CHAPTER TWO

Literature Review

The review paper presented here addresses the various aspects of landslide such as vulnerability, Risk assessment, slope stability analysis, Large scale mapping and slope stabilization measures. The literature review is categorized into International, National and Regional landslide reviews, further subdivided into review papers in decadal order. The literature review reveals the various methodologies used in landslide Risk mapping, Geotechnical and Geological studies, slope stability analysis and stabilization measures. Critical review on various landslide analysis models and method have been provided from the literature review of various journals, books, Scientific Reports and Magazines, Govt project reports, Thesis works and Government and Non-Governmental Websites 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. Cruden (2003) in his article stated that "Dana's, 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., et.al (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 studies and research on landslides Tsunaki Ryosuke., (2002). 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

McDonald, H. C., (1975) during the launch of LANDSAR satellite, he proposed the use LANDSAT satellite imageries for identification of landslide sites. He explained that linear zones such as lineaments, faults and fracture zones are some of the most prominent sites for landslide studies. He concluded that the National Highways built along the fault and fracture zones are prone to landslides and needs further study.

Nilsen, T. H., (1975) researched on the role of rainfall and ancient landslide deposits on the recent landslide incidents along the costa county, USA. He explained the reactivation of ancient landslide deposits due to man-made intervention such as construction, adding of water to slopes and grazing. He concluded that a detailed inventory of preexisting landslide events and sites, coupled with rainfall data would provide fruitful in the future plans of disaster management.

Brunsden, D., 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 Rotational landslide 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.

Fussgänger, E., (1977) used the combined method of engineering and geological exploration to study the stress existing in the soil mass along the Okolicne in the north Slovakia. He concluded that the presence and magnitude of cohesion forces on the bedding planes are probable causes for slope failure.

Bogoslovsky, V. A., (1977) explored various geo-physical methods for landslide studies. He proposed the measurement of parameters such as self-potential, electrical conductivity and temperature measurement which can be used to measure the soil seepage and pore pressure that leads to prediction of slope failures

Coates, D. R. (1977). Wrote a book on "Landslide Perspectives". The book includes on various landslide terminologies, types, previous work on landslides around the world, classification of landslides and case studies around the world.

Lundgren, L. (1978). Studied about the soil and vegetation development of the landslide scars. Mgeta valley from the western Uluguru mountains, Tanzania were chosen as the study area. He analyzed parameters such as bulk density, pH, plant texture as a way of measuring the landslide scars. He found the increase in organic carbon content and decreased clay content due to the high erosion rate. He concludes that landslide stabilization through vegetation has been ineffective.

Fleming, R. W., (1979) researched about various landslide hazards and their control measures. He insisted that landslide control and management should be multi-disciplinary that should include geologist, engineers, planners and NGO's to reduce loss due to landslides.

Kanukabo, T., et.al, (1980) studied the importance of 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 results obtained they 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

Kienholz, 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 Mountain hazard maps.

Brown, W. J. (1983) researched on how mass movements where changing the natural landscapes of the New Zealand. He explained the role of human intervention for agricultural purposes, grazing and building construction have led to the increased landslide activity in the country. He concluded the research by suggesting various stabilizing the landslides through tree plantation and afforestation.

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 plane, 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 unstable.

Alexander, D. (1986) studied regarding the intensity of damage to the buildings due to landslides. He proposed an intensity scale for classifying buildings due to various landslide events. The intensity scale was based on numerical eating ranging from 1 to 7 where 1 denotes the building is intact and 7 denotes the total collapse of the building.

Schuster, R. L. (1986) wrote a book on a phenomena called "Landslide Dams". The book has been compiled based on various case studies around the world. These case studies include the dimension estimation of the landslides, Natural, Social and Economic impact of the landslide dams. The books been concluded by studying various processes that cause landslide dams, its risk and mitigate measures.

Bernknopf, R. L., (1988) used a probabilistic method for landslide hazard mapping. Cincinnati, Ohio was chosen as the study area to develop an economic evaluation due to the landslide activities. They have estimated that due to the proper study of landslide mapping and constructing mitigative measures they can save an amount of 5 billion $.

Pike, R. J. (1988) analyzed various terrain structures that are prone to landslides. He has conducted the research on two landslide sites in the Marlin county, California. He concluded that higher resolution DEM can provide better estimation into dimension estimation and also pre determining the areas that prone to landslide failure.

Guzzetti, F., (1989) stressed about the necessity of Digital elevation models for the preparation of landslide hazard maps. He proposed the role of aerial photographs derived from DEM in determining landslide information and distribution as a cost effective of developing landslide hazard maps.

Lee, S. W., (1990) assessed the impacts of landslides on watershed managements. He explained that the increased stream bank erosion and landslides along the majors during the monsoon season have blocked the stream channels and along the down streams. He concluded that stabilizing the river banks and slopes would provide to be useful in water management problem of Taiwan.

