Landslide Hazards in Himalayas: A study on factors responsible and possible remedial measures with special reference to Jammu region.

[1]Gautam Salaria, [2]Munish Loona, [3]Monika Verma

[1,2] UG scholar , Department Of Civil Engineering, Lovely Professional University, Phagwara, Punjab, India

[3] Assistant Professor, Department Of Civil Engineering, Lovely Professional University, Phagwara, Punjab, India

Abstract : All over the world soil is widely used natural material for construction. But when this material is available in the form of natural slope can cause landslide due to instability of slope because of various factors. The objective of this study is to understand behaviour of different factors of landslide at Jammu region and then suggest possible remedial measures. For this, reports by Geological Survey of India, past thirty years data of annual precipitation of every district from Indian meteorological department are collected and studied. The data of seismic activities is also collected. Also the work of different authors in this area is analysed deeply. It can be stated that the climatic conditions change such as earthquakes, rainfall pattern variation and various anthropogenic activities has increased the landslide vulnerability of the area. The suggested remedial measures are as, landslide susceptibility zonation mapping, future landcover/land use pattern, use of advance technology solutions like construction of gabion walls, soil nailing and analyzation of slope stability by numerical modelling.

Keywords: Landslide, slope stability, rainfall, landslide susceptibility zonation, remedial measures.

I. INTRODUCTION

Landslide is a term which is used to describe the downward or outward movement of slope forming materials like mass of rock, soil or debris under the influence of gravity. Varnes(1978) provided an idealised schematic presentation that displays the features of a landslide in soil material. Varnes classified landslide on the basis of type of material and type of movement as falls, topples, slides, lateral spreads, flows and combination of two or more type of movement [1]. In India, nearly 0.42 million sq. km or 12.6 percent area of land, not including snow covered area, is prone to landslide hazard. Out of this, 0.14 million sq km falls in North West Himalaya including Jammu & Kashmir. Himalayan mountains are geologically seen as very young mountains. In these young and not so stable slopes, the events of landslides are increasing due to activities like cutting of roads, deforestation and agricultural changes that require intense watering [2]. In Jammu & Kashmir, the land sliding is a very serious problem, particularly in hilly areas, which initiates either by the natural processes including erosion, rainfall and thrusting etc. or by anthropogenic activities like road cutting, excavation of foot slopes, etc. The govt. of Jammu and Kashmir is spending huge amount of money to stabilize the areas where landslide creates high risk to the society. In recent years the landslide incidences have increased in the state because of upcoming new developmental projects. Almost all districts of Jammu and Kashmir are vulnerable to landslides. Some of the known landslides in Jammu and Kashmir State include Khairi (Udhampur), Nashri (Ramban), Sadal (Udhampur), Panthal (Udhampur), Surankote (Poonch) and Sunergund (Pulwama) landslides etc . According to the research done by Surya Prakash, the west and north-west regions of Himalayas suffer more from landslide compare to north-east and south of India [3]. Objective of present study is to understand factors affecting landslide in study area and provide feasible solutions for landslide as there is a need of more scientific and engineered study of landslide problem at Jammu region.

II. Factors Affecting Landslide

As stated by Popescu in his study that the understanding of responsible factors is very important for finding the best cost-effective solution for landslide problem. IUGS WG/L Commission made a list of factors on causes of landslides in a well-arranged manner. There are two types of factors affecting landslide: Preparatory or internal factors and Triggering or external factors. As name states internal factors responsible for making slope vulnerable whereas external factors initiate the movement [4]. Most of the time there are several factors responsible for landslide such as geomorphic process, ground condition, physical process, anthropogenic interference etc. But in most landslides the triggering factor is precipitation. Excess water increases the pore water pressure in soil which decreases the shear resistance resisting force of soil. If it is present in rock it may generate inside discontinuity and hydrostatic pressure [5].

Table 1
Brief list of factors responsible for landslide

Physical Processes	Ground conditions	Geomorphological Processes	Man-made Processes
1. High intensity short-duration rainfall. 2. Rapid melting of deep snow. 3. Prolonged high precipitation. 4. Earthquakes. 5. Volcanic eruption.	1.Plastic weak material. 2.Sensitive material. 3.Collapsible Material. 4.Jointed or fissured material. 5.Sheared material.	1.Vegetation destruction (by erosion, forest fire, drought). 2.Tectonic uplift. 3.Volcanic uplift. 4.Erosion of soil.	1.Excavation of slope or its toe. 2.Drawdown of reservoirs. 3.Irrigation. 4.Water leakage from services. 5.Deforestation.

