Synopsis on

Site Specific Landslide Investigation using Geospatial Techniques - A case study on selected Landslides of Shimla and Mandi Districts, Himachal Pradesh, India

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1. Introduction

"Landslides are simply defined as down slope movement of rock, debris and/ or earth under the influence of gravity. This sudden movement of material causes extensive damage to life, economy and environment". **(Sharpe (1938), Varnes (1978), Cruden (1991)**. Landslides occur in hilly regions due to various natural and Anthropogenic cause. These causes includes cloudburst, thunderstorm, construction for various activities etc. (**GSI, 2001**). The most sensitive areas are the Himalayan belt, Western and Eastern Ghats. Hill ecosystem is one of the most fragile ecosystem in the world, when these ecosystems are disturbed either due to natural process or Anthropogenic process or the combined effect of both results in Geohazard and environmental problems such as landslides, soil erosion, reservoir siltation and land degradation. Among other various problems that affect hill ecosystem, landslides have observed as fast spreading epidemic due to its multivariate morphodynamic process and also due to improper interaction of human being on nature, especially terrain ecosystem. Countries in the Himalayan region is global hotspot for landslides, frequently faces the dangerous outfall of landslides **(Martha R Tapas et.al,2012)**. In India, about 0.42 million sq.km of areas are prone to landslide hazards. These areas includes the North Western and North Eastern Himalayas and the Western & Eastern Ghats (**GSI website**). Statistics on world landslides and its impacts is given in Table 1. Figure 1 represents the global landslide hotspots.

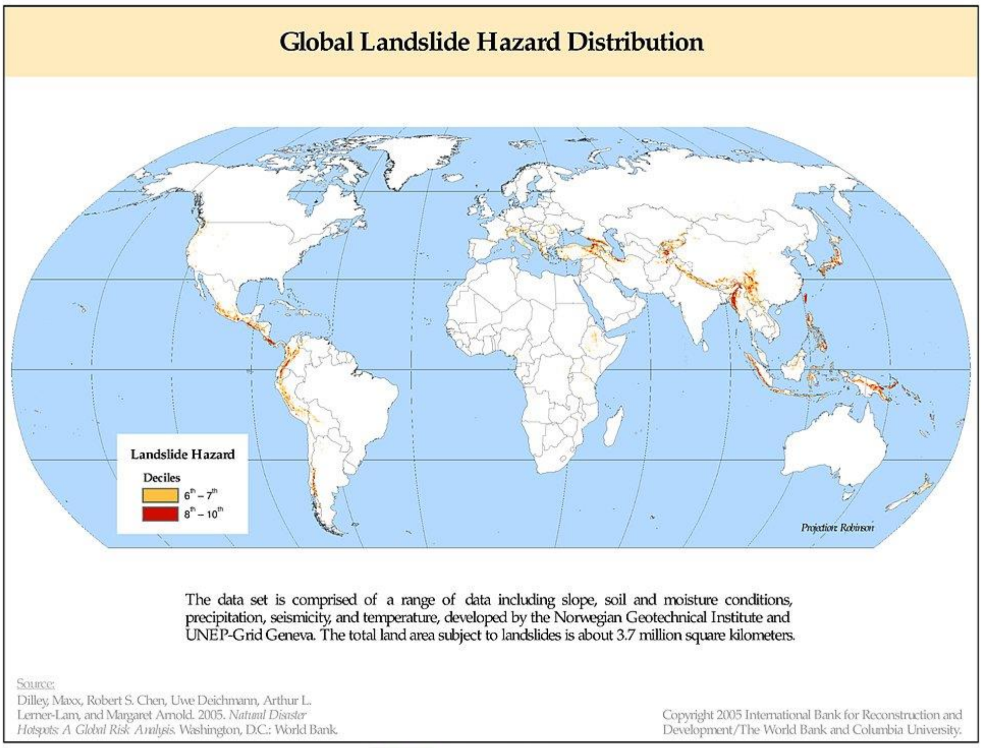


Figure 1: Global landslide hotspots (2017), Source (World Bank)

Continents	Events	Killed	Injured	Homeless	Affected	Total Affected
Africa	23	745	56	7,936	13,748	21,740
Avg. Per event		32	2	345	568	945
America	145	20,684	4,809	1,86,752	44,85,037	46,76,598
Avg. Per event		143	33	1288	30931	32252
Asia	255	18,299	3,776	38,25,311	16,47,683	54,76,770
Avg. Per event		72	15	15,001	6,462	21,478
Europe	72	16,758	523	8,625	39,376	48,524
Avg. Per event		23	7	120	547	674
Oceania	16	542	52	18,000	2,963	21,015
Avg. Per event		34	3	1,125	185	1,313

Table 1: World statistics on landslides (1900 – 2010)

Landslides of Various types, Pose severe hazards in the Himalayan mountains. Some of the worst disasters in the world have been caused by landslides. It has been estimated that the damage caused by landslides in the Himalayan region is about US$ 1 billion dollars and an average of 200 deaths in a year which is 30% of the such losses around the world, **Naithani (1999)**.

Landslide is the most common type of natural hazard found in Himachal Pradesh, causing immense risk to life and properties. Each year the state is affected by one or more major landslide causing social and economic losses. Loss of life, Damages to houses, Roads, communication lines and agricultural lands are some of the examples. The fragile nature of rocks forming mountain along with climatic and various anthropogenic causes has made state vulnerable to landslides. Deforestation, Unscientific road construction, Terracing and water intensive agricultural practices and encroachment have led to increased intensity and frequency of landslides (**SDMP, Himachal Pradesh**) makes it one of the important and necessary form of natural disaster to addressed in Himachal Pradesh.

Surya Prakash (2011) compiled a list of historical socio-economically significant landslides around India, where 371 events of reported landslides event occurred for the year 1800-2011.Based on his findings he concluded that West and northwest of Himalayas are highly prone to landslides accounting for about 49% of the people killed and 51% of the landslide occurrences. The data on various occurrences and fatalities is given on table 2.

Sl.no	Year	No.of socio economically significant events	Persons killed	No.of fatal events
1	2007 – 2017	893 (Nasa Catalog)	6614	893
2	2011	26	74	19
3	2010	85	368	53
4	2009	47	270	46
5	2008	36	220	30
6	2007	54	409	39
7	1800 - 2007	123	2630	61

Table 2: Data on various events and fatalities between (1800-2011)

2. Literature Review

The review paper presented here address the various aspects of landslide such as vulnerability, Risk assessment, slope stability analysis, Large scale mapping and slope stabilization measures. The period of review of these papers are from 1838 – 2017, the papers are categorized into Foreign, National and Regional landslide reviews, further subdivided into review papers on decadal order. This paper reveals the various methodologies used in landslide Risk mapping, Slope stability analysis and stabilization measures and various Geotechnical and Geological studies. Critical reviews on each method is provided with help published research journals (Elsevier, Springer, Taylor & Francis) etc.

2.1 Landslide reviews: International status

Early 18th century to 1970

Landslides are one of the most damaging and widespread natural hazards in the world. They have been occurring along the mountainous regions since time immemorial. The landslides were only studied with some scientific background during the early 18th century. **(Dana, J, D., 1862)** classification distinguished three kinds of landslides, now recognizable as debris flows, earth spreads and rock slides, without naming the landslides. As the first use of the term 'landslide' was recorded in 1838, Dana's may be the earliest classification of landslides. The study of landslides has global attention in the recent years due to increasing awareness on social and economic impacts, especially their impacts on mountainous regions due to human activities **Aleotti, P., & Chowdhury, R. (1999)**. Extensive researches on various aspects of landslide have been conducted by many researchers all over the world. These studies include making of landslide inventory maps, impacts of Geological, Hydrological, Anthropogenic and Topographical factors on landslide occurrence, future prediction of landslides, Rainfall thresholds and assessments of vulnerable of zones etc are some among them. Some of the earliest record of landslide studies dates back as far as 1783 when numerous landslides affected settlements and blocked rivers and streams creating 215 lakes as part of co-seismic effect of major earthquake occurred in Calabria in Italy. Information related to field based data on landslide maps were created by Almagia during 1910 in 1:50,000 scales. The Japanese Landslide society was formed during 1963 to study the landslides and landslide related hazards. International landslide symposiums were conducted by the Japanese landslide society (JLS) during 1972 and 1977 to explore various studied and research on landslides. The "Landslide News Letter" is being published since 1987, to provide opportunities on publishing articles and to closer international communications through the help of UNESCO and various international organizations.

1971 - 1980

Brunsden et.al, 1976 studied the forms and evolution of fairy dell, an active landslide complex along the Dorset coast using Cartographic, Air photo and field investigations. The authors addressed the dominant mechanism of the landslide Rotational landsliding and Block disruption. Erosion rates of the landslides were demonstrated using sequence of maps and geological cross sections. The spatial pattern of the active landslide was compared with dormant landslide in an inland area and concluded that geomorphological and subsurface characters can be better interpreted using evolutionary sequence of the active landslides. **Kanukabo, T., et.al, 1980** studied the importance Natural hazard mapping. They have stated that interaction between disaster occurrence and land conditions are important in studying three types of disaster namely, Earthquake, Mass-movement and Flood. Based on the result obtained the have concluded that there is significant study made between disasters and land categories. They have also stated more tools and parameters must be established for detailed mapping interaction between natural disasters and land information.

1981 – 1990

Keinholz, Hanz., et.al, 1982 studied the use of Air photographs for natural hazard mapping along the Colorado mountains, USA. Hazard details about Rockfall, Debri flow, Landslides and flood were mapped for different regions using Air photos and classified into Visible, Inferred and Potential through various criteria etc. Finally, these were combined to produce Mountainous hazard maps. **Keefer, D. K. (1984)** gave a general introduction on assessing the landslides using 1970 Peruvian Andes earthquake as an example. He indicated the factors responsible for landslides are Rainfall, Seismic and Anthropogenic activities, Landscape alteration and natural process. He concluded that landslide mitigation strategies are of two types Site specific analysis and Regional scale analysis. **Aniya, M. (1985)** studied landslide susceptibility modelling for Amahata river basin, Japan. The study includes in defining critical factors responsible for landslides and preparing landslide susceptibility map. Using Aerial photographs and field survey ten terrain parameters were considered among which Slope gradient, Aspect, Slope plan, elevation and Vegetation were considered as important factors through Failure rate analysis and quantification scaling. Landslide susceptibility maps were prepared using Slope gradient, Aspect and Slope plan as parameters and the results were categorized into stable and un-stable.

1991-2000

Yahota, Kumaki., et.al, 1996 discussed the possibilities of mass-movement hazard assessment through Geomorphological survey. The authors stated that the Geographical Survey Institute of Japan, have prepared maps on 1: 25,000 and 1: 5,000 scale Geomorphological maps with special emphasis to mass-movement landforms such as dissection fonts where the landslides are concentrated and Streams & Piedmont landforms where debri flow have occurred. **Dikaku et.al, 1996** correlated landslide database information with recent and historical landslide triggering factors to forecast occurrence of landslides using landslide frequency analysis. The results concluded that different combination of landslide data with factor maps were used to produce susceptibility and hazard assessment maps. **Miller, D. J., & Sias, J. 1998** worked with a two dimensional Finite Element model (MODFE) to calculate unconfined groundwater flux and water table elevations to study large landslides using Bishop's simplified method of slice along individual slope transect. **Sagar, Amod, Dhakkal., et.al, 1999** studied landslide hazard mapping using statistical analysis for Kulekhani watershed, Nepal. Frequency ratio and Quantification scaling were used to predict landslide susceptibility Slope gradient, Aspect, Elevation, Geology, Landuse, Faults and Drainage as parameters. Three susceptibility maps were produced based on the analysis. The results revealed that geology, Elevation and Landuse was found to be the important factors. Findings conclude that 2% of the area comes under high vulnerability and more than half of the area comes under less vulnerability. Dymond et.al, 1999 used a computer based simulation model to predict shallow landslides and associated sediment transport for different rainstorm events and landuse scenarios.

2001 - 2010

Ali, mohammadi., Safih., et.al, 2005 studied the efficiency of various statistical models to predict landslide susceptibility Seyedkalateh, Ramian, Northwest of Iran. Slope, Geology, Landuse, River and fault buffer were used as parameters. Based on the above factors landslide susceptibility map was produced for Valuing Information, Valuing Area Accumulation, Relative Effect and Landslide Numerical Risk Factor (LNRF) methods. The findings concluded that Relative effect method could produce accurate results compared to other models. **David, J, Wachal., et.al, 2017** studied landslide susceptibility modelling for Travis county, Texas, USA using empirical approach. Four parameters Slope, Geology, Vegetation and proximity to faults were considered. The data were analyzed using weighted overlay analysis and the output were categorized into areas of low, medium and high landslide susceptibility. The authors concluded that high susceptibility occupies Streams, Reservoir banks, rock escarpments and agricultural lands. **Dai, F., & Fan Lee, C., 2002** studied the relation between landslide sand its dominating terrain variables for Lantau island, Hong Kong. Data compiled from various digital maps and Aerial datasets were used to describe physical characteristics of landslides. Slope gradient, Lithology, Aspect, Elevation and landuse cover are considered as important factors in predicting landslide susceptibility. Landslide susceptibility map was created using logistic regression model with accuracy of 85.2% of actual landslides classified within the study area. **Lydia, Elena, Espizua., et.al, 2002** prepared landslide hazard and risk zonation mapping for Rio grande basin, Argentina. Landslide length, width, Slope, geomorphology, orientation, geology, Lithology, Curvature and Hydrology were considered as parameters. Two maps were produced using Aerial photo interpretation and field maps. Landslide types and susceptibility maps. Landslide types were classified into Rockfall, Slide, Flow and complex landslide. Risk hazards were classified into High, Moderate and Low. **Wu., et.al, 2002** focused on zonation of landslide hazards using integrated information model based of field investigation and landslide statistics. The results were divided into destructive, Disastrous, Slightly disastrous, Likely disastrous and non-disastrous area. Western Van et.al, 2003 analyzed the evolution of Tessina landslide using Aerial photo interpretation and Direct field mapping. The interpretation was done various multi-temporal maps resulting in detailed geomorphological maps of Tessina landslide. The author concluded that different elevation data sets are required for different time period to calculate the volume of the materials removed. **Hervas., et.al, 2003** demonstrated a new method for mapping landslides occurrences and monitoring ground surface changes using Optical remote sensing Imagery. The model was demonstrated using multi-temporal Panchromatic images through digital change reduction and thresholding techniques. They have concluded that more frequent observations are needed to monitor the change in ground dynamics. **Wilcke., et.al, 2003** studied the impacts of landslides on soil fertility and compared the properties of shallow transitional landslides to that of undisturbed soil. The results revealed that complete removal of organic layer along the top part of the soil where the obvious cause of land sliding. **Solana, Carmen and r Kilburn, Christophe., 2003** demonstrated the public awareness programmer of landslide hazards around the vulnerable communities that are exposed to landslides. A survey has been conducted among the vulnerable communities in the Barranco de Tiranjana basin on Canaria. Results revealed that the communities are aware towards the natural hazards. **Chau, K, T., et.al, 2004** have studied landslide inventory and GIS based frame work for systematic landslide hazard analysis for Hong kong. Parameters such as Slope, Elevation, Lithology, Soil, Rainfall and Past landslide data were used in GIS environment to produce landslide susceptibility maps. Cheng et.al, 2004 stated the possibilities of using landuse and landcover change to determine the landslides. Gray level threshold of the band ratio difference of image is determined to predict the landslide areas. The results were then refined using Digital elevation model to restrict landslides along the steep slope areas. **Huat Bujang, B, K., et.al, 2005** evaluated the possibilities of occurring landslides along four major roads of the mountainous regions of Malaysia using newly developed slope analysis software. They choose 13 parameters such as slope location, height, angle, plane profile, cross profile etc for this analysis. The analysis was carried out using old and newest SAS software. The resulted concluded that the new software predicts the failure of slope up to a 90% accuracy when compared to the old one where only 28% accuracy. **Neaupane, K, M., et.al, 2006** proposed an Analytical Network Process (ANP) model for landslide susceptibility analysis. The study area chosen lies in the eastern part of Nepal along the lower Himalayas. Various causative factors such as Slope angle, Slope aspect, Landuse, Geology and Landuse were used as parameters for susceptibility analysis. Weightage between 0 to 1 were used to demarcate areas into Low risk, moderate and High risk. **Nichol, J., et.al, 2007** created landslide inventory maps using Change detection and Image fusion techniques Lantau island, Honkong. Two spot images for December 1991 and February 1995 were acquired pre and postdating a Rainfall induced landslide events on November 1993. The overall classification accuracy for two images were 85% and 87% respectively. 551 landslides events were occurred between 1991 and 1995 among them 417 were occurred on woodlands and 75 on grasslands. **Anbalagan, R., Singh, Bhoop., Chakraborty, D., Kohli, Atul., 2007,** publish a book on field manual for Landslide Investigations. The book explains about various techniques for landslide hazard mapping. It also explains about various slope stability analysis and the procedures to carry out. **Tassetti, Nora., et.al, 2008** studied about the use of remote sensing and GIS techniques for susa valley, Italy using a mathematical linear predictive model to assign values for landslide hazards. The parameters used are Landuse, precipitation, Lithology, Aspect and slope. The output was created in ARCGIS environment and classified into five types from high stability to high instability. Low and medium instability constitutes about 28 and 35% respectively. **Jian, Wang., et.al, 2009** investigated landslide susceptibility Zhongxian-Shizhu Segment in the Three Gorges Reservoir region of China using data driven object based Bivariate analysis. Various parameters such as Elevation, Slope, Distance to Road, Drainage and Settlements, Aspect, Geology and Shape of slope have been used. Weighted overlay analysis was carried out to produce landslide susceptibility map. The results indicate that 3.6% of the study area comes under high susceptibility, Very low and low vulnerability accounts for about 31.6% and 27.9% of the area. **Hong, Yang., et.al, 2008** created a frame work for preliminary real time prediction system for rainfall induced landslides around the world. Two components such as surface landslide susceptibility and Space based rainfall analysis system were integrated for this process. Parameters such as Elevation, Slope, Soil and Land cover were analyzed in GIS environment using weighted linear method and relation between rainfall intensity duration and landslides were established to predict areas of high susceptibility. **Dahal, R, K., et.al, 2008** created a predictive model for rainfall induced landslides over south-western marginal hills of Kathmandu valley, Nepal using weight of evidence model. Parameters such as Slope, Elevation, Aspect, Relief, Flow accumulation. Distance to Drainage and Road, Geology, Landuse Soil type and depth and extreme rainfall events were used to create Landslide susceptibility map. The results were validated using historical rainfall triggered landslides data with an accuracy of 88%. **Dahal, R, K., et.al, 2008** studied the probability of Landslide failure using DEM based Hydrological model and landslide susceptibility for extreme rainfall events using deterministic based method. Parameters such as Elevation, Slope, Soil, Soil depth, Landuse were used to estimate susceptibility map for various rainfall return periods. The results were validated with landslide map produced from June 2002 rainfall event. The results reveal that 50% of the landslide pixels were in 50% to 100% failure probability, 20% of the pixels shows 1 to 25% of probability failure. Wang Jian et.al, 2009 studied GIS based landslide hazard zonation for the country of wan using ordinal scale relative weighting-rating technique. The parameters chosen for the study were buffer map of thrusts, lithology, slope angle and relative relief, NDVI, buffer map of drainage and Lineaments. The output was classified into High stable slope zone, Stable slope zone, Quasi-stable slope zone, relatively unstable slope zone, Unstable slope zone and Defended slope zone account for 2.20%, 14.02%, 39.88%, 28.27%, 12.17% and 3.47% respectively. **Khattak, Ghazanfar, A., et.al, 2010** conducted post landslide studies for October 2005 earthquake occurred along the western Himalaya of northern Pakistan. Sixty-eight landslide locations were chosen and photographed during November 2005, May/June