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.

Daikaku 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.

Dhakkal, A. S., 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, J.R., 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

Wu, S., et.al, (2001) 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.

Van Western, C.J., et.al (2003) analyzed the evolution of Tessina landslide using Aerial photo interpretation and Direct field mapping. The interpretation was done through 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.

Ali, Mohammadi., et.al, (2009) 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.

Dai, F., et.al (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, L. E., 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.

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.

Anbalagan, R., et.al (2011) published 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.

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 Normalized Difference Vegetation Index (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, S. B., 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.

Shroder, J.F., et.al (2010) 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.

2011 – 2021

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, R., 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 twelve zones of landslide susceptibility four high risk zones, seven medium risk zones and One low risk zones. Based on the No of lives lost he divided the twelve into two very high risk zones, five high risk zones, two medium risk zones and three 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.

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, L. C., 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 one using AHP yields an accuracy of 74% were as model two 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 Very low susceptibility among which 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 the village for early warning signs.

Zhang, Wenjun., et.al (2012) used Contribution rate weight stack method to quantify areas that are 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 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.

Feizizadeh, B., et.al (2014) 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, Amar Deep., 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.

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 been carried out by Aerial photographs associated with radar and Optical imagery. Remote sensing data have been used to map and monitor various types of landslides on large scales preferably (1:5,000 to 1: 25,000) in conjuncture with other thematic layers.

Mollaee, S., et.al (2014) studied landslide inducing factors for Cameron island, Malaysia. The have overlaid past landslide occurrence over Soil, Lithology, Vegetation, Slope and Lineament maps to study the particular characters of landslide inducing areas.

Torkashvand, A. M., et.al (2014) studied landslide susceptibility for a basin located on the Ardebil province, Iran. Factors such as Precipitation, Elevation, Faults and Lithology 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 Satellite imageries and aerial photos. The results show that 67.8% and 24.3% of the basin has high and low instability.

Formetta, Giuseppe., et.al (2014) used Physical 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.

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 of landslides, Accounting for locational errors and false positive 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.

Altin, Turkan Bayer., 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, S. H., 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, T. K., 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 ARC slopetab 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, H., 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 gridded 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 Lithology, Aspect, Elevation, Slope have been used as causative parameters. 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 (FLOW-2D) to predict the debri flow. The model has been recreated for an debri flow event occurred during 1^{st}-2^{nd} of February, 2017 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 was 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 results compared to rule-set based framework.

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.

Saponaro, A., et.al (2015) 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. 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 for 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, A., et.al (2015) 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 Physical based Hydrological-Geotechnical model to predict rainfall induced landslides. Mendatica a small town of Lugria, Italy was chosen as the study area. The results revealed that the model can be used for proper risk evaluation and land use planning purposes.

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. The proposed methodology is implemented at various urban centers in the Daunia and Lucanian Appenines, southern Italy. The results revealed that most of the landslides occurred along the failed slopes and reactivated due to slow to very slow mass movements. 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.

Yan, Fei., et al (2019) Yan studied the landslide susceptibility mapping using AHP and Normalized Frequency ration model based on cloud computing. Yan came up with new method to study landslides using spatial logistic regression and

Geodetectors for Duwen Highway Basin, Sichuan Province, China. They concluded that both AHP and Normalized frequency model can increase the accuracy of the results compared to other statistical models.

Lee, S. R., et.al (2020) studied the spatial probability of the landslide occurrences based on the increasing pore water pressure due to rainfall and earthquakes. Two different landslides were used as case studies for the research. The research has been conducted in two phases, in the first phase change in water table due to rain water infiltration and subsurface water movement has been studied. In second phase the slopes are tested for stability factor through the rainfall and earthquake data. Based on their results they classified the chances of landslide occurrences into four levels ranging from High to Very Low due to the rainfall – earthquake induced landslides.

Phong, T. Van., et.al (2019) studied the landslide susceptibility assessment for Muong Lay district, Vietnam using various Artificial Intelligence methods such Support Vector Machine (SVM), Artificial Neural Network, and Logistic Regression (LR). The author has used Slope, Aspect, Curvature, Geology and Distance to roads, rivers etc as landslide causative factors for susceptibility mapping. The results revealed that compared to the ANN and LR model, SVM model produces accurate results with an ROC value of (0.99).

Du, J., et.al (2020) conducted landslide susceptibly modelling for the Jilong valley, Tlibet, Chinese Himalayas. The study has been conducted using both Heuristic and various statistical model to overcome the scarcity in the landslide inventories. The data employed consists of landslide Inventory mapping from both field and satellite imageries, Geomorphology, Geology, NDVI and flow accumulation as landslide susceptibility indicators. The results indicate that the MLR model produce more accurate results with an ROC value of (0.862) compared to the other statistical and Heuristic model for landslide susceptibility mapping.