2.1 Climate of the area

The area falls in sub-tropical to temperate climate zone and witnesses moderate to extreme climate characterized by hot summers and cold winters. The higher reaches experience extreme cold and occasional snowfall during winter months. From July to September there is rainy season. Rains during winter months are also common [6]. The regional drainage of the area is controlled by Chenab River, Tawi River and their tributaries. Except rainy seasons, when these are fully charged, these tributaries generally remain dry during the year. Sub-surface drainage is also a peculiar character of the area being dolomitic in nature.

2.2 Rainfall Behaviour in the Area

The number of case studies on the area has shown that rainfall was the main triggering factor for landslides in Jammu. A series of landslide occurrences observed in July and August[7]. It can be seen during the period (1989-2018) that the state gets highest rainfall (33%) of south west monsoon rainfall in July month while the August month get 32% of the south west monsoon rainfall. June and September receive 15% and 18% of south west monsoon rainfall. Almost 44% of annual rainfall is received during the southwest monsoon season only. The variability of monsoon and annual rainfall is 24% and 21% respectively [6].

Table 2 Mean rainfall (mm) and CV (coefficient of variation) of J&K state for the monsoon months, SW monsoon season and annual.

	June	July	August	September	Monsoon	Annual
Mean	84.1	184.8	178.5	101.2	554.5	1256.1
CV	42.6	45.7	47.1	79.9	24.0	21.0

2.2.1 District rainfall mean

The reports by Indian meteorological department has shown that the districts Reasi and Kathua receive highest rainfall over other districts throughout all the months and season [6]. The rainfall received over these districts are around (100-170 millimetre) in June, around (400mm-580mm) in July and August, (160-240mm) in September and during the South-West monsoon and annual 1200-2100mm. The lowest amount of rainfall received during the SW monsoon season over Ganderbal disrtict(257.9mm) and Badgam district(197.5mm) while both of these districts also receive lowest annual amount of rainfall (1007.4mm and 715.7mm respectively).

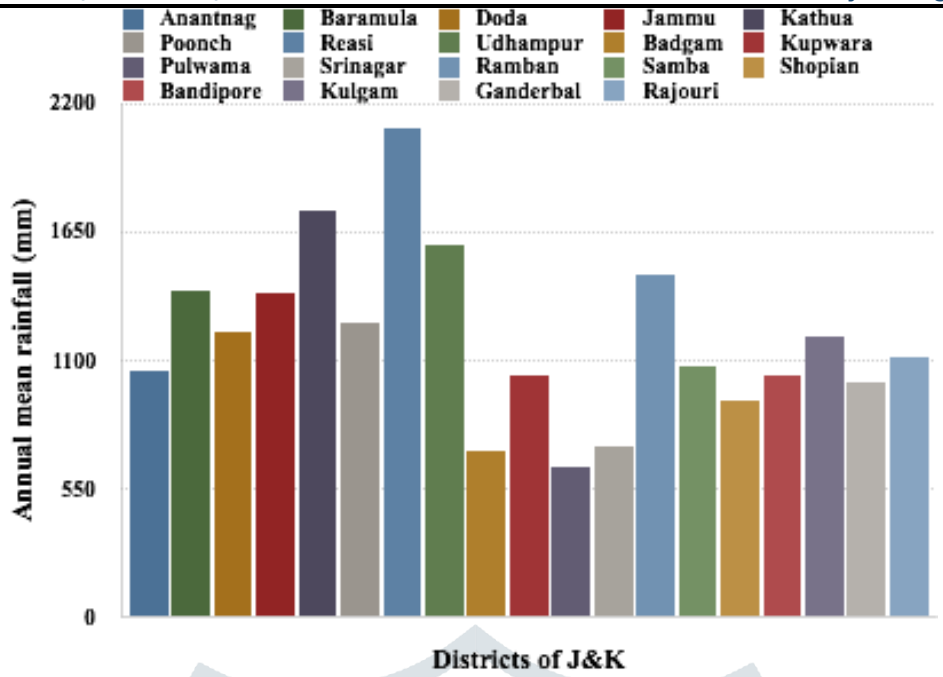

Fig. 1. Annual mean rainfall data for the districts of Jammu and Kashmir (1989-2018).

