Comprehensive study of Landslide Susceptibility Mapping for Jammu & Kashmir, India using GIS based Bi-Variate Probabilistic Approaches

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CANDIDATE'S DECLARATION

I, Sheikh Romana, Roll No. 2K21/GTE/17, student of M.Tech (Geotechnical Engineering), hereby declare that the project dissertation entitled "Comprehensive study of Landslide Susceptibility Mapping for Jammu & Kashmir, India using GIS based Bi-Variate Probabilistic Approaches" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi **SHEIKH ROMANA**

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CERTIFICATE

I hereby certify that the Project Dissertation entitled "Comprehensive study of Landslide Susceptibility Mapping for Jammu & Kashmir, India using GIS based Bi-Variate Probabilistic Approaches" which is submitted by Sheikh Romana, Roll No. 2K21/GTE/17, to Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by him under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

The Himalayan region of India is susceptible to landslides and its mitigation has always been of concern. Planners and local communities benefit from the study of landslide disasters for the development of an area that increases societal safety. The geological and topographical features of Jammu & Kashmir make it prone to natural hazards like landslides. Landslide Susceptibility mapping (LSM) of an area has proven to be efficient to detect hazardous zones. This research develops a zonation map for the Jammu & Kashmir, India using ArcGIS software to examine landslides as a risk. Twelve causal factors were found in the prepared land slide inventory to create the thematic maps. Major factors considered were elevation, stream power index (SPI), slope, aspect, topographic wetness index (TWI), curvature, average annual rainfall, lineament percentage, earthquake, land use land cover (LULC), distance from roads and lithology. Application of four bi-variate statistical models, namely Shannon Entropy, Frequency Ratio, Statistical Information Value and Weight of Evidence, have resulted in accuracy of 87.5%, 87.2%, 88.2% and 88.1% respectively, thus validating the maps devised. A thorough examination of LSM can help identify the area's landslide-prone areas and their primary causes in advance, hence minimizing their adverse effects.

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TABLE OF CONTENTS

CANDIDATES'S DECLARATION…………………….……….……… i

CERTIFICATE……………………………………………….………. ii

ABSTRACT…………………………………………………….…….. iii

ACKNOWLEDGEMENTS…………………………………….……. iv

TABLE OF CONTENTS……………………………………...….v

LIST OF TABLES…………………………………………….……. viii

LIST OF FIGURES……………………………………...…... ix

LIST OF ABBREVIATIONS……………………………...……... xi

CHAPTER 1 INTRODUCTION

1.1 General……………………………………………………………….…….1

1.2 Landslides………………………………………………………….…………1

1.3 Problem Statement……………………………………………….……...1

1.4 Objectives……………………………………………………….…………3

1.5 Thesis Overview……………………………………........…...……..3

CHAPTER 2 LITERATURE WORK

2.1 Literature Review…………………………………………….………………4

2.2 Research Gaps………………………………………………….…………….8

CHAPTER 3 METHODOLOGY

3.1 Study Area……………………………………………………………..……..9

3.2 Landslide Inventory Preparation…………………………………………………10

3.3 Causative factors and thematic maps……………………………………………12

3.3.1 Elevation……………………………………….………………...…...12

3.3.2 Aspect……………………………………………………..…………..........12

3.3.3 Curvature………………………………………...……………….……13

3.3.4 Lineament Density…………………………………………………......14

3.3.5 Slope…………………………………………………………..……….14

3.3.6 TWI……………………………………………………..…...……........15

3.3.7 SPI……………………………………………….........................16

3.3.8 LULC ………………………………..………………………..…….17

3.3.9 Annual Average Rainfall ………………………………………..…….18

3.3.11 Distance to Roads………………………………………..……….......18

3.3.10 Earthquake…………………………………………………..…..……19

3.3.12 Lithology……………………………………….……..……………...20

3.4 Bi-Variate Model application…………………………………………..…...21

3.4.1 Frequency Ratio..……………………………………………….………..21

3.4.2 Statistical Information Value……………..………………….....................22

3.4.3 Weight of Evidence……………..……………………………………….22

3.4.4 Shannon Entropy………………………..………………………………..23

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Frequency Ratio Results…………………………………………………………24

4.1.1 Tabulated Results………………………………..……………………24

4.1.2 LSM Outcome…………………………………………..………….29

4.1.3 Validation Results………………………………………….……….…...30

4.2 Statistical Information Value Results………….………………………………,…31

4.2.1 Tabulated Results………………..…………….………………….………31

4.2.2 LSM Outcome………………………..……………………………….….….35

4.2.3 Validation Results……………………..………………………….……..…...37

4.3 Weight of Evidence Results………..…………………………………….…..….38

4.3.1 Tabulated Results………………..………………………………..……38

4.3.2 LSM Outcome…………………..………………………………..…….42

4.3.3 Validation Results………………………………………………..……44

4.4 Shannon Entropy Results………..…………………………………….……….45

4.4.1 Tabulated Results……………..……………..……………………………45

4.4.2 LSM Outcome…………………………..……..……………………….50

4.4.3 Validation Results…………………………..……..……………….....52

4.5 Comparative Study…………...……………………………..….……………….53

CHAPTER 5 CONCLUSION

5.1 Conclusion……………………………………………………..…………….…55

5.2 Recommendations……………………………………………………..…....56

5.3 Future Scope……………………………………………………………..…..…56

REFERENCES……………………………………………………………………..57

CONFERENCES………………………………………...………………………61

LIST OF TABLES

Table 1.1. Landslide Classification…………………………………………………...…...2

Table 4.1 Calculated Results obtained from FR method…………………………….....24

Table 4.2. Landslide percentage area using FR approach…………………………..…29

Table 4.3. Calculated Results obtained from SIV method………………………….…....31

Table 4.4. Landslide percentage area using SIV approach…………………………..…...36

Table 4.5. Calculated Results obtained from WoE method…………………….….….38

Table 4.6. Landslide percentage area using WoE approach...……………………...…43

Table 4.7. Calculated Results obtained from SE method…………………………..…45

Table 4.8. Landslide percentage area using SE approach………………………….....51

LIST OF FIGURES

Fig 1.1. Landslide Features……………………………………………………………2

Fig. 3.1. Study Area- Jammu & Kashmir………………………………………………..9

Fig 3.2 Landslide points taken for study area…………………………………………..10

Fig 3.3 Flow Chart of Methodology……………………………………………………11

Fig. 3.4 Map of Elevation………………………………………………………………12

Fig. 3.5 Map of Aspect…………………………………………………………………13

Fig. 3.6 Map of Curvature……………………………………………………………...…13

Fig. 3.7 Map of Lineament Density……………………………………………...……14

Fig. 3.8. Map of Slope………………………………………………………….……15

Fig. 3.9. Map of TWI………………………………………………………….….16

Fig. 3.10. Map of SPI……………………………………………………….………….17

Fig. 3.11. Map of LULC………………………………………………………………17

Fig. 3.12. Map of Average Annual Rainfall……………………………………………...18

Fig. 3.13. Map of Distance to Roads……………………………………………………..19

Fig. 3.14. Map of Earthquake………………………………………………………….20

Fig. 3.15. Map of Lithology……………………………………………………….…..21

Fig. 4.1. Dominance of factors inferred from prediction rate…………………………28

Fig 4.2. LSM using FR approach……………………………………………..…....29

Fig 4.3 Landslide zone distribution as per FR……………………………..…...…..30

Fig 4.4 SRC as per FR model…………………………………………….………...30

Fig 4.5. PRC as per FR model……………………………………………….………..31

Fig 4.6. LSM using SIV approach……………………………………….………36

Fig 4.7. Landslide zone distribution as per SIV……………….……………………..…..37

Fig 4.8. SRC as per SIV model……………………………………………….……..37

Fig 4.9. PRC as per SIV model………………………………………..……….….38

Fig 4.10. LSM using WoE approach……………………………….……………..43

Fig 4.11. Landslide zone distribution as per WoE……………………………….…44

Fig 4.12. SRC as per WoE model……………………………………………......44

Fig 4.13. PRC as per WoE model……………………………………………..…45

Fig 4.14. Dominance of factors inferred from SE approach……………………..…..50

Fig 4.15. LSM using SE approach……………………………….……………..…51

Fig 4.16. Landslide zone distribution as per SE……………………………….…51

Fig 4.17. SRC as per SE model…………………………………………………......52

Fig 4.18. PRC as per SE model…………………………………………………..…53

Fig. 4.19. Comparison of landslide area for different methods…………………......…53

Fig. 4.20. Comparison of SRC for different methods...…………………..………...54

Fig. 4.21. Comparison of PRC for different methods……………………..………..54

LIST OF ABBREVIATIONS

AUC – Area Under Curve

CRU- Climate Research Unit

DEM- Digital Elevation Model

FR – Frequency Ratio

GSI- Geographical Survey of India

LSM- Landslide Susceptibility Mapping

LULC- Land Use Land Cover

NASA- National Aeronautics and Space Administration

PRC- Prediction Rate Curve

ROC- Receiver Operator Characteristics

SDMP- State Disaster Management Plan

SIV- Statistical Information Value

SE – Shannon Entropy

SRC- Success Rate Curve

SPI- Stream Power Index

TWI- Topographic Wetness Index

USGS- United States Geological Survey

WoE- Weight of Evidence

CHAPTER 1

INTRODUCTION

1.1 General

One of the most devastating natural disasters, landslides cause a great deal of harm to both people and property. The complexity of landslides has made it an intricate field of study, demanding cooperation from various disciplines to develop more effective and comprehensive approaches.

India has a long history of catastrophic occurrences, most notably landslides in the Himalayan and Ghat mountain ranges. The Himalayan evolution is relatively more recent, and it is identified by volatile geology and the existence of significant faults. Since past ten years, anthropogenic influences have worsened the issue together with other triggering factors including earthquakes, excessive rains, and flash floods.

1.2 Landslides

Terzaghi's [1] original phrases about landslides was the abrupt outward or downslope movement of slope-forming materials adjacent to a slope caused by the force of gravity. Since then, a range of definitions have surfaced in several publications and research papers as a result of the challenge of coming up with a comprehensive explanation for such a complex occurrence. Fig. 1.1. provides an overview of landslide occurrence from USGS 2004. Lee and Jones (2004) [2], provide an in depth classification of landslides as in Table 1.1.

1.3 Problem Statement

Almost 15% of India's land area is at risk of landslides [3]. Himalayan region in particular are under threat. Between 1800 and 2011, landslides in the Himalayas claimed 2,000 lives, whereas the Indian Himalayan regions saw 1,500 fatalities during the same time [4]. As per Global News Service, 2021, there have been 169 major landslides in Jammu and Kashmir in the past five years, which have had severe impact on infrastructure and life. Ramban, Udampur, Reasi & Doda districts of Jammu &

Kashmir has been afflicted with several landslides over years creating grave situation for the inhabitants.

Since it connects Jammu and Kashmir Union Territory to the rest of the nation, National Highway (NH-44) is of utmost significance to the UT. Due to frequent landslides, this highway is shut down for many days each year. In addition to natural elements human activities like building infrastructure, blasting, slope excavation for road widening, and deforestation have all contributed to the occurrence of new landslides as well as the reactivation of inactive landslides.

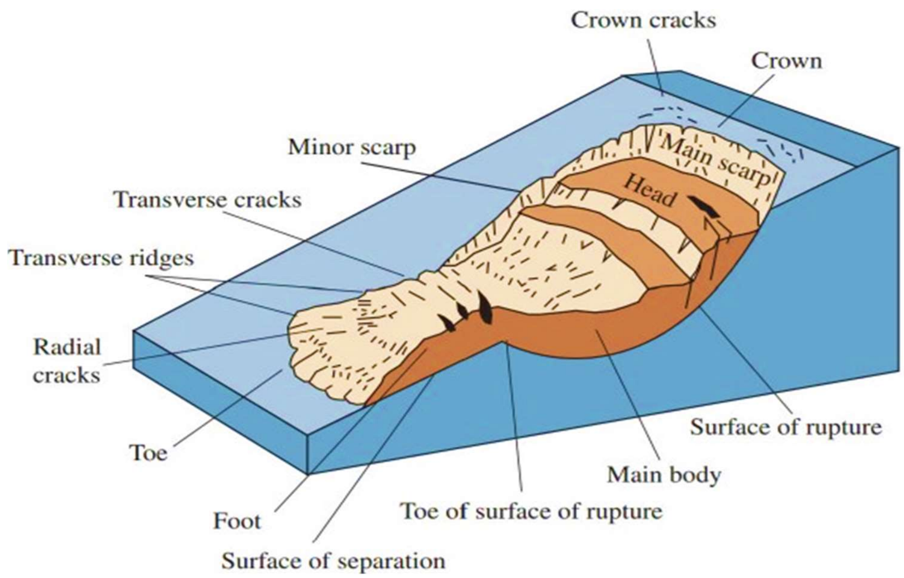

Fig 1.1. Landslide Features

Table 1.1. Landslide Classification

			Material Type		
			Rock	Debris	Soil
Movement Type	Falls	Falls	Rockfall	Debris Fall	Soil Fall
		Topples	Rock Topple	Debris Topple	Soil Topple
	Flows		Rock Avalanche	Debris Flow	Mud Flow
	Slides	Rotational	Single rotational slide	Multiple rotational slides	Successive rotational slides
		Non-Rotational	Block slide	Slab slide	Spreading Failure
		Planar	Rock slide	Debris slide	Mud Slide

Highway closures are followed with significant financial losses and fatalities. Shah et al., 2021 documented 739 reported landslides in 506 days during a 30 year period (1990 to 2020), resulting in 1000 fatalities and 267 physical harm. According to a National Institute of Disaster Management estimate from the year 2011, landslides cause India to lose between Rs 150 and Rs 200 crore in financial terms per year. Hence identification of hazardous areas has become important for necessary measures and mitigation.