Kutlug, E., et.al (2020) developed a comprehensive geocomputational tools for landslide susceptibility mapping known as "LSM tool Pack". The pack uses five main modules namely, "Data Preparation, Feature Selection, Logistic Regression, Random Forest and Performance Evaluation". The authors have various landslide inducing factors namely aspect, curvature, lithology, NDVI Distance to roads etc as causative factors for landslide mapping. The results suggested that Random Forest model produces an overall accuracy model of 88% compared other models with an accuracy of only 81%.

Panahi, M., et.al (2020) used two different models Hybrid Support Vector Regression (SVR) and Adaptive Neuro – Fuzzy Inference System (ANFIS) to predict susceptibility. The model has been carried out for Icheon township, South Korea using various causative factors namely Slope, Aspect, valley depth, geology and forest density. The results indicate that he SVR model produce highly accurate results compared to the other models at 83%. ANFIS models produced an accuracy of 81%.

Shao, X., et.al (2020) studied how different resolution of raster images affect the quality of preparing landslide vulnerability map and collecting landslide inventory datasets. The author stated the role of high resolution DEM for preparing inventory on earthquake induced landslides. The study was carried out using DEM of various resolutions ranging from (2.5 mts to 80 mts) for the 2013 Minxian earthquake induced mass movements and slope failures. Eight landslide inducing factors such as aspect, lithology, slope profile and curvature etc were used for susceptibility assessment for landslides. The results conclude that the high resolution DEM provide much better accuracy in terms of dimension estimation of individual landslides occurred due to earthquakes.

Ngo, P. T. T et.al (2021) studied the role of deep learning algorithms for landslide mapping at a national level for Iran. They used the Recurrent Neural Network (RNN) and Convolutional Neural Network (CNN) for susceptibility mapping using various landslide causative factors namely fault, geology, rainfall and Landuse. The authors concluded that the RNN model provides greater accuracy Upto 86% compared to the CNN model with an accuracy of 85%.

Wang, L., et.al (2020) studied the effect high step slopes due to the constructions of buildings. The authors reported that the buildings suffered heavy damage located along the steep slope loess. Greater the damage to the slope and the buildings located closer to the slope. Buildings affected during the Minxia - Zhangxian earthquake were taken as case studies. The result concluded that the distance between the building and the edge of the slope must be 0.7 greater than the height of the slope to increase the slope stability.

Youssef, A. M., et.al (2020) used machine learning algorithms for landslide susceptibility mapping for the Abha basin, Asir region, Saudi Arabia. The study was carried out using various landslide contribution factors namely NDVI, LULC, Slope angle, Curvature etc. The result was concluded with among various models Random forest (RF) model produces 95% accuracy in susceptibility mapping.

Yang, D., Qiu et.al (2021) studied the role of multi-temporal high resolution data sets on evaluating the topographic changes that influences landslides. The have studied hoe local terrain relief parameters such as slope, aspect, TWI and gradient plays an active role in landslide initiation. The results provide an insight into terrain conditions and morphological parameters for landslide assessment.

Mondini, A. C., et.al (2021) gave a critical review on the role of Synthetic aperture radar for landslide studies. The authors have reviewed a total of 54 research articles and concluded that SAR based imaging has been fruitful in evaluating phenomena such as morphology, geology, seismic, meteorology and climate which are critical in landslide studies.

Escobar-Wolf, R., et.al (2021) developed an Arcmap based extension for Slope stability analysis. The software uses various physical parameters such as morphology, soil, geology, field datasets used in a numerical rating to estimate the slope stability.

2.2 Landslide Reviews: National Status

In India landslides are quite common along the Himalayan regions, Western and Eastern Ghats. Many researchers and scientist had investigated 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 Indian Institute of Technology-Roorkee, Geological survey of India, Central Road Research Institute, National Remote Sensing Centre, Wadia Institute of Himalayan Geology, Bureau of Indian Standards, Defense Terrain Research Laboratory and some academic institutions and experts etc.

Early 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 1890 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 (NDMA, 2009).

1970 – 1980

Natarajan, T. K., (1977) studied about the landslide in detritus in the Himalayan Region. The have estimated the effective shear strength of the detritus using the limit equilibrium model. They concluded that peak shear stress of the soil material governs the stability at limiting equilibrium.

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.

Chinnamani, S., et.al (1972) studied about landslide and land slips in the peninsular India. They have chosen Nilgiri and other hilly regions of the peninsular India. They have concluded that intense storm and rainfall, bad management of agriculture lands, forest lands and improper disposal rainwater are the major reasons for soil erosion and landslides.

Krishnaswamy, V.S, (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.

