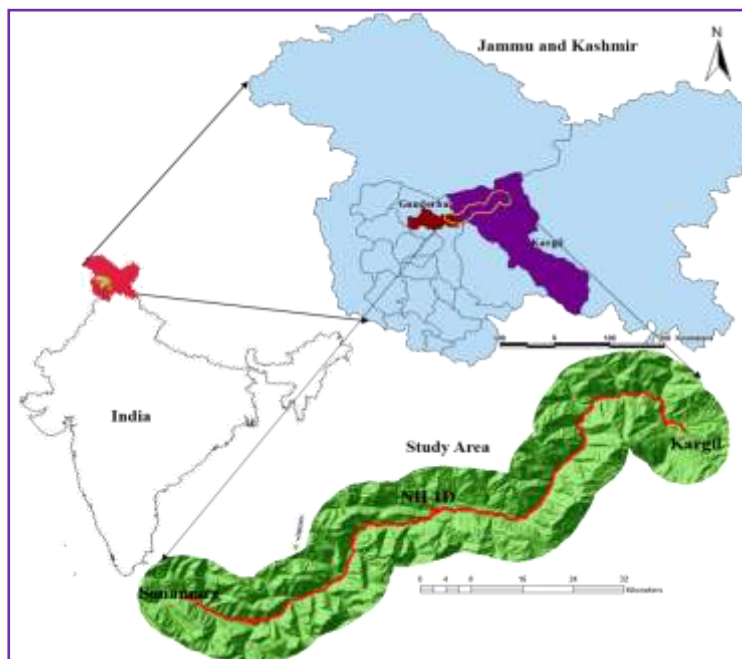
I.INTRODUCTION

Landslides are one of the most common geohazards in many parts of the world (Shahabi *et al.*, 2012). To minimize losses incurred by landslides, it is essential to develop a good understanding of their causative factors which are useful for assessing landslide susceptibility of an area. The identification of landslide-prone regions is useful for carrying out quicker and safer mitigation programs, as well as future development planning of the area (Saadatkhah *et al.*, 2015). National Highway 1D from Sonamarg to Kargil lies at the north western Himalayan mountain range, which is one of the tectonically most active zones on earth. Among the various land degradation process prevalent in the Himalaya, landslides are one of the most significant phenomena (Ahmad and Joshi 2010) as this region is tectonically very unstable with rugged topography, unstable geological structures, soft and fragile rocks, common earthquakes, along with heavy and prolonged rainfalls during monsoon periods (Deoja *et al.*, 1991; Dhital 2000; DPTC 1996). Landslides are among the most damaging natural hazards in mountainous regions. Every year, hundreds of people all over the world lose their lives in landslides; furthermore, there are large impacts on the local and global economy from these events. The frequency of landslide occurrences increases with growing human population. The needs of protecting natural and agricultural areas have further pressed human developments ever closer to unstable slopes. Thus the impact of human interventions on mountain slopes including expansion of built up and agricultural land, overgrazing has compounded the landslide disaster problem in the country (Rajbhandari *et al.*, 2002). This study adopted a widely-accepted statistical model on a GIS platform referred to as frequency ratio model. This model is based

on the observed associations between the allocation of landslides and each associated factor of landslide occurrence to display the correlation between landslide locations and the parameters controlling landslide occurrence in the area (Lee, 2005). The study of landslides has drawn worldwide attention mainly due to increasing awareness of its socio-economic impact as well as the increasing pressure of urbanization on the mountain environment (Aleotti and Chowdhury 1999).

II.STUDY AREA

The study area lies in the Trans-Himalayan region, which has an average height of 3000 to 4000 m above mean sea level. The total length of the study area along NH 1D highway from Sonamarg to Kargil is 125 kms. The topography of the area includes incised valleys and barren mountains cut into very steep and narrow gorges which are devoid of any vegetation cover. The study area is located between $34^{\circ} 18' 11''$ N to $34^{\circ} 32' 28''$ N and $75^{\circ} 17' 35''$ to $76^{\circ} 08' 21''$ E (Figure 1.1). The climate is characteristic of the Mediterranean type with temperate in summers and rainy season normally lasting from late winter to early spring with occasional rainfall during early autumn, provided monsoon currents are strong enough to cross the Pir Panjal ranges. Kargil, situated on the rain shadow side of the Himalayas receive winds that are dry with little or no moisture. The district combines the condition of both arctic and desert climate. Rainfall in the area is negligible. Heavy snowfall is experienced in winter. In winter, the mercury drops to minus 48 degree Celsius at Drass (Kargil), which is the second coldest inhabited place in the world after Siberia. The NH 1D is characterized by complex and rugged topography with very high section relief and steep slopes. Rocks as old as Precambrian are encountered in this section.