2006 and June/August 2007 for potential geomorphic changes. The results revealed that 80% of the area showed no or very little change. 11% of the area showed partial vegetation recovery and 9% of the area shows active landslides. **Lodhi, Mahtab, A., 2011** investigated post-earthquake landslide assessment for October 5th,2005 occurred along the western Himalayas. Data acquired from Advanced space borne Thermal emission and Reflection Radiometer (ASTER) were used as a source for delineating landslides. Various image processing techniques such as Principle component analysis (PCA), Normalized difference Vegetative Index (NDVI), Iterative Self-Organizing Data Analysis Technique (ISODATA) were used. Accuracy of the data was estimated using visual interpretation landslide data from high resolution satellite imagery (IKONOS) with 77% accuracy. The result revealed that most the landslides were located along the tectonically active region of Western Himalayas. **Ray, R, L., et.al, 2006** studied slope stability using remotely sensed soil moisture data to predict landslides. The Cleveland corals locate in the Sieera Niveda mountains, California, USA was chosen as the study area. Parameters such as NDVI, Albedo and LST were used to estimate soil moisture content. The landslide inventory maps compared using two different models Advanced microwave scanning radiometer (AMSR-E) and Variable infiltration capacity (VLC). The results indicate that 0.42% and 0.49% of the study area were high vulnerability under (AMSR-E) and (VIC) model. **Saba, Sumbal, Bahar., et.al, 2010** conducted spatiotemporal analysis for 2005 Kashmir earthquake. Muzaffarabad and Balakot- Bagh fault line, located in the eastern Pakistan. The landslide inventory was created for pre and post-earthquake data and for following three consecutive years using visual interpretation high resolution of satellite imageries. The results revealed that 158 landslides were occurred along the Balakot-Bagh fault line and landslide activities were high for two consecutive years and reduced in further years due to stabilization of slopes and Re-vegetation.

2011 – 2018

Ilanloo Maryam, 2011 used Fuzzy logic approach to map landslide susceptibility zones for Karaj dam basin in Iran. Five parameters such as Slope angle, Elevation, Aspect, Land cover and Annual rainfall were used. The output was created using Modified Landslide Hazard Evaluation Factor (MLHEF) rating. The result concludes that 10%, 23% and 38% of the study area comes under Very high, High and Moderate probability zones. **Huang Runqiu et.al, 2011** studied landslide susceptibility for entire china. Various causative factors such as Topography, Geology, Tectonics and Climatic conditions have been used as indicators landslide activities. His findings concluded that china can be divided into 12 zones of landslide susceptibility 4 high risk zones, 7 medium risk zones and 1 low risk zones. Based on the results the 12 zones were divided into 2 very high risk zones, 5 high risk zones, 2 medium risk zones and 3 low risk zones considering the extent of loss of human life and external property. **Khezri Saeed, 2011** studied landslide susceptibility for Zab river basin located on the Wets-Azerbaijan, Iran using Analytical Hierarchical process (AHP). Parameters such as Slope angle, aspect, Distance to Drainage, Road, Faults, Geology and Landuse were used as landslide inducing factors. The output was categorized into five ranging from high susceptibility to no susceptibility. The results indicated that 90% of the occurred landslides were located along the high and relatively high susceptibility areas. **Yu, Guoqing., et.al, 2011** conducted landslide risk analysis for Miyun reservoir, central south zone of Yanshan subsidence, China. The risk analysis was modelled through Analytical Hierarchical Process (AHP) using various parameters such as Slope, Elevation, Landuse, Vegetation cover, Soil type and rainfall. The results were classified into five types from Landslide easily happening to landslide hardly happening. Validation of the results were not provided. **Guirong Zhang et.al, 2011** developed real-time warning system of regional landslides using WEBGIS platform for Zeijang Province, China. The study area is divided into Typhoon and Non-Typhoon region and thresholds of effective rainfall and rainfall intensity were obtained from rainfall data. These data were combined with landslide hazard maps to produce early warning system of rainfall induced landslides in a WEBGIS platform. **Yin, Jianzhong., et.al 2011** studied the relationship between change in vegetation cover and debri flow. The author reviewed various study regarding to debri flow and conclude that change in vegetation alone cannot be responsible for Debri flow. The author concluded his research by indicating drawbacks of taking vegetation only into account, that landslides are controlled by many factors. **Hsien, Liao, Chin., et.al, 2011** addressed the use of Spatial analysis techniques for mapping Natural hazard areas in Taiwan. The author presented a comprehensive framework to map the natural hazard areas based on Natural hazard, Natural environment and social development. The authors concluded that the comprehensive framework using GIS database will help urban-planners in decision making process. **Yu Wenjuan et.al, 2012** studied the relationship between precipitation and debri flow for Siachan province, China. Daily rainfall data were collected for the year 1981-2004 and historical landslide records were collected for the 1951-2004 with 467 landslide occurrences. The results were calculated using various GIS techniques and logistic regression model for Intraday rainfall and a 10 day before period and effective antecedent rainfall. The findings conclude that 83% of the rainfall occurred after intraday day rainfall. By comparing both results effective antecedent rainfall shows significant relation to debri flow than a 10-day rainfall model. **Othman, Ainon, Nisa., et.al, 2012** created GIS based Multi criteria decision model for assessing landslide hazard zonation using

Analytical Hierarchical process. The parameters considered are Slope, Soil, Aspect, Landuse, Lithology, Elevation, Geomorphology, Rainfall, Proximity to River and Road. Using two different models encompassing various parameters the vulnerable areas were mapped into three types namely low, medium and high. Model 1 using AHP yields an accuracy of 74% were as model 2 yielded only 64%. Finally, AHP method was proposed for calculating landslide hazard assessment. **Kayastha. P et.al, 2013** studied landslide susceptibility for Tinau watershed, Nepal using Analytical Hierarchical process. Eleven various parameters such as Slope aspect, angle, curvature, Relative relief, Landuse, Geology, faults, annual rainfall, distance form anticline and syncline folds were used. The output was categorized into four zones ranging from Very high to low susceptibility. 39% and 30% of the area constitutes about very high and high susceptibility zones. The results were validated using success rate curve (statistical analysis) with an accuracy of 77.5%. **Li, Xue, Ping., et.al, 2012** came up with an GIS based Monitoring and early warning system for Wangshui village, south west of Zhong county, China. The system uses GIS based platform as base for monitoring the landslides. The system runs sixteen models in three categories Long-term prediction, Medium range forecast and Critical sliding model. The information processed in these software can provide base for early warning signs. **Zhang Wenjun et.al, 2012** used Contribution rate weight stack method to quantify areas that prone to landslides for the southern coastal areas of china. Factors such as Stratum, Slope, Aspect, Elevation and Slope shape as parameters. The output is derived using various statistical analysis such as equalization, normalization and weight conversion. The results derived were compared with actual landslides and found to be higher accuracy. **Antinao, José, Luis., et.al, 2013** studied the landslide triggering factors for Juliette tropical cyclone of 2001 along the Baja California sur, Mexico. The authors stated that storm rainfall and intensity, Aspect, Geology and Vegetation were primal factors for landslide occurrence. The authors concluded that two process were responsible for slope failure, one being accumulated rainfall over exposed bedrocks and other is combined wind and overland flow along the upper slopes. **Yu, Zhishan., et.al, 2011** published landslide disaster information using WEBGIS AND MAPGISK9-IMS as map release platform for Lanzhou city. The software includes three modules rainfall management, early warning analysis and early warning management. The system runs with early warning analysis at its core and other modules as secondary development. The various Key technologies, Structure of the system were explained briefly on the paper. **Feizizadeh Bakhtiar et.al, 2012** did a comparative study on landslide susceptibility mapping using various methods of Multi-criteria decision model. Urmia lake basin of Iran was used as study area to conduct research. Nine various landslide inducing parameters were used to model landslide susceptibility using AHP, Weighted Linear and Weighted Average method. The respective results were validated using landslide inventory maps indicating AHP method produced highest accuracy of 21.2% while Weighted Linear and Weighted Average produced 20.1 and 10.5%. **Regmi Deep Amar et.al, 2014** conducted a post landslide assessment for Mauri Khola landslide occurred along the Mauling-Narayanghat road, Chitwan district, Central Nepal. Various data's gathered from Geological, Geomorphological and Geomechanical surveys revealed that the landslide is affected by Rock Toppling. The study revealed that the Mauling-Narayanghat road section are affected by repeated landslide activities and geology plays an important role in triggering of landslides. **Mollaee, Somayeh., et.al, 2014** studied landslide inducing factors for Cameron island, Maleysia. The have overlaid past landslide occurrence over Soil, Lithology, Vegetation, Slope and Lineament maps to study the particular characters of landslide inducing areas. **Tofani, V, S., et.al, 2013** conducted a questionnaire survey about the use of remote sensing data for landslide mapping. The results were compiled from compiled from 17 different European countries. The results conclude that landslide detection and mapping have carried out by Aerial photographs associated with radar and Optical imagery. Remote sensing data have been used to map and monitor types of landslides on large scales preferably (1:5,000 to 1: 25,000) in conjuncture with other thematic layers. **Xu, Chong., et.al, 2015** indicated the necessity of establishment of unified principles for preparing inventory maps of earthquake triggered landslides. The key points considered for preparing the maps are visual image interpretation, demarcation of boundary, spatial extension landslides, Accounting for locational errors and false positive and errors etc. He created inventory maps for four earthquakes occurred in China, Haiti and Chile. The result shows a significance difference in distribution of landslides. **Torkashvand Ali Mohammedi et.al 2014** studied landslide susceptibility for a basin located on the Ardebil province, Iran. Factors such as Slope, Distance from faults, Lithology, Elevation and Precipitation were used as parameters. Landslide Numerical risk factor (LNRF) model was used to assign weights for each causative factors and overlay analysis was conducted to create landslide hazard zonation map. The results were validated using landslide maps prepared from Aerial photos, Satellite images and field surveys. The results show that 67.8% and 24.3% of the basin has high and low instability. **Feizizadeh Bakhtiar et.al, 2014** studied landslide susceptibility using integrated Fuzzy Set Theory and Analytical Hierarchical Process for Izeh basin in the Khuzestan province, South-western Iran. Factors such as Slope, Aspect, Lithology, Landuse, Drainage, Faults and Precipitation etc were used as causative parameters. The results indicated that integration of Fuzzy set theory with AHP process increases the accuracy of the results. 53% and 31% of the known landslides occurred in Very high and high susceptibility zones. **Formetta Giuseppe et.al, 2014** used Physically based approach for modelling the Rainfall induced shallow landslides. The authors present an integrated system for early warning rainfall induced landslides. The model was tested for two river basins in Calabria, South Italy. The results were produced in terms of evolution and depth and compared with landslide maps. **Altin Bayer Turkan et.al, 2015** investigated the landslide triggering factors for Korucak subbasin, North Anatolian, Turkey. Datasets such as Slope, Elevation and Geology were used as parameters to compute Stream power index (SPI) and Compound topographic index (CTI). The results concluded that Slope and Lithology were important landslide triggering factors, North and Western Korucak sub basin were under high risk vulnerability. **Sahin, Emrehan, Kutlug., et.al 2015** compared Feature and expert based weighted method (Chi square and Fisher) along with Analytical Hierarchical Process (AHP) for landslide susceptibility mapping. Arakli district of Trazbon provinence, Turkey was chosen as study area. Parameters such as Elevation, Drainage density, Landuse, NDVI, Slope, Lithology etc were used. The results were validated using success rate curve analysis, indicating an accuracy of 84.4%, 89.4% and 90.3% by AHP, Chi square and Fisher methods. **Chang Hsun Shih et.al, 2015** used discrete set analysis to two different soil behavior landslide incidents. Shei-Pa national park, Taiwan is used a study area to study landslide trigger factors. Geomorphology and Vegetation condition were used as parameters. Discrete set tool was used to analyze the threshold of each factors on landslide occurrences. The study revealed that NDVI, VI, Elevation and Distance from road are the major factors influencing landslide occurrences. **Raghuvanshi, Tarun, Kumar., et.al, 2015** conducted comparative study for landslide susceptibility mapping using Grid overlay and GIS modelling for Meta Robi district, Ethiopia. Parameters such as Slope, Slope material, Elevation, Aspect, Landuse and Groundwater were used as indicators. Landslide susceptibility map was created using a 10 x 10 m grid model and GIS model. The results were validated using past landslide data and indicated that GIS modelling is better suited for landslide analysis with an accuracy of 95%, than Grid overlay with an accuracy of 84%. **Sitanyiova Dana et.al, 2015** indicated the advantages of using GIS in Geotechnical evaluation of landslides. Using ARCslopetab an extension of ARCGIS software was used to calculate the slope stability of the area. The article was summarized with the role of GIS in planning, data analysis and monitoring of landslide prone areas. **Nugraha Henky et.al, 2015** study the relationship between landslides and Geomorphometric properties. Tinalah watershed located in Menoreh mountains, Indonesia was chosen as study area. Elevation, Slope, Aspect, Profile and Plane curvature were used as parameters derived from 2x2 m grided DEM data. The output was analyzed in conjuncture with past landslides. The result revealed that most of the landslides occurred above 400m M.S.L, Slope angle of 20 degrees, East to West slope direction and flat curvature. **Hong Haoyuan et.al, 2015** studied landslide susceptibility using Frequency ratio model. Xiushui of the Jinagxi Province, China was used as study area. Various parameters such as Slope angle, Altitude, Aspect, Topographic wetness index (TWI), Slope length and Lithology were used. The results reveal that 48.2% of the study area comes under high and very high risk areas. The results were validated using ROC curve with an accuracy of 80.2%. **Castelli Francesco et.al, 2017** used mono-phase model (FLO-2D) to predict the debri flow. The model has been recreated for an debri flow event occurred during 1st-2nd of February Enna city, South Italy. DTM, Hydrological and Sediment-Water mixture were used as causing factors. The results obtained by the model were found to be on par with evidence collected from actual events. **Heleno Sandra et.al, 2015** used supervised classification methods to delineate rainfall induced landslides from Very high resolution satellite images. The model was implemented for Madiera island in the North Atlantic Ocean. The landslide were demarcated using Pixel based classification and Object based classification (Support vector machine and Rule-set based frame work.) The findings reveal that Support vector machine and pixel based classification produce accurate compared to rule-set based framework. **Nikolakopoulos, Konstantinos, G., et.al, 2015** used Remote sensing, GIS and GPS data for landslide mapping. The study was conducted for Lefkas island, Greece using multi-temporal and Multi-resolution data and DEM data. 7 possible areas were detected using vegetation indices difference and 5 using height difference from DEM data. The results validated using Ground control points (GCP) indicated that four of the areas were correctly mapped. **Xu Chong et.al, 2015** constructed landslide databases for 2013 earthquake of Lushang county, Sichaun province, China. Pre and Post earthquake high resolution images were collected to create database on landslide inventory. A Total of 22,528 coseismic landslides were mapped on pre and post-earthquake satellite images. The results were compared with landslide data from historical events such as 1999 chi-chi and 2008 Wenchaun shocks. The results revealed that Lushang area more prone to landslides due to its steep and rugged topography, fractured and densely joined lithology. **Patriche, Cristian, V., et.al, 2016** did a comparative study on demarcating landslide prone zones using Binary Logistic Regression and Analytical Hierarchical process for 130 sq.km of Maldovian Plateau of Eastern Romania. Five parameter namely Altitude, Slope angle, Slope aspect, Lithology and Landuse were used to categorize landslide. The results achieved from both the models shows Statistical based BLR model produces more accuracy with 82.2% of the area coming under Very high and High susceptibility zones compared to analytical Hierarchical process. **Behling Robert**