1.4 Objectives

The primary objectives of the research work are stated as under:

- To locate the critical landslide points for the region of Jammu & Kashmir, analyze the factors responsible, identify dominating factors and create thematic maps of the causative attributes.
- Application of GIS based Bi-Variate statistical probabilistic approaches using thematic maps to prepare Landslide Susceptibility Maps for the area.
- Validation of the prepared landslide susceptibility map using AUC method of ROC tool.
- Comparative study of the applied approaches for Landslide Susceptibility Mapping and determining the most suitable model.
- Analysis of the prepared LSM and its inference for cause and location detection of most vulnerable areas.

1.5 Thesis Overview

The document begins with literature survey and research gaps identified in chapter 2, then study area and methodology adopted in chapter 3, with chapter 4 presenting the results and interpretations. Final review on the research work and conclusions are provided in Chapter 5.

CHAPTER 2

LITERATURE WORK

2.1 Literature Review

Owen et al. [5] investigated the Kashmir earthquake of October 8, 2005, which produced thousands of landslides. These largely consisted of rock and debris falls. It was discovered that, in addition to lithology, the steep slope played a significant role in the concentration of earthquake-induced landslides.

The Information Value methodology for landslip susceptibility zonation described by Vijith et al. [6] was presented along with a study region in Kerala's Western Ghats. The prediction accuracy was evaluated using the AUC. The areas under the curve were computed again in order to compare the findings quantitatively because a total area of one indicates excellent prediction accuracy. The prediction accuracy was 80.45%.

Gosh et al. [7] built predictive algorithms to evaluate the Darjeeling Himalayas' propensity for shallow translational rocksliding and debris slide. Using a multivariate analysis technique like logistic regression to estimate landslip susceptibility is likely to produce high success rates, but not certainly high forecasting rates.

Rai et al. [8] found in the study area of Uttarkashi, 76.2 percent of the landslides were predicted using a hazard map from a multiple linear regression model. As a result, the model's success rate (76.2%) demonstrated great forecast accuracy. The study area had been divided into Poor, Average, High, and Very High relative landslip susceptibility classifications. There were six aspects to speculate consider.

Oh et al. [9] used aerial photograph interpretation to map the location of landslides after extracting many landslide-causing elements from satellite data, including slope, lineaments, aspect, curvature, land cover, and NDVI. The final map of landslip susceptibility was created and validated using frequency ratio and logistic regression models. The authors emphasised how challenging it is to conduct field surveys in mountainous places and to forecast when land sliding episodes will occur.

According to topographical characteristics and data availability, Van Westen et al. [10] provided four case studies from distinct regions of India: West Bengal, Uttarakhand, Kerala and Tamil Nadu. These case studies discussed the use of several approaches for landslip mapping and hazard evaluation.

Ramesh and Anbazhagan [11] employed data from remote sensing and a GIS technique to map the landslip susceptibility along the Ghat road of the Kolli Hills in Tamil Nadu utilising frequency ratio, relative effect, and fuzzy gamma operator models. It took into account seven variables. The frequency ratio model provided superior prediction accuracy, according to validation data.

Ansari et al. [12] examined the rockfall situation as it stands in India. Analysis was done on the causes of rockfall, including rain, freeze-thaw, snowmelt, channelled runoff, erosion, springs, and seepages. It was determined that hydrology played a crucial role in the bulk of the landslides.

To classify landslide susceptible slopes, Laskmanan et al. [13] took into account the significance of the route and area of Manali. They calculated Yule's Co-efficient and Landslide Occurrence Favourability Score and determined the weightage for factor class using the Weighted Multiclass-index Overlay Method. Using a SRC and the cumulative distribution of landslides, the rating maps were merged into a GIS to create a susceptibility score map that was ultimately classed as high, moderate, and low. Eight variables were considered.

Pandey [14] discusses the key geological difficulties encountered by road construction firms. It was found that human-made factors including irrigation of cropland, deforestation, and slope digging for construction operations also disrupted the naturally occurring slope of hills and created temporary slide zones, occasionally reactivating older landslides. From Jammu to Banihal, the angle of the hill slope varies greatly, ranging from 30° to vertical and coated with heavy colluvium and extensively weathered rock, making the hill slope unreliable.

Sharma and Mahajan [15] compared the effectiveness of statistical models based on geographic information systems for LSM of the Himalayan watershed in India. When weighed against AHP and IV, the FR model demonstrated most accuracy.

Riaz et al. [16] created a map of landslip susceptibility using a data-driven methodology and Muzaffarabad district in Pakistan's northwest Himalayas as a case study. A map showing the region's susceptibility to landslides was created using nine causative factor rasters. As a result of the WoE, it was determined that 79% of the region is in a low-landslide susceptibility zone, 9.26% is a moderate-landslide susceptibility zone, 5.12% is a high zone, and 6.30% is a very high.

To identify failure zones along National Highway 1, Hussain et al. [17] performed GIS-based LSM utilising FR and weight of evidence (WoE) approaches. For GIS modelling, thematic layers representing multiple landslip causative elements have been created.

Thanh et al. [18] map indicating the likelihood of landslides was created for the Vietnamese city of Da Lat. The frequency ratio approach was used. Eight elements were taken into account, and data was gathered in a shape file from many reliable sources. According to the findings, 36.36% of the region is at risk of landslides.

To map rainfall-induced vulnerable zones, Negi et al. [19] used a GIS-based multi-criteria evaluation (MCE) method that combined topographical, environmental, and hydrological characteristics. The modelled high, medium, low, and very low risk susceptibility zones determined for the 2015 episodes are evaluated with field research and pre-post satellite imageries, and found to be in excellent alignment (ROC = 76.6%).

Roy et al. [20] used a novel ensemble approach combining the weight-of-evidence (WoE) and support vector machine techniques with remote sensing datasets and geographic information systems to delineate landslip hazard zones in the Darjeeling and Kalimpong districts of West Bengal, India. The WoE & Linear-SVM model was superior to the other ensemble models in terms of accuracy, as shown by the outcomes of both validation techniques.

Chowduri & Pal [21], the frequency ratio model was used to assess the association between ten potential causes of landslides and their occurrences, and it identified the Lachung River basin's leading landslide causes. AUC curves' success rate (92.3%) and prediction rate (88.9%) serve as evidence for the validity of the map. The landslip susceptibility map was categorised into extremely high (0.591%), high (1.867%), moderately high (5.172%), moderate (19.682%), moderately low (25.685%), low (29.816%), and very low (17.187%).

Using the Frequency Ratio Method in a GIS , Nanda et al. [22] assessed the susceptibility to landslides along National Highway 1D, a lifeline to the Ladakh region. Most of this zone's locations are quite close to roads, rivers, and streams. Moderate to high steep slopes, bedded limestone, gravel, sand silt with clay, built-up areas, farming, loamy calcareous, loamy pieces, close proximity to the road (often less than 500 m), low to mid elevations, and a southern aspect were characteristics of the extremely high Landslip Susceptibility Index (LSI).

Alsabhan et al. [23], the study area was chosen in the Himachal Pradesh state of India's sub-Himalayan region to outline LSM maps using SIV, WOE and FR techniques. Based on the in-depth field trips, a map of the land slides was created. It had been decided on the slope, aspect, curvature, elevation, soil, LULC, lithology, and drainage density. As shown by the success rates of 76.27, 78.20, and 76.09 for the WOE, FR, and IVM models, respectively, the FR model-based LSZ map is more accurate.

According to Ikram et al. [24], a study was carried out to map the susceptibility of landslides in the NW Himalaya utilising popular statistical (FR, WoE, and SIV) and machine learning (ANN, SVM, and LR) approaches. The study also showed that the primary influencing factors on the landslide activity in this area include lithology, slope , yearly rainfall, and land usage.

Chanu and Bakimchandra [25] examined how multi-resolution Digital Elevation Models (DEMs) affected the mapping of landslide vulnerability along a significant roadway in Manipur, India. LULC, slope, aspect, curvature, elevation, Normalised Difference Vegetation Index (NDVI), distance to roads, distance to streams, and distance from faults were chosen as the nine precondition factors. The conditioning elements received the proper weights using the Analytical Hierarchy Process technique, and the weighted factors then merge to create the landslide vulnerability maps.

Zaz & Ramshoo [26] examined semi-quantitative Multi-Criteria Evaluation (MCE) models and deterministic Stability Index Mapping (SINMAP) for the Kashmiri Himalaya. In order to calculate the susceptibility to landslides, the two models incorporate fourteen different features relating to topography, water management, substrate, LULC, and internal frictional angle. The maps from the two methodologies were blended using FR, which increased the precision of landslip susceptibility to 78%.

2.2 Research Gaps

- Limited research has been carried out on Jammu & Kashmir as whole for landslide susceptibility mapping.
- Earthquake-induced landslides have been taken into consideration separately but not included in the landslide susceptibility mapping together with other factors. Hence the effect of earthquake is neglected in a lot of research works.
- Since the availability of data for Jammu & Kashmir is restricted, therefore less causative factors have been taken into account, which in turn have led to negligence of dominating causes.
- Less models have been applied for Jammu & Kashmir region and the ones applied have projected less accuracy and prediction results.
- Proper validations have not been carried out which creates ambiguity about the fitness of the model.

CHAPTER 3

METHODOLOGY

3.1 Study Area

The extreme north of India is covered by Jammu and Kashmir with latitudes 32º 17” to 36º 58” North and longitudes 73º 26” to 80º 26” east. The Union Territory has its strategic position and shares borders with Pakistan, Tibet and China in west, east and north respectively. Punjab and Himachal Pradesh states of India are surrounding the south. Fig. 3.1 shows the study area.

While winds from the Mediterranean create precipitation in Kashmir in the winters, winds of monsoon in the summer bring rain to the outlying plains and outer hills. The moisture-laden winds bring rain to the hills, lowering summer time temperatures.

The total area of the union territory is 1,01, 387-kilometre square and is administered into 22 Districts (SDMP). As per the Census, the Jammu and Kashmir population in 2023 is estimated to be 13.62 million. Flash floods and lithology have become one the major causes of landslides in Jammu & Kashmir. Both natural and anthropogenic activities have led to instability of slopes and thus caused landslides.

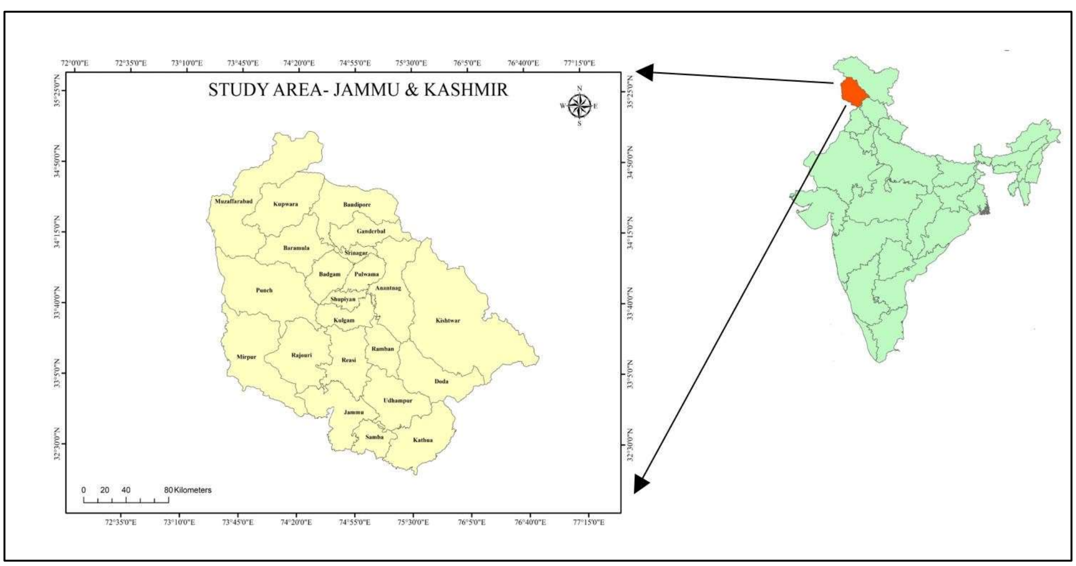

Fig. 3.1. Study Area- Jammu & Kashmir

3.2. Landslide Inventory Preparation

For the identification of pertinent landslide causative elements and their mapping, it is required to investigate the general causes of landslides [27]. To identify the factors that affect landslides. LSM requires the collection of geographical data and the construction of a map for each parameter [28]. LSM has been created as a result of the study area's twelve main causal elements being identified. 1000 landslide points were taken into account while generating the map of landslides as depicted in Fig 3.1, of which 80% were used for training and 20% for testing.

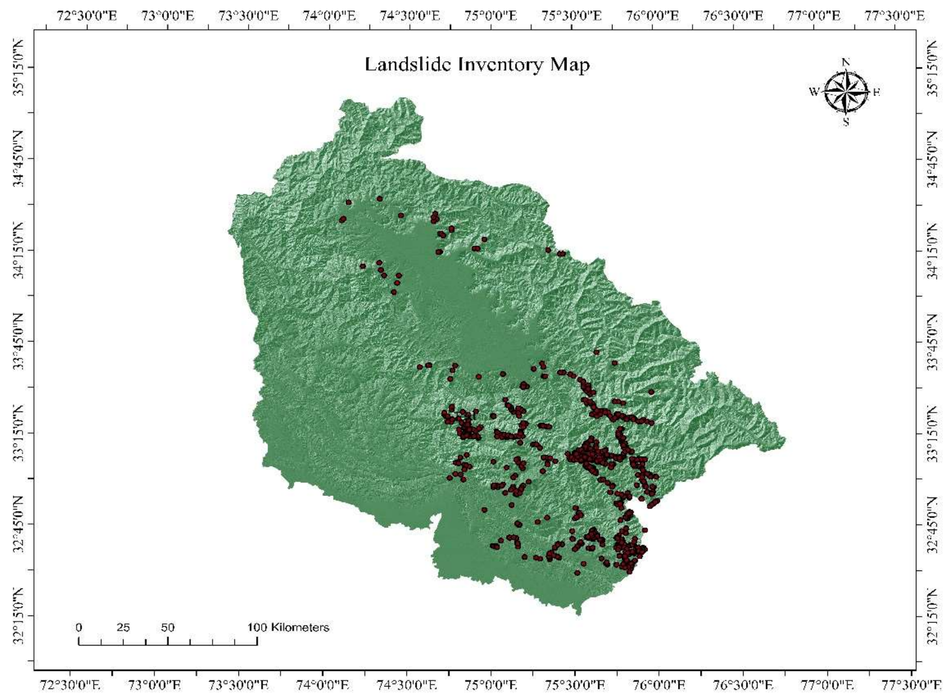

Fig 3.2 Landslide points taken for study area

Data was gathered in the form of raster and shape files to create thematic maps of the twelve causal components. The bulk of the information was obtained from the Indian Geological Survey (GSI). Several scholars have investigated DEM-derived parameters, such as curvature, slope, SPI, aspect, and TWI, as landslide-inducing factors for analysis. For the preceding ten years (2011-2020), rainfall data was collected from the Climate Research Unit, and seismic data has been compiled from the Bhukosh Portal of GSI due to its relevance to landslides. As lithology is a controlling component that leads to slope instability, it is also considered . Furthermore, GSI and Google Earth datasets of percent lineament and proximity from roads have been scrutinised. Table 3.1 represents the sources of data collected.