Bhattacharya, A., (1982) researched about the mass sinking phenomena along the Sunil - Joshimath complex in Uttar Pradesh. He revealed that water seepage along the pore spaces of soil plays an important role in soil subsidence. He also stated that

Gneissic boulders are present in loose sandy coupled with the springs in the area increases seepage causing soil creep and displacement of the boulder.

Tiwari, A. K., (1986) studied the landslide affected areas along the central Himalayas. Factors related to landslides such as Land use, forest types, landslide zones, frequency of landslides were obtained from aerial photographs. The results revealed that agriculture were the pre dominant activity around the old landslide sites followed by forest, scrub and wasteland. The potential and active landslide zones were mostly concentrated along the geologically active thrust and faults.

Sharma, E. (1988) researched about the role of altitude variation in the nitrogenase activity from the Himalayan alder that are growing on the old landslide sites. Ten different landslides were chosen for the study from Kalimpong forest in the eastern Himalayas. Results concluded that the nitrogenase activity was less during the night and high during the day. They also stated the nitrogenase activity were low below 1500 mts and above 2000 mts.

Haigh, M. J., (1988). Studied about the various causative which are responsible for mass movements along the hilly roads of Almora and Nainital, U.P, India. They have revealed that the sites prone to mass movements can be detected by factors such as apparent dip, rock strength, slope angle, Roadcut height and upslope vegetation cover. Their results on hilly roads of Almora and Nainital revealed that 32% of the roads are prone to rockfall and 27% to rock lump.

Bartarya, S.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 tonnes during the year 1985 and 1986.

Haigh, M. J., (1989). Studied the environmental indicators of the landslide activity for the 6 km section of the Kilbury Road, Nainital, Kumaun, Lesser Himalaya. Their results reveal that 38% of the roads are prone to slumping and rotation of debri slides. 39% of the area prone to debri slides of undeformed blocks of rock which are high in the areas of road cut slope.

Manjusha, J. (1990) studied the behavior of soil nutrients and vegetation cover post landslide along five different sites in the Kumaun region, Uttar Pradesh. Based on their results they concluded that the sites are sandy in nature and dominated by vegetation. The increase in soil nutrients, species diversity and density has been the reason of landslides along this region.

Joshi, M., (1990). Conducted extensive research on cause and remedial measures for rockfalls and landslide along the Naina peak in Nainital, Kumaun, Himalaya. The landslide site located in Nainital peak has been studied for its geological and geo-technical parameters to derive the factor of safety. The FOS was conducted at regions Middle and Lower Krol formation. The FOS indicated a value of 0.5 for the middle krol and 0.1 – 0.2 for the lower krol region.

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

Gerrad, J., 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 landslide 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 study 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 type of landslide due to the accumulation of pore water pressure along the shattered rocks which resulted in a river uplift of 4mts and widening of 25mts.

Sarkar, S., et.al (1995) studied about the landslide hazard zonation in the Garhwal Himalayas. Srinagar - Rudraprayag has been chosen as the study area. Causative factors such as geology, lithology, slope angle, Landuse, Drainage, relief has been to identify hazard zones. Based on the numerical rating they categorized the area into five zones ranging from very low to very high in hazard.

Anbazhagan, R., et.al (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.

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.

Barnard, Patrick L., (2001) conducted a post-earthquake landslide investigation for 1999, Garhwal earthquake. 336 active landslides mapped within 226km^2 of the Garhwal region. The data was collected through field investigations and analysed 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, C., et.al (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.

Nagarajan, R., (2000) researched the landslide hazard for tropical monsoon region based on terrain and climatic factors. Konkan coast between the Mumbai and Goa has been taken has the study area. Parameters such as Landcover, Drainage Density, Relative Relief, Slope, Weathering and soil types are considered for hazard zonation. They concluded that a total 75% of the area comes under very low to low hazard zones and 15% comes under moderate hazard zones.

2001 – 2010

Landslide Hazard Zonation along the pilgrim road routes in the Himalayan regions of Uttaranchal and Himachal 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 NRSC, Hyderabad (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.

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 was 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 (2001) 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 No 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 (GSI, 2005) (Table No 3). 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 (Figure No 3).