2.3 Seismic conditions of the area

Whenever earthquake happens, the level of magnitude and distance from epicentre give level of shaking to susceptible slopes. The most vulnerable materials to earthquake induced landslides are weakly cemented rocks, residual and colluvial sand, granular man-made fill, granular deltaic deposits loess, high-indurated rocks with pervasive or prominent discontinuities, cemented soils, granular alluvium and volcanic soils containing sensitive clay [8]. South Kashmir districts and North Kashmir districts fall in Zone V. Whereas Muzaffarabad, Punch, Mirapur, Reasi, Udhampur, Leh, Jammu, Samba, Kathua, Ladakh, Anantnag and districts having tribal territory fall in Zone IV. As in India the earthquake database is still not complete, especially if considered earthquakes around the historical period (before 1800 A.D.), these zones offer a rough guide of the earthquake hazard in any particular region and need to be updated regularly . On the morning of 8 October 2005, a major earthquake struck the India-Pakistan border. The magnitude of the earthquake was Mw=7.6 and was felt strongly in much of northern India, eastern Afghanistan and Pakistan. This earthquake resulted in more than eighty thousand deaths in northern parts of Pakistan and adjoining parts of J & K, India and is by far considered as one of the deadliest earth-quake in the subcontinent. Tremors from the earthquake were felt quite 1000 kilometres away within the Indian states of Gujarat, Madhya Pradesh and U.P [2].

A study was done by Roger that was based on seismological data to identify segments of Himalayan regions that remain enraptured. It showed that out of fifteen segments the ten segments of the Main Himalayan Thrust arc are sufficiently mature to generate earthquake of more than magnitude of 8 Mw. Estimated deaths considered to be a huge number due to increased population and poor quality of construction activities[9].

Table 3
List of some earthquakes occurred in past

Earthquake	**Magnitude**
8 Oct. 2005, Kashmir, J&K	7.6
12 Feb. 2021, tremors all over J&K	6.3
11 Jan. 2021, 63km NE of Katra	6.1
24 Sep. 2019, 64 km WSW of Rajouri, J&K	6.0
12 Sep. 1951, 15 km E of bhadatwah, J&k	5.6
02 Aug. 2013, 19 km E of Kishtwar, J&K	5.5
23 Aug 1980, 47 Km E of Udhampur, J&k	5.2

2.4 Landuse/landcover of area

The Landuse/ landcover pattern of an area is the result of natural factors as well as socio-economic factors and their utilisation by humans in time and space. The increase in density of population is directly proportional to the Land-use and Landcover. The study area covers prominent localities, viz., Samba, Ghagwal, Vijaypur, Supwal, Battal, mansard, Ramkot and Nagrota Gujru, Udhampur, Ramnagar, Malahar, Nagrota, Salgetar, Bani, Mandhal, Mandi and Chunthal, Doda, Ramban, Reasi etc. Which are in a dynamic state with moderately dense population, in terms of local and tourist residence. As multiple vegetation layers reduce the risk of landslides [10]. So the Land-use and Landcover pattern in the area mainly covered by cultivated land and possess patches of

moderate and sparse vegetation in and around the settlement zones. The settlements are surrounded by large areas of cultivated land which covers major part of the area. Village settlements have been located on flatter lands or on the gentle slopes and cultivation is being done either on flat river terraces or on the gentle slopes. As the roads in the Jammu and Kashmir are a decade old, creation of new roads is posing a major problem as a result of the unscientific cutting of upslope of the roads. Many small sized landslides are often occurring along these areas. The vertical to sub-vertical escarpments present within the area are totally devoid of vegetation and are often seen encompassing exposures of rock.

III. Spatial distribution of some landslides present in the area

In total, 221 landslides were mapped during the pre-field mapping from remote sensing for the areas of Kathua and Samba Districts alone. More than 90% of landslides are shallow translational debris/rock slides, with depth of slip plane being less than 5 meters. Smaller landslides on the cut slopes are found to have a short run-out as the road provided a horizontal base for accumulation of the debris. Most of the landslides are located to the north-east and north-west part of region[11].

(a) Debris Slide along Nad-Mansar state highway road.

(b) Rock fall sandstone along Nad-Mansar state highway road near Naun village.

Fig. 2. Field photographs showing the landslides along the roads in the study area.