Source: Generated from SOI toposheets and Landsat 7 ETM + satellite data, 2016

Figure 1.1: Location Map

III. MATERIALS AND METHODS

In frequency ratio, the ten conditioning factors used as input data include- slope angle, land-use land-cover, distance to faults, rainfall, soil, aspect, lithology, altitude, distance to streams and distance to road (Figure 1.2). Statistically integrating weightages and overlaying the thematic maps developed from these conditioning factors in a GIS platform, specific landslide susceptibility map was developed. This approach is based on the observed relationships between each factor and the distribution of landslides (Shahabi *et al.*, 2012). To calculate the frequency ratio, the area ratio for landslide occurrence and non-occurrence was calculated for the type of each factor, and an area ratio for the class or type of each factor to the total area was also calculated. Therefore, frequency ratios for the type of each factor were calculated by dividing the landslide occurrence ratio by the area ratio. The relationship between the landslide occurrence area and the landslide-related factors can be represented by the relationship between areas with non-landslide and effective factors. To quantitatively show this relationship, the frequency ratio method (Lee *et al.*, 2004) was used. This ratio represents the ratio of the probability of an event occurrence to the probability of an event on an occurrence for given attributes (Bonham-Carter, 1994).

Landslide Susceptibility Index using FR

The first step was to calculate the frequency ratio for each parameter based on its relationship to landslides. Next, the frequency ratio for the sub-criteria of each parameter was calculated. These ratios were used to find the landslide susceptibility index (Lee and Pradhan 2007). The landslide susceptible index (LSI) was calculated by the summation of each factor's frequency ratio value using Eq. 1.

$$LSI = Fr1 + Fr2 + \dots + Frn \quad (1)$$

Where LSI is landslide susceptibility index and Fr is the rating of each factor's type or range. According to the frequency ratio method, an average LSI has a value of unity. If Fr value is equal to 1, it indicates an average correlation and if the value of the ratio is greater than 1, it shows a strong relationship between the event and the effective factors. However, If the ratio is less than 1, the relationship is weak (Lee, 2004).

$LSI_{FR} = (\text{Slope}) r_1 + (\text{landuse/ land cover}) r_2 + (\text{distance to faults}) r_3 + (\text{rainfall}) r_4 + (\text{soil}) r_5 + (\text{aspect}) r_6 + (\text{lithology}) r_7 + (\text{altitude}) r_8 + (\text{distance to rivers/streams}) r_9 + (\text{distance to road}) r_{10}$

Where $r_1, r_2, r_3, r_4, \dots, r_{10}$ is the frequency ratio respectively.

Landslide Inventory

Landslide inventory map is considered to be the base for producing landslide susceptibility map. In addition, a landslide inventory map can provide the base for evaluating and reducing landslide hazards or risk on a regional scale (Wieczorek, 1984).

Landslides in the study area were identified using the historical records of the Border Roads Organisation of Haripora, Srinagar, and Kargil, as well as Landsat 7 ETM + images, Google earth images, and

secondary sources. Google maps were used due to their high resolution and available GCP's which enable to identify the landslides precisely. An extensive field survey was conducted in course of the study in which location and measurement of landslides were carried using GPS and Brunton Compass. A detailed questionnaire was prepared to identify and assess the type, magnitude, and dimensions of the landslides. The secondary data was collected from various departments like Border Roads Organization, Srinagar and Kargil, Sonamarg Development Authority (SDA), and Central Police Range (CPR), Srinagar.