et.al, 2016 studied Spatiotemporal variability of landslide activity over the eastern rim of Fergana basin, southern Kyrgyzstan. The landslide activity was estimated using Object based Vegetation changes specific to landslide activities for the year 1986 – 2013 using various sensors such as Landsat TM&ETM+, SPOT, IRS LISS III and Rapideye data. The results of spatiotemporal activity revealed that more than one third of the landslides occurred in same areas indicating the reactivation of old landslides and most number of landslide occurred during the year 2003 and 2004 by more than five times that of normal occurrences. **Mahalingam Rubini et.al, 2016** studied LIDAR based landslide susceptibility mapping for Gales creek Quadrangle, North-west Oregon, United states of America. Parameters such as Slope, Slope roughness, Terrain roughness, Stream power index and Compound topographic index was used. The analysis was carried out using various statistical methods such as Discrete analysis, Artificial Neural Network (ANN) and Support Vector Machine (SVM). The results were validated with ROC curve with 70% accuracy. **Vakshoori V et.al,2016** Studied the landslide susceptibility of Qaemshahr area of northern Iran using various statistical models. Parameters such as Elevation, Slope angle, Aspect, Landuse, Distance to drainage, Fault, road and Rainfall were considered for susceptibility mapping. Various susceptibility maps were created using Frequency Ratio, Weight of Evidence and Fuzzy logic method. The results were validated through historical landslide datasets, indicated that Frequency Ratio and Weight of Evidence methods were more suitable in demarcating landslide susceptibility zones. **Freeborough, K, A., et.al, 2016** conducted landslide hazard assessment for Great Britain's National Rail Network. Historical landslides data, Land instability map and Geologically mapped landslides were overlaid to produce landslide susceptibility maps. The results were differentiated into five class from A(low) – E(high) depicting the degree of vulnerability. **Barrile Vincenzo et.al, 2016** used Fuzzy logic method for mapping landslide susceptibilities. The province of Reggio Calabria, Italy chosen as study area. Parameters such as Elevation, Slope, Lithology, Rainfall and Landuse were assigned values and processed in GIS environment. The output subdivides into five categories ranging from Very low to Very high. The results indicate that 22%, 36% and 20% of the area comes under Very high, High and Moderate risk zones. Tryggvason Ari et.al, 2016 created new algorithm for mapping landslides in postglacial and glacial sediments in Sweden. Using topographical and Quaternary sediment data landslides were mapped. The results were compared with other two algorithms (Global visibility operator and Shadow casting algorithm) and found to be more accurate than existing algorithms. **Passalacqua Roberto et.al, 2016** developed a new Physically based Hydrological-Geotechnical model to predict rainfall induced landslides. Mendatica a small town of Lugria, Italy was chosen as the study area. **Bovolenta Rosella et.al, 2016** provided series maps to mitigate counter measures for various landslide prone areas. Genoa province, Italy were chosen as a study area. To provide various counter measures Geomorphological, Geological, Climatic and Anthropogenic causes were taken into account. Based on these parameters six countermeasures such as Reprofiling, Drainage, Retaining walls, Reinforcement with inclusions, Protective measures with soil bioengineering and for rock slopes have been provided for landslide mitigation. **Cotecchia Federica et.al, 2016** proposed a Multiscalar method for Landslide Mitigation (MMLM) approach for intermediate to regional landslide hazard assessment. This paper entails first of the two phases which is to analyze landslide at regional level. The proposed methodology is implemented at various urban centers in the Daunia and Lucanian Appenines, southern Italy. The results revelaed that most of the landslides occurred along the failed slopes and reactivated due to slow to very slow mass movments. Most of the landslides are activated due to seasonal variation in pore pressure. **Winter, Mike, G., 2016** proposed a strategic based risk reduction for debri flow sites along the A83 road of the Scottish road network. The proposed methodology is subdivided into two outcomes exposure reduction and Hazard reduction. The exposure reduction comprises of educating the people, usage of warning signs and early warning system, whereas hazard reduction uses building fence and concrete structures to protect the elements at risk, reduce failure probability by vegetation and other measures and removal of elements at risk. **Kachi Noriyasu et.al, 2016** proposed a disaster recovery system for landslides that occurred along the urban fringe of the Japanese cities. Aso-shi in Kumamoto prefecture is chosen as study area. They have recommended the migration of peoples whose properties were destroyed due to landslides to other safer places which has not been practiced and the villagers were forced to live in the disaster prone area. **Reid Mark E et.al, 2016** used a statistical based approach to model the inundation areas due to a debri-flow. The model is based on an empirical growth function analyzed in a GIS framework. The model was applied to debri- flow prone area along the coastal ranges of Oregon, USA. The results revealed that erosions were predominant along the stream channels with a slope angle greater than five degrees. The methodology provided reliable results on distribution pattern compared to other methods. **Hamza Tilahun et.al, 2017** used a statistics based probabilistic approach to predict landslide susceptibility for Jeldu district of Central Ethiopia. Various parameters such as Lithology, Soil, Slope, Elevation, Aspect and Landuse. The weights of each parameter were calculated using frequency ratio method. The result revealed that 32%, 21% and 8% of the area comes under moderate, High and Very high hazard. The results were validated with past landslides, 92% occurring in high and very high hazard zones. **Tacconi, Stefanelli, Carlo.,**

et.al, 2016 studied the causes and evolution of landslide dams around Italy. The authors proposed two new model such as Morphological Obstruction index and Morphological dam stabilization index to assess landslide dam evolution over large areas. The models use river width, Landslide volume and River energy as base data to monitor the landslide activity in a real-time scale. The result reveals that proposed methodology is accurate compared to existing models. **Leonardi Geovani et.al, 2016** used a Fuzzy approach to analyze landslide susceptibility for Reggio Province, Calabria, Italy. Rainfall, Elevation, Slope, Landuse and Lithology were used as landslide influencing parameters. The output signifies that 22% and 36% of the area comes under high and very high risk areas. The results were validated with accuracy of 80% with the data. **Montrasio Lorella et.al, 2016(a)** used mathematical based model to predict rainfall induced shallow landslides. Various parameters such as rainfall, geometry, Soil state, Mechanical and Hydrological characteristics of soil were used as influencing factors. The results were analyzed using SLIP (Shallow landslide Instability Prediction) model and validated using lab based experiments (flume test). The results show the model is on high accuracy. **Montrasio Lorella et.al, 2016(b)** is used physical based SLIP model to ascertain rainfall induced shallow landslides at Regional and National level. The analysis was carries out for central Emilian Apennine, Emilia Romagna Region, Northern Italy. The ability of SLIP model to create site specific time varying landslide susceptibility maps and early warning systems have been addressed. **Catani Filippo et.al, 2016** studied the spatial dimension landslides for Arno river basin, central Italy. The overall landslide events (27,000) were taken into account to study the volumetric extent. Geological and Geomorphological factors were also taken into account to predict the influence on landslides. Based on the findings the authors concluded that structural setting and valley density of the basin have greater influence on mass movement dimensions. **Hsu, Chih, Hao., et.al, 2016** studied landslide hazard prone areas along the south link railway section of Taiwan. The landslide hazard map was built using a logistic regression model using various causative parameters such as DEM, Geology, Hydrology, Topography and Anthropogenic activities. The results concluded that 48 sites along the railway link are prone to shallow landslide among which 11 are rock fall sites and 7 sites belong to debri flow. **Li Hui et.al, 2016** proposed a Semi-Automatic based method to map large shallow landslides from high resolution satellite images. The proposed methodology was implemented for Wenchaun earthquake, China. Four Post-earthquake high resolution imageries were obtained for May 18-28, 2008. Using the threshold value created for lighter tones rest of the images are ignored. Shape and textural parameters were employed to remove false positives like Road, buildings and farmland. The resultant images produced has accuracy of 77% and 68% in terms of landslide numbers and areas respectively. **Cao W et.al, 2016** extracted landslide information from various data source for various region of landslides using Object based classification. Dujiangyan, Baoying and Neiliu railway landslide were chosen as study area. The texture features of the area were extracted using Gray Level Co-occurrence Matrix (GLCM). Spectral, Shape and Thematic features were used to refine the results using semi-automatic classification. The authors concluded that the results are in consistent with the expert's field interpretation. **Feizizadeh Bakhtiar et.al, 2017** used Object based image analysis to predict landslide areas and landslide related change detection from multi-temporal satellite images for Lake Urmia basin, North-western Iran. 11 parameters such as Brightness, Slope, Elevation, Flow direction, Mean curvature and shape index were used to compute landslide areas. The landslide areas were demarcated using various segmentation process and the results were validated using Fuzzy Synthetic Evaluation (FSE) approach. The results revealed that AND operator provided with upto 93.8% accurate results. **Peruccacci Sivia et.al, 2017** studied rainfall threshold induced Shallow landslide for Italy. Rainfall data was collected between Jan 1996 to Feb 2014 from 2228 rainfall gauge station to build a catalogue. Using rainfall and landslide information 2309 rainfall induced landslide events were mapped for Italy. The authors evaluated the threshold using Rainfall threshold model and suggested to a new threshold values for Italy. The results revealed that 20% exceedance of the threshold value can correlate rainfall induced landslides between 1996 to 2014. **Zhao, wei., et.al, 2017** conducted post-earthquake landslide assessment for 2015 Nepal earthquake induced landslides. Trishuli and Sun koshi river valley were chosen as study area. Pixel based classification was conducted for two LANDSAT 8 images pre and post-earthquake. The results obtained was validated using data retrieved from Google earth images. The ability of LANDSAT 8 images to detect landslide areas were addressed in this paper. **Postance Benjamin et.al, 2017** studied the impacts of landslides along a National road transport network of Scotland. The impact of landslide is assessed by integrating landslide hazard data over Transport network model. Set of possible road segments are generated using landslide susceptibility data. The results conclude that 34% of the road segments are prone to direct or indirect economic losses due to landslides. **Shroder F John et.al, 2017** addressed the Geomorphology of the Lake Shewa landslide dam, Afghanistan using remote sensing data. He addressed that the Rock avalanche of the lake is due to fault shattered and highly weathered Archaen Gneiss of Zirnokh peaks along the Arakht river valley. The author mapped four other landslides using remote sensing data, historical maps and Google earth. The authors concluded that prolonged exposure of the area to landslides could threaten the lakes integrity, otherwise it could be used as source for hydro-electric power and Irrigation purposes. **Roback Kevin et.al, 2018** mapped the size, distribution and mobility of landslides caused by the caused by 2008 Gorkha earthquake in Nepal. Using High resolution satellite imageries more than 25,000 landslides were mapped along the deep seated Himalayan mountains of central Nepal. The results obtained were consistent with previous earthquake triggered landslides around the world. (Yan et al. 2019; Yang et al. 2019) Yan studied the landslide susceptibility mapping using AHP and Normalized Frequency ration model based on cloud computing. They concluded that both AHP and Normalized frequency model can increase the accuracy of the results compared to other statistical models. Yang came up with new method to study landslides using spatial logistic regression and Geodetectors for Duwen Highway Basin, Sichuan Province, China. He concluded that the current methods produced 86.1% accuracy which is 11.9% more compared other logistic regression models.

Over the years' various scientist and researchers have addressed the landslide problems using various qualitative, Quantitative, Statistical and Numerical methods. Every methodology used has its own merits and demerits. The type of landslide involved depends upon varying condition such as slope, geology, geomorphology, nature of landslide, type of causative factor etc. Based on the literature it can be concluded that no methodology is global for landslide studies. The accuracy of estimating landslide risk zones various for each method. It is imperative that suitable methodology need to be used for regional preparation of landslide risk maps. Addressing the nature and causative factor of individual landslide is as important as preparing landslide risk maps. Most of the literature address the mapping risk zones or slope stability analysis, it is imperative that all these problems should be addressed together. The landslide risk maps in conjunction with early warning system will provide useful insight in landslide prediction thus reducing social and economic losses. The authors followed their own methodology and choice of parameters depending upon the type of landslide analysis. Based on the literature it can be concluded that various methodologies are in existence ranging from weighted overlay to Neural Networks etc. The need exists for new, standardized landslide maps covering regional and local areas of risk map preparation is very high especially in regions such as Himalayas where the chances of landslides occurring are high. Review of the literature has shown that the best approaches in detecting landslide is that use of VHR images both monoscopic and stereoscopic and also high resolution 3D modelling of topography using LIDAR sensors. Imageries acquired using UAV drones coupled with LIDAR datasets have produced greater accuracies for site specific detailed landslide investigation.

Landslide reviews: National Status

In India landslides are quite common along the Himalayan regions, Western and Eastern Ghats. Many researchers and scientist have attempted to investigate landslides in different parts of the country, among which few scientists provided significant contribution in understanding the problems and factors causing landslides. The studies and preparation of landslide maps were started during the early 1960's. Studies on landslides with respect to their impact on environments and ecology gained speed during (1990-2000) "International decade for landslide disaster risk reduction". In conjunction with IDLDR by United Nations (UN), the Department of Science and Technology, Government of India came up with a Programme called "National Technology Mission on Landslide Reduction" to formulate guidelines on preparing landslide hazard zones. Since then many government institutions involved in landslides hazard studies and management, these includes Geological survey of India, Central Road Research Institute, Indian Institute of Technology-Roorkee, Wadia Institute of Himalayan Geology, National Remote Sensing Centre, Bureau of Indian Standards, Defence terrain Research Laboratory and some academic institutions and experts etc.

18th Century

Some of the earliest study about landslides in India where conducted by Geological Survey of India. This includes the study of Nainital landslide by **Sir R.D Oldham in 1880 and C.S Middlemiss in 1990** and the Gohana landslide in 1893 along the Uttar Pradesh of the Himalayan region. Geological Survey of India has conducted intensive study on more than 1,500 landslide incidents. Landslide Hazard Zonation maps were prepared in the scales of 1:50,000 and 1: 25,000 for 45,000 sq.km prone areas of hilly terrain. 4000 kms of important National and State highway were also studied for landslide hazard zonation. The GSI have prepared detailed landslide hazard maps for five landslide affected townships at the scales of 1:5,000 and 1: 10,000.

1970 – 1980

Chopra B.R 1977 studied the hotspot zones for landslide and other mass movements along the 600 km road of North Bengal to Sikkim. Nearly 40 hotspots extending a total of 16km were marked as vulnerable places to landslides. The conclusions were achieved using various topographical, Hydrological, Seismological, geological and meteorological parameters. Various measures have been proposed such as Benching, Proper Drainage systems and Retaining structures etc. **Krishnaswamy (1980)** was the first to attempt landslide zonation at the national level. He made the three-fold geomorphic division of India into the peninsular, the

Indo-Gangetic plain and the Extra-Peninsular as the basis for evaluating the relative incidence of landslides.