Also there are 364 number of landslides together in Jammu, Samba and Udhampur district. Most of the landslides in the area are triggered by structural disturbances and later escalated by rainfall particularly in the north of Udhampur and Ramnagar towns. NHA1 which connects Jammu with Srinagar, is passing across two thrust zones (Tanhal thrust and Mundan thrust) in the north of Udhampur near Kheri village. Due to this factor, the study area has witnessed by various dominant landslides like Kheri landslide[12].

(a) photograph showing extent of Kheri landslide at present.

(b) rock slide along Udhampur to Kishanpur Nagrota road at Darsu.

Fig. 3. Field photographs showing some landslides of Udhampur district.

Landslides caused under natural conditions (structure, drainage, slope gradient) are relatively large in size and constitute more than 70% of the inventory. Smaller landslides on the cut slopes are found to have a short run-out as the road provided a horizontal base for accumulation of the debris. Most of these slides are located within a distance of 50m from either side of the roads and resulted due to removal of toe by road cuttings. It has been observed in the field that advancement of the existing landslides in the area is driven by the action of water on the slopes, anthropogenic activities and more over by the removal of vegetation.

The most common Bhawan landslide incidence which occurred on the intervening night of 13-14th March 2016 at Katra Shri Mata Vaishno Devi of Reasi District[13].

Fig 4. View Of Bhawan Landslide, Katra.

During the intervening night of 13-14th March 2016, the heavy rainfall has resulted in widespread seepage of water into area which led to landslide at this particular spot and subsequent caving/subsidence on foot track leading to Bhawan.

IV. Possible remedial solutions

Landslide mitigation, prevention and preparedness are the methods used by state disaster management authority to reduce the effect of landslide hazard getting converted into disaster. In case of landslide hazard the susceptible mapping is strongly suggested to be used in mitigation process which is done by producing landslide susceptibility zonation mapping with help GIS software's like ArcGIS [14]. From point of view of prevention the use of remedial measures like retrofitting of existing infrastructure or replacing the old one is recommended. During preparedness process the use of information technology methods, medical training and preparedness and use of pre warning systems are strongly suggested. [2].

4.1 Landslide Susceptibility Zonation for Prediction

Landslide susceptible zonation is a spatial prediction technique used to find place of landslide with the help of various causal factors by preparing maps. There are different approaches for LSZ mapping. But broadly these are classified as qualitative and quantitative approach which can be subdivided as distribution analysis, Geomorphic Analysis, Map Combination Approach, Quantitative Approaches, Statistical Analysis, Probabilistic Approach, Distribution-Free Approaches [15].

Table 4
List of LSZ work in Jammu Division.

	LSZ area	Method	Author
1	Nad-Mansar road (Jellebi Morh), Samba.	A weighted Multiclass Index Overlay method.	Varun Mandotra, Imran Khan.
2	Nad-Mansar road (near Channi village), Samba.	A weighted Multiclass Index Overlay method.	Varun Mandotra, Imran Khan.
3	± 200 m upslope to Baghani Malli on Pangot - Semalkhali road, Shore village, Kathua.	A weighted Multiclass Index Overlay method.	Varun Mandotra, Imran Khan.
4	Khairi, 5 Km from Udhampur.	Weighted Multiclass Index Overlay method.	Aijaz Ahmad Bhat, Vaseem Akaram
5	Paryote, Doda District.	Weighted Multiclass Index Overlay method.	Pradeep Pal Singh, Sanjeev Kumar Sharma.
6	4 Km from Batote toward Lalhote, Ramban.	Weighted Multiclass Index Overlay method.	Pradeep Pal Singh, Sanjeev Kumar Sharma.

Varun Mandotra and Imran Khan performed Landslide susceptibility zonation for parts of Samba and Kathua districts in the eastern part of Jammu. The Google Earth images is used to discover and confirm landslides. Various parameters were considered like physical state of slope, lithology, spatial variation in depth of slope forming mass, geomorphological processes, rock structure, geo-hydrology, and the land cover including road and other physical features were mapped at 1:50,000 scale. Pixel was selected as the basic mapping unit for the susceptibility modelling so that the smallest landslide can be represented by a single pixel. A weighted Multiclass Index Overlay method was used to categorize the landslide susceptible slopes. Arc GIS and ILWIS software are used for the process of data preparation and analysing susceptibility. And the landslide susceptibility map was made as shown in figure.