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 No 3: Landslide studies in Himachal Pradesh

(Source: GSI special publication, 2005)

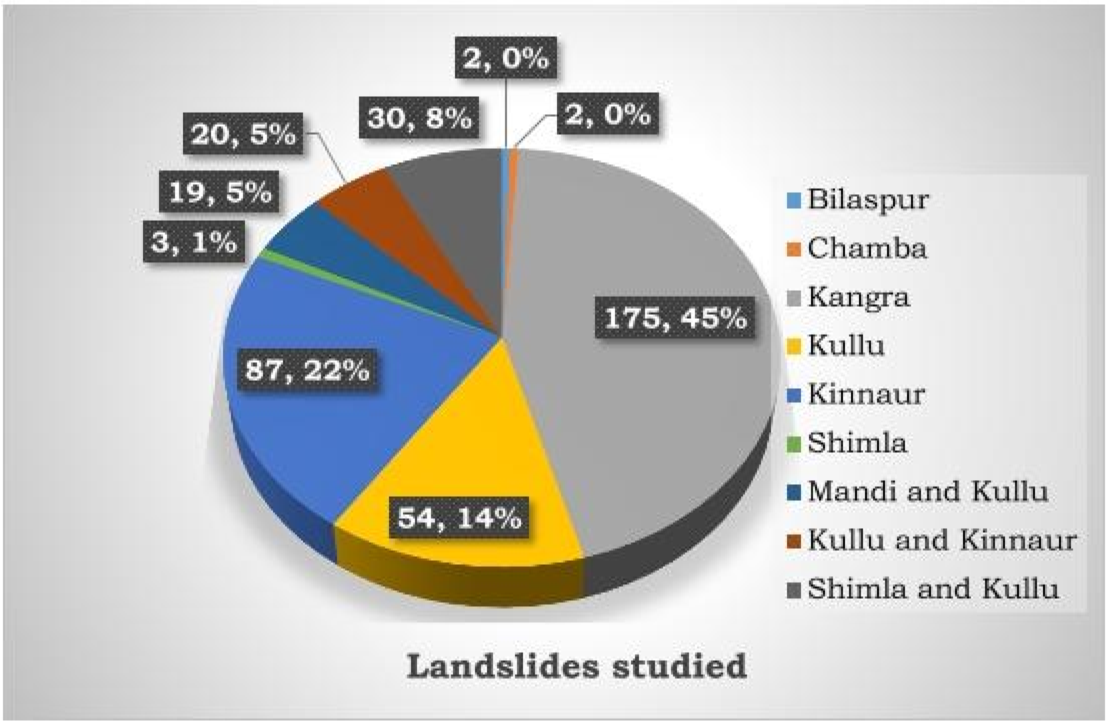

Figure No 3: Landslide studies in Himachal Pradesh

(Source: GSI special publication, 2005)

Ray, P.K Champathi., 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, D. 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.

Das, Iswar., et.al (2012) 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 reveals 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 Chauhan, S., 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 occurrences.

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 - 2021

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 output was generated in ARCGIS environment and classified into four types ranging from high to low. The study reveals that 80% of the area are prone severe high risk zones.

Kanungo, D. 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 (2011) created predictive models to assess the susceptibility of shallow transitional and debri landslides 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.

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.

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, Jawan singh., 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.

Various parameters such as presence of faults, land use and Landcover, Drainage density, Lineaments were used for analysis. The output was segmented into six categories 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, S 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 economic structures.

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 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, B. M., 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.

Kumar, Deepak., et.al (2017) studied landslide susceptibility of Mandakini river basin 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, Uttarakhand. 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., et.al (2017) published a book on "Landslide Research The DST's Initiatives". 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%.

Kumar, V., et.al (2019) investigated about the application of machine learning algorithms and sedimentological characteristics for landslide assessment for the Nahan – Rajgarh National Highway corridor. The stud employs the use of four different models Boosted Regression Tree (BRT), Generalized Linear Model (GLM), Random Forest (RF), Support Vector Machines (SVM) for mapping. The susceptibility maps we classified based on various input factors such as proximity to streams, roads, scrubs and wasteland etc. The results indicate the Random Forest model has higher accuracy of 90% compared to other models.

Sachdeva, S., et.al (2019) used novel voting ensemble techniques for the prediction of landslides along the Brahmaputra valley region, Assam & Nagaland. Factors that are responsible for landslides such as Elevation, Slope, Aspect, NDVI and LULC were used as parameters. The result states that the models used in the research produce more accuracy of 98% than the conventional used models such as Random Forest, Support Vector Machines etc.

Feby, B., et.al (2020) conducted a research on landslide susceptibility mapping for the Wayanad district, Southern Western Ghats, India. The authors have used Evidence Belief model to classify landslide susceptibility areas using causative factors such as lithology, LULC, lope, NDVI, lineaments etc. They concluded that the accuracy of the evidence model was greater compared to conventional multivariate models with an accuracy of 93%.

Thakur, M., et.al (2020) studied the Neotectonic activity of the Himalayan frontal thrust, Nahan Salient, NW Himalayas, India using geological and geomorphic evidences. The study reveals that the HFT has different geometries which will have many different implications in the Nahan salient where Himalayan Frontal Thrust (HFT), Nahan Thrust (NT) and Main Boundary Fault (MBF) are located.