A total of 317 landslides were mapped, the smallest landslide that was identified in the field had an area of 77 m² at Hardas, while the largest one was 107 m², at Zojila (Figure 1.2). Landslides are frequent in the middle part of the study area, which is Sonamarg to Gumri stretch occupied by highly fractured, steep slope, high drainage density, limestone and sandstone formations, denudation and active weathering processes. Whereas, they are less frequent in the Kargil part of the region, with gentle middle spurs, where geological formations consist of massive granite plutonic rocks.

Source: SOI toposheets 1971, ASTER DEM, Landsat 7 ETM +, IMD, ICAR, 2008 and Thakur & Rawat, 1992

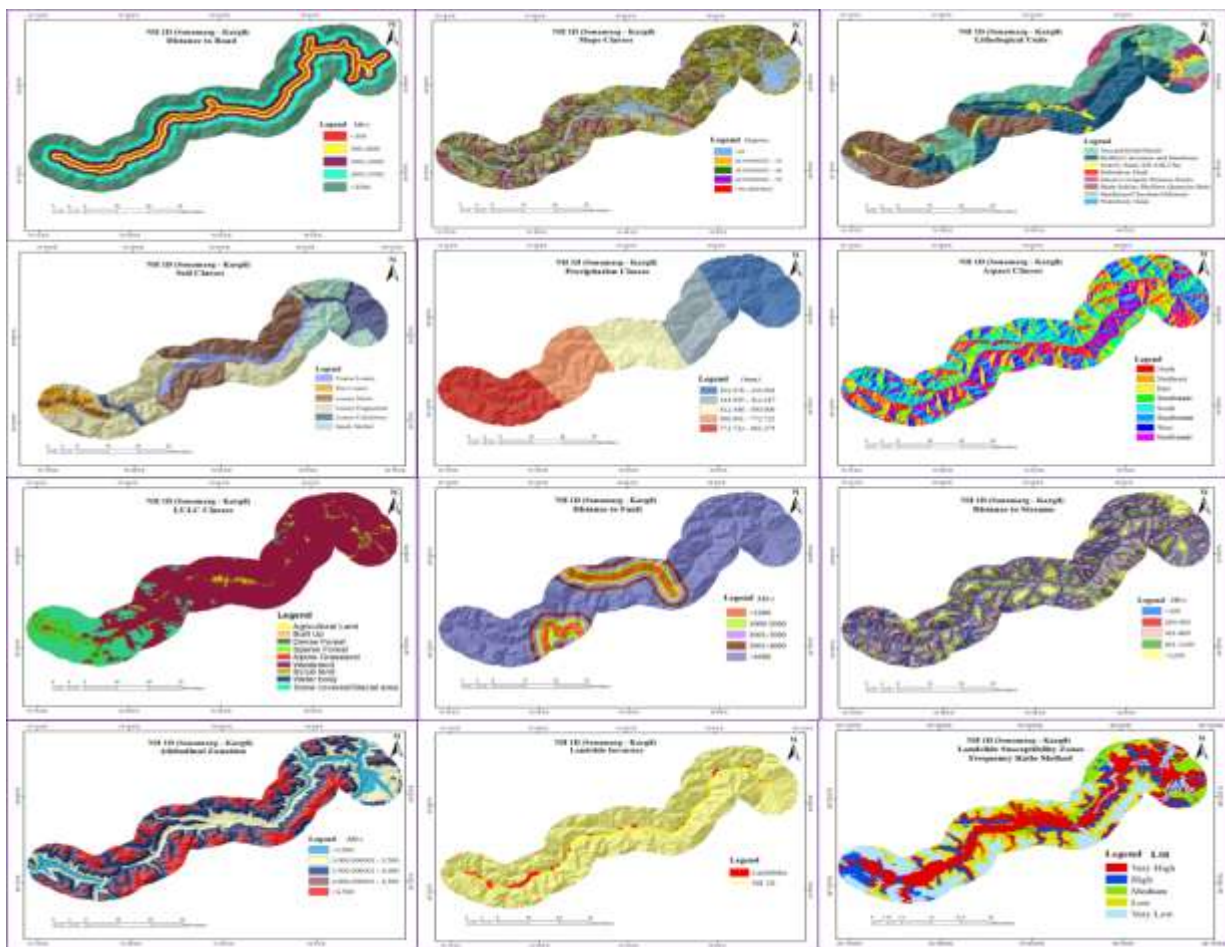


Fig. 1.2: Conditioning Factors, Landslide Inventory and Landslide Susceptibility Zonation.