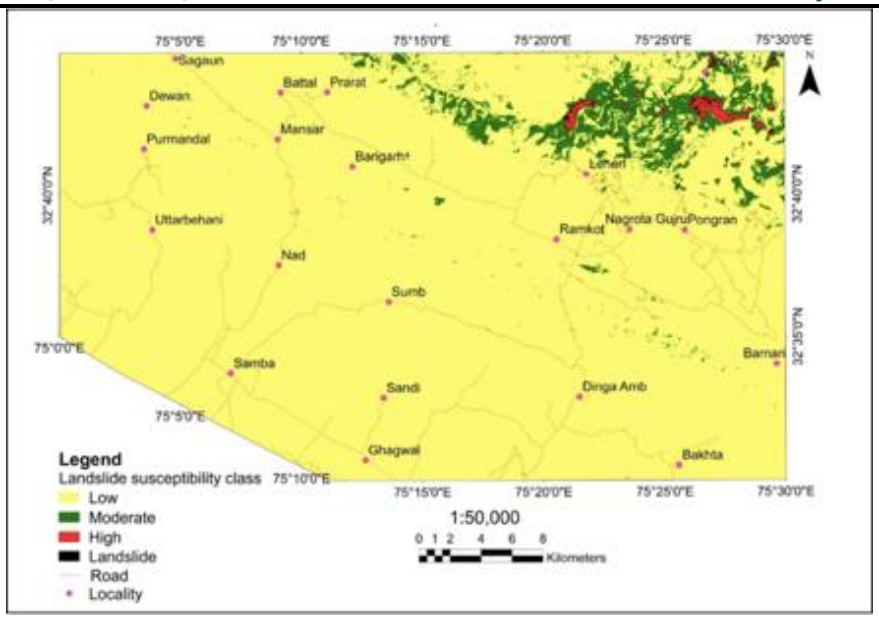

Fig. 5. Landslide susceptibility map of area.

High susceptible zone (red) covers about 0.5% (5.8 sq. km) of the total study area (1221 sq km). Moderate susceptible zone (green) covers about 4.7 % (57 sq. km) of the study area. Almost 95% of the study area falls in low susceptible zone (yellow)[11].

In another study by Aijaz Ahmed Bhat and Vaseem Akaram, developed landslide susceptibility maps for areas falling in parts of Udhampur and Samba districts, and lies in the north-eastern part of Jammu. The area is occupying a total area of 1296 sq. km.The landslide susceptibility analysis of all recorded data sources has been done using the Weighted Multiclass Index Overlay method in the same manner as by Varun Mandotra and Imran khan, Geologists. It was revealed from the statistical attribute table of the success rate curve for resulted landslide susceptibility map for 1296 sq km area that 15.30 cumulative percent map area falls under "High" susceptible zone while 41.76 cumulative percent map area falls under "Moderate" susceptible zone and rest of the cumulative percent map area falls under "Low" susceptible zone[12].

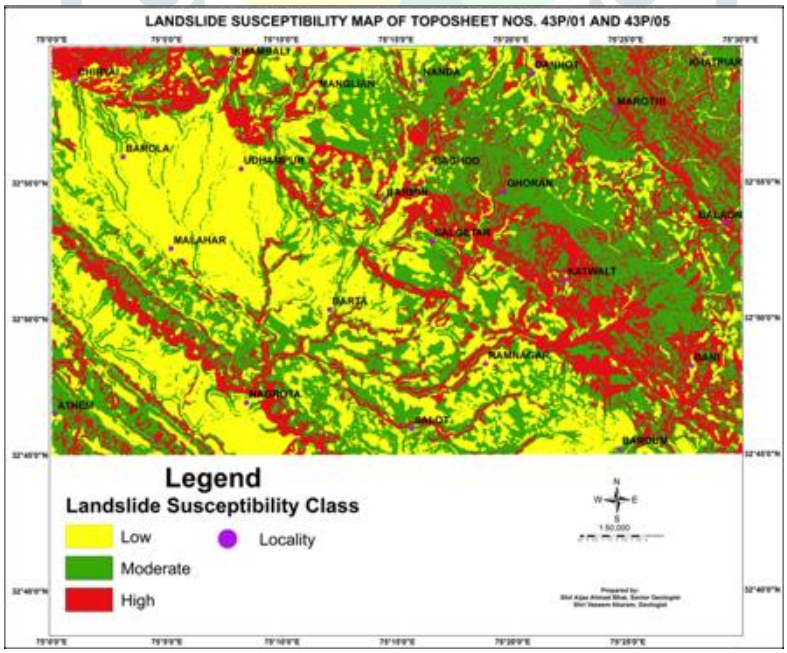

Fig 6. Landslide susceptibility map of area.