1981-1990

"One of the early projects on zonation was carried out by **Central Road Research Institute in 1984**, in which hazard zonation techniques were used to choose a most suitable alignment from the possible alternative alignments on landslide affected stretches in Sikkim area. Subsequent monitoring has shown that the choices made have been proved to be successful. During 1989, a hazard zonation map was prepared for a part of kathgodam- Nainital highway. This map was prepared with the objective of enabling the department to evolve a suitable maintenance strategy to keep the hill slopes along the road free of landslide problem" (Sharma 1999).

Bartarya A.K et.al, 1989 investigated the active landslides of a catchment along the Gaula river situated along the southern – part of kumaun district, Uttarkhand. About 550 active landslides were investigated in the catchment. The landslide occurrences have been related to slope failures. The results reveal that the erosion rates were accelerated (1.3mm/year) due to recurrent landslides which enables the river to transport a large quantity of sediment upto 2.33&2.1 million tonne during the year 1985 and 1986. **Gupta R.P et.al 1990** studied risk factor for landslides along the Ramganga catchment lying in the lower Himalayas. They have used ordinal scale rating system to classify the landslides into low, moderate and high risk.

1991-2000

Bureau of Indian Standards has published a code (IS 14496 (part 2):1998) on 'preparation of Landslide Hazard Macro Zonation Maps in mountainous terrains – Guidelines' based on LHEF rating scheme for different causative factors.

Jerrad, John et.al, 1994 studied the relationship between Geology and landslides along the Himalayan region. His findings concluded that the there is a close relation between types of rocks and landslide susceptibility. The Phyllite rocks are most susceptible to landslide while Quartzite are least susceptible to landslide. He also revealed that the siwalik hills are highly prone to landslides due to poorly consolidated rocks, while the middle himalayas are prone to landlside due to human effects. The upper Himalayas are under high stress due to gravity. **Bartarya S.K et.al,1995** studied the landslide induced river bed uplift along the Tal valley, Pauri district. The studied revealed that landslide occurred due to the gravitational force that dislocated a block of rock along the slip plane. It resulted in a rotational and slump types of landslide due to the accumulation pore pressure along the shattered rocks which resulted in a river uplift of 4mts and widening of 25mts. **Anbazhagan, R and Singh Bhawani 1996**

conducted a risk mapping for Sukidang area, Kumaun Himalaya for landslide susceptibility. They have derived the results using Structural, Slope morphometry, Landuse, Hydrogeological and relative relief as parameters. Their results indicate that High risk and very high risk areas are located along the sides of Rhe-la-khoia streams and Khagota streams. Human settlements and agricultural land comes under low to high risk. Landslide hazard zonation studies in parts of Beasvalley, Himachal Pradesh (Prakash Chandra 1996) and in parts of Bhagirathi valley, Garhwal in North Western Himalayas (Gupta 1996, Sharma 1996) are mostly confined to small area and limited number of slides. Studies along NH31A of Sikkim in Eastern Himalayas (Sengupta and Gohosh 1996) are mostly based on the Landslide Hazard Evaluation Factors (LHEF) rating scheme, which is mainly a quantitative way to ascertain relative importance to factors for slope instability. **Barnard L. Patrick, 2000** conducted a post-earthquake landslide investigation for 1999, Garhwal earthquake. 336 active landslides mapped within 226km^2 of the Garhwal region. The data's were collected through field investigations and analyzed in lab environment. The results reveal that two-third of active landslides were due to human activity. The total volume of landslide debri was estimated at 1.3 million m$^{3.}$ Three ancient landslides were discovered and two of them were dated back to early middle-holocene. Jeganathan and Chauniyal (2000) conducted landslide investigations for Kelani area in Kumaun Himalaya using evidential weighted approach. The study revealed that most of the active, old and slumping landslides were located along very high and high hazard zones.

2001 – 2010

Landslide Hazard Zonation along the pilgrim road routes in the Himalayan regions of Uttranchal and Hiamchal Pradesh was done using remote sensing and GIS techniques based on the Analytical Hierarchical Process and Saaty's principle of pair wise Comparison model by NRSA, Hydrabad (2001). They modeled landslide hazard zonation based on true topographic conditions without the effect of triggering factors.

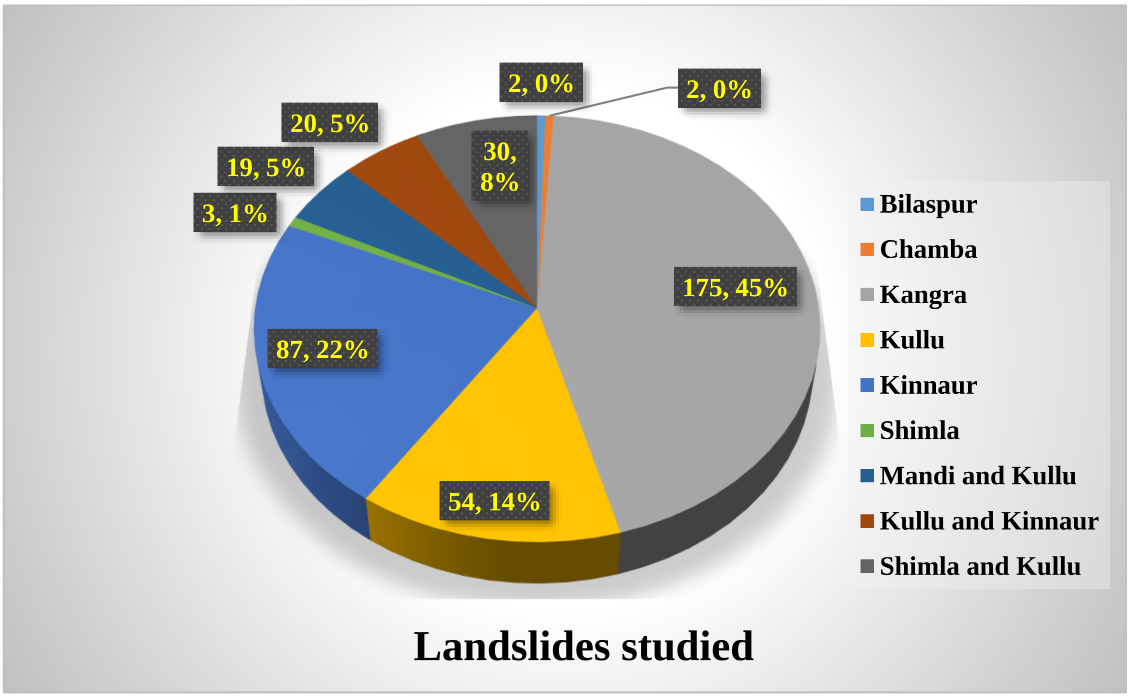
Bhasin Rajendar et.al, 2002 studied landslide hazards and proposed mitigation measures for Gangtok, Sikkim. They have compiled reports for previously occurred four landslides such as Chanmari landslide, Tathangchen landslide, Six-mile landslide, Burdang landslide. They have concluded that increasing settlements activities have caused more slope instability. Natural areas also have also subsequent landslides. The authors proposed various measure to control the landslide. **Ramakrishnan et al (2002)** developed a methodology to identify landslide prone areas using Photogrammetry with 3D GIS. A small area in the Kothagiri taluk of the Nilgiris district was selected for this study. Landslide zonation map presented in the study was not validated. **Saha A.K et.al, 2002** studied landslide hazard zones for Bhagirathi valley, Garhwal

Himalayas using weighted overlay techniques. Parameters such as Lineaments, Slope angle, Relative relief, Landuse, Drainage and Thrust were used. The data's were processed in ARCGIS environment and classified from very low to very high. The results revealed that 50% and 36% of the landslide comes under moderate and very high to high vulnerability. The BMPTC (2003) has taken the effort to produce the Landslide Hazard Zonation Atlas of India on 1: 6 million scale. This small landslide hazard maps only provide a mega view of landslide hazard distribution across our country. **Arora M.K et.al, 2004** created landslide hazard zonation maps using Artificial neural network (ANN) model for Bhagirathi valley, Himalayas. Several parameters were used such as Drainage, Landuse, Lithology, Relative relief, Lineament, Slope and Thrust as parameters. The output was created using both ANN and conventional weighted overlay model and validated using historical landslide occurrences. The results reveal the superior performance of ANN model compared to Conventional overlay model. **Kanungo D.P et.al, 2006** presented an integrated approach for landslide hazard mapping for the parts of Darjeeling, Himalayas using numerical rating scheme. They considered many geological and hydrological parameters such as fault, slope, lineament, rainfall, drainage, groundwater conditions etc. The output was classified into four types namely High, Moderate, Low and Very low which was further validated with historical landslide data's. **Gupta Vikram, 2005** conducted a Lichen based study on pawari landslide to estimate the spatial and temporal change in Debri flow and other mass wasting. The study is conducted for Pawari village, Kinnaur district, Himachal Pradesh. The results revealed that the growth of lichens on rock boulders indicates a stable slope while compared to other debri masses with less lichen cover. The study indicates the use of lichens as parameter to map the spatial and temporal changes in landslides. **Geological Survey of India** prepared inventory on landslide incidents over various districts of Himachal Pradesh in its special publication 2005. Most of these slides have been investigated during the geotechnical investigations of river valley projects, and for feasibility study of road alignments rural as well urban areas. According to Geological Survey of India the worst affected road alignment runs along Ravi river between Gehra and Brahmaur in Chamba district. The nine major landslides in this stretch are at Poo, Mailing, Urni, Han, Akpa, Shillu, Shiasu, Dabling and Chango. settlements.

Sl.No	Districts	SOI Toposheets No	Landslides studied
1	Bilaspur	53A/11,15	2
2	Chamba	52D/01	2
3	Kangra	52D/03,04,07,08,11,12	175

4	Kullu	53E/10	54
5	Kinnaur	53I/02,06,09,10	87
6	Shimla	53E/04	3
7	Mandi and Kullu	53E/07	19
8	Kullu and Kinnaur	53E/14	20
9	Shimla and Kullu	53E/11	30

Table: Landslide studies in Himachal Pradesh (Source: GSI special publication, 2005)



Landslide studies in Himachal Pradesh (Source: GSI special publication, 2005)

Ray Champathi P.K et.al, 2007 assessed the vulnerability of uttarkashi town located in the Garhwal region of Himalaya using fuzzy based method. Parameters such as Lithology, Soil, Landuse, Drainage, Lineament and faults etc, were used to create susceptibility map. Data's were integrated and results were obtained in ARCGIS environment. The results revealed that 73% of landslides including the uttarkashi landslide on 2002 comes under very high and high vulnerability classes. **Kanungo A.P et.al 2006** did a comparative study on Darjeeling, Himalayas using conventional, ANN, Black box, Fuzzy weighting and Combined neural and fuzzy models. The maps produced by the various models was validated using data collected from historical landslides. The results revealed that the combined neural and fuzzy weighting produced more accurate results compared to other models. Only 2.3% of the total area was categorized as high hazard zone and nearly 30% of the landslide occurrences accounts for this area. **Mathew John et.al, 2007** modelled landslides for the parts of Bhagirathi valley, Uttarkhand using Baysian approach log- linear form. Lithology, structure, slope, slope aspect, land use/land cover, drainage were parameters considered for the study. The model was further validated using receiver operator characteristics curve analysis with accuracy of 84%. **Anbalagan R et.al, 2008** created a meso scale level Landslide hazard mapping for Nainital town. The parameters used are Slope, Lithology, Drainage Morphometry, Landuse etc. The results were obtained using weighted overlay techniques ranging from Very low to Very high. 75% of the area were classified under Very high and high vulnerability. **Gupta R.P et.al 2008** did a comparative study on Darjeeling, Himalayas using conventional, ANN, Black box, Fuzzy weighting and Combined neural models have used. The evaluation has been done using Landside density, Error matrix and difference image analysis. The role of various analysis process and their advantages in various models have been discussed. The results conclude that using various models increases the accuracy of spatial variation of landslide susceptibility rather than using any one model. **Deshpande P.K et.al, 2009** attempted a study on landslide hazard mapping for Gopeshwar, Nandaprayag and Pipalkoti areas of Uttarkhand. Data's such as Slope, Drainage, Roadways, Landuse, Flow accumulation were used as parameters. The results revealed that most of the landslides were occurred due to the excavation for construction of roadways. **Ghosh A et.al, 2009** studied the instability of slopes at Agrakhal, Uttarkhand state. Geological and Geotechnical investigations were carried out t assess the slope instability and risk assessment. The results revealed that the area contained weathered Phyllite rocks. The slope is found to be highly instable under saturated conditions. **Bali Rameshwar et.al, 2009** mapped active tectonics of the outer Himalayas using an landslide event. The study was conducted using Amiyan landslide of the central Himalayas. The study revealed that the landslide increased from 0.02 sq.km in 1968 to 0.05 in 1992 due to the continuous release of stress along the Main thrust boundary. Gupta and Joshi, 2009 studied vulnerability of Ramganga catchment of the Himalayas for landslide hazard. The have related the landslide activity to a number of parameters such as Lithology, Landuse, distance from shear zone and azimuth directions etc. The results have been catagorixed into low, moderate and high vulnerability risk. **Matha Tapas R et.al, 2010** delineated the landslide zones through Object –oriented methods using spatial, spectral and morphometric characteristics of landslides. Mandagini river catchment of Uttarkhand state was chosen as the study area. The type of landslides were delineated using morphometric properties and terrain curvature. The results reveals that Object-oriented method produces an accuracy of 69.1% for five types of classified landslides. **Das Iswar et.al,2010** calculated the susceptibility of landslide using Linear regression model and was validated using slope stability probability classification along the national highway 108 of the northern Himalayas. The result was that 80% and 72% of the landslide were classified as high and very risk. 90% of the area were classified into high and very high susceptibility by comparing both the susceptibility maps. **Nithya, S Evany et.al, 2010** used Remote sensing and GIS techniques for identifying landslide susceptibility for Kundalpallam watershed, Nilgiris. They have used a combination of six parameters aspect, Slope, Geology, Landuse and Runoff for this study. The study revelas about 90% of the area is prone to Very high and high risk vulnerable zones. **Ganapathy G.P et.al, 2010** published a report regarding urgency of Landslide risk planning for Nilgiris district, Tamilnadu. He Postulated that different risk based approaches should be carried out for places with different phenomena such as Place without Human intervention, Anthropogenic causes based landslides etc. **Chauhan Shivani et.al, 2010** evaluated landslide susceptibility using Artificial neural network based blackbox approach. Parts of Chamoli and Rudraprayag of Uttarkhand district were chosen as study area. Slope, Aspect, Relative relief, Landuse, Drainage density etc were used as parameters. The results were validated using historical landslide occrences. **Singh T.N et.al, 2010** conducted slope stability analysis for Amiyan landslide at Kathgodam, Uttarkhand state. Various Physio-mechanical parameters such as Shear strength, Tension strength and Uniaxial strength were considered for analysis. The results were computed using finite difference, finite element and dynamic analysis model and validated through field investigations. The results revealed that the slope is stable and might become vulnerable when subjected to local and global disturbances.