Abraham, M. T et. al (2021) studied the usage of antecedent rainfall to estimate the rainfall thresholds in landslide early warning system. The study is an attempt to improve the performance of conventional meteorological thresholds by considering the effect of soil moisture, using a probabilistic approach. The results conclude that the work contributes to strengthen the advancing trend of hydro-meteorological thresholds based on soil moisture, which is gaining a growing attention in landslide studies.

Saha, S et.al (2021) examined the landslide susceptibility in Rudraprayag district of Uttarakhand, India using the conditional probability (CP) statistical technique, the boost regression tree (BRT) machine learning algorithm, and the CP-BRT ensemble approach. The study showed that the areas of fallow land, plantation fields, and roadsides with elevations of more than 1500 m. with steep slopes of 24° to 87° and eroding hills are highly susceptible to landslides.

Satyam, N. (2021) conducted a research on early warning system for Kalimpong town, in the Darjeeling Himalayas of India. Different approaches in defining rainfall thresholds were followed and real time field monitoring has been carried out using Micro Electro Mechanical (MEMS) tilt sensors and volumetric water content sensors.

The study proves that the rainfall thresholds can be used as a first line action for issuing early warning to the public and its performance can be improved by using real time monitoring data.

2.3 Landslide Reviews: Regional Status

1970 – 1990

Srivastava, L. S. (1970) studied the stability of rock slopes in 3D. He stated that stability of the lower part of the rock slopes in the high mountain region are controlled by deformation modulus of the rock. He concluded that when estimating the stability of the whole mountain face we need to consider the stability of the near surface material and stability of the entire mountain.

Singh, S., et.al (1977) studied about the damages done due to the Jan, 1975, Kinnaur earthquake, Himachal Pradesh. The earthquake caused considerable loss of life, damage to buildings and landslides. The paper briefly explains about various damages to the transportation and building sector.

Agrawal, P. N., et.al (1972) studied about the crustal deformation near Koyna and Dakpathar region of Dehradun. They have conducted tilt observations along the two study areas. The result revealed that earth surface has not deformed during the earthquake energy release in Koyna region and rate of secular creep of the Nahan Thrust is 0.4mm/month in the Dakpathar region.

Srikantia, S. V. et.al (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.

Ramana, Y.V., (1990) Studies on saprolitized charnockites associated with a landslip observed in the Blue Mountains in close proximity of the Porthimund Dam (11°22'E 76°342 303N), Nilgiris District, Tamilnadu State, South India, are reported. Such studies should prove valuable in the mapping of weather ability zones and the assessment and determination of foundation conditions.

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.

Haigh, M. J., et.al (1988) correlated the occurrences of landslide frequency with various environmental factors along the National Highways of Himalayas. He Studied about the various causative which are responsible for mass movements along the hilly roads of Almora and Nainital, U.P, India. They have revealed that the sites prone to mass movements can be detected by factors such as apparent dip, rock strength, slope angle, Roadcut height and upslope vegetation cover. Their results on hilly roads of Almora and Nainital revealed that 32% of the roads are prone to rockfall and 27% to rock lump.

Mehtra, G. S., et.al (1989) studied the geologic, geomorphology and morphometry parameters to diagnose the landslide vulnerable areas and slope instability along the Kaliasaur landslide, Garhwal Himalaya. The authors have proposed various remedial measures such as modification of existing drainage pattern, stitching of slopes, construction of retaining walls and plantation of vegetational covers.

Ramana, Y. V., et.al (1990). Studied the case histories of two different hard rock slips along the Nilgiri Hills of Tamilnadu, India. He reported that the first slip is close to power project along the porthimund dam and second is located along a railway structure near Adilabad district, Andhra Pradesh, India.

1991 – 2000

Badal, R., et.al (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.

Sharma, S., et.al (2000) used the Hoek and Bray method to study the plane failure analysis along the release joint inclination. The have modified the equation to calculate the factor of safety and various parameters and proposed the equation for the estimation of the stability of slopes.

Bartarya, S. K., et.al (1996) Sutlej 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 aggravated 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.

Mehrotra, G. S., et.al (1996) researched on delineating the safe and unsafe zones through terrain analysis and spatial assessment for Sikkim, Himalayas. Factors such as slope, Drainage and landslide inventory have been used as causative parameters. T. he zones was divide into five zones based on a numerical rating ranging from 1 to 2. Values ranging 1 to 22 are considered very low and values above 28 are considered very high.

Sah, M. P., et.al (1996). The Sutlej 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, glacio fluvial and lacustrinal deposits occurring at various levels along the Spiti, Ropa, Baspa and the Sutlej itself. The Sutlej river was blocked twice during 1993 due to a major landslide and a rockfall near Jhakri and Nathpa respectively. A partial block also occurred at Palingi in 1988 where Soldan Khad joins the Sutlej. These major blockades and many zones of land subsidence along NH – 22 between Bhabanagar and Jhakri 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 Sutlej valley. Pachauri, A. K., et.al (1998) studied landslide zoning in part of Garhwal, Himalayas based on geological and geomorphological factors like relative relief, slope, fault, altitude, and lineaments etc. Landslide zoning was classified into two groups namely terrain classification and landslide susceptibility mapping. The authors have concluded that the active faults and micro earthquakes has been the cause of mass wasting.