Pradeep Pal Singh and Sanjeev kumar Sharma performed Landslide susceptibility zonation for parts of Doda, Reasi, Ramban and Udhampur Districts of Jammu and Kashmir. The study was occupying total of 1293 Sq Km of area. Various parameters were considered and land cover including road and other physical features were mapped at 1:50,000 scale. Pixel was selected as the basic mapping unit for the susceptibility modelling. A weighted Multiclass Index Overlay method was used to categorize the landslide susceptible slopes. The whole process of preparing data and analysing susceptibility was performed in Arc GIS and ILWIS. The Landslide susceptibility map for 1293 Sq Km of area reveals that around 10% (129 Sq Km) of area comes under high susceptibility

zone. The area which comes under moderate susceptibility zone is around 30% (388 Sq Km) and is located consecutively with high susceptible area particularly where the slope gradient is >45° while rest of the area falls under low susceptibility zone [16]. The landslide susceptibility map of the area is shown in the figure.

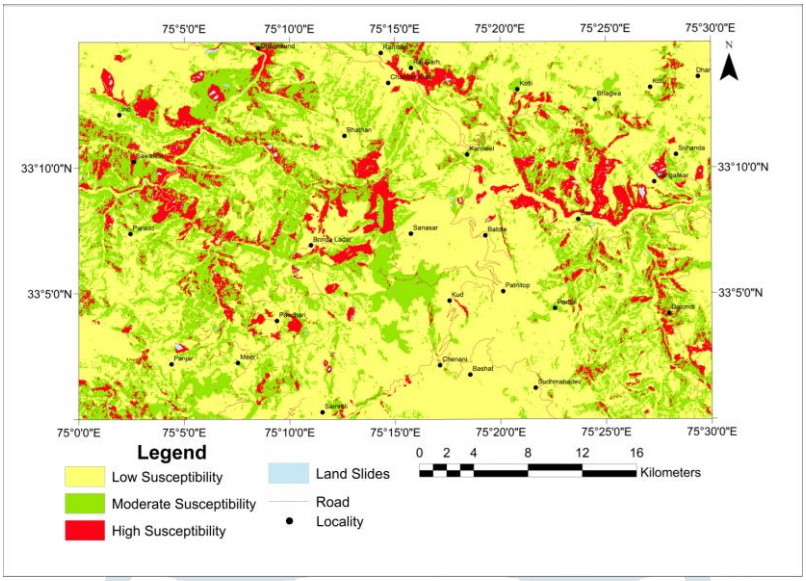

Fig. 7. Landslide susceptibility map of the area.

4.2 Feasible solution for Mitigation

A list of mitigation options has been stated by Popescu which can be implemented, which include options like , avoiding it, accepting it , decreasing its consequences, early pre warning systems and monitoring of landslides. The chances of landslide can be reduced either by decreasing the driving force or increase the resistance towards the driving force. The remedial solutions stated in the study can be broadly classified into four groups as; internal slope reinforcement, drainage, retaining structure, and modification of slope geometry [17]. The most important remedial method for landslide is drainage as presence of water in soil decreases the shear strength of the soil and increase its pore water pressure and reduce the resisting capacity of slope. Drain helps to reduce the pore water pressure [18]. Slope geometry as remedial solution is suggested in case of deep-seated landslide. And it is observed that the remedial methods are used in combination most of the times. There are different remedial methods available that can be applied by considering the type of factors affecting landslide . Ramli in his study developed some new interlocking systems in gabion wall to improve resistance. The block having hexagonal shape instead of usual rectangular shape was suggested as these blocks are more stable under application of load. The study showed that the gabion wall has more advantages than retaining wall by many ways such as: 1) By providing reinforcement that can withstand stresses. 2) gabion walls have better load distribution properties. 3) drainage properties provided by them are very good [19]. The use of such remedial methods can also be seen in most of case studies of landslides in Jammu region [20].

Table 5. A brief list of remedial measures as per Popescu.

Internal slope reinforcement	**Modification of slope geometry**	**Drainage**	**Retaining structures**
Rock bolts, Micro piles, Soil nailing, Anchors, Grouting, stone columns, Heat treatment, Vegetation planting.	Removing or Adding material Reducing slope angle	Surface drains Drainage tunnels, Vacuum dewatering Electro-osmotic	Gravity- retaining walls, Crib-block walls, Gabion walls.