Table 3.1. Sources of collected data

ATTRIBUTES	DATA SOURCE
Elevation	Open Topography
Slope, Aspect, Curvature, SPI, TWI	DEM derivatives
Lithology	Global Lithological Map (GLiM)
LULC	USGS
Distance to roads	GSI, Google Earth
Lineament Density	GSI
Rainfall	Climate Research Unit
Earthquake	GSI
Landslide	NASA, Bhukosh
Region Boundary	Geographical Analysis

Systematic representation of the methodology has been depicted through flow chart in Fig. 3.2

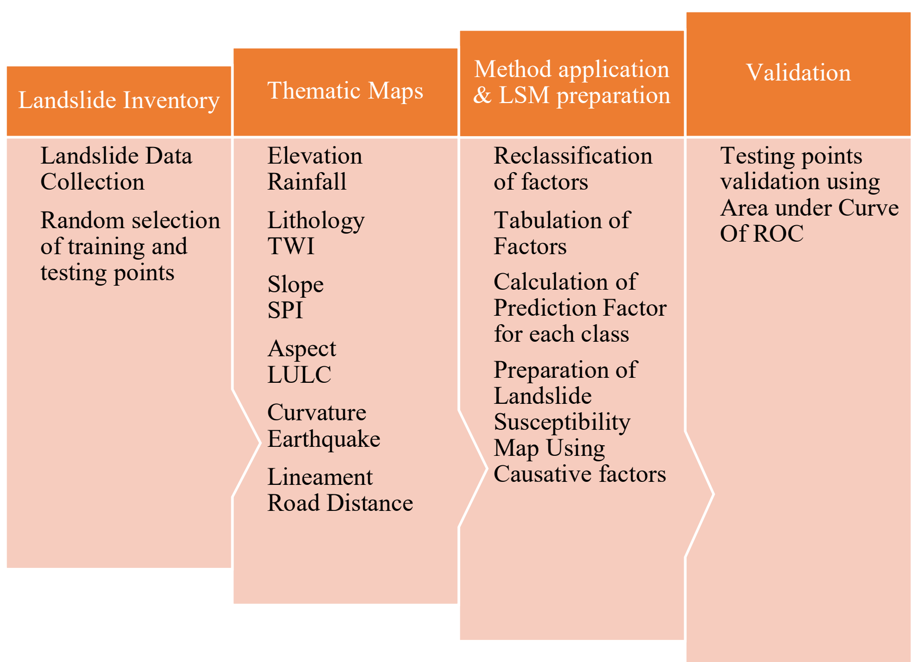

Fig 3.3 Flow Chart of Methodology

3.3. Causative factors and thematic maps

Many factors cause landslides but its imperative to identify the dominating ones. In this research twelve factors have been considered which were analysed to find influence on landslides in Jammu & Kashmir study area. Amongst these factors, a few are derivatives of DEM and others collected from authentic sources and created using tools in ArcGIS. The influencing factors have been elaborated under.

3.3.1 Elevation

Elevation factor is one of the dominating factors and is created as derivative of DEM. Five classes ranging from 159m to 7047 m have been depicted for the thematic layer of the factor as depicted in Fig. 3.2

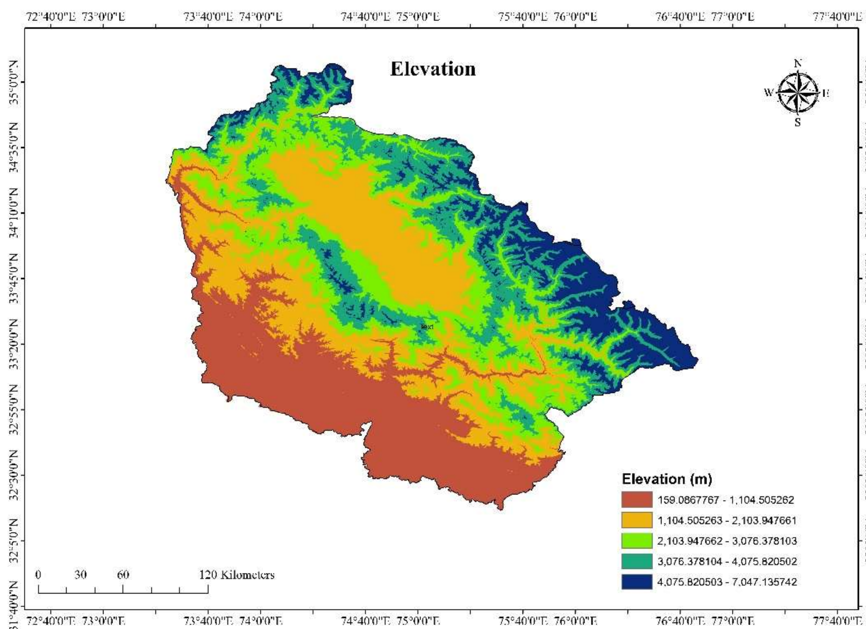

Fig. 3.4 Map of Elevation

3.3.2 Aspect

The slope direction is represented using aspect. Ten classes have been taken to cover whole directions with negative values depicting flat surfaces. Thematoc map of aspect has been depicted in Fig. 3.3.

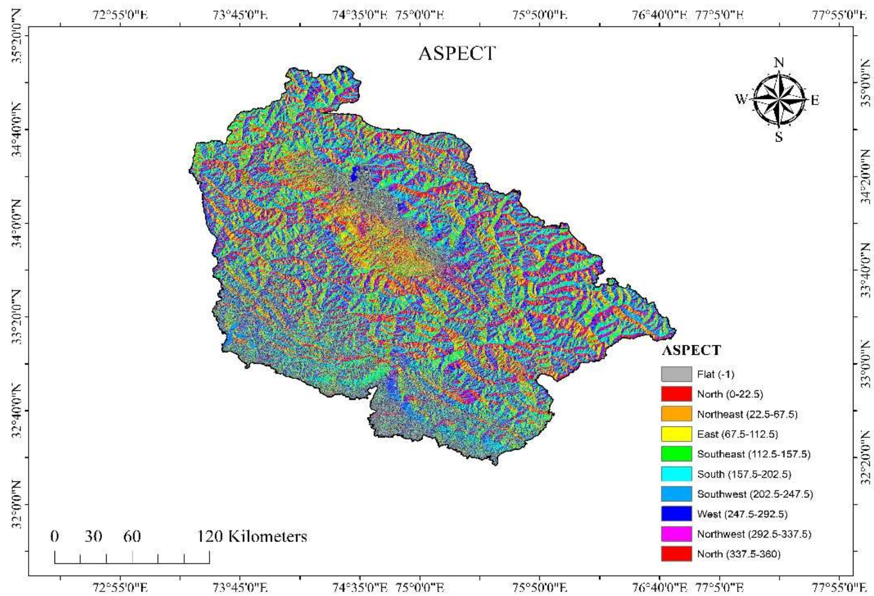

Fig. 3.5 Map of Aspect

3.3.3 Curvature

In order to determine the degree of concavity, convexity, and linearity of surfaces which are defined as the geometries of a slope face, the curvature map was created from the DEM. The negative, positive and near zero values represent convexity, concavity, and linear surfaces respectively as in Fig. 3.4.

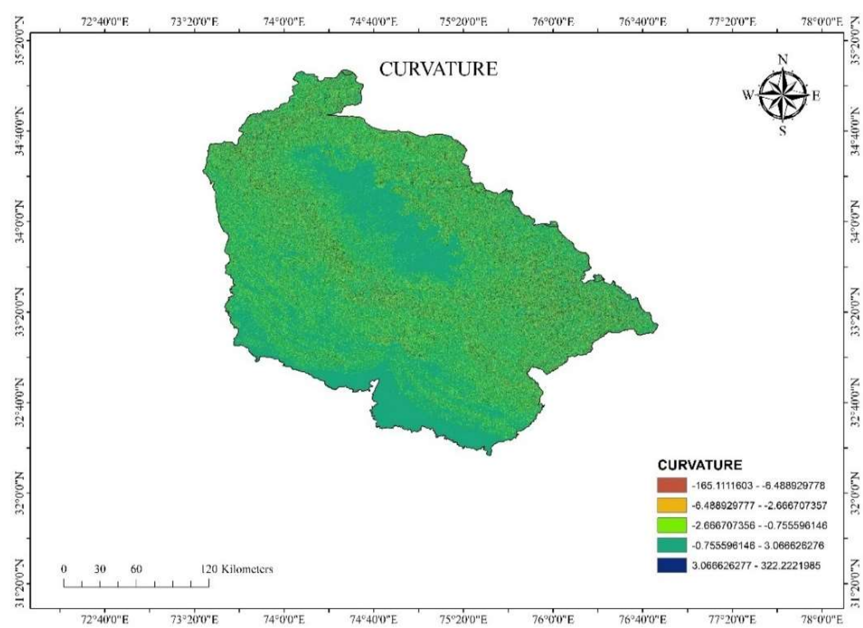

Fig. 3.6 Map of Curvature

3.3.4. Lineament Density

It is possible that the irregularities and fractures present in faulted and cracked zones will weaken the overall strength and stability of slopes, enhancing the possibility of landslip events in those areas [29]. Faults and fissures are one of the reasons that trigger landslides. Fig 3.5. shows percentage density of lineaments in the study area ranging from 0 to 0.43% that has been distributed into five sections each as (0-0.0548%), (0.0548-0.113%), (0.113-0.178%), (0.178%-0.259%) and (0.259-0.43%)

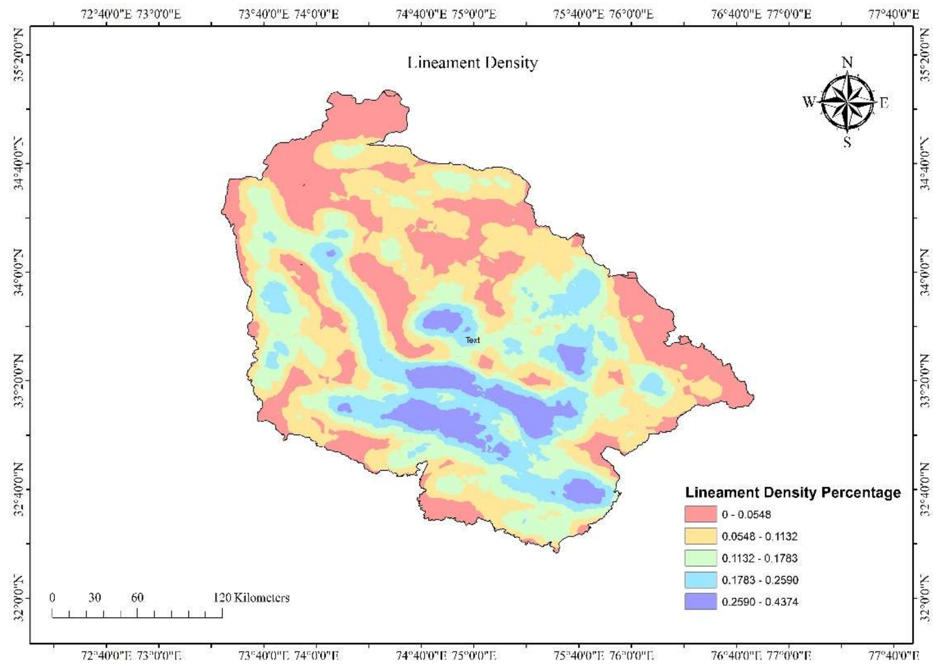

Fig. 3.7 Map of Lineament Density

3.3.5. Slope

A landslide's likelihood is primarily determined by the slope. Landslides typically occur in areas with very high slope values. It may be claimed that the likelihood of a landslip activity occurrence increases with increasing slope value, establishing a direct correlation between both. The DEM shapefile can be used to create the map. In this research, slope factor has been divided into five sections in degrees as (0 degrees - 9.77 degrees), (9.77 degrees - 20.85 degrees), (20.85 degrees – 31.27 degrees), (31.27 degrees – 42.68 degrees) and (42.68 degrees – 83.08 degrees). Fig. 3.6 shows the slope nature of the study area, with maximum area lying in the range of 31.27 degrees to 42.68 degrees, thus depicting slopy nature of the mountainous area. Fig. 3.6 shows variation of slope along the area of study which is Jammu and Kashmir

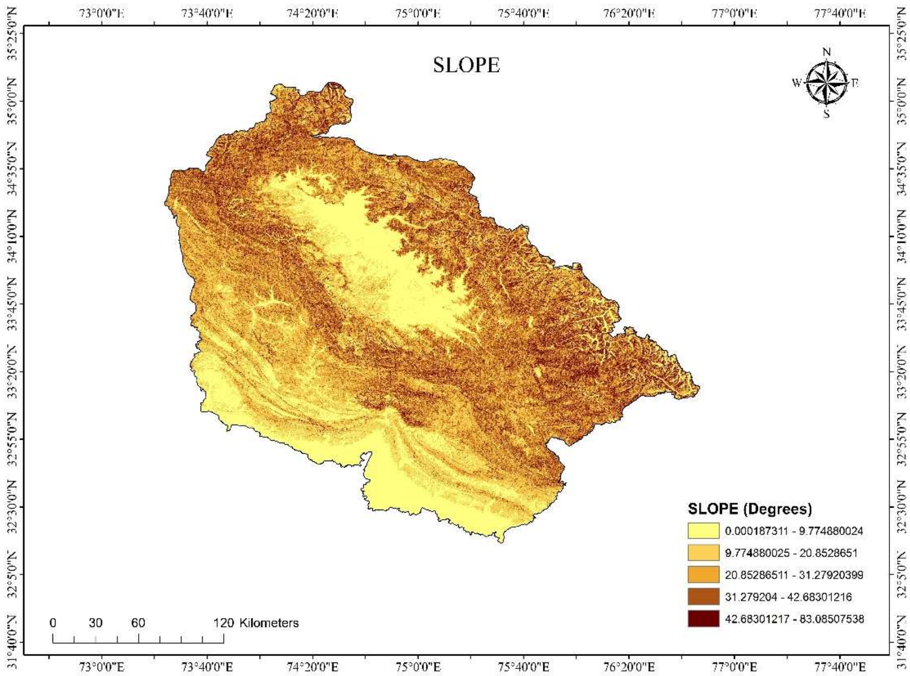

Fig. 3.8. Map of Slope

3.3.6 TWI

TWI takes into account the area that makes up the upslope region and computes the water flow and accumulation as well as the steady-state moisture content existing in the chosen area .The TWI was developed to evaluate the effects of regional factors on the hydrological process. It can be applied to a variety of organic processes, including yearly net primary production, botanical arrangement, and the quality of an ecological area.The 5 categories vary with values between 1.29 to 34.46. Formulations are used to create the map using DEM file as in equation 3.1.

$$TWI = \ln (\text{Accumulation of flow} + 0.001) / ((\text{Slope in } \% /100) \quad (3.1)$$

Fig. 3.7 demonstrates the thematic map of TWI created from obtained DEM file.