Rautela, P., et.al (2000) The area around Sataun in the Sirmaur 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 plates, 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., et.al (2001) Morphometric assessment of five major and active landslides (mainly translational type) in the Sutlej 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, E (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 (2006) 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 weathered rocks, heavy rainfall and lack of vegetation cover.

Dortch, J. M., et.al, (2009) 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., et.al (2008). made an attempt 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 No and some protections of it need proper understanding to stabilize it.

Gupta, V., et.al (2007) studied the spatial variability of mass movement along the Sutlej valley for the year 1990-2006. The findings concluded that there was a significant increase in landslide areas from 1.35km^2 to 11.83 km^2 in 2006. Nearly 28.43 km of Nanitinal 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, P., et.al (2005) 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., 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., et.al (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 was recorded in anticlinal slopes of Katarigali Formation (20%), Morang Formation (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., et.al (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., et.al (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 rock mass and intensive rainfall further accelerated the slope failure.

2011 – 2021

Chandel, V. B. S., et.al (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., (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., 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 raster were given the experience based weightage and analysis was made in the GIS environment to prepare the final landslide susceptibility zonation map.

Pareta, K., (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., et.al (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., et.al (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.

Chandel, V. B., (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.

Pandey, V. K., et.al (2017) 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, V., et.al (2019) 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 25 m/s with a flow height of 15 mts while it (debris flow) reaches the valley floor. Finally, it is also estimated that further slope failure may detach as much as 0.80 to 0.32 million m^3 mass that will completely dam the river to a height of 76 mts above the river bed.

Jamwal, A., et.al (2019) conducted the research on application of GIS for vulnerability assessment along the upper Sutlej basin, Kinnaur, Himachal Pradesh. The vulnerability assessment was done based on the factors slope, aspect, LULC, soil and lithology etc. The end results indicate the various vulnerability of the hilly region due to natural hazards and anthropogenic causes.

Prasad, S., et.al (2019) conducted slope stability assessment for 20 slopes along the National Highway – 58 connecting Delhi to Badrinath, India. The slope stability was estimated using Nonlinear Generalized Hoke-brown criterion. The results concluded that out of twenty slopes under investigation five slopes are unstable, four slopes are marginally stable and eleven slopes stable.

Achu, A. L., et.al (2020) studied the spatial modelling of shallow landslides along the southern western Ghats of Kerala, India using the Dempster – Shafer model and the

Logistic Regression model. The authors have collected an inventory of 82 landslides from field observation and satellite data and used to predict the landslide susceptibility for various factors namely lithology, geomorphology, soil, proximity from streams, roads, lineaments etc.

Bera, S., et.al (2020) studied the susceptibility of household buildings to landslide hazards along the Kalimpong hilly region, India. The authors considered four different indicators for the scenario namely environmental, social, economical and physical. A total of three hundred and thirty-two house from thirteen sites were subjected to evaluation. The findings suggest that households located at the eastern side of the region are less resilient compared to other areas. It has been reported this is due to lack of knowledge, unequal infrastructure development and economic status.

Gobinath, R., et.al (2021) researched on slope stabilization using natural plant roots (soil bioengineering) as a reinforcing agent. The authors collected indigenous plants around the study area and conducted lab test for the shear strength of the soil with plant roots of different growth. The results show that the shear strength of the soil increase with the increase in the area of plant roots providing grater binding concentration.

Prakasam, C., et.al (2019) study the landslide hazard mapping for the Shimla Tehsil using Geo-environmental parameters. Parameters such as Hydrogeology, Lithology, Slope morphometry and relative relief were used as causative factors. The final results were categorized into five types based on Total Hazard Estimation Index model. It appears that 62% of the study area comes under low prone area and 26.10% very low and 11.82% covers moderate & high prone zones.

Prakasam, C., et.al (2020 b) study the vulnerability of the National and State highways of Rampur Tehsil, Himachal Pradesh to landslides. Inducing parameters such as LULC, Slope, Relative Relief, Geology and landslide Inventory etc. Based on the Inventory and landslide vulnerability it has been concluded that 44% of the landslide occurs along high vulnerable zones and 56% occurs along the moderate zones.

Prakasam, C., et.al (2020 a) studied the Debri Slope failure of the Jhakri landslide, Shimla, Himachal Pradesh. He indicated that the landslide is due to the exposed unstable slope along the National Highway that lead to the damaged settlement along the main scarp of the slope. Reinforced bench slope with soil nailing has been suggested as remedial measure. Five benches with 70° angle has been proposed with the soil nailing of varying width between 5.5 to 13 mts. The foot of the bench is suggested to protect with gabion walls to increase the stability of slopes.