Table 6. List of some landslides in Jammu.

1. Nad-Mansar road (Jellebi Morh), Samba **2. Paryote landslide, Doda district.**	
Triggering Factor	Steep slope and rainfall.
Landslide causes	Heavy Rainfall, high angle slope causes after rainfall got rapid sliding along slope. This incidence has occurred as a result of combined effect of multiple factors. The major geological causes for the incidence are joints pattern.
Remedial measures (brief)	• Construction of retaining wall at toe. • Plantation of deep rooted plants. • Cultivation of bushes.
3. Nad-Mansar road (near Channi village), Samba **4. Landslide at Batote towards Lalhote, Ramban**	
Triggering Factor	Heavy Rainfall.
Landslide causes	Heavy rainfall causes the saturation of the debris material which resulted loss of cohesion and inter friction angle of overburden mass and eventually started moving down. The major geological causes for the slide is poor lithology, at the time of high rainfall the development of the pore pressure and reduction of the shear strength of the material due to saturation by water percolation, gully erosion in old debris.
Remedial measures (brief)	• Construction of retaining wall at toe. • Plantation of deep rooted plants. • Cultivation of bushes • Removal of existed slide material.
5. 200 m upslope to Baghani Malli on Pangot - Semalkhali road, Kathua	
Triggering Factor	Heavy Rainfall, rill erosion by spring.
Landslide causes	Flowing springs causes rill erosion. Loose and unconsolidated strata.
Remedial measures (brief)	• Construction of retaining wall at toe. • Plantation of deep rooted plants. • Cultivation of bushes • Removal of existed slide material.

6. Khairi landslide 5km from Udhampur	
Triggering Factor	Rainfall.
Landslide causes	Heavy rainfall causes landslide after rainfall got rapid sliding along slopes.
Remedial measures (brief)	• Construction of retaining wall trenches at toe and slope stabilization by concrete measures. • Plantation of deep rooted plants. • Cultivation of bushes.
7. Landslide at Bhawan, Katra	
Landslide causes	During the intervening night of 13-14th March 2016, the rainfall have resulted in widespread seepage of water into area which led to landslide at this particular spot and subsequent caving/subsidence on foot track leading to Bhawan.
Remedial Measures	• The affected stretch should be covered with some draping cover/curtain so that rain water percolation could be stopped, which may otherwise further aggravate the problem and pose danger to other nearby structures. • Surface drainage should be properly systematized and slopes should properly be stabilised.

8. The Landslides along the Jammu- Srinagar national highway (1A), J&K	
Landslide causes	Heavy rainfall.
Remedial Measures	Retaining wall at the toe, it is recommended that the slope be broken up by providing at least one berm, say of 5 ft. (1.5 m). A drain should be provided at the hill side of the berm, to carry away the under seepage and the surface flow.

V. Conclusion

In Jammu and Kashmir heavy rainfall is considered to be the main triggering factor for most of the landslides. The landslides at National Highway 1D from Sonamarg to Kargil, Jammu, and Kashmir is an example of rainfall induced landslide. Researches has shown, for heavy to extremely heavy rainfall (daily rainfall >=6.5mm) the maximum number of heavy rainfall days lies in the range of 2 to 3 days especially in some parts of Samba district, Jammu district, Kathua district and Reasi district. . While minimum number of Heavy rainfall days lies in the range of 0 to 1 day especially in some parts of Kulgam, Anantnag, Srinagar, Budgam, Shopian, Kupwara and Baramulla districts. Research has also shown high probability of earthquake more than 6 Mw in future which makes it important to ensure safety in term of earthquake induced landslide. Landslide susceptibility zonation, a prediction technique is a very important tool for landslide mitigation. By this the areas under high susceptibility zone that comes in high hazard category should be given due attention while executing the civil construction works by government or domestic constructional works by public. More areas of the state needed to be covered under landslide susceptibility maps. As the roads in the Jammu and Kashmir are a decade old, creation of new roads is posing a major problem as a result of the unscientific cutting of upslope of the roads. So, there is a need of more research for understanding impact of anthropogenic and physical factor on landslides in area. Retaining wall is most of the time used for stabilizing slopes in the area, so there is need of highly engineered methods. The use of gabion walls and drain system is strongly suggested as much number of landslides are triggered by heavy rainfall.