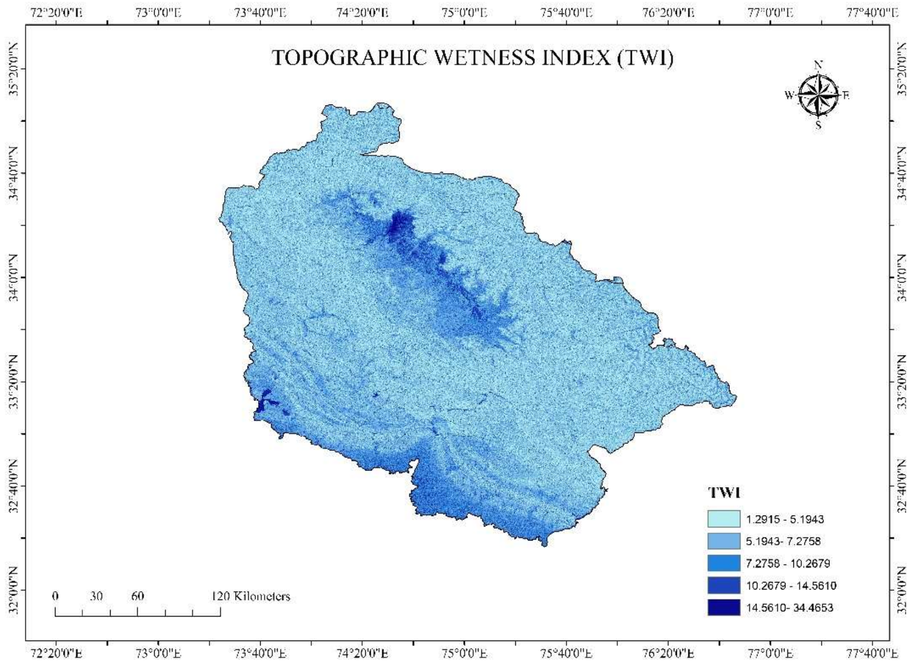

Fig. 3.9. Map of TWI

3.3.7 SPI

SPI is another DEM derivative that measures how much a stream may change the physical characteristics of a region by eroding gullies and transporting sediment. SPI ties along with the capacity of flowing water to erode land through catchment and discharge zones. SPI brings out the region were traveling water is more likely to result in erosion.. Formulation used for SPI is as:

SPI= Ln (Accumulation of flow + 0.001) * ((Slope in Percentage/100) + 0.001)) (3.2)

Fig. 3.8. depicts the thematic map prepared for SPI using the DEM shape file and tools present in the ArcGIS software. The map has been prepared with five categories ranging from approximately -13 to 29.

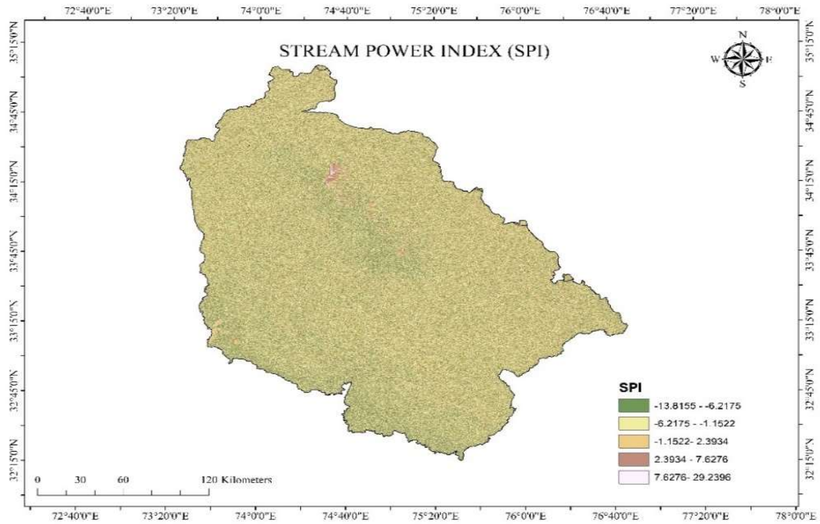

Fig. 3.10. Map of SPI

3.3.8. LULC

Alterations in the harmony between the forces that keep the soil anchored and those which lead it shift might increase the vulnerability of slopes to landslides. LULC can alter this ratio of forces thus can trigger landslide as well. In order to reduce the risk of landslides in areas where such operations take place, it is crucial to assess how human operations affect the landscape and to put appropriate safeguards in place. Fig. 3.9. shows LULC map.

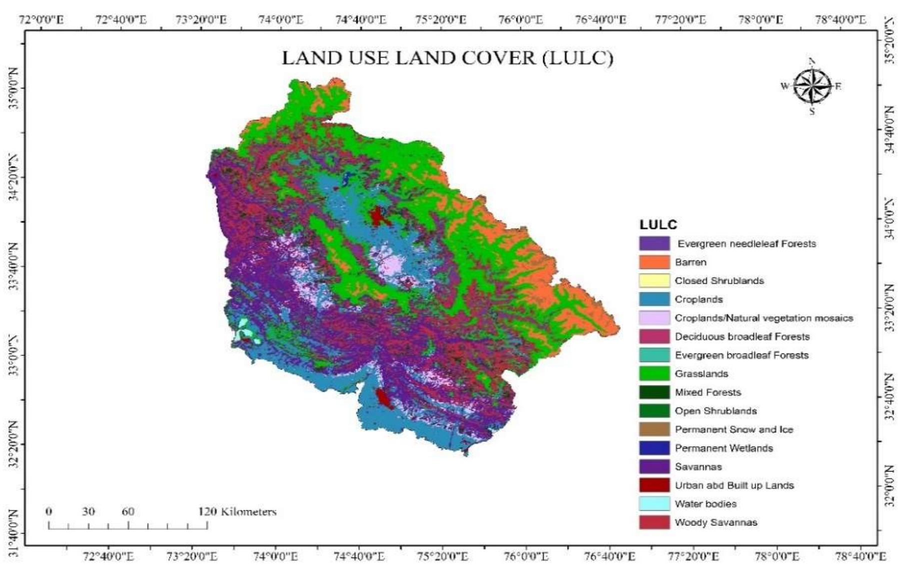

Fig. 3.11. Map of LULC

3.3.9. Average Annual Rainfall

Rainfall induced landslides is a common term and well known phenomenon. Intensive rainfall loosens up the soil and the anchorage doesn't remain firm enough to hold up the soil thus invoking landslides. Fig 3.10. represents average annual rainfall over the area collected from 2011 to 2020 from CRU. It can be inferred that the distribution of the factor is quite varied over the study area.

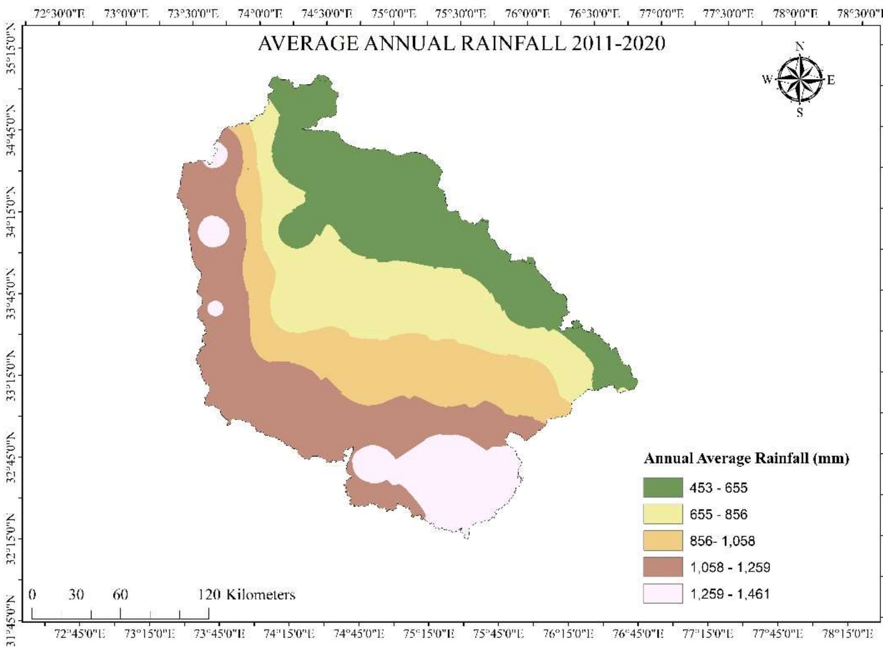

Fig. 3.12. Map of Average Annual Rainfall

3.3.10. Distance to Roads

The map for distance to roads as shown in Fig. 3.11 has been prepared using data collected from Google Earth and processed further with Euclidian tool of ArcGIS. The chance of a landslide is significantly influenced by the road. Roads are constructed by making cuts into the steep terrain. Cutting slopes makes the earth more prone to instability, thus raising the possibility of a landslip. Additionally, research has shown that the majority of landslides appear close to highways. The map has been prepared for five classes ranging from zero to 44 kilometres.

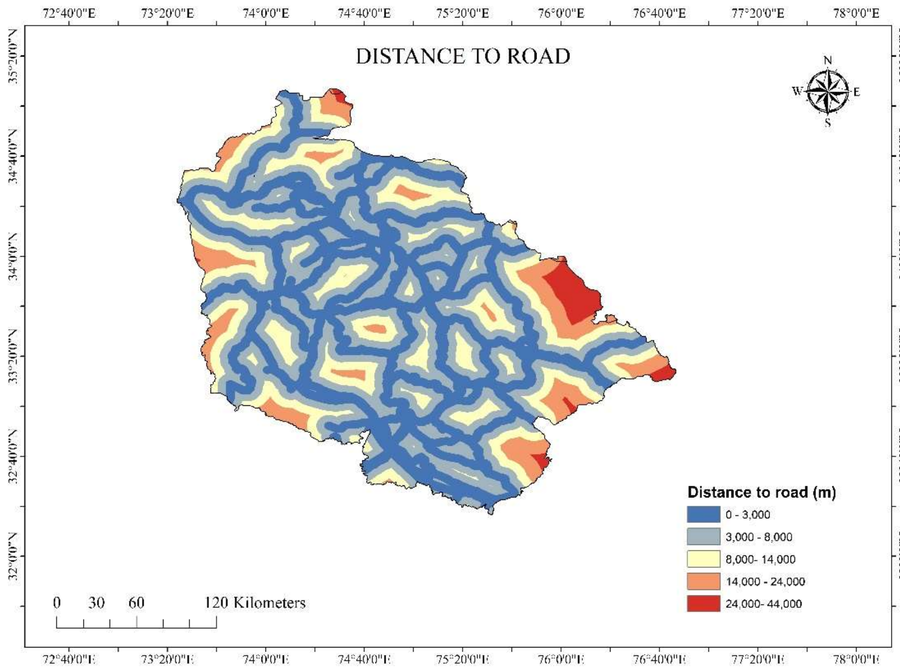

Fig. 3.13. Map of Distance to Roads

3.3.11. Earthquake

Landslides were shown to be spatially distributed in a way that was significantly influenced by geology, human activity, earthquake-caused fault split and remote sensing-derived terrain characteristics. These are then used to create a map showing the susceptibility of different places to landslides, so defining those zones. The area of Kashmir hit by the earthquake is situated in one of the world's seismically active areas. Zone V include the districts of Kashmir North and Kashmir South. In Zone IV, there are the districts of Anantnag, Muzaffarabad, Ponch, Reasi, Udhampur, Mirapur, Kathua and Jammu. 2005 year was witnessed by a massive earthquake of magnitude 7.6 in Jammu and Kashmir which further triggered series of landslides [30]. Fig. 3.12 represents thematic map of earthquake with regard to the data collected from 1967 to 2019 and has been categorized into three classes. Earthquake data collected from GSI was used to create raster file of the causative factor with the help of spline tool in Spatial analyst category of the ArcTools present in ArcGIS software.