2011 - 2018

Chandel, Vishwa, B, S., et.al, 2011 mapped landslide prone areas for kullu district, Himalayas using weighted overlay approach. various parameters like slope, aspect, relative relief, drainage density, geology/lithology and land use/land cover were chosen for the study. The out was generated in ARCGIS environment and classified into four types ranging from high to low. The study revelas that 80% of the area are prone severe high risk zones. **Kanungo A.P et.al 2011** compared various models such as combined neural network with fuzzy, certainty and likelihood ratio for spatial prediction of landslides. Darjeeling state present along the Himalayan region was chosen as study area. Several parameters such as Slope, Aspect, Drainage, Lineaments, Lithology and Landuse & Landcover were used as parameters. The results reveal that only 2.3% of the total area come under very high probability and accounts for about 30% of the past landslides. **Ghosh Saibal et.al, 2012** created landslide inventory maps using event based landslides for the year 1968 – 2007. Various landslide types and landslide density was calculated to analyze the spatial extent of landslide and for temporal change landslide event dates and associated rainfall was considered. Importance of using past landslide datasets to predict future landslides were expressed. **Ghosh Saibal et.al, 2011** created predictive models to assess the susceptibility of shallow transitional and debri landslides susceptibility along the Kurseong town, Darjeeling district of west Bengal. Factors such as Slope, Aspect, Landuse, Lineaments, Rock and Soil type were used as parameters. Four models were validated using Multiclass, Weighted overlay and logistic regression analysis. The result reveals the use of models to various places on Himalayan region as the topographical setting is almost same. **Sharma L.P et.al, 2011** conducted a statistics based analysis for landslide susceptibility along the Rumtek-Samdung area, Sikkim district. 14 causative parameters such as Slope, Drainage, Aspect, Soil, Lineaments, Roads etc were used and classified under three models High density, Average density and co-efficient of variations. The output was classified into five zones ranging from least vulnerable to most vulnerable and the results reveals the accuracy of the statistical model with 84%. **Rawat singh Jawan et.al, 2012** conducted weighted overlay analysis along the Igo river basin situated in the west Siang district of Arunachal Pradesh. Parameters such as Landuse, Lineaments, Soil, Drainage, Slope angle and aspect, roads and altitudes etc were used. The results classified the area into 7 vulnerability classes ranging from very low to very high. 30% of the area comes under moderate to low moderate vulnerability. Various landuse features were quantified based upon their vulnerability zones. **Ganapathy, G, P., et.al, 2012** proposed various mitigative strategies for areas that are under high risk zones. He proposed remedial measure such as increasing the stability of buildings and infrastructures, Soil bio engineering, Growth of deep rooted plants to prevent landslides to some extends. **Pareta, Kuldeep., et.al, 2012** conducted Landslide studies for Giri watershed of the Yamuna basin using quantitative methods. They have considered parameters like Landuse, Slope, Soil, Geology and Drainage to identify vulnerable places. The results conclude that most of the area comes under low to moderate vulnerable areas. **Negi R.S et.al, 2012** studied a landslide hazards for Giri valley, Sirmaur district, Himachal Pradesh. Parameters such as Slope, Aspect, Road, Drainage, Lineaments and NDVI were considered. Datasets were then processed and analyzed in ARCGIS environment using weighted overlay analysis. It has been observed that 70% of the study area comes under moderate to Very high vulnerability. **Kishore, K., et.al, 2012** conducted a micro-level landslide hazard zonation for Kaliasaur landslide, Rudraprayag formation in Lesser Himalayas. He used Lithology, Slope gradients, Landuse, Groundwater conditions and Structure relationships as parameters. The output reveals that the slopes are highly unstable and area comes under high hazard. Martha R Tapas et.al, 2012 studied landslide hazard and risk assessment using semi-automatically created landslide inventories. The landslide inventories were created for 13 years (1997-2009) and risk assessment was carried using parameters such as Slope, Geology, Landuse, Soil etc. The result revealed that 67.6% and 29.3% of all landslides for the years (1997-2009), and 14.7% and 34.8% of the total area, are in the high and moderate susceptibility classes. **Das Iswar et.al 2012** did a comparative study on landslide susceptibility using Bayesian Linear regression and Ordinary linear regression models for Bhagirathi valley in the Himalayan region. The results were achieved using Drainage, Lithology, Landuse, Lineaments and faults as parameters. The results reveal that the accuracy of the results produced by BLR model and OLR model were 86% and 79% respectively. BLR model was suggested to study landslide susceptibility modelling. **Martha, Tapas, R., et.al, 2012** indicated the use of semi-automatically created landslide inventories for landslide hazard assessment. Okimath of Rudraprayag district of Uttarkhand was chosen as the study area. Seven parameters such as Landuse, Soil, Geology and structure etc were used and analyzed using weighted overlay technique. The study reveals the advantage of semi-automatic method in data poor environment. **Singh Rajesh et.al, 2013** conducted a slope stability analysis on the Amiyan landslide at Kathgodam, Uttarkhand state. Probabilistis slope stability analysis (PSSA) and Finite element method (FEM) were used calculate slope stability. Parameters like Slope geometry, stratigraphy and geo-chemical properties were used. The result reveals that PSSA method and Fem method puts the probability of slope failure at (13-16%) for PSSA and 1.05 as critical SRF for FEM. **Lallianthanga, R, K., et.al, 2013** studied landslide prone areas for Mamit town, Mizoram. Five parameters were considered such as Slope, Aspect, Fault and Lineaments, Soil and Landuse for this study. The output was created using weighted overlay analysis. The study indicates that 92% of the area comes under moderate to low vulnerability zones. **Devanjan Bhattacharya et.al 2013** developed an autonomus system to automatically predict the landslide susceptibility zone along the Theri – Gharwal region of lower Himalayas, India. The system has been divided into expert system, understanding module, Knowledge and interference system to categorize the Landslide prone areas. The generated output was then overlaid with spatial data's like settlements, population, forestry and agriculture categorizing the socio – economical vulnerable regions for landslide. **Lallianthanga, R, K., et.al, 2013** studied landslide prone areas for Lawnhtlai town, Mizoram. Five parameters were considered such as Slope, Aspect, Fault and Lineaments, Soil and Landuse for this study. The output was created using weighted overlay analysis. The study indicates that 67% of the area comes under moderate vulnerability zones. **Lallianthanga, R, K., et.al, 2013** studied the landslide hazard zones of Aizwal district, Mizoram through Remote sensing and GIS. Factors such as slope morphometry, geological structures like faults and lineaments, lithology, relative relief and land use / land cover were used as parameters for delineating hazard areas. The hazard zonation map was generated using weighted overlay technique, the sites were classified into five types from very low to very high vulnerable. About 63% of the area constitutes high and medium hazard areas. **Lallianthanga, R, K., et.al, 2013** prepared landslide hazard zonation map for lunglei town, Mizoram, India. Various thematic layers such as lithology, geological structures, slope morphometry, geomorphology and land use/land cover were used as parameters. The prone areas were classified into five types ranging from very high to very low through weighted overlay analysis. The study revealed that 60% of the area comes moderate and low vulnerable areas. **Lallianthanga R.K., et.al, 2013** studied landslide prone areas for saitual town, Mizoram. Five parameters were considered such as Slope, Aspect, Fault and Lineaments, Soil and Landuse for this study. The output was created using weighted overlay analysis. The study indicates that 90% of the area comes under High to moderate vulnerability zones. **Chingkhei, R, K., et.al, 2013** carries out the research on landslide prone area mapping along the NH-1A from Udhampur to Banihal in Kashmir using AHP method. Various parameters such as slope, aspect, lithology, soil data, drainage density, lineament density, presence of faults, land use and landcover. The output was sebmented into six catagories from severe to very low. Most of the area comes under low vulnerable zone. **Pareek Naveen et.al, 2013** studied the effects of seismic displacements over the landslide susceptibility zone along the Gharwal region of Himalaya. They prepared Landslide hazard zonation maps both pre and post Chamoli earthquake. The extent of seismic displacement was mapped and overlay analysis were conducted for the landslide inventory map. The result revealed that the area susceptible to landslide increased compared pre earthquake landslide inventory map. **Sarkar Shantanu et.al, 2015** conducted a quantitative approach on landslide hazard assessment along the NH-58 of Alaknanda valley, Garhwal Himalya. Parameters such as volume, Intensity, velocity were used. 18 landslides were identified along the potential zones using remote sensing data and field investigations. The results concluded that out of the six hazard zones two zones fall in both very high and high hazard zones and one in moderate and low hazard zones. **Saha, A. K et.al, 2014** conducted a quantitative risk assessment for rockfall along the parikrama path of the Sapthashrungi temple, Nashik, Maharastra. The risk analysis was evaluated considering elements of rockfall events, risk of human life and the probability of the rockfall reaching the point of risk. The result obtained signifies that the pathways are at high risk to social and economical structures. **Nalina et al. (2014),** have studied the land use land cover dynamics of Nilgiri district from 1990 to 2010 using satellite remote sensing technique. The temporal changes of land use and land cover changes of Nilgiris district over the period of 1990 to 2010 were monitored using LISS I and LISS III of IRS 1A and IRS-P6 satellites. From the remote sensing investigation, they found that during the study period of 1990 to 2010, the area of dense forest increased by 27.17%, forest plantation area decreased by 54.64%. Conversion of range lands, forest plantation and open forest by agriculture and settlement leading to soil erosion and landslides. **Bairavi et al. (2014),** have prepared a Landuse / land cover map of the Nilgiri district. Overlay analyses were carried out with existing landslide locations with the Landuse/landcover map. The higher number of 128 landslides occurred in plantation class and medium number of 85 landslides occurred in deciduous class and lower number of 25 landslides occurred in the evergreen forests. **Srileka, s., et.al, 2014** conducted an analysis on Sirumalai hills, of Dindugal district regarding landslide susceptibility. She used Landuse, Drainage, Lineaments, Slope and contour as parameters and categorized susceptibility zones from Very high to low. The results indicated that 27% comes under high risk and 70% comes under moderate risk. **Anbalagan, R., et.al, 2014** studied the effects pre and post-earthquake landslides hazard areas along the Lachung basin, Sikkim, India. Landuse, Slope, Lineament, Drainage, Relative relief, Soil, Lithology data's were used to delineate the study area into five classes ranging from very high to very low. 74% and 6% respectively comes under moderated to high vulnerable area, where the observed landslide contributes about 42% and 52% in moderate to high vulnerable areas. **Marrapu, Balendra, Mouli., et.al, 2014** gave a critical review on various methods of assessing the landslide prone areas. He reviewed two different types of methods such as qualitative and quantitative. The qualitative was sub divided into Field analysis, AHP process and quantitative was divided into statistical and Geotechnical / Physical based models. **Islam, M.A et.al, 2014** studied the causes and consequences of ukimath landslide, Uttarkhand. The study revealed that the landslide was mainly due to downpour of heavy rainfall along the less resistant highly fractures low grade metamorphic rocks. This event triggered the debri flow along the Rudraprayag district of Uttarkhand that resulted in heavy social and economical losses. **Metha, Rakesh, L., et.al., 2015** studied the effects of landslide for the areas surrounding Mahabaleshwar, Maharastra. They have used multivariate statistical analysis in combination with spatial analysis to predict Landslide susceptibility and hazard zonation. They considered various parameters like lithology, slope, morphology, slope aspect, soil, relief, drainage, land use and pre-occurred landslides to delineate vulnerable areas. The study reveals that a total of 29% of area is under higher risk and about 59% is under moderate risk. **Bilwa, L, Mahesh., et.al, 2015** delineated potential landslide hazard zones in Kohima region, Nagaland using heuristic method. The parameters used are Landuse, Slope, Aspect ratio, Geology and Geomorphology. The studied concluded that most of the area were prone to high vulnerability of landslides. **Rawat M.S et.al, 2015** studied vulnerability of Mandakini valley of Rudraprayag district, Uttarkhand to landslides. Parameters such as Lineaments, Slope, Landuse, Fault, Lithology, Geomorphology and Drainage were used as used. Landslide hazard maps were created for pre and post flood areas (June 2013) of the valley using ordinal scale rating based weighted analysis. The output was categorized into five zones from very high to very low. The results revealed that 5.9% and 22.7% of the area comes under very high to high vulnerability. Sharma Gopal et.al, 2015 conducted landslide studies for Katteri watershed, Nilgiris. Vulnerability of the landslides were calculated using Geomorphology, Lineament, Drainage, Lithomarge thickness and NDVI. The results were analyzed using weighted overlay analysis. The results were verified using historical landslide occurrences and indicated that 80% of the landslide were occurred during moderate to high vulnerability. **Gupta, Vikram., et.al, 2016** did a slope stability analysis using finite element method. The study was carried out for Surabhi resort landslide, Mussoori township, Garhwal, Himalayas. Two separate models for Overlying debris and underlying rock mass were taken into account for analysis. The results revealed that the critical strength factor were observed at 0.28 and 0.83 for debris and rock masses demarcating the entire slope as highly unstable. **Mathew John et.al, 2016** investigated Slope stability with varying Hydrological Conditions for Garigon watershed, Uttarkhand, India. Deterministic approach coupled with steady state hydrological model was used to analyze slope stability conditions. The result indicates that the slope instability increases from 7.5% to 13.8% for rainfall intensity variations 50 to 100 mm/day. The area underlain by granitic Gneiss shows most unstable (23.1%), under rainfall conditions 135mm/day. Followed by Amphibolite (16%), Limestone (13.7%) and Quartzite (10%). The results were validated using ROC curve analysis with 84% accuracy. **Kumar, Rai, Praveen., et.al, 2014** stated the use of remote sensing and GIS for Landslide hazard mapping with special emphasis to Himalayan region. He considered slope, aspect, relative relief, drainage density and landuse as parameters for the study. He concluded that the integration Remote sensing and GIS can play a vital role for construction and planning purposes both at macro and micro scale. **Prakash Indra et.al, 2016** studied landslide susceptibility assessment using machine learning ensemble techniques for parts of northern Himalaya. The parameters used are Slope, Landuse, Rainfall, Lineaments and River density etc. The results concluded that the multi-boost model of machine learning produced higher accuracy (0.8) compared to other models. The use of machine learning has been preferred rather than conventional methods. **Sarkar, Shraban., et.al, 2016** analyzed the susceptibility of eastern part of Darjeeling, Himalayas to shallow debri landslide through deterministic approach. The analysis was carried using DEM and Soil data collected from field samples. The results were concluded using three different conditions, Free of vegetation, Presence of vegetation and presence of natural and anthropogenic activities. The results reveals that 28%, 9% and 10% of the area comes under unconditionally unstable. **Kumar, Amit., et.al, 2017** conducted a post landslide investigation for a landslide that occurred on September 2014, Sadal village, Udampur district, Jammu and Kashmir. Parameters such as Geology, Local terrain characters such as Lineament, Lithology, faults and climatic conditions were considered. The results indicate that numerous ground fissures developed parallel to weak surface of Sadal village combined with extreme rainfall resulted in extreme ground saturation that triggered the landslide. **Kumar Deepak et.al, 2017** studied landslide susceptibility of Mandakini river bain of Uttarkhand using three variants of support vector machines (PSVM, L_2-SVM and L_2-SVM-MFN). Several factors such as Landuse, slope, Lithology, Faults and Lineaments were used as parameters. The result revealed that L_2-SVM-MFN has higher accuracy (0.82) compared to PSVM (0.79) and L_2-SVM (0.80). **Pandey, Vijendar, Kumar., et.al, 2017** used Frequency ratio method to determine the landslide susceptibility along the Tipri–Ghttu highway of Garhwal district, Uttarkhand. Parameters such as Landuse, NDVI, Slope, Aspect, Soil, Distance to Road and Streams were used. Field investigation revealed that 76% of the landslide occurred during the monsoon period. The landslide susceptibility map revealed that 80% of the area comes under high to very high vulnerability. **Ramasamy, S,M., Singh, Bhoop., 2017** published a book on "Landslide Research". The book explains about various aspects of landslide research such as Landslide risk mapping, Geotechnical investigations, Early warning systems, landslide inventory and High resolution mapping. **Mondal Subrata et.al, 2018** conducted a statistical analysis to model susceptibility of Balason river basin, Darjeeling, Himalayas to landslides. Various causative factors such as Altitude, Slope angle, Aspect, Curvature, Geology, Geomorphology, Soil, Landuse, Drainage density, Lineaments, NDVI etc, were used to categorize the vulnerability zones. The output was derived using Linear Regression model in the GIS environment. The results predict the accuracy of the landslide up to 96.4%.

Based on the literature survey it can be concluded that many researchers and scientist have tackled the problem of landslide along various regions of India. Significant progress has been made in the field of landslide hazard assessment using GIS technology. However, landslide phenomena are still poorly understood, particularly at the local scale. Evaluation of landslide hazard is a complex, multidimensional problem, which requires expertise pertaining to earth science, statistics, computer science, information technology and economics, depends on the effectiveness of finding the hidden information and deriving indexes to predict landslide susceptibility in a timely manner, and calls for a new scientific practice capable of coping with large uncertainties, varying experts' judgements and social issues associated with landslide hazard evaluation. The authors have addressed either geological or Geo-technical aspect of the landslides. It is important that both the aspects of the landslide must be studies together. Remote Sensing and GIS coupled with Geological and Geo-technical analysis provides greater accuracies of landslide assessment. However along with regional and local studies, efforts should be put in site specific landslide studies and their stabilization measures. It might be impossible to detect every landslide but steps can be taken to negate the future occurrences of landslides through proper geotechnical and field based studies.

(Basu and Pal 2019) studied the multi criteria approach to the landslide susceptibility modelling through morphometrical and geological characterization for Gish river basin, West Bengal. They concluded that high frequency of landslides tend to fall in high vulnerability zone with an accuracy 86.60%.

Landslide reviews: Regional Status

1970 – 1990

Srikantia, S. V. and Bhargava, O. N. (1972). Studied the sinkholes of Runhj village in himachal pradesh. Their stud revealed that the sinkhole is caused due to solvent action of water on salt along the sub-thrust side of basic volcanic. **Srivastava, L. S. (1988).** Studied the 1975 earthquake induced landslide of Kinnaur district, Himachal Pradesh. The study revealed that most of the landslides are surficial landslides that occurred on rock slopes. This lead to evaluation of the stability of the rock slopes in that area.