Acknowledgement

The authors would like to acknowledge Geological Survey of India, Bhukosh for publishing landslides reports and Indian metrological centre, Jammu for providing valuable information related to the work. The authors also acknowledge the support of Monika Verma (Assistant Professor, Lovely Professional University). Authors also like to thank the national disaster management authority (J&K).

References

[1] Varnes, David J. "Slope movement types and processes." Special report 176 (1978): 11-33.

[2] Jammu and Kashmir state disaster management authority, 2020.

[3] Parkash, Surya. "Historical records of socio-economically significant landslides in India." J. South Asia Disaster Stud 4, no. 2 (2011): 177

[4] Popescu, Mihail E., and Katsuo Sasahara. "Engineering measures for landslide disaster mitigation." In Landslides–Disaster Risk Reduction, pp. 609-631. Springer, Berlin, Heidelberg.

[5] Schuster, Robert L., and Gerald F. Wieczorek. "Landslide triggers and types." In Landslides. Procedings of the 1st European Conference on Landslides, pp. 59-78. 2002.

[6] Indian meterological department, J&K.

[7] Assessment of landslide hazards induced by extreme rainfall event in Jammu and Kashmir Himalaya, northwest India Amit Kumar , AKL Asthana, Rao Singh Priyanka, R. Jayangondaperuma, Anil K Gupta and SS Bhakun.

[8] Investigating Landslides caused by earthquakes – A historical review David K. Keefer.

[9] Bilham, Roger. "Himalayan earthquakes: a review of historical seismicity and early 21st century slip potential." Geological Society, London, Special Publications 483, no. 1 (2019).

[10] Using multiple vegetation layers to reduce the risk of rainfall-induced landslides and facilitate post-landslide slope rehabilitation Pei-Luen Lu (2014).

[11] Macro-scale(1:50,000) Landslide susceptibility mapping in parts of toposheet nos. 43P/02 AND 43P/06, Samba and Kathua districts, Jammu and Kashmir (J&K) By Varun Mandotra, Geologist, Geological Survey of India.

[12] Macro-scale(1:50,000) Landslide susceptibility mapping in parts of toposheet nos. 43P/01, 43P/05, Jammu, Samba and Udhampur districts, Jammu and Kashmir (J&K) By Aijaz Ahmad Bhat, Sr. Geologist, Geological Survey of India.

[13] Preliminary Geotechnical Assessment of Katra Vaishno Devi Bhawan landslide, Jammu And Kashmir By Devender Singh, Sr. Geologist, Suresh Kumar Rana, Sr. Geologist Geological Survey of India.

[14] Integrated remote sensing and GIS techniques for landslide hazard zonation: a case study Wadi Watier area, South Sinai, Egypt Mohamed O. Arnous.

[15] Landslide Susceptibility Zonation (LSZ) Mapping - A Review D. P. Kanungo*, M. K. Arora, S. Sarkar and R. P. Gupta (2019).

[16] Macro-scale(1:50,000) Landslide susceptibility mapping in parts of toposheet nos. 43O/4 AND 43O/8, Doda, Reasi, Ramban and Udhampur districts, Jammu and Kashmir (J&K) By Pradeep Pal Singh, Geologist, Sanjeev Kumar Sharma, Senior Geologist, Geological Survey of India.

[17] Popescu, Mihail E. "Landslide causal factors and landslide remediatial options." In 3rd International Conference on Landslides, Slope Stability and Safety of Infra-Structures, pp. 61-81. CI-Premier PTE LTD Singapore, 2002. Zhu, J-H., and S. A. Anderson. "Determination of shear strength of Hawaiian residual soil subjected to rainfall- induced landslides." Géotechnique 48, no. 1 (1998): 73-82.

[18] Zhu, J-H., and S. A. Anderson. "Determination of shear strength of Hawaiian residual soil subjected to rainfall- induced landslides." Géotechnique 48, no. 1 (1998): 73-82.

[19] Ramli, Mahyuddin, TJr Karasu, and Eethar Thanon Dawood. "The stability of gabion walls for earth retaining structures." Alexandria Engineering Journal 52, no. 4 (2013): 705-710.

[20] Report on post disaster studies of landslides along NH-44 & NH-244, Doda and Ramban districts, Jammu & Kashmir by N. K. Nayak Geological Survey of India.