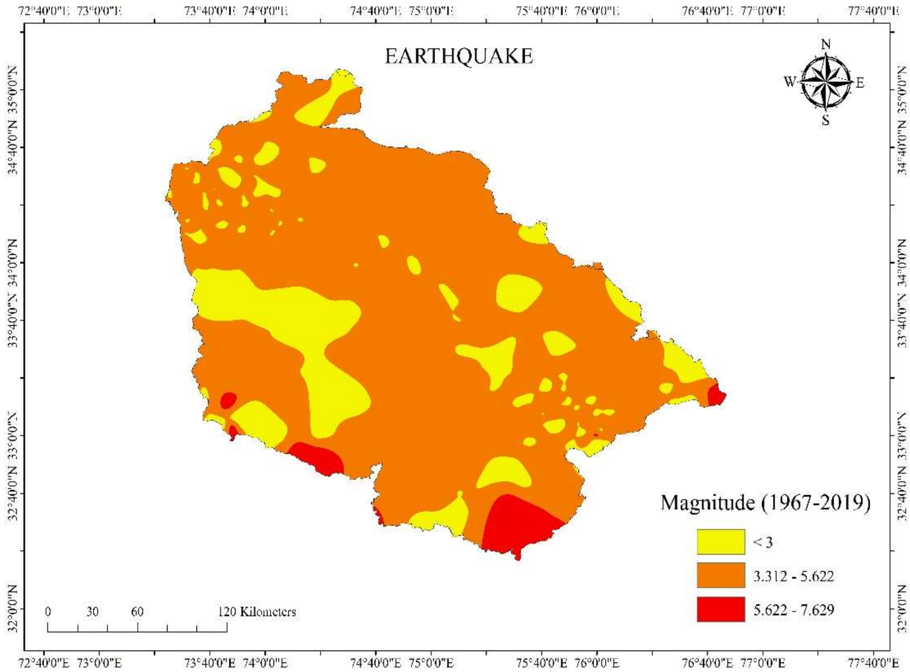

Fig. 3.14. Map of Earthquake

3.3.12. Lithology

Lithology is one of the most influencing factors for landslides. Lithology, or the type of rock or soil that composes an area, can greatly impact frequency and characteristics of landslides. Lithology serves as the structural underpinning and the starting point for the formation of landslides. Certain lithologies are more vulnerable to landslides than others due to their mechanical and physical characteristics. Fig. 3.13 shows the lithological characteristics of the study area, Jammu and Kashmir. Nine lithological features are present in the study area with sedimentary rocks being dominant over the area. The data for the study area has been collected from Global Lithological Map site and masked with proper raster cell resolution of 30 x 30.

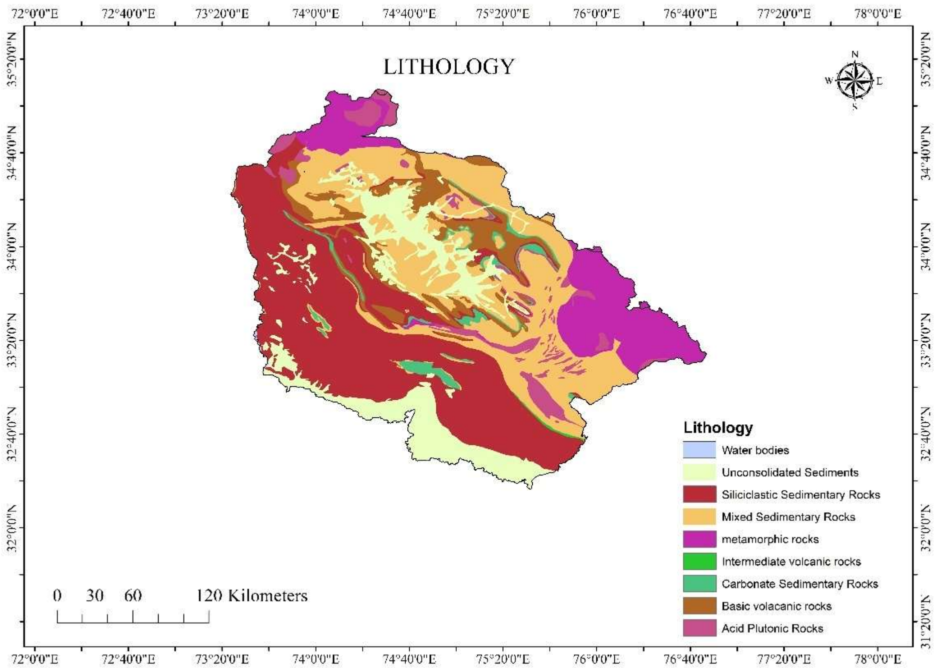

Fig. 3.15. Map of Lithology

3.4. Bi-Variate Model Implementation

A crucial pre-hazard management tool, landslip susceptibility zonation is the act of delineating an area depending on its vulnerability to sliding events [31]. It has been used extensively throughout the globe.

Since probabilistic methods rely on data from previous landslides to anticipate upcoming slides, they are sometimes referred to as data-driven techniques. Bi-variate models concentrate on how each parameter class relates to previous slope failure events, whereas multi-variate models also take into account how the factors' proportions are established consequently [32].

The Bi-Variate models used in the research are FR, SIV, WoE and SE which have been discussed briefly in the sections following up.

3.4.1 Frequency Ratio (FR)

The FR technique is an observation-driven, bi-variate, probabilistic methodology that is entirely dependent on the direct correlation of past information to conditional parameters with specified weights. This approach of connecting historic landslide data to particular criteria has been effectively applied and validated by several researchers [12]. To obtain the final LSM, prediction rates are determined and multiplied with reclassified maps in the raster calculator. Following formulae are used for the model:

$$\text{Frequency Ratio (FR)} = \frac{\%\ \text{Pixels of Landslide}}{\%\text{Pixels of Class}} \tag{3.1}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency Ratio}}{\text{Sum of causal factor F R}} \tag{3.2}$$

$$\text{Prediction Rate (PR)} = \frac{\text{RFmax – RFmin}}{(\text{RFmax}-\text{RFmin})\text{min}} \tag{3.3}$$

$$\text{LSM}_{(FR)}: \mathbf{\Sigma}\ (\text{PR* reclassified FR map})_{\text{causal factor}} \tag{3.4}$$

3.4.2. Statistical Information Value (SIV)

For the susceptibility evaluation of a landslide, the method estimates the association between the landslide inventory and each database layer of the triggering component [13]. To forecast a future landslide, Yin and Yan [14] first put forth and used the modelling approach. To construct the LSM, the reclassified layers are summed up in the raster calculator.

$$\text{LSM}_{(IV)} : \text{Summation of } (\text{IV})_{\text{causal factor}} \tag{3.5}$$

3.4.3. Weight Of Evidence (WoE)

Several researchers have used and confirmed this method for mapping landslide susceptibility [35] [36]. In this approach, the presence or absence of landslide events determines the positive and negative weights for each contributing element as follows:

$$W^{+} = \ln \frac{\frac{N1}{N1+N2}}{\frac{N3}{N3+N4}} \tag{3.6}$$

$$W^{-} = \ln \frac{\frac{N2}{N2+N1}}{\frac{N4}{N4+N3}} \tag{3.7}$$

N_1 = landslide pixels of a causative class,

N_2 = landslides pixels absent from a causative class,

N_3 = pixels in a particular factor class excluding landslide pixels

N_4 = pixels excluding provided factor and the landslide

A certain value of constant factor is calculated using positives and negatives as:

$$C = W+ - W- \tag{3.8}$$

LSM is generated using this constant values of each factor calculated using summations in raster calculator.

3.4.4. Shannon Entropy (SE)

For the objective of implementing information theory, Shannon designed an entropy model. It can be calculated to determine the imbalance, disorderliness, and uncertainty of landslide events [37]. In this model, frequency ratio values and corresponding relative frequencies for each class factor are determined. Information coefficient (I_{ij}) is obtained using entropy values (H_j). The weight index (W_j) obtained is used in raster calculations to create LSM.

$$H_j = -\boldsymbol{\Sigma}(R.F)*\log_2(R.F) \tag{3.9}$$

$$I_{ij} = \frac{Hjmax - Hj}{Hjmax} \tag{3.10}$$

$$W_j = I_j * R.F \tag{3.11}$$

$$LSM = \boldsymbol{\Sigma}\{(\text{thematic maps})_{reclass} * W_j\} \tag{3.12}$$

Using the formulae described above LSMs are created for each approach and validation is carried out to check the fitness of the model being used.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Frequency Ratio Results

FR model shows lithology, lineament percentage, elevation and rainfall as most influential factors for triggering landslides in the area of Jammu and Kashmir.

4.1.1 Tabulated Results

Table 4.1 illustrates the PR results obtained after applying FR method.

Table 4.1 Calculated Results obtained from FR method

FACTOR	Factor Classes	Landslide Pixels	Class Pixels	PR
ELEVATION (m)	159-1104	207900	14374167	8.870553
	1104-2103	369000	16309695	
	2103-3076	71100	12359658	
	3076-4075	13500	10279144	
	4075-7047	900	5941670	
ASPECT	Flat	59400	5338314	1
	North	53100	5497987	
	North-East	51300	5579925	
	East	56700	5690966	
	South-East	63900	5948310	
	South	90900	6675651	
	South-West	103500	6668263	
	West	69300	6463971	

	North-West	58500	5655454	
	North	55800	5710827	
SLOPE (degrees)	0 - 9.77	27000	14668933	5.9146967
	9.77 - 20.8	79200	12962370	
	20.86 - 31.28	185400	14306175	
	31.29 - 42.68	277200	12162167	
	42.69 - 83.09	93600	5130023	
CURVATURE	(-165) - (-6.4)	1800	285161	3.0432738
	(-6.4) - (-2.6)	30600	1954296	
	(-2.6) - (-0.75)	91800	6191986	
	(-0.75) - (3.06)	466200	46717820	
	3.06 - 322.22	72000	4115071	
EARTHQUAKE	0 - 3.3	4500	656189	5.2407208
	3.3 - 3.9	74700	11676925	
	3.9 - 4.38	508500	39201573	
	4.38 - 4.86	72900	6323812	
	>4.86	1800	1411404	
LITHOLOGY	water bodies	11700	8283723	12.827376
	unconsolidated sediments	336600	15264249	
	siliciclastic sedimentary rocks	16200	7258677	
	mixed sedimentary rocks	9900	1289678	

	metamorphic rocks	32400	2875382	
	intermediate volcanic rocks	227700	19793193	
	carbonate sedimentary rocks	0	27908	
	basic volcanic rocks	14400	4394543	
	acid plutonic rocks	13500	82550	
TWI	1.29 - 5.19	331200	22303353	4.2256896
	5.19-7.27	252000	23336184	
	7.27-10.26	58500	9324183	
	10.26-14.56	15300	3258874	
	14.56-34.46	5400	998311	
SPI	(-13.8) - (-6.21)	143100	15565491	1.1693177
	(-6.21) - (-1.15)	196200	16451739	
	(-1.15) - 2.39	221400	17304641	
	2.39 - 7.62	84600	8097679	
	7.62 - 29.23	17100	1801355	
DISTANCE TO ROADS (m)	0-3000	368100	24586046	4.5414622
	3000-8000	105300	18920069	
	8000-14000	70200	10364470	
	14000-24000	97200	4174526	
	24000-44000	21600	1224792	
LINEAMENT (percentage)	0-0.054	38700	14569549	9.8286603
	0.054-0.113	91800	18008456	

	0.113-0.178	148500	14275934	
	0.178-0.259	171900	8576258	
	0.259-0.437	211500	3839706	
RAINFALL (mm)	453-655	20700	16341333	8.5949804
	655-856	37800	11697268	
	856-1058	325800	9505508	
	1058-1259	99900	13156520	
	1259-1461	178200	8569274	
LULC	Evergreen needle leaf Forests	4500	2385024	5.3682065
	Evergreen broadleaf Forests	0	6148	
	Deciduous broadleaf Forests	0	37993	
	Mixed Forests	1800	1248240	
	Closed Shrublands	0	230	
	Open Shrublands	0	959	
	Woody Savannas	131400	9195863	
	Savannas	310500	13792662	
	Grasslands	143100	16041686	
	Permanent Wetlands	900	206092	
	Croplands	58500	8643652	
	Urban and Built-up Lands	4500	452262	

	Croplands/and rural vegetation mosaics	5400	1925020	
	Permanent Snow and Ice	0	659911	
	Barren	1800	4527962	
	Water bodies	0	144104	

As per the prediction rates obtained from the Table 4.1 , dominating factors can be identified. Fig 4.2 shows the influence of different factors on landslides as obtained from FR method based on prediction rates obtained. Greater the prediction rate, higher is the influence of the factor on landslide in the area.

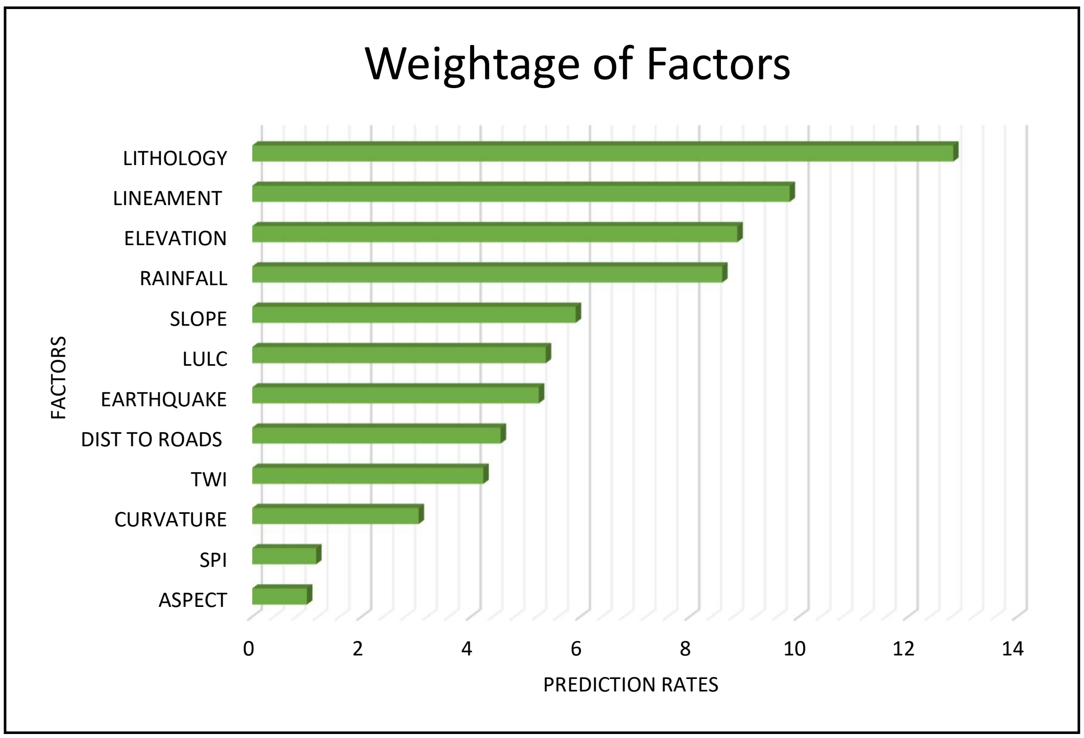

Fig. 4.1. Dominance of factors inferred from prediction rate

4.1.2 LSM Outcome

The LSM has been generated using the PR values obtained with the help of formulations. The raster calculator takes up the values and produces the LSM as per FR method as shown in Fig. 4.1.