IV.RESULTS AND DISCUSSIONS

Using the resultant Landslide Susceptibility Index map, the study area was delineated into five zones of landslide susceptibility i.e., very high, high, moderate; low and very low (Figure 1.3). The frequency ratio values for all the sub-categories of conditioning factors are shown in Table 1.1. The slope sub-category $< 20^\circ$ has a Frequency Ratio less than 1 (0.66) depicting a low probability of landslide occurrence while as $20-30^\circ$, $30-40^\circ$ and $40-50^\circ$ has a Frequency Ratio more than 1, (2.51, 2.74 and 1.91) indicating a high probability of landslide occurrence. More than 50° slopes with Frequency Ratio (0.09) indicate low chances of landslides clearly establishing the fact that the rock fall occurrence dominates with the increase in slope angle. The nearest distance to road (< 300 meters) has a higher Frequency Ratio of 8.32 demonstrating a high probability of landslide occurrence. The distance between 3000-4000 m to faults have the highest Frequency Ratio (7.10) due to the operation of human activities in the thrust and Main Mantle Thrust (MMT) fault from Sonamarg to Gumri and Pandras to Drass stretch. In the lithology, bedded limestone & gravel, sand, silt with clay, have Frequency Ratios of 2.83 and 2.54 respectively. In the case of land use classes like built up, agricultural land and sparse forest class have highest FR values of 21.92, 5.90 and 5.69 respectively. Built up with an FR of 21.92 indicates that human activities can trigger landslides more frequently than any other factor.

Very high susceptibility zone: - The area of 519.89 Km² is covered by very high landslide susceptibility zone constituting 31 percent of the study area (Figure 1.4 & Table 1.2). The very high Landslide Susceptibility Index (LSI), is characterized by moderate to high steep slopes, bedded limestone, gravel, sand silt with clay, built up, agriculture, loamy calcareous, loamy fragments, close proximity to the road mostly < 500 meters, low to mid altitudes and southern aspect. Most of the villages fall under this category from Sonamarg to Gumri and this zone is mostly prone to landslide activity.

High susceptibility zone: - The high susceptibility zone covers 176.01 Km² of the area constituting 10.6 percent of the study area (Table 1.2). This zone is characterized by steep slopes, high altitudes, mostly granite, plutonic rocks, and quartzite beds. The high landslide susceptibility zonation mostly falls in very high precipitation zone covering the sparse forest area of Sonamarg belt. The distance to road and rivers/streams are very low in most parts of this zone.

Table 1.1: Frequency Ratio to landslide occurrences

Factor	Classes	Landslide occurrence Points	Landslide occurrence points (%)	Pixel in domain	Pixel (%)	Frequency Ratio
Slope	< 20	47	14.78	410636	22.25	0.66
	20.0000001 -30	86	27.22	200243	10.85	2.51
	30.0000001 -40	103	32.49	218514	11.84	2.74
	40.0000001 -50	68	21.48	207440	11.24	1.91
	> 50	13	4.03	808723	43.82	0.09