Prakasam, C., et.al (2020 c) did a comparative evaluation of Weighted Overlay and Fuzzy logic method for landslide vulnerability mapping for Rampur Tehsil, Himachal Pradesh. Datasets such as LULC, Geomorphology, Geology, Soil and Slope were used as causative factors. The results suggest that 57% and 47% of the study area comes under very high and high category for the fuzzy logic method and for weighted overlay method 80.24% and 13.68% comes under high and moderately vulnerable category.

Saha, A., et.al (2020) compared the efficiency of Weight of evidence, support vector machines and ensemble approaches for landslide susceptibility mapping. Kurseong region of Darjeeling, Himalayas were chosen as study area. The research uses landslide inventory maps, soil depth, slope, lineaments and LULC as causative factors. The authors conclude that among the various models used ensemble model produces results with highest accuracy of upto 94.45%.

Yunus, A.P., et.al (2021) studied the various landslide inducing factors along the Western Ghats of India. They have used random forest method to study the major control factors of landslides. Their results conclude that cut slopes and plantation is mainly related to landsides within 700 mts buffer. They have concluded that anthropogenic effects on natural ecosystem have caused an increase in landslide initiation.

Pandey, V. K., et al (2021) evaluated the changes in the landslides, their size, location, and up to some extent, gradual stabilization impacts on susceptibility assessment. The model result was validated with a landslide test dataset using the area under the curve (AUC) method. The AUC value is 0.89 and 0.91 for 2013 and 2019, respectively. The study finds that annual updating of landslide inventory is essential for susceptibility modeling for assessment of associated risks and implications of mitigation measures along the highway corridor.

Devara, M., et al (2021) used a IS-based multi-criteria decision analysis to prepare LSMs is proposed, with MT-InSAR derived displacement estimates used as a critical input parameter. The results indicate that the majority of the unstable zones along the Alaknanda River are correctly identified. The result generated an updated susceptibility map, which helped in the identification of 44.5% new landslide susceptible zones (LSZs).

Various authors have studied the different aspects of landslides ranging from vulnerability modelling, Rainfall threshold mapping, Geotechnical analysis and simulations. However, no single 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. 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 No 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.

2.4 Critical Review

Over the years' various scientists 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 conditions 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 varies for each method. It is imperative that suitable methodology need to be used for the regional preparation of landslide risk maps. Addressing the nature and causative factors of individual landslides 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.

2.5 Research Gap

Based on the literature survey it can be concluded that many researchers and scientists have tackled the problem of landslides along various regions of India. The authors followed their methodology and choice of parameters depending upon the type of landslide analysis 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 the Himalayas where the chances of landslide occurrences are high. Review of the literatures has shown that the best approaches in detecting landslides is the use of VHR images both monoscopic and stereoscopic and also high-resolution 3D modeling of topography using LIDAR sensors. Imageries acquired using UAV drones coupled with LIDAR datasets have produced greater accuracies for site-specific detailed landslide investigation. The landslide risk maps in conjunction with the early warning system will provide useful insight in landslide prediction thus reducing social and economic losses. The authors have addressed either the geological or Geotechnical aspect of the landslides. It is important that both aspects of the landslide must be studied together. Remote Sensing and GIS coupled with Geological and Geotechnical analysis provide greater accuracies of landslide assessment.

Landslide studies are complex and diversified in nature. They range from analysis of geological indicators, vulnerability and risk mapping, Geotechnical investigation and slope stability analysis etc. However, these studies should be correlated as every aspect of these analysis requires in-depth study of the landslides. Conjugation of 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. 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 Geological & Geo-technical investigation and slope stability analysis. Large scale mapping of the study area will be done through Worldview 2 / CARTOSAT – 2A site specific landslide investigation. The study provides the necessary information for the construction of suitable slope stabilization structures.

Conclusion

Chapter three concludes in various literature reviews of landslide research on International, National and Regional status. The research articles and books details out on various aspects of landslide research. The research is diversified into spatial studies, vulnerability and risk assessment, stabilization measures, early warning system, high resolution mapping and site specific morphometry analysis etc. The research articles partly / Wholly address a particular problem that could be applied either at regional level or at local level. No single methodology exists that could address all the landslide critical problems and provide solutions. It is imperative that more than one number of research methodologies or complex of research methods need to be used to address the landslide problems. The literature review concludes that many scientist and researchers in India have tackled the problem in various degrees through their own methodology and using their own choice of parameters. Review has shown that best approach for site specific landslides are stereoscopic analysis of the landslide sites coupled with high resolution 2D & 3D modeling and site specific in-depth analysis. 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.