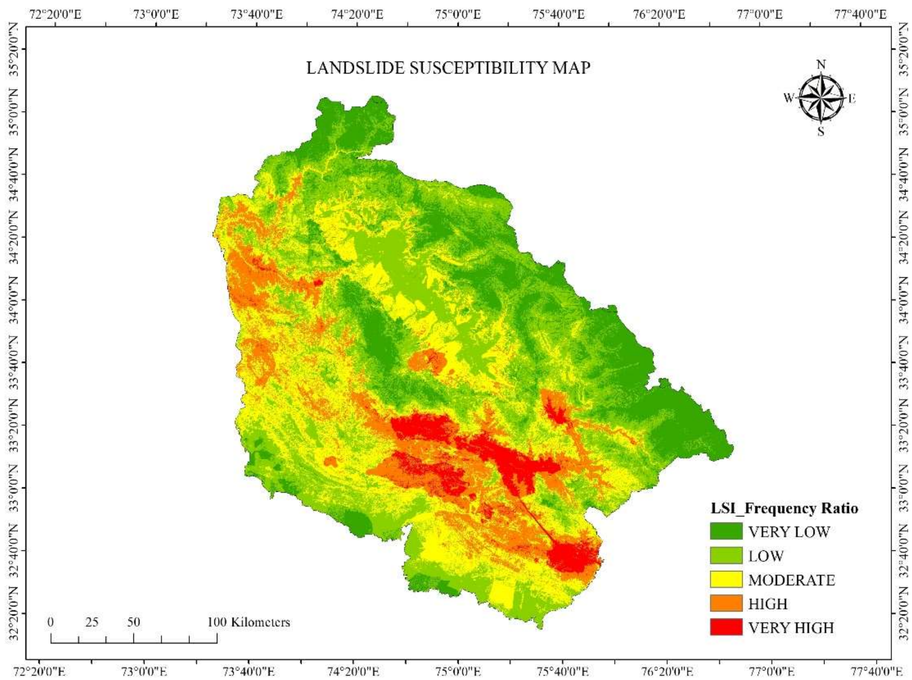

Fig 4.2. LSM using FR approach

Table. 4.2 shows the calculations of the landslide area in different zones and Fig. 4.2 depicts the pictorial representation of the zonation created.

Table 4.2. Landslide percentage area using FR approach

Method Used	Zone	Class Pixel	%age Class Pixel	Landslide Pixel	%age Landslide Pixel
Frequency Ratio	Very Low	11505793	19.42860	6300	0.951086
	Low	19813658	33.45720	29700	4.483695
	Moderate	16294682	27.51508	91800	13.85869
	High	9014679	15.22212	289800	43.75000
	Very High	2592090	4.376985	244800	36.95652

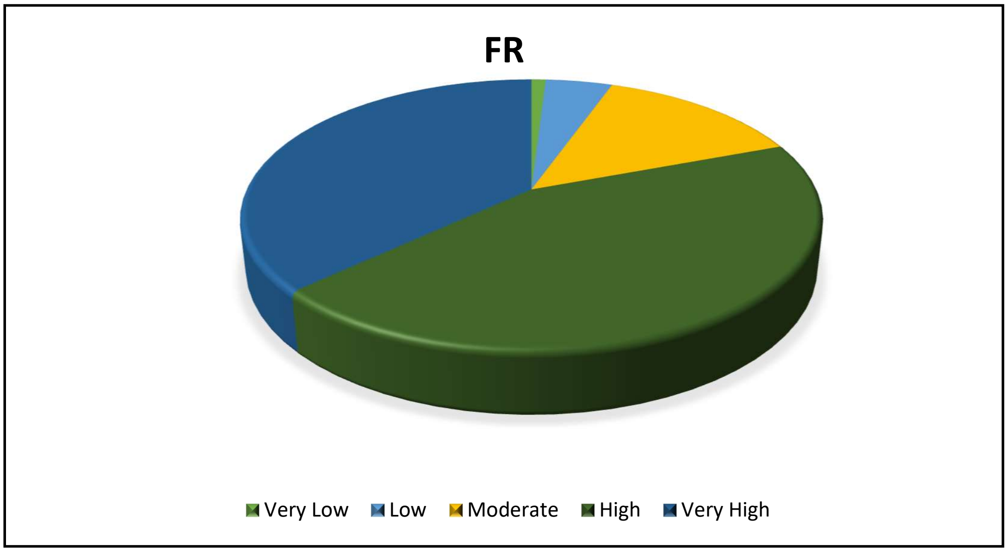

Fig 4.3 Landslide zone distribution as per FR

4.1.3 Validation Results

The accuracy check and validation of results has been carried out using AUC of ROC tool in ArcGIS software ToolBox. With the help of ROC , success rate curve (SRC) is produced with inputs of training points which is 90% of the total landslide points taken. Similarly, PRC is produced using the remaining 10% of the total 1000 landslide points considered. In Fig 4.4 and Fig 4.5 SRC of 87.2% and PRC of 86.3% have been depicted for the FR model.

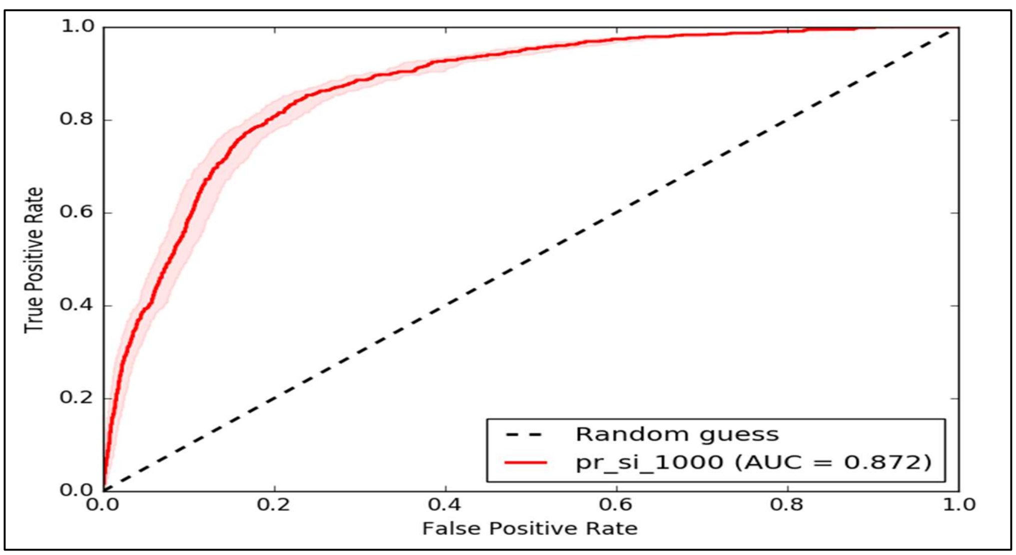

Fig 4.4 SRC as per FR model

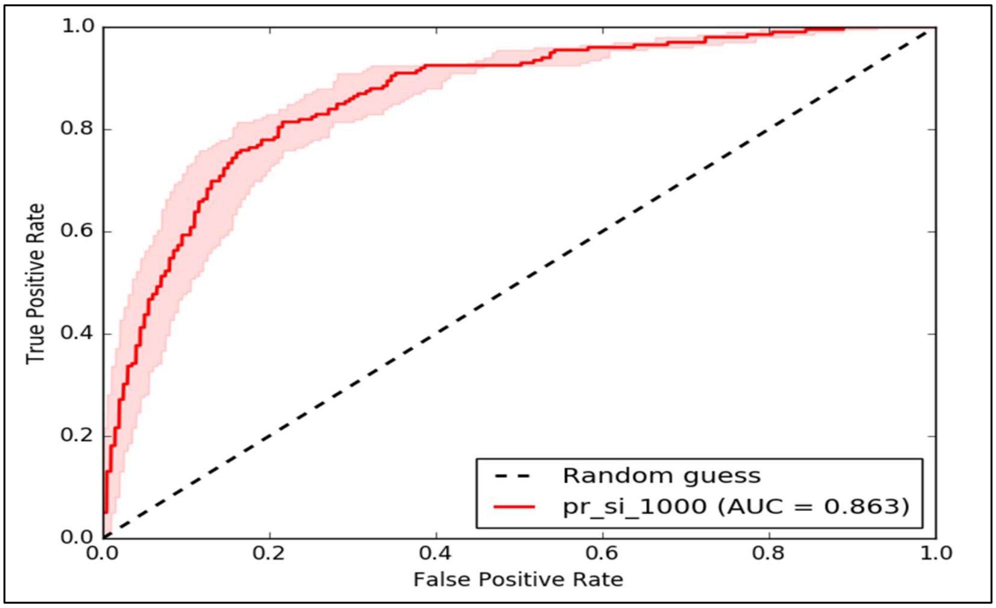

Fig 4.5. PRC as per FR model

4.2 Statistical Information Value Results

SIV model is one of the accurate bi-variate model that is used and gives good SRC and PRC results.

4.2.1 Tabulated Results

Table 4.3 illustrates the results obtained after applying SIV method.

Table 4.3 Calculated Results obtained from SIV method

FACTOR	Factor Classes	Landslide Pixels	Class Pixels	IV
ELEVATION (m)	159-1104	207900	14374167	0.257762
	1104-2103	369000	16309695	0.705175
	2103-3076	71100	12359658	-0.66421
	3076-4075	13500	10279144	-2.14128
	4075-7047	900	5941670	-4.30121

ASPECT	Flat	59400	5338314	-0.00506
	North	53100	5497987	-0.14665
	North-East	51300	5579925	-0.19593
	East	56700	5690966	-0.11555
	South-East	63900	5948310	-0.04023
	South	90900	6675651	0.196846
	South-West	103500	6668263	0.327765
	West	69300	6463971	-0.04224
	North-West	58500	5655454	-0.07804
	North	55800	5710827	-0.13503
SLOPE (degrees)	0 - 9.77	27000	14668933	-1.80434
	9.77 - 20.8	79200	12962370	-0.60452
	20.86 - 31.28	185400	14306175	0.147377
	31.29 - 42.68	277200	12162167	0.711962
	42.69 - 83.09	93600	5130023	0.489473
CURVATURE	(-165) - (-6.4)	1800	285161	-0.57137
	(-6.4) - (-2.6)	30600	1954296	0.337108
	(-2.6) - (-0.75)	91800	6191986	0.282494
	(-0.75) - (3.06)	466200	46717820	-0.11337
	3.06 - 322.22	72000	4115071	0.448148
EARTHQUAKE	0 - 3.3	4500	656189	-0.48838
	3.3 - 3.9	74700	11676925	-0.55790
	3.9 - 4.38	508500	39201573	0.148980
	4.38 - 4.86	72900	6323812	0.030998

	>4.86	1800	1411404	-2.17056
LITHOLOGY	water bodies	11700	8283723	-2.06847
	unconsolidated sediments	336600	15264249	0.679613
	siliciclastic sedimentary rocks	16200	7258677	-1.61095
	mixed sedimentary rocks	9900	1289678	-0.37562
	metamorphic rocks	32400	2875382	0.008204
	intermediate volcanic rocks	227700	19793193	0.028922
	carbonate sedimentary rocks	0	27908	0
	basic volcanic rocks	14400	4394543	-1.22690
	acid plutonic rocks	13500	82550	2.683272
TWI	1.29 - 5.19	331200	22303353	0.283390
	5.19-7.27	252000	23336184	-0.03517
	7.27-10.26	58500	9324183	-0.57817
	10.26-14.56	15300	3258874	-0.86812
	14.56-34.46	5400	998311	-0.72650
SPI	(-13.8) - (-6.21)	143100	15565491	-0.19610
	(-6.21) - (-1.15)	196200	16451739	0.064108
	(-1.15) - 2.39	221400	17304641	0.134401
	2.39 - 7.62	84600	8097679	-0.06823

	7.62 - 29.23	17100	1801355	-0.16405
DISTANCE TO ROADS (m)	0-3000	368100	24586046	0.292407
	3000-8000	105300	18920069	-0.69717
	8000-14000	70200	10364470	-0.50080
	14000-24000	97200	4174526	0.734001
	24000-44000	21600	1224792	0.456154
LINEAMENT (percentage)	0-0.054	38700	14569549	-1.43686
	0.054-0.113	91800	18008456	-0.78499
	0.113-0.178	148500	14275934	-0.07175
	0.178-0.259	171900	8576258	0.584147
	0.259-0.437	211500	3839706	1.595061
RAINFALL (mm)	453-655	20700	16341333	-2.17733
	655-856	37800	11697268	-1.24081
	856-1058	325800	9505508	1.120644
	1058-1259	99900	13156520	-0.38651
	1259-1461	178200	8569274	0.620955
LULC	Evergreen needle leaf Forests	4500	2385024	-1.77893
	Evergreen broadleaf Forests	0	6148	0
	Deciduous broadleaf Forests	0	37993	0
	Mixed Forests	1800	1248240	-2.04775
	Closed Shrublands	0	230	0

	Woody Savannas	131400	9195863	0.245689
	Open Shrublands	0	959	0
	Savannas	310500	13792662	0.700243
	Permanent Wetlands	900	206092	-0.93973
	Grasslands	143100	16041686	-0.22545
	Croplands	58500	8643652	-0.50160
	Urban and Built-up Lands	4500	452262	-0.11623
	Croplands/and rural vegetation mosaics	5400	1925020	-1.38234
	Water bodies	0	144104	0
	Barren	1800	4527962	-3.33628
	Permanent Snow and Ice	0	659911	0

4.2.2 LSM Outcome

The LSM has been generated using the SIV values obtained with the help of formulations. The thematic maps are reclassified and tabulated as per the SIV values obtained and then raster calculator is used to add up these reclassified maps , consequently LSM is produced using SIV method shown in Fig. 4.6.