Landuse/Land cover	Agriculture	29	9.27	29008	1.57	5.90
	Built Up	7	2.09	1759	0.10	21.92
	Dense Forest	0	0	1989	0.11	0.00
	Sparse Forest	105	33.19	107702	5.84	5.69
	Alpine Grassland	0	0	4541	0.25	0.00
	Snow Covered/Glacial Area	3	1.08	281998	15.28	0.07
	Wasteland	172	54.37	1365968	74.01	0.73
	Scrubland	0	0	43617	2.36	0.00
	Water body	0	0	8974	0.49	0.00
Distance to Faults	(<1000)	7	2.06	4301	2.33	0.88
	(1000-2000)	12	3.89	4533	2.46	1.58
	(2001-3000)	22	7.05	4890	2.65	2.66
	(3001-4000)	56	17.67	4591	2.49	7.10
	(>4000)	220	69.33	166241	90.80	0.77
Precipitation/Rainfall	102.678-244.094	45	14.14	445041	24.11	0.59
	244.095-412.447	22	7.06	312134	16.91	0.42
	412.448-590.900	34	10.81	311226	16.86	0.64
	590.901-772.721	70	21.95	331207	17.95	1.22
	772.722-961.275	146	46.04	445949	24.16	1.91
Soil	Fine Loamy	45	14.20	86372	4.68	3.03
	Coarse Loamy	67	21.14	226265	12.26	1.72
	Loamy Calcareous	107	33.75	121253	6.57	5.14
	Loamy Fragmental	38	11.99	896756	48.59	0.25
	Sandy Skeltal	53	16.72	40233	2.18	7.67
	Loamy Mesic	7	2.21	474677	25.72	0.09
Aspect	North	6	1.89	221467	12.00	0.16
	Northeast	16	4.94	239922	13.00	0.38
	East	23	7.13	221467	12.00	0.59
	Southeast	70	21.93	239922	13.00	1.69
	South	99	31.17	221467	12.00	2.60
	Southwest	59	18.59	239922	13.00	1.43
	West	26	8.21	221467	12.00	0.68
	Northwest	19	6.14	239922	13.00	0.47
Lithology	Amygdaloidal Basalt	51	16.17	64570	34.99	0.46

	Bedded Limestone	117	36.83	24027	13.02	2.83
	Gravel, Sand, Silt with clay	58	18.32	13306	7.21	2.54
	Massive Granite Plutonic Rocks	21	6.71	15726	8.52	0.79
	Shale/ Schists/Phyllites Quartzite Beds	70	21.97	60811	32.95	0.67
	Sandstone/ Claystone/ Siltstone	0	0	2584	1.40	0.00
	Habitation Mask	0	0	1078	0.58	0.00
	Waterbody Mask	0	0	2455	1.33	0.00

Altitude	<3000	75	23.61	15715	8.51	2.77
	(3000-3500)	118	37.24	41598	22.54	1.65
	3501-4000)	100	31.47	50789	27.52	1.14
	(4001-4500)	24	7.68	47688	25.84	0.30
	(>4500)	0	0	28766	15.59	0.00
Distance to Streams	(<200)	119	37.53	49337	26.73	1.40
	(200-400)	92	29.03	42231	22.88	1.27
	(401-800)	66	20.87	54341	29.44	0.71
	(801-1200)	30	9.51	23692	12.84	0.74
	(>1200)	10	3.06	14955	8.10	0.38
Distance to Road	(<300)	135	42.63	9457	5.12	8.32
	(300-1000)	156	49.29	21036	11.40	4.32
	(1001-2000)	26	8.08	29155	15.80	0.51
	(2001-3500)	0	0	42160	22.84	0.00
	(>3500)	0	0	82748	44.84	0.00