1991 – 2000

Badal, R., Sharma, V. M., Venkatachalam, K. (1995). Studied the landslide blockade of Sanjay Vidyut Pariyojana project located in Kinnaur district, Himachal Pradesh. The study revealed to use the surface and underwater blasting to remove the landslide blockade. **Bartarya, S. K., Virdi, N. S. & Sah, M.P. (1996).** Satluj Valley of Himachal Pradesh. Though, a combination of several factors is responsible for these landslides, however, anthropogenic activity is the single most common cause. Road construction and provision of irrigation canals, without proper feasibility studies, on vulnerable slopes has greatly aggrevated their stability and has promoted landslides. The landslides are also related to water seepage, down cutting and toe erosion by rivers and streams, excavation of slopes for widening of existing roads and construction of new ones. **Sah, M. P., Virdi N. S. & Tarya S. K. (1996).** The Satluj valley and its major and minor tributaries have faithfully recorded the past history of damming due to glacial moraines, landslides and rock falls and creation of temporary lakes which were subsequently drained out. These are now reflected by extensive fluvial, glaciofluvial and lacustrinal deposits occurring at various levels along the Spiti, Ropa, Baspa and the Satluj itself. The Satluj river was blocked twice during 1993 due to a major landslide and a rockfall near Jakhri and Nathpa respectively. A partial block also occurred at Palingi in 1988 where Soldan Khad joins the Satluj. These major blockades and many zones of land subsidence along NH – 22 between Bhabanagar and Jakhri call for detailed investigation and preventive measures since the construction of a number of mega run – off – the river hydel schemes are in progress in this section of the Satluj valley. **Rautela, P. and Lakhera, R. C. (2000).** The area around Sataun in the Sirmur district of Himachal Pradesh, India (falling between the rivers Giri and Tons; both tributaries of the Yamuna River) was studied for landslide vulnerability on behalf of the inhabitants. The study was made using extensive remote sensing data (satellite and airborne). It is well supported by field evidence, demographic and infrastructural details and aided by Geographic Information System (GIS) based techniques. Field observations testify that slope, aspect, geology, tectonic planes, drainage, and land use all influence landslides in the region. These parameters were taken into consideration using the statistical approach of landslide hazard zonation.

2001 – 2010

Gupta, V., Virdi, N. S. & Parkash, S. (2001) Morphometric assessment of five major and active landslides (mainly translational type) in the Satluj river valley of Indian Himalaya has been done. Various morphometric parameters like classification index, dilation index, tenuity index, flowage index, displacement index etc. have been determined as per the technique suggested by Crozier (1973), for morphometric analysis of landslips using field data of these landslides and topographic information. It has been observed that the technique holds good in interpreting slope stability and the potential process group but there is a need to set the limits of the morphometric indices for various processes of slope movement and the degree of instability that are appropriately defined to suit for the Himalayan terrain. The variations in the limits are also expected due to changes in the nature of slope mass, topography, geology and climate of the terrain. **Pradhan B et.al, 2005** studied the stress pattern of active seismic zone in the part central Himalayas. Lineaments and stress have used in calculating landslide prone area. Landcover, Geology, Mega fault, Geomorphology and Drainage have been used as parameters in Qualitative analysis to produce landslide susceptibility maps. The author conclude that high susceptible zones are found near areas of high lineament density, Moderate to low drainage density and high slope terrains. He further suggested that combined nature of weatherd rocks, heavy rainfall and lack of vegetation cover. **Dortch M. Jason et.al, 2008** studied the nature and timing of four large landslides in Himalaya and Trans Himalaya in northern India. Four study areas Darcha, Patseo, Kelang seari and Chilam were chosen study the movement of landslides. The landslides were studied and examined using 10Be terrestrial cosmogenic radionuclide surface exposure dating. The results suggest that the landslide might have been triggered due to Pore water pressure, Seismic shaking or combination of both process. The results have been compared 12 previously occurred landslides in the region and the results conclude that fourteen out of sixteen landslides occurred during the period of intensified monsoons. **Sarkar, K. and Singh, T. N. (2008).** In this paper, an attempt has been made to determine the stability of road cut slope in Luhri area, Himachal Pradesh using three dimensional numerical simulation tool Fast Lagrangian Analysis of Continua in 3 Dimensions (FLAC 3D). The representative rock samples were collected from the study area to determine the important geotechnical properties, which were later on used as an input parameter for the numerical simulation. The deformations and the stress distribution along the failure surface have been established for suitable, economical and scientifically proved method to design the existing slope. The stress distribution and overall factor of safety has been determined to assess the condition of the slope and suggest possible remedial measure. The study indicates slope is marginally stable and some protections of it need proper understanding to stabilize it. **Gupta Vikram et.al, 2008** studied the spatial variability of mass movement along the Satluj valley for the year 1990-2006. The findings concluded that there was a significant increase in landslide areas from 1.35km2 to 11.83 km2 in 2006. Nearly 28.43 km of Natinal highway is affected in 2006 compared to 4 km in 1990. The authors concluded that human induced factors such as road cutting, settlements and road widening has increased the spatial coverage of landslide. **Rautela Piyoosh et.al, 2008** studied landslide risk analysis for Sataun area located in the Sirmaur district of Himachal Pradesh. Parameters such as Slope, Aspect, Geology, Tectonic plates, Drainage and Landuse were used. Landslide risk analysis was estimated in GIS environment using Statistical index method. The result concludes that the landslide risk is high in almost all part of the area. The landslides in the area where greatly influenced by Rocks, Slope and Landcover. **Gaikwad, S., Chandak, P. G., Kumthekar, M. B., et al. (2009).** Garhwal Himalaya is a disaster prone part of the state of Uttarakhand especially known for huge landslides and torrential floods. Many efforts were made so far for landslide hazard zonation mapping along with mitigation plans. NRSC has published landslide zonation maps along with landslide management maps for the state of Uttarakhand and Himachal. But supportive geotechnical data for the same has not been made available. Therefore, in present paper the mitigative recommendations put by National Remote sensing centre (NRSC), Hyderabad is being explained with pictorial examples. This work may be useful for a construction manager handling the vulnerable sites in Garhwal Himalaya. **Avasthy, R. K. and Kumar, H. (2009)** The landslide hazard zonation is carried out in parts of Ravi catchment, Chamba District, Himachal Pradesh with the objective of identification of old landslides, preparation of inventory and demarcation of landslide prone zones. The methodology adopted is based on Probabilistic approach for the determination of failure probability value (Pv) of various slope classes in each litho unit. Based on statistically determined Pvs, the slopes are classified within High Hazard (Pv >50%), Moderate (Pv 20 -50%) and Low Hazard prone (Pv < 20%) respectively. Higher vulnerability of slopes were recorded in anaclinal slopes of Katarig ali Formation (20%), Morang Forma tion (16.6 6%) and cataclinal slopes of Katarigali Formation while the lowest vulnerability was recorded in cataclinal slopes of Morang Formation (2.43%). The high hazard zones are restricted to the river valley along Chamba - Bharmaur road, where the hill slopes are subjected to under cutting by river and greater influence of anthropogenic activities. **Mehta, B. S., Parti, R. and Sharma, R. K. (2010).** An attempt has been made to identify, evaluate and prepare a landslide hazard zonation map for Panarsa to Manali stretch on National Highway - 21 in the state of Himachal Pradesh taking in to account the lithology, slope morphometry, relative relief, structure, lineament, land-use, drainage and rainfall distribution of the area using the deterministic approaches along with the Bureau of Indian Standards (1998) guidelines. **Sarkar, K. and Singh, T. N. (2010).** The present paper demonstrates the slope stability analysis along the road section (NH-22) of Luhri area, Himachal Pradesh which connects border district Kinnaur (near to China border) to rest of India. A detail field study has been carried out to collect the representative rock samples for determination of geotechnical properties of rock. These properties have been used as input parameters for the three dimensional finite difference slope analysis using FLAC-3D code. The present study reveals that the slope is critically stable but any external factors may further reduce the Factor of Safety (FoS) and causes the instability. The presence of random and intense jointing in rockmass and intensive rainfall further accelerated the slope failure.

2011 – 2018

Chandel, V. B. S., Brar, K. K. and Chauhan, Y. (2011) This work conducts a landslide hazard zonation in western Himalayan district of Kullu in Himachal Pradesh using remote sensing and GIS. The satellite imageries of LANDSAT ETM+, IRS P6, ASTER along with

Survey of India (SOI) topographical sheets formed the basis for deriving baseline information on various parameters like slope, aspect, relative relief, drainage density, geology/lithology and land use/land cover. The weighted parametric approach was applied to determine degree of susceptibility to landslides. The landslide probability values thus obtained were classified into no risk, very low to moderate, high, and very high to severe landslide hazard risk zones. The results show that over 80 per cent area is liable to high severe landslide risk and within this about 32 per cent has very high to severe risk. **Rentala, V. and Neelima Satyam D. (2011)** In this research paper, an endeavor has been made to model an active slope between Longitudes 32°07'N-32°13'N and Latitudes 77°08'E-77°11'E in the Manali area of Himachal Pradesh, India. The slope has been modeled using PLAXIS 2D a Finite Element Method considering both static and dynamic cases. In the present research work, detailed analysis has been carried out by considering different joint sets in three stages for predicting the behavior of the rock slopes for different joint sets considered in the present research work. This research paper provides very useful information in the deformation mechanism of the rock slopes in Siwalik Hills. In first and second cases the slope is stable but in dynamic case the slope is critical since the displacements observed in the model will reflect the settlement. Excavation profiles of the slopes can be optimized and analyses can be carried out for those displacement profiles. **Negi, R. S., Parmar, M. K., Malik, Z. A. et al. (2012).** The Himachal part of extra-peninsula that has been compressed about 65% and resulted in the orogenesis to form very steep mountain range. The structural disturbances like folding, faulting and shearing are very common in this region. Slopes, deforestation, heavy precipitation and the road construction itself have found to be the main cause of slope instability. In this work, the effort has been made to make the land slide susceptibility zonation map by using the integrated geoinformatics along with the information value technique. Various generated rasters were given the experience based weightage and analysis was made in the GIS environment to prepare the final landslide susceptibility zonation map. **Pareta, K. and Pareta, U. (2012).** Giri river watershed of Yamuna basin was selected for the model implementation. Important terrain factors, contributing to landslide occurrences in the region, were identified and corresponding thematic data layers were generated. These data layers represent the soil, land use, geological, topographical, and hydrological conditions of the terrain. A numerical rating scheme for the factors was developed for spatial data analysis in a GIS. The resulting landslide susceptibility map delineates the area into different zones of four relative susceptibility classes: very high, high, moderate, and low. The very high susceptibility class has located in the Rawana, Jabyana, Gusan, Chandesh and Parar villages. The susceptibility map was corroborated by correlating the andslide frequencies of different classes. This has shown a close agreement with the existing field variability condition **Sharma, R. and Mehta, B. (2012).** The paper discusses the preparation of macro-zonation maps of landslide susceptibility in an area of about 100 sq km on 1:50,000 scale across Garamaura- Swarghat section of National Highway-21. The map has been prepared by superimposing the terrain evaluation maps in a particular zone such as lithological map, structural map, slope morphometry map, relative relief map, land use and land cover map and hydrological condition map using landslide susceptibility evaluation factor rating scheme and calculating the total estimated susceptibility as per the guidelines of IS: 14496 (Part-2). Numerical weightages are assigned to the prime causative factors of slope instability such as lithology, structure, slope morphometry, relative relief, land use and groundwater conditions as per the scheme approved by Bureau of Indian Standard for the purpose of landslide susceptibility zonation. **Balasubramani, K. and Kumaraswamy, K. (2013).** This paper evaluates application potential of geospatial technology and information value technique (quantitative) in landslide hazard zonation. To evaluate the application potential and result, a part of Giri valley of Himachal Pradesh, India has been chosen as the study area. The major parameters considered in the landslide zonation include lithology, lineament, slope, streams, vegetation, land use/land cover and road. The layers are generated from satellite images coupled with collateral data. ll these layers are processed through information value technique to find out different landslide hazard zones. Further, the final hazard zonation map is compared with the actual landslide map for validation. **B.S.Chandel, Vishwa., (2015)** studied the geo-physical disasters of Himachal Pradesh. He mainly concentrated on the topics of Earthquakes, landslides and Slope failures. He discussed that the Himalayan region is highly prone to earthquakes and landslides due to its active seismic zone and high rainfall season. He concluded that the earthquakes are temporally large but spatially located only in few regions. The landslide activities are restricted to high altitudes and steep slopes of the Himalayan region. **Kumar Pandey, Vijendra., et.al., (2018)** discussed the characteristics of large landslides and the possibility of mapping them using frequency ratio model. The predictive variables he used are slope instability such as slope angle, aspect, plan curvature, lithology, distance to faults, soil type, Landuse, distance to road, distance to stream and dissection index for the landslide susceptibility modelling of the study area. The result shows the severity of the phenomenon. The landslide susceptibility analysis was validated using the 20 landslide locations dataset. The validation results revealed that landslide susceptibility map has 87% accuracy for predicting the landslides in the study area. **Kumar, Vipin., et.al (2018)** studied the potential damming activity of urni landslide along Kinnaur, Sutlej valley. He concluded that extreme rainfall in the June, 2013; 11 June (100 mm) and 16 June (115 mm), are considered to be responsible for the slope failure in the Urni landslide that has partially dammed the river. The debris flow runout simulation of the detached mass in the landslide showed a velocity of w25 m/s with a flow height of w15 while it (debris flow) reaches the valley floor. Finally, it is also estimated that further slope failure may detach as much as 0.80 _ 0.32 million m3 mass that will completely dam the river to a height of 76 _ 30 m above the river bed.

Various authors have studied the different aspects of landslides ranging from vulnerability modelling, Rainfall threshold mapping, Geotechnical analysis and simulations. However, no method is solid for landslide studies. Numerous methods ranging from numerical rating scheme to AHP process and neural network approach have been used to study landslide disasters. Every articles address the certain aspect of landslide such as vulnerability modelling, Landslide dam simulation, Slope stability analysis etc. Since every landslide is unique in nature due to varying physical and anthropogenic causes efforts should be put in to study the suitable stabilization measures and cost estimation of constructional activities let along conducting local level mapping and geotechnical analysis.

Base on the above literature survey it can be concluded that the Landslide Hazard Zonation (LHZ) can be briefly divided into Qualitative and Quantitative analysis. The Qualitative methods such as Field based Geomorphologic investigation and Inventory based approach are some of the simplest and most widely used methods during the 1970's (Kanungo et.al, 2013). The accuracy of these data's is based upon the knowledge and experience of the researcher and for inventory based approach it depends upon the reliability of the data collected either field work or data retrieved from Government and other organizations. The Disadvantage of this methodology is the necessary of knowledge and sufficient experience in conduction field works and thrust areas, insufficient knowledge and experience can lead to unacceptable conclusion of the area surveyed.

The quantitative analysis became popular in the last decade due to the advancement in Remote sensing and GIS technologies. Quantitative methodology can be categorized into Statistical, Probabilistic, Multi-Criteria Decision Making (MCDM) and Physical based approach. Quantitative method uses mathematical and statistical analysis to establish relationship between landslide distribution and landslide causative factors. This approach is more Objective in nature due to its data- dependency nature and much less experience is needed. This method involves in assigning quantitative value to various causative factors known as factor of safety. Disadvantage of statistical analysis is that it uses large amount of data and the accuracy of the result depends upon the quality of the data collected. Multi-criteria decision making uses to estimate the dependency of various factors causing landslide susceptibility. Non-parametric model such as Analytical Hierarchical process and Analytical Neural Network were used in determination of rating scheme of various parameters. Advantages and disadvantages of Various LSM methods have been discussed by various authors. Physical based model establishes the relative stability/instability of a slope using simple mechanical laws. It uses field based investigation and lab tests as datasets to analyze stability of an area. The main disadvantage of this methodology is it does not account for various landslide inducing factors and the reliability of the result is based upon the data collected at time of observation.

Research Gap

1. Landslide studies are complex and diversified in nature. They range from analysis of geological indicators, vulnerability and risk mapping, Geo-technical investigation and slope stability analysis etc.
2. The current research addresses the Landslide risk modelling and Risk assessment for selected Tehsils using Remote sensing and GIS.
3. However, these studies should be correlated as every aspect of these analysis requires in-depth study of the landslides. The current research will be focused on evaluating the risks of the study area considered and also providing in-depth studies of selected landslides within the area assessing their causative factor, detailed Geo-technical investigation and slope stability analysis.
4. Large scale mapping of the study area will be done through Worldview 2 / CARTOSAT – 2A.
5. The study will also provide with the necessary information of suitable slope stabilization structures to negate the occurrence of landslides in the future.