Table. 4.4 shows the calculations of the landslide area in different zones and Fig. 4.7 depicts the pictorial representation of the zonation created.

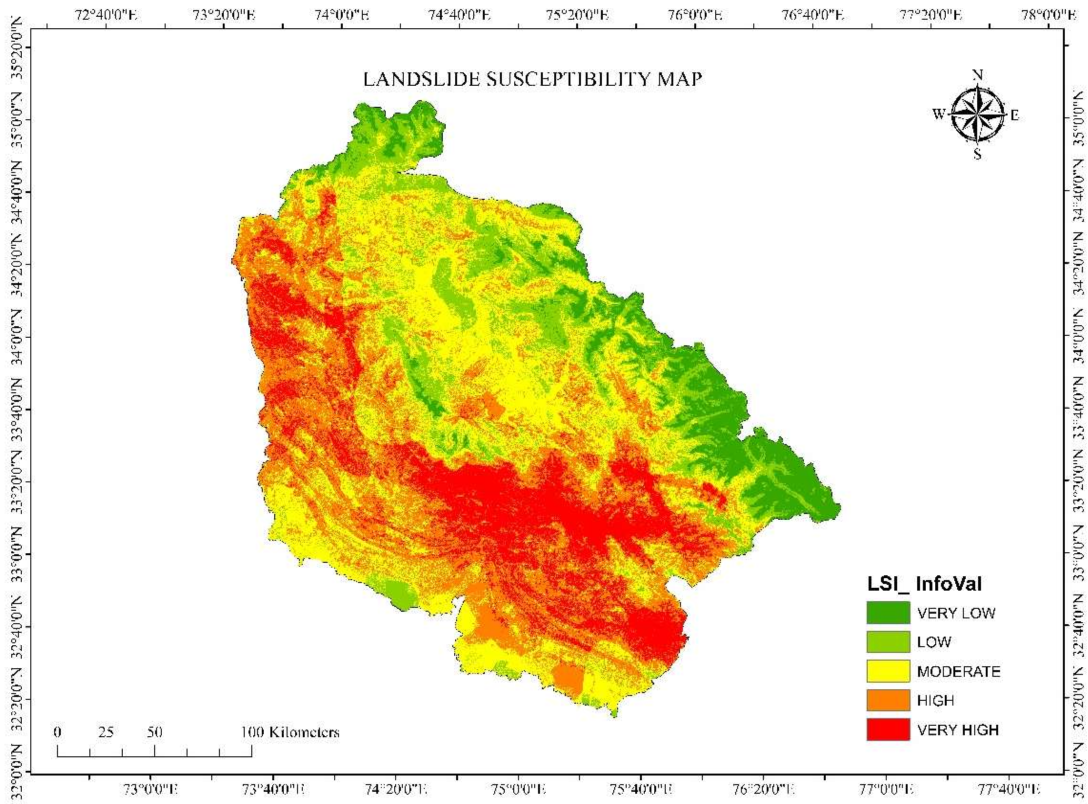

Fig 4.6 LSM using SIV approach

Table 4.4. Landslide percentage area using SIV approach.

Method Used	Zone	Class Pixel	%age Class Pixel	Landslide Pixel	%age Landslide Pixel
Statistical Information Value	Very Low	4709922	7.953141	900	0.13587
	Low	8776527	14.81998	5400	0.815217
	Moderate	18618030	31.43827	33300	5.027174
	High	17514519	29.57489	99000	14.94565
	Very High	9601904	16.21370	523800	79.07609

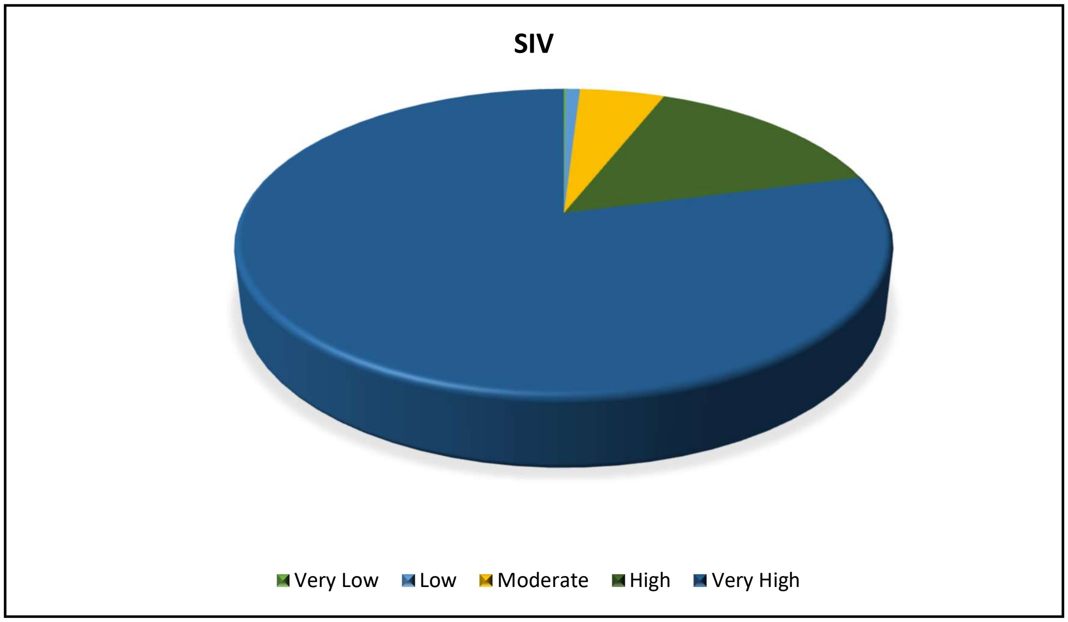

Fig 4.7 Landslide zone distribution as per SIV

4.2.3 Validation Results

AUC method shows accuracy of 88.2% for SRC and 86.4% result for PRC as shown in Fig. 4.8 and Fig. 4.9 respectively.

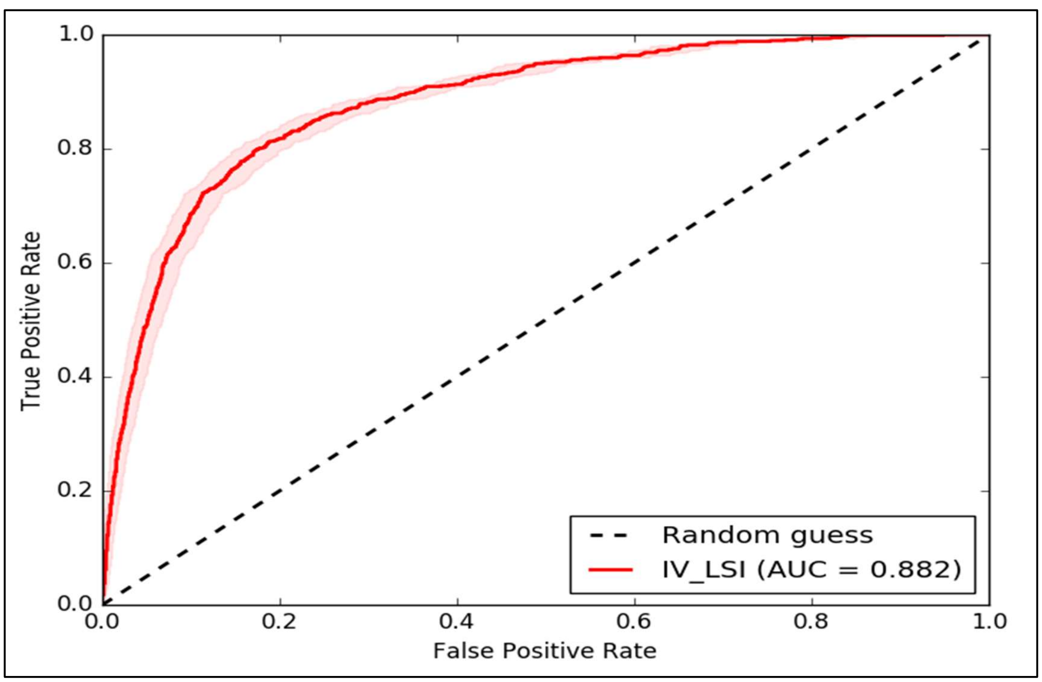

Fig 4.8 SRC as per SIV model

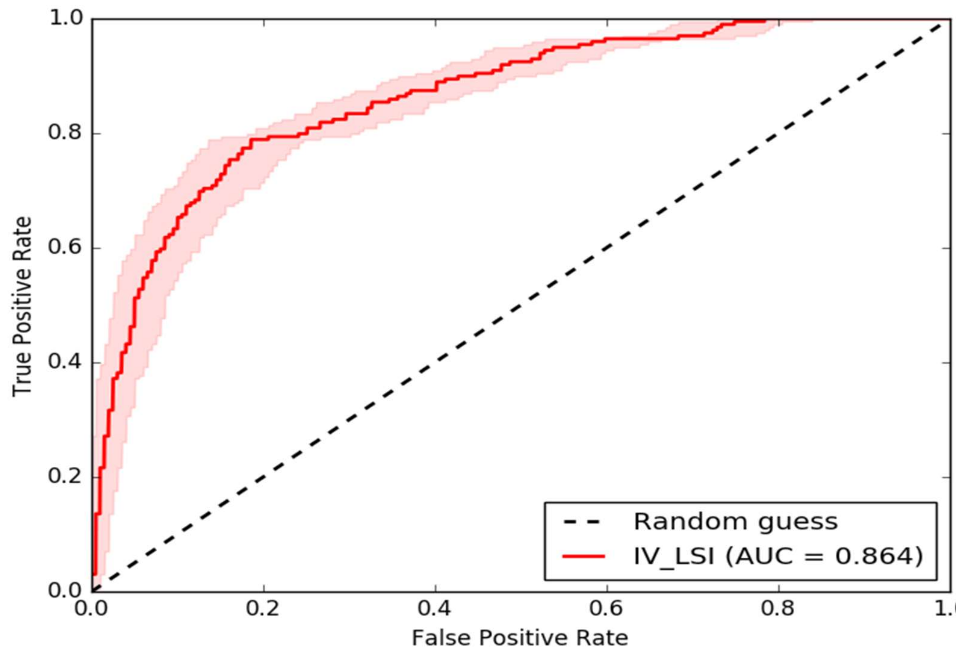

Fig 4.9 PRC as per SIV model

4.3 Weight of Evidence Results

The positive and negative values are calculated for each parameter and then contrast values are obtained using equation 3.8

4.3.1 Tabulated Results

Table 4.5 shows calculated contrast values using WoE model

Table 4.5 Calculated contrast values obtained from WoE method

FACTOR	Factor Classes	Landslide Pixels	Class Pixels	C
ELEVATION (m)	159-1104	207900	14374167	0.3610
	1104-2103	369000	16309695	1.2136
	2103-3076	71100	12359658	-0.7914
	3076-4075	13500	10279144	-2.3232
	4075-7047	900	5941670	-4.4178

ASPECT	Flat	59400	5338314	-0.0056
	North	53100	5497987	-0.1622
	North-East	51300	5579925	-0.2164
	East	56700	5690966	-0.1284
	South-East	63900	5948310	-0.0451
	South	90900	6675651	0.2276
	South-West	103500	6668263	0.38317
	West	69300	6463971	-0.0478
	North-West	58500	5655454	-0.08687
	North	55800	5710827	-0.1500
SLOPE (degrees)	0 - 9.77	27000	14668933	-2.0159
	9.77 - 20.8	79200	12962370	-0.7307
	20.86 - 31.28	185400	14306175	0.2016
	31.29 - 42.68	277200	12162167	1.03906
	42.69 - 83.09	93600	5130023	0.5590
CURVATURE	(-165) - (-6.4)	1800	285161	-0.5784
	(-6.4) - (-2.6)	30600	1954296	0.3555
	(-2.6) - (-0.75)	91800	6191986	0.3254
	(-0.75) - (3.06)	466200	46717820	-0.4593
	3.06 - 322.22	72000	4115071	0.49814
EARTHQUAKE	0 - 3.3	4500	656189	-0.4971
	3.3 - 3.9	74700	11676925	-0.6636
	3.9 - 4.38	508500	39201573	0.53094
	4.38 - 4.86	72900	6323812	0.03516

	>4.86	1800	1411404	-2.20215
LITHOLOGY	water bodies	11700	8283723	-2.2126
	unconsolidated sediments	336600	15264249	1.10628
	siliciclastic sedimentary rocks	16200	7258677	-1.7271
	mixed sedimentary rocks	9900	1289678	-0.3861
	metamorphic rocks	32400	2875382	0.00872
	intermediate volcanic rocks	227700	19793193	0.04424
	carbonate sedimentary rocks	0	27908	0
	basic volcanic rocks	14400	4394543	-1.2905
	acid plutonic rocks	13500	82550	2.8700
TWI	1.29 - 5.19	331200	22303353	0.5098
	5.19-7.27	252000	23336184	-0.0580
	7.27-10.26	58500	9324183	-0.6629
	10.26-14.56	15300	3258874	-0.9082
	14.56-34.46	5400	998311	-0.7412
SPI	(-13.8) - (-6.21)	143100	15565491	-0.2604
	(-6.21) - (-1.15)	196200	16451739	0.0909
	(-1.15) - 2.39	221400	17304641	0.1979
	2.39 - 7.62	84600	8097679	-0.0795