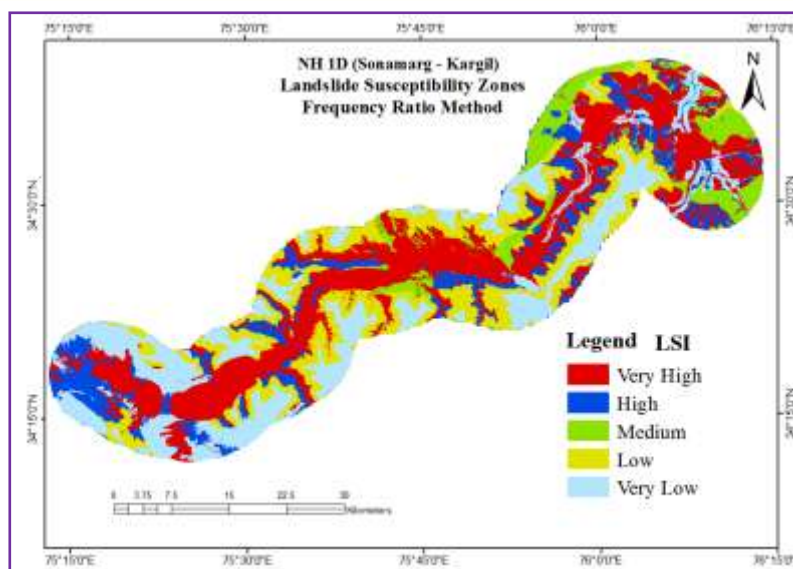


Figure 1.3: Landslide susceptibility zonation using FR

Moderate susceptibility zone: - The moderate susceptibility zone covers an area of 136.2 Km² constituting the lowest 8.2 percent (Table 1.2) mostly on the wasteland ramparts of Kargil stretch. Moderate slopes, sandy skeletal soil and very low precipitation are other distinguishing features of this zone. The moderate landslide susceptibility zone consists of a small valley on high as well as low altitude with moderate slopes and very less distant to rivers and faults.

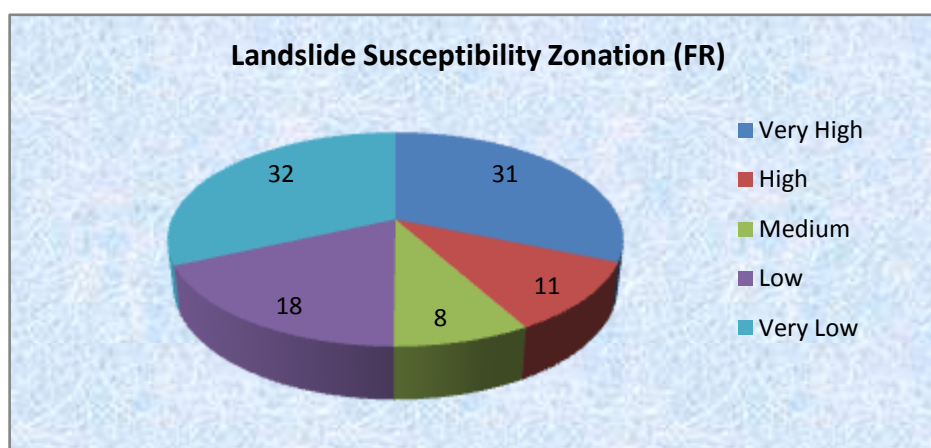


Figure 1.4: Percentage distribution of landslide susceptibility zonation using FR

Table 1.2: Landslide susceptibility zonation using Frequency Ratio

S. No.	Priority category	Area in sq. km	Percentage
1	Very High	519.89	31
2	High	176.07	11
3	Medium	136.20	8
4	Low	300.64	18

5	Very Low	528.20	32
Total		1661.00	100

Source: Landslide susceptibility zonation map using FR

Low and very low susceptibility zones: - The low and very low susceptibility zones constitute 50 percent of the study area covering an area of 864.84 Km² (Table 1.2). These landslide susceptibility zones are more dominant on high altitudinal ridge and escarpments with extremely steep slopes. These are located at a considerable distance to the road and rivers/streams on loamy and sandy skeletal soils covered by wastelands and intermittently with alpine grasslands.

V. CONCLUSIONS

The present study conducted frequency ratio modelling in a GIS environment to obtain the Landslide Susceptibility Index utilizing ten conditioning factors (i.e., slope angle, land-use land-cover, distance to faults, rainfall, soil, aspect, lithology, altitude, distance to streams and distance to road and landslide inventory. The model employed in this study showed reasonably good accuracy in predicting the landslide susceptibility along NH 1D road section. The major factors which emerged to determine the landslide occurrence are human activities like an increase in built up (roads and buildings) and agricultural practices with maximum impact on steep slopes. The increasing population pressure has forced people to concentrate their activities on steep mountain slopes. Thus, in order to safeguard the life and property from landslides, the susceptibility maps can be used as basic tools in planning and management of future construction projects in this area. While, the low susceptibility zones are relatively safe for the development of infrastructures, the high and very high susceptibility zones require further engineering geological and geotechnical considerations. The villages which emerged highly prone to landslide activity are Sonamarg, Gumri, Pandras, and Matayan. These are the most tortuous and rugged zones with high occurrence and impact of landslides resulting in a frequent incidence of traffic disruptions. Thus there is an urgent need to mitigate the landslide hazard, particularly at these points to avert the disruption from Srinagar to Leh which causes huge inconvenience, economic and human losses.

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