3. Objectives

1. Preparation of various thematic layers such as Soil, Geology, Geomorphology, Landuse and Landcover, Slope, rainfall, Transport network etc.

    Landslide is a natural process, which occur in certain geologic and geomorphological areas under certain conditions. The rising costs of landslide damages are a direct consequence of the increasing vulnerability of the people, structures and resources to the hazard. The landslide risk assessment is determined by the relationship between the occurrence of extreme events, the proximity of people to these occurrences, and the degree to which the people are prepared to cope with these extremes of nature. The risk assessment is estimated by analysing the gathered information from various sources and evaluating the risk to individuals or population, economic and environmental hazard. These assessment involves both natural and manmade causative factors. Physical parameters such as Landcover, Soil, Geology, Geomorphology, Rainfall, Lineament density and Slope have been taken into account to estimate the landslide vulnerability for the proposed study area. These vulnerability maps will then be correlated with Socio-Economic factors such as Population, Transportation, Agricultural lands, Forest etc to estimate the various degree of risk areas for the study area. The landslide risk maps will prove to be helpful in assessing the areas that needed to be concentrated for further detailed study.

2. Large scale LULC mapping of the study area

   Detailed study of individual landslides requires large scale mapping of the study area. These large scale mapping usually done through high resolution maps or field survey. These large scale maps reveal the detailed information regarding landslide morphometry, associated risk of the landslides such as Built-up lands, Population and Agricultural lands etc. 3D modelling of the landslide is also necessary part of the study that reveals the mode of subsidence, Failure angle and velocity of material involved etc. The contours for individual landslides are derived through detailed survey of the area using total station.

3. Detailed Geological and Geo-technical and field investigation using Slope Mass Rating method to assess the stability of the slope for the proposed study area.

   The final assessment of landslide study involves estimating the stability of slopes and proposing suitable stabilization measures. These studies are conducted through detailed geo-technical investigation of the landslides. Both field and lab studies will be conducted to assess the stability of the slopes and provide suitable stabilization measures such as concrete wall, net mesh, vegetation growth etc to negate the further occurrences of landslides.

4. To propose suitable slope stabilization measures for Selected landslide sites based on above parameters.

4. Research Methodology

- ✓ Landslide risk mapping is the first step to identify key areas that are highly vulnerable to landslides.
- ✓ Landslide risk maps provides spatial information on damages to settlements, transport lines, communication lines and agriculture lands, so as to take necessary precautionary measure and/or remedial measures to reduce the risk of landslide occurrences.
- ✓ Site specific Geo-technical investigation is carried out for specific landslides within the study area. Geo-technical investigation provides an insight into the nature of specific landslides such as Landslides movement, mode of occurrence, it's causative factors that are assessed through extensive field observation and Lab based analysis.
- ✓ The first step in Geo-technical investigation is to analyze the stability of slopes through Slope mass rating method.
- ✓ Once the stability of the slopes has been studied proper remedial measures such as construction of retaining wall, mesh construction and/or other suitable biological control measures are provided depending upon the nature of landslide to negate the re activation of landslides in future.

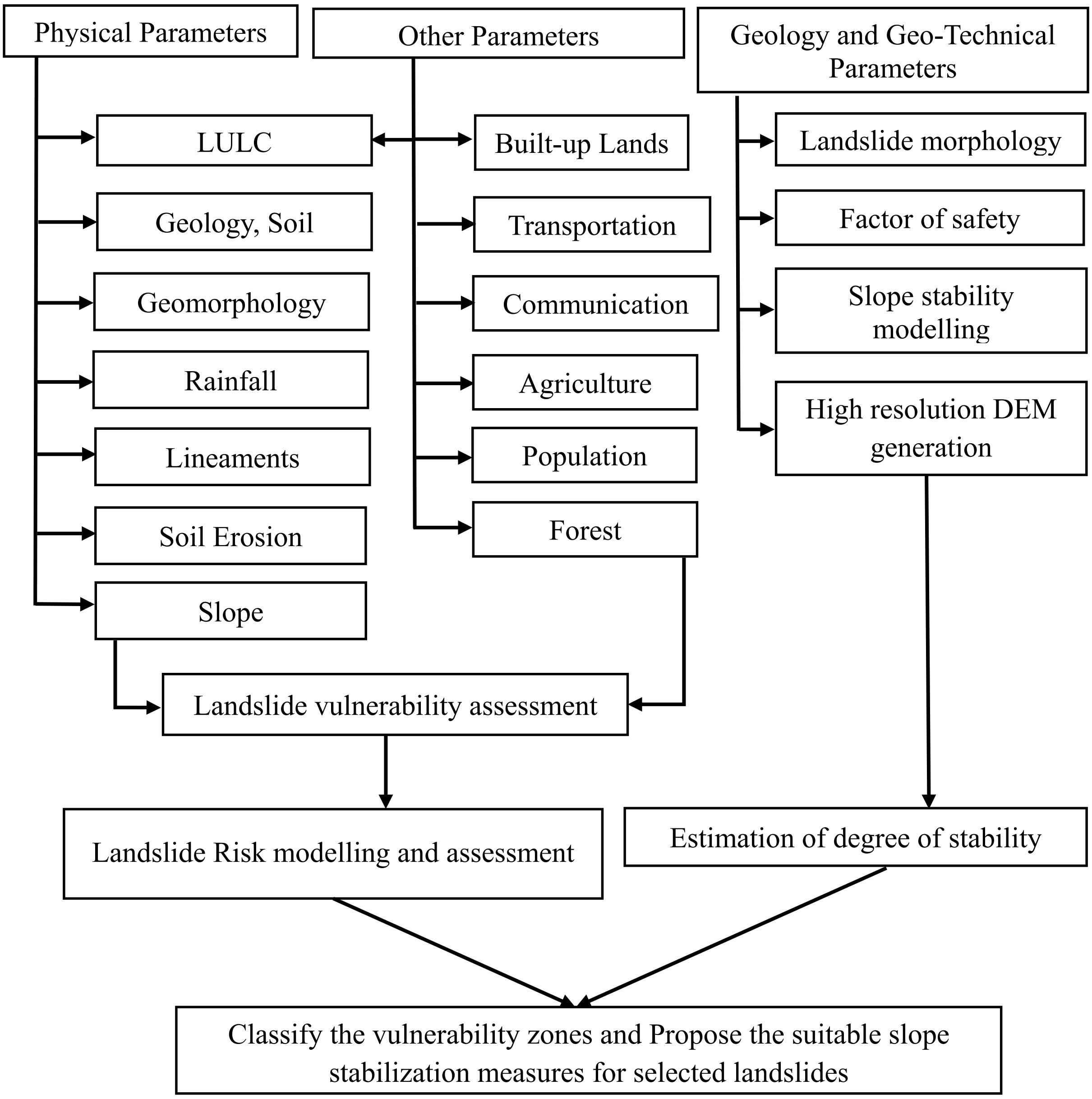


Figure: Proposed Research Methodology

5. Technology used

- ✓ The technology used in this research covers both lab based and Field equipment's.
- ✓ Various Raster and Vector data processing software's both freeware and licensed have been used for spatial data creation, attribute editing and database creation and storage and have been used to study the landslide risk assessments.
- ✓ Field equipment's such as total station and GPS device has been used for contour mapping, point location and detailed surveying of the individual landslides.
- ✓ Brunton compass and other soil sample procuring instruments have been used to collect geological and structural information from the study area.

- ✓ Worldview 2 / CARTOSAT 2A and UAV drones will be used to for large scale mapping of the study area and landslide morphometry analysis.
- ✓ Total station will be used to generate elevation data to create High Resolution Digital Elevation Model (DEM) of the landslide sites and aerial images obtained from UAV drone for site specific mapping.

6. Data used

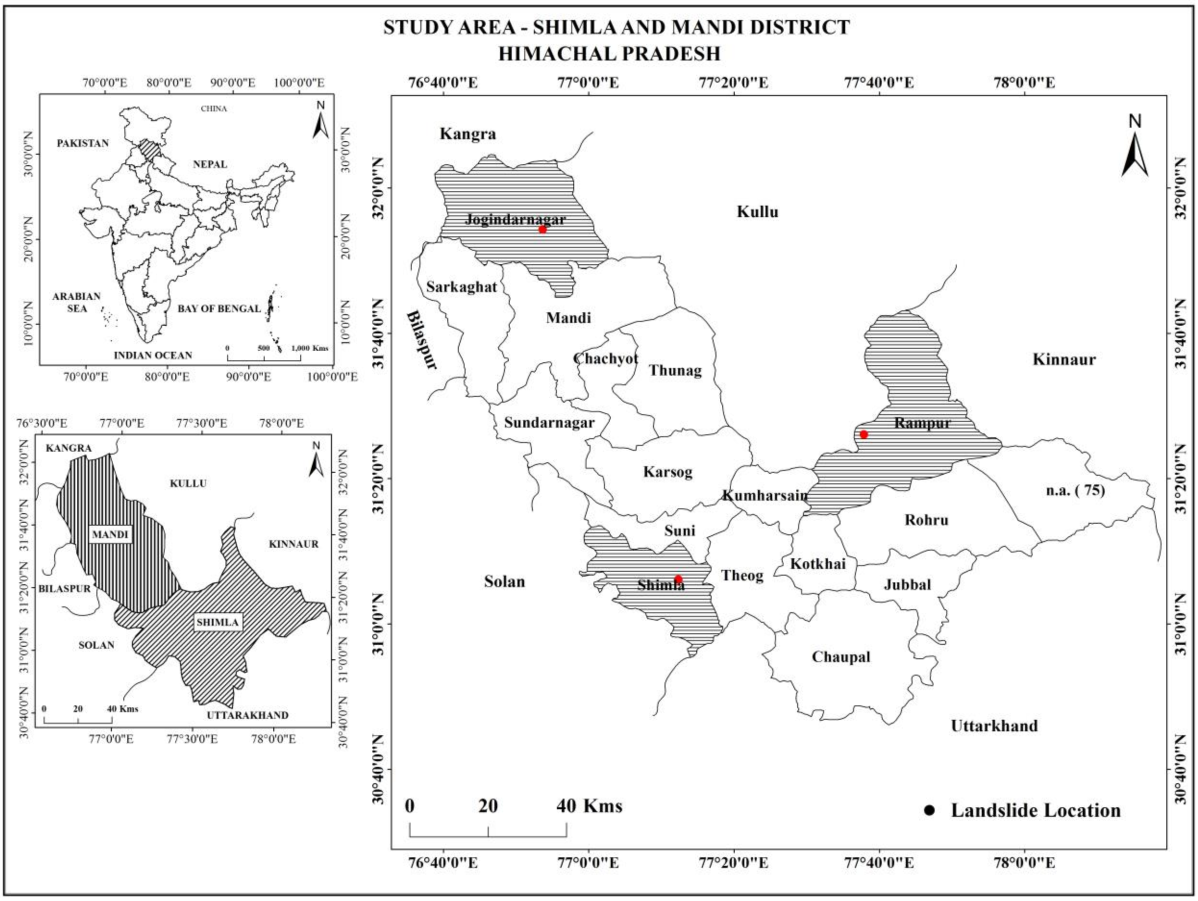
- ✓ The base map of the study area will be created using Survey of India Toposheets 53E/04, 53E/08 and 53F/05 (Shimla Tehsil), 53E/10, 53E/11, 53E/14, 53E/15 (Rampur Tehsil, Shimla) and 53A/13, 53A/14, 53E/01, 53E/02 (Jogendarnagar Tehsil, Mandi) at 1: 50,000 scale.
- ✓ The decadal changes in Landuse and Landcover will be prepared using LANDSAT 8 OLI/TIRS and LISS III sensors obtained from United States Geological Survey (USGS) and National Remote Sensing Centre (Bhuvan) website.
- ✓ The Geology, Geomorphology and Soil depth, texture and structure map was prepared using data obtained from Soil and Landuse Survey of India (SLUSI), New Delhi.
- ✓ Information regarding contour generation will be extracted from field survey using Total Station.
- ✓ Soil samples and other required information will be acquired through detailed Geological and geo-technical investigation of the landslide sites and also results retrieved from lab tests.

SL.NO	Data	Source	Year	Resolution
1	Toposheets	Survey of India	1974	1:50,000
2	LANDSAT 8 OLI	Earth explorer (USGS)	Two decades	30 mts
3	LISS III	NRSC, Bhuvan	Two decades	23.5 mts
4	Geology	SLUSI	-	1:50,000
5	Geomorphology	SLUSI	-	1:50,000
6	Soil Depth	SLUSI	-	30 mts
7	Soil Structure	SLUSI	-	30 mts
8	Soil Texture	SLUSI	-	30 mts
9	Contour	Total station		1:2000
10	Large scale mapping	Worldview / Cartosat	2017	0.4mts / 1 mts

11	Geo-technical information	Field survey and lab analysis	-	-

7. Study Area

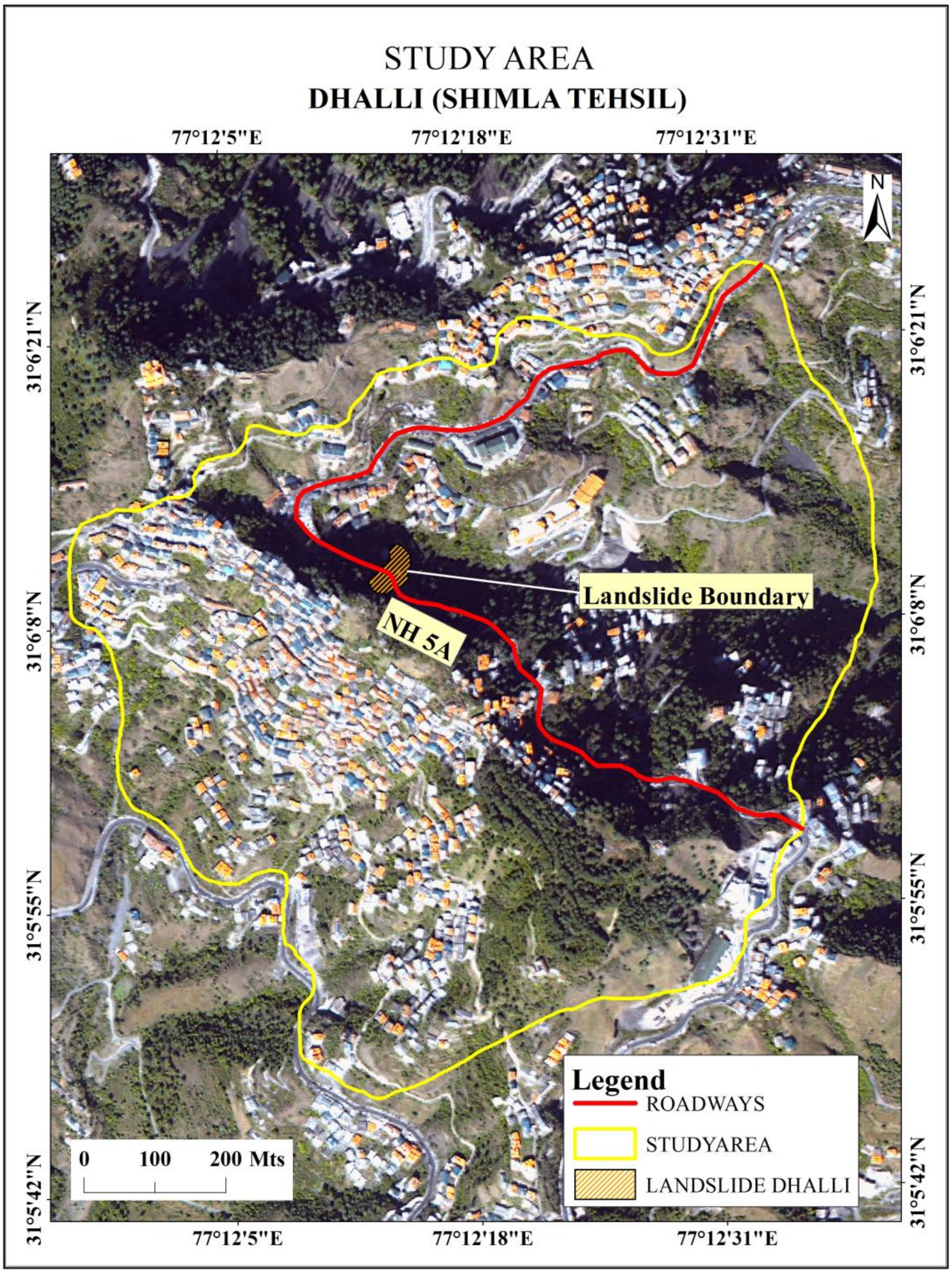
Based on the suggestions of expert committee meeting on Landslide Hazard Mitigation by DST, the Pre field investigation was conducted to choose the location of the study area. The investigation was conducted along the NH-22 from Shimla town to Jhakri. Shimla district extends from 77°0'45" to 78°17'28" east longitude and latitude 30°4'45" and 31°43'44" north latitude covering an area of 5131 square kilometres. As of 2011 census data the total population of Shimla is 8,14,010 people. The altitude of the district ranges from 600 meters at Tata Pani to 5760 meters at Gushu Pishu in Pandrabis area. The major rivers in the district are Sutlej, Tons, Pabbar, Giri and Ganga. Some of the major forest produce of this area are Timber and Charcoal. Besides major produce some resins, Grass, Medicinal herbs and Bamboos are also produced in Minor Quantity. Geologically, the rock formations in Shimla district ranges from Pre-Cambrian to Quaternary period. The climate is Sub-tropical in the valleys and temperate in the hilltops. The average annual rainfall of the district is 999.4mm out of which 75% occurs during the monsoon period June to September.

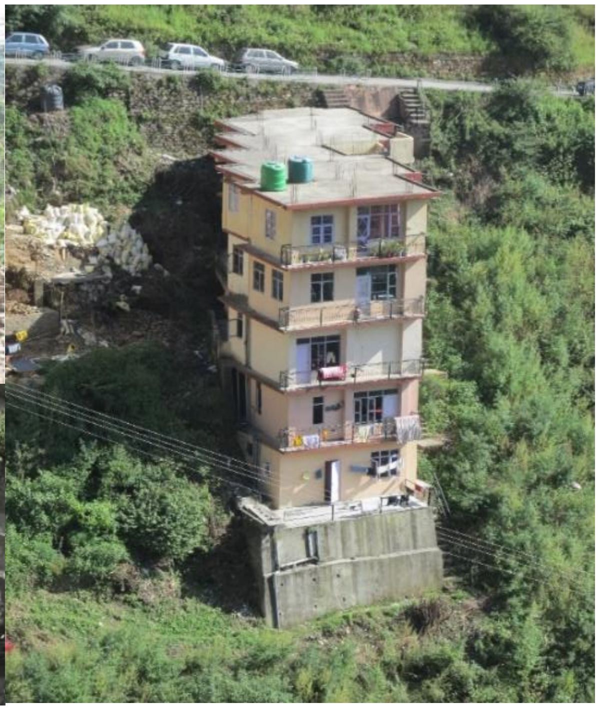


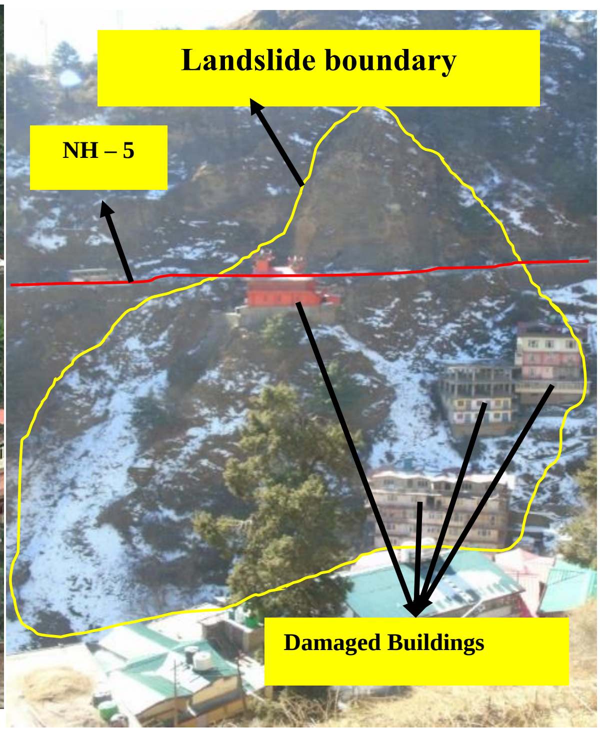
Site 1

The first site is located at NH – 5, near Dhalli area, Shimla Municipal corporation. Heavy monsoon rainfall triggered a massive rock slide (reactivated) on NH-5 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.

Site 1 - DHALLI LANDSLIDE



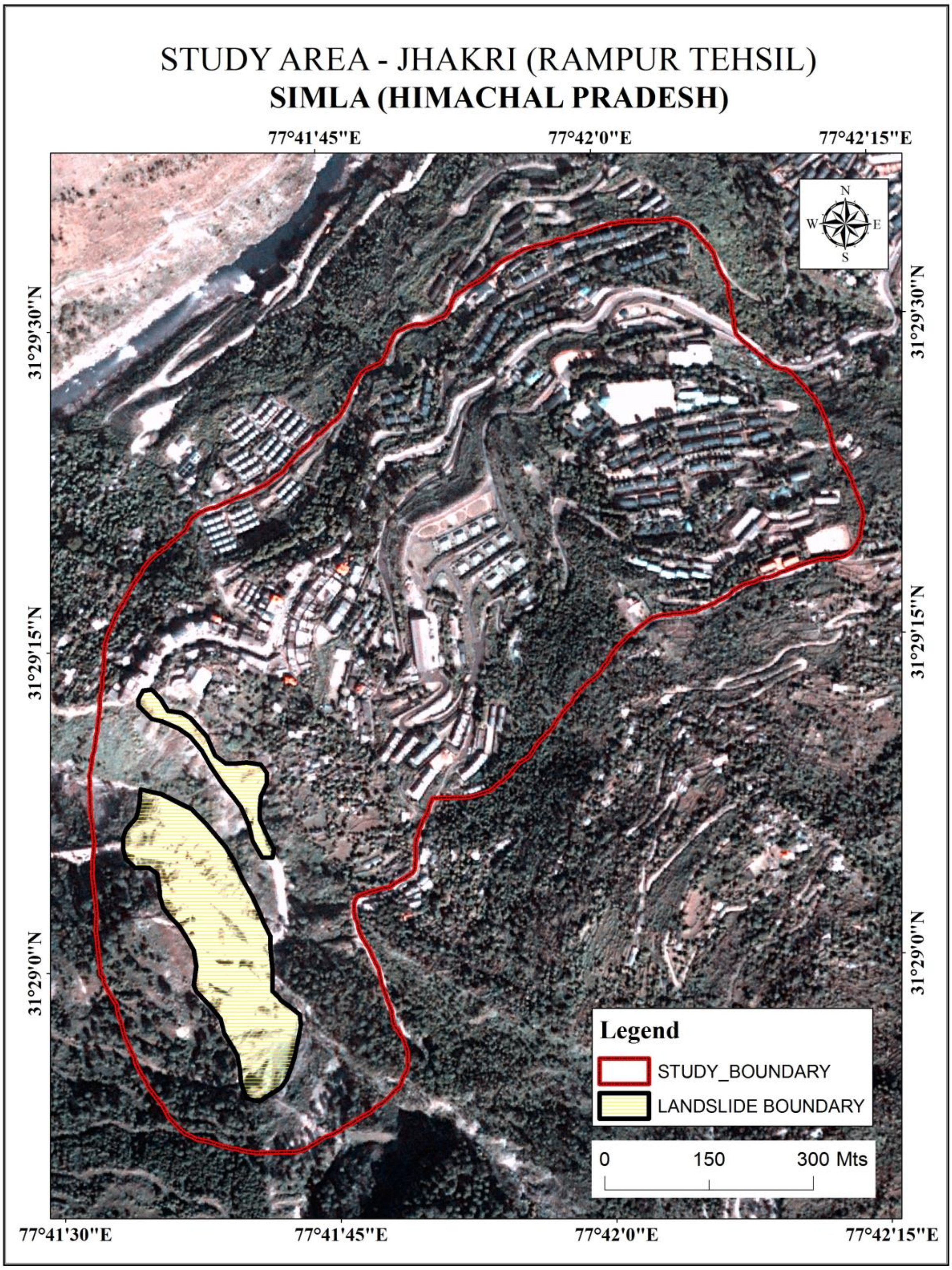


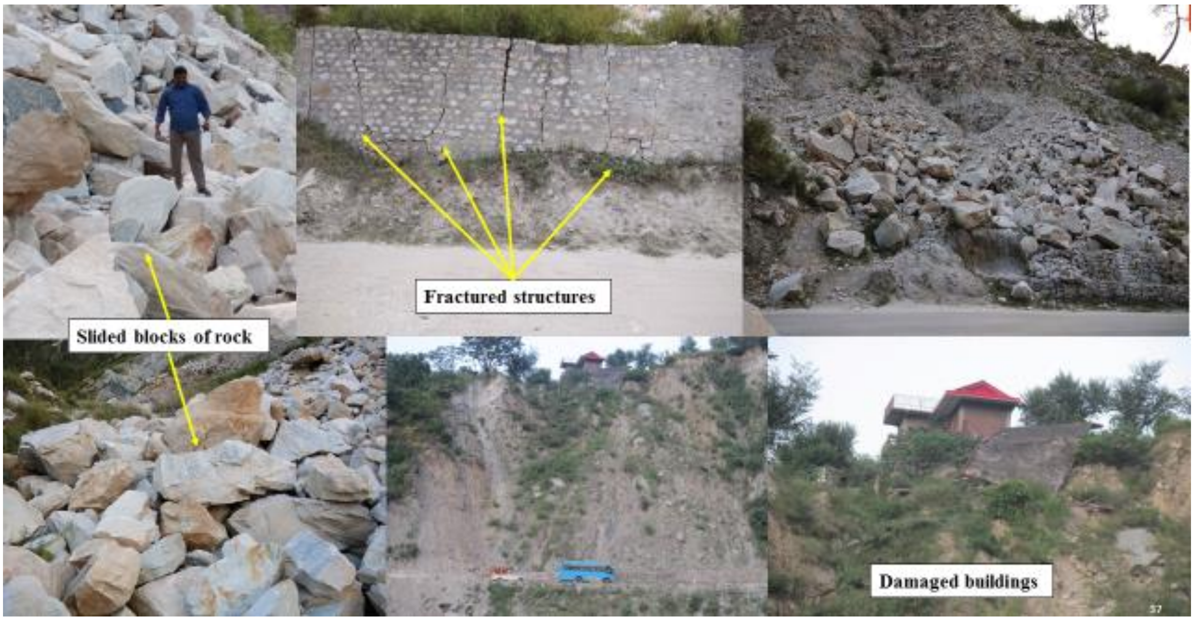


<u>Site 2</u>

Another place with more of landslides observed in Jhakri is situated along the bank of river Sutlej along NH-22. Several landslides ranging from 30 – 50 mts were observed. Buildings with no solid basements were observed along the banks of the river Sutlej. A massive debris slide was located near Jhakri town located along the NH – 22 and the river banks of Sutlej. The landslide was over 200 metre in length and spanning a width of 50 meters.

Site 2 - JHAKRI LANDSLIDE



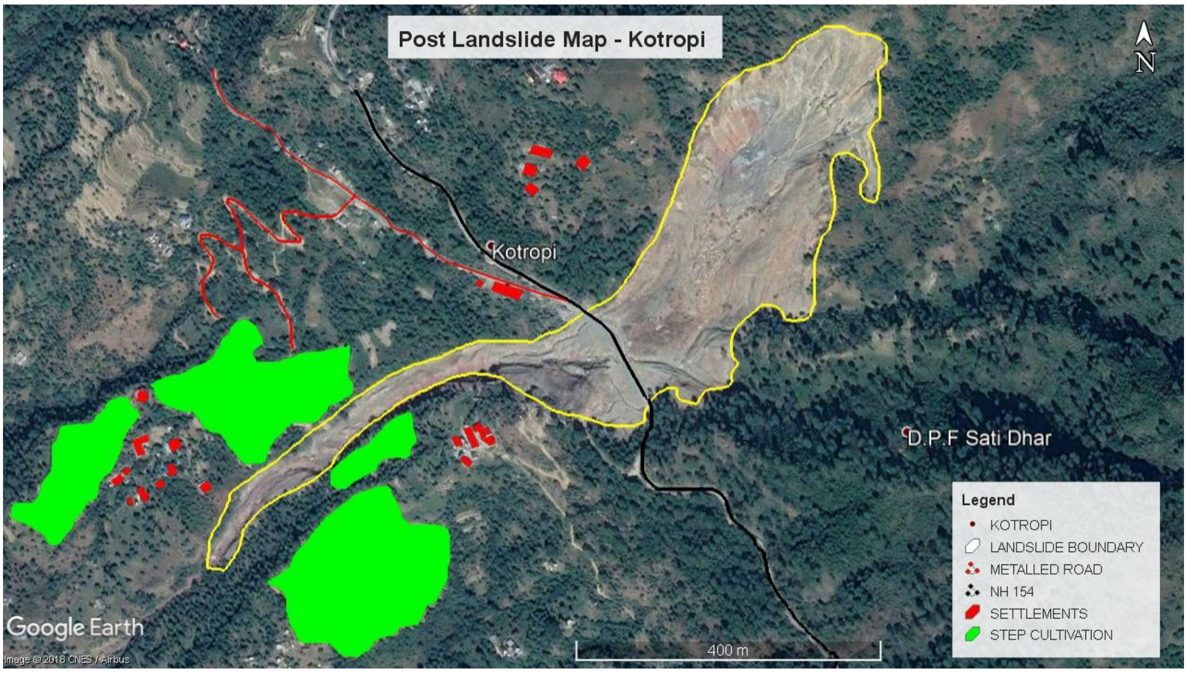


Above landslides have damaged the slope stabilization structures that had been already constructed in that area. The stabilizations walls were not properly maintained. Fractures and cracks were found in the walls. Based on the results derived from pre-field investigation two areas namely Dhalli (Shimla Tehsil) and Jhakri (Rampur Tehsil) have been take up for study.

Site 3:

Kotropi landslide is located at Jogendarnagar tehsil of Mandi district. 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. 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 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.

Kotropi Landslide (Mandi District)



8. WORK PLAN

First Year		Second Year		Third Year		Work Progress
00-06 Months	07-12 Months	13-18 Months	19-24 Months	25-30 Months	31-36 Months	Work will be done
						Course Work, Literature review, Study area selection, data purchase/collection, Field survey (Establishing control points), Finalize Research methodology.
						Preparation of various thematic layers, Landslide risk mapping of the study area, Collection of Soil and Structural information of landslides, High resolution mapping of the study area.
						High resolution DEM generation of study area, Slope stability analysis based Lab and field test. Finalizing suitable slope stabilization measures for the landslide sites.

							Post field verification, Prepare the report and submit Cost estimation of stabilization structures, it to the concerned state government department.

9. Completed Work

- ✓ The literature survey was conducted on the various aspects of landslide susceptibility, both Qualitative and Quantitative studies.
- ✓ The Pre field investigation was conducted to choose the location of the study area. Three sites namely Dhalli are in Shimla town and Jhakri area in Rampur tehsil and Kotropi landslide in Jogendarnagar Tehsil of Mandi district has been selected as study sites.
- ✓ The research methodology is composed of Landslide risk assessment for regional level studies, Large Scale Mapping & DEM generation (1:2000 scale) and also Site specific detailed Geotechnical investigation for slope stability analysis and provide suitable remedial measures of the selected landslide sites.
- ✓ Datasets were obtained from different government agencies for preparation of thematic layers. Soil texture, structure, depth, Geology, Geomorphology and Hydrological layer were obtained from Soil and Landuse survey of India, New Delhi. Elevation data's and other Geo-technical information were obtained through detailed field investigation and lab analysis.
- ✓ Rainfall data for the period of (1971 to 2017) were obtained from Indian Meteorological Centre, Shimla. High resolution satellite imagery (Worldview 2) was obtained from NRSC for detailed mapping of study area. Groundwater related data and reports were received from CGWB, Dharamshala, HP. Information related to Geology and other geotechnical reports were received from Geological wing, Department of Industries, HP.
- ✓ Primary control points were established around the study area for DEM generation and also high resolution mapping.
- ✓ Field visit have been conducted every two months to update the information on landslide.

- ✓ Field information regarding slope stability analysis for Dhalli and Jhakri sites have been acquired. High resolution mapping of the Dhalli landslides and surrounding areas have been completed.

10.Expected Outcome

The final results retrieved from the research will be Landslide Risk Assessment maps for the proposed study area. Site specific Geological and Geo-technical analysis of the landslides and estimated results of the slope stability. Detailed large scale mapping will be done for the proposed landslide area and creation of DEM models at (1:2000) scale. The results will be used and interpreted to propose suitable stabilization measures for the study area. The outcome of the research will prove to be fruitful for the local community and government for constructing the stabilization measures.

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