	7.62 - 29.23	17100	1801355	-0.17055
DISTANCE TO ROADS (m)	0-3000	368100	24586046	0.57441
	3000-8000	105300	18920069	-0.9168
	8000-14000	70200	10364470	-0.5863
	14000-24000	97200	4174526	0.8329
	24000-44000	21600	1224792	0.47511
LINEAMENT (percentage)	0-0.054	38700	14569549	-1.6701
	0.054-0.113	91800	18008456	-1.0068
	0.113-0.178	148500	14275934	-0.0945
	0.178-0.259	171900	8576258	0.73881
	0.259-0.437	211500	3839706	1.96119
RAINFALL (mm)	453-655	20700	16341333	-2.4819
	655-856	37800	11697268	-1.41188
	856-1058	325800	9505508	1.65090
	1058-1259	99900	13156520	-0.47869
	1259-1461	178200	8569274	0.78958
LULC	Evergreen needle leaf Forests	4500	2385024	-1.8229
	Evergreen broadleaf Forests	0	6148	0
	Deciduous broadleaf Forests	0	37993	0
	Mixed Forests	1800	1248240	-2.07632
	Closed Shrublands	0	230	0

	Savannas	310500	13792662	1.08286
	Open Shrublands	0	959	0
	Woody Savannas	131400	9195863	0.30192
	Permanent Wetlands	900	206092	-0.94874
	Croplands	58500	8643652	-0.57199
	Grasslands	143100	16041686	-0.30081
	Croplands/and rural vegetation mosaics	5400	1925020	-1.41589
	Permanent Snow and Ice	0	659911	0
	Water bodies	0	144104	0
	Barren	1800	4527962	-3.42479
	Urban and Built-up Lands	4500	452262	-0.11832

4.3.2 LSM Outcome

The map generation is done using the contrast values in the calculator tool for raster. Final map is shown in Fig. 4.10. The values were initially reclassified and then tabulated to create landslide pixels and class pixels, which further were used is calculations of negative and positive values of formula to end up being used in obtaining the contrast value for each class pixel. Table 4.6 shows landslide area distribution with Fig. 4.11 as its pictorial representation.

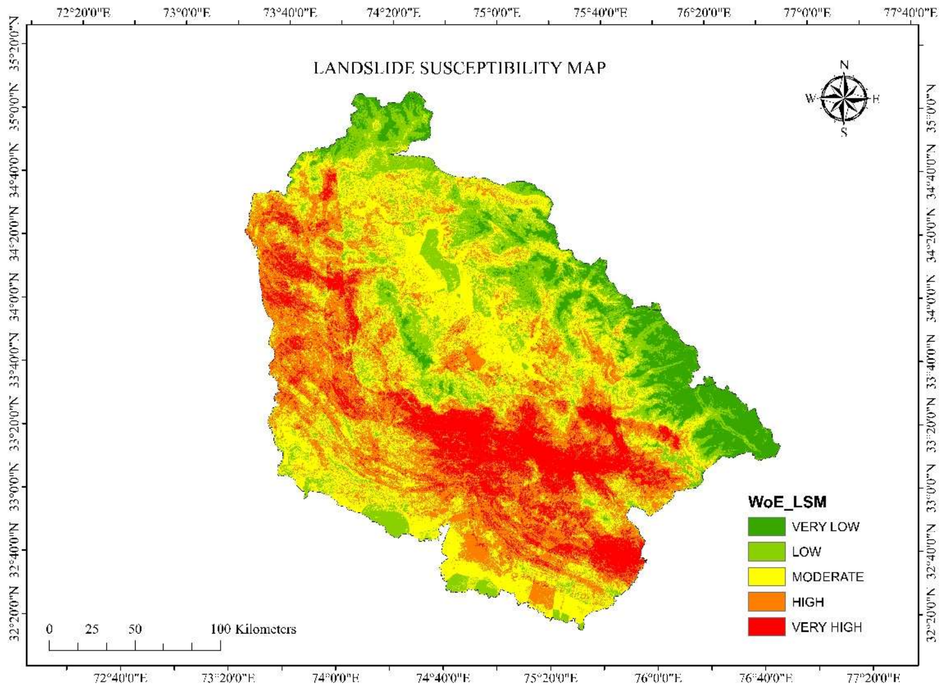

Fig 4.10 LSM using WoE approach

Table 4.6. Landslide percentage area using WoE approach.

Method Used	Zone	Class Pixel	%age Class Pixel	Landslide Pixel	%age Landslide Pixel
Weight of Evidence	Very Low	16654015	28.121	10800	1.630
	Low	25197068	42.547	59400	8.967
	Moderate	13090510	22.104	279000	42.119
	High	4197220	7.087	299700	45.244
	Very High	82089	0.138	13500	2.0380

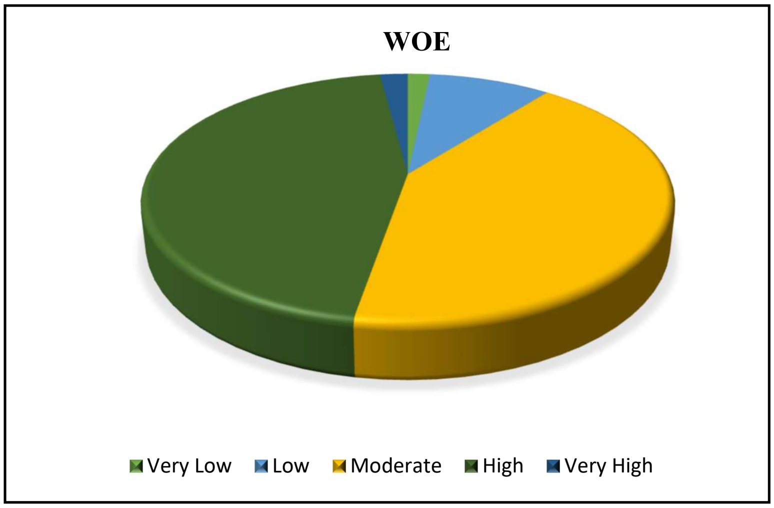

Fig 4.11. Landslide zone distribution as per WoE

4.3.3 Validation Results

Validation is carried out using AUC method which shows accuracy of 88.1% for SRC and 86.3% result for PRC as shown in Fig. 4.12 and Fig. 4.13 respectively.

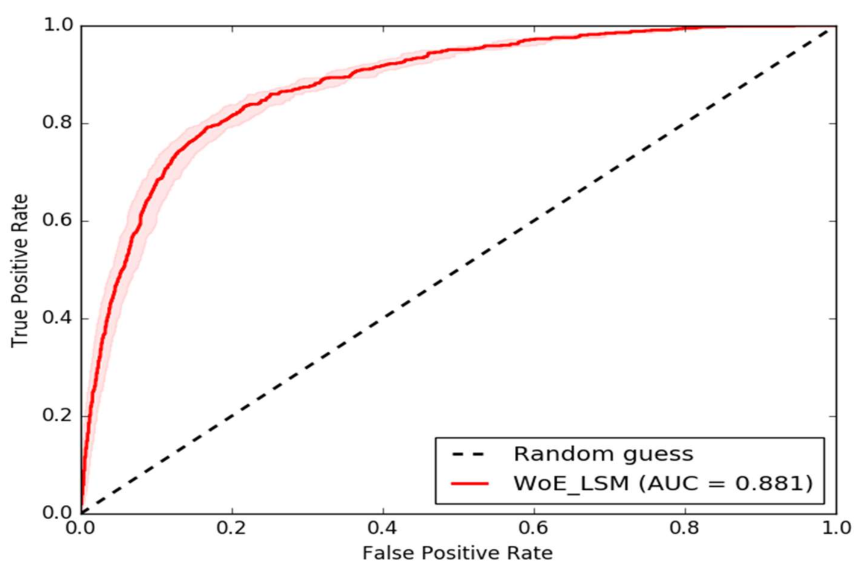

Fig 4.12. SRC as per WoE model

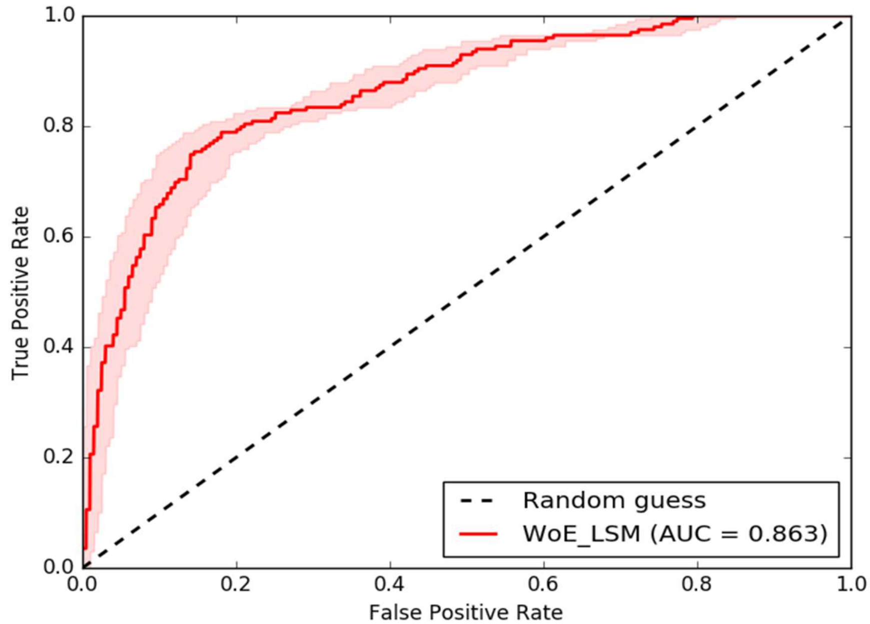

Fig 4.13. PRC as per WoE model

4.4 Shannon Entropy Results

As per SE results lithology, lineament percentage, rainfall and distance to roads and slope play an important role for study of landslides in the study area.

4.4.1 Tabulated Results

Table 4.7 shows calculated weightage values using SE model.

Table 4.7 Calculated Results obtained from SE method

FACTOR	Factor Classes	Landslide Pixels	Class Pixels	W_j
ELEVATION (m)	159-1104	207900	14374167	0.54175
	1104-2103	369000	16309695	
	2103-3076	71100	12359658	
	3076-4075	13500	10279144	

	4075-7047	900	5941670	
	Flat	59400	5338314	
	North	53100	5497987	
	North-East	51300	5579925	
	East	56700	5690966	
	South-East	63900	5948310	0.662713
ASPECT	South	90900	6675651	
	South-West	103500	6668263	
	West	69300	6463971	
	North-West	58500	5655454	
	North	55800	5710827	
	0 - 9.77	27000	14668933	
	9.77 - 20.8	79200	12962370	
SLOPE (degrees)	20.86 - 31.28	185400	14306175	0.66411
	31.29 - 42.68	277200	12162167	
	42.69 - 83.09	93600	5130023	
	(-165) - (-6.4)	1800	285161	
	(-6.4) - (-2.6)	30600	1954296	
CURVATURE	(-2.6) - (-0.75)	91800	6191986	0.634491
	(-0.75) - (3.06)	466200	46717820	
	3.06 - 322.22	72000	4115071	
	0 - 3.3	4500	656189	
EARTHQUAKE	3.3 - 3.9	74700	11676925	0.408236
	3.9 - 4.38	508500	39201573	

	4.38 - 4.86	72900	6323812	
	>4.86	1800	1411404	
LITHOLOGY	water bodies	11700	8283723	2.0367
	unconsolidated sediments	336600	15264249	
	siliciclastic sedimentary rocks	16200	7258677	
	mixed sedimentary rocks	9900	1289678	
	metamorphic rocks	32400	2875382	
	intermediate volcanic rocks	227700	19793193	
	carbonate sedimentary rocks	0	27908	
	basic volcanic rocks	14400	4394543	
	acid plutonic rocks	13500	82550	
TWI	1.29 - 5.19	331200	22303353	0.12913
	5.19-7.27	252000	23336184	
	7.27-10.26	58500	9324183	
	10.26-14.56	15300	3258874	
	14.56-34.46	5400	998311	
SPI	(-13.8) - (-6.21)	143100	15565491	0.518
	(-6.21) - (-1.15)	196200	16451739	
	(-1.15) - 2.39	221400	17304641	

	2.39 - 7.62	84600	8097679	
	7.62 - 29.23	17100	1801355	
DISTANCE TO ROADS (m)	0-3000	368100	24586046	0.6900
	3000-8000	105300	18920069	
	8000-14000	70200	10364470	
	14000-24000	97200	4174526	
	24000-44000	21600	1224792	
LINEAMENT (percentage)	0-0.054	38700	14569549	1.1170
	0.054-0.113	91800	18008456	
	0.113-0.178	148500	14275934	
	0.178-0.259	171900	8576258	
	0.259-0.437	211500	3839706	
RAINFALL (mm)	453-655	20700	16341333	0.7940
	655-856	37800	11697268	
	856-1058	325800	9505508	
	1058-1259	99900	13156520	
	1259-1461	178200	8569274	
LULC	Evergreen needle leaf Forests	4500	2385024	0.3390
	Evergreen broadleaf Forests	0	6148	
	Deciduous broadleaf Forests	0	37993	
	Mixed Forests	1800	1248240	

	Open Shrublands	0	959	
	Closed Shrublands	0	230	
	Woody Savannas	131400	9195863	
	Savannas	310500	13792662	
	Grasslands	143100	16041686	
	Permanent Wetlands	900	206092	
	Croplands	58500	8643652	
	Permanent Snow and Ice	0	659911	
	Croplands/and rural vegetation mosaics	5400	1925020	
	Urban and Built-up Lands	4500	452262	
	Water bodies	0	144104	
	Barren	1800	4527962	

As per the weightages obtained from the Table 4. , influencing factors can be identified. Fig 4. shows the influence of different factors on landslides as obtained from SE method based on Wj obtained. Greater the value, higher is the influence of the factor on landslide in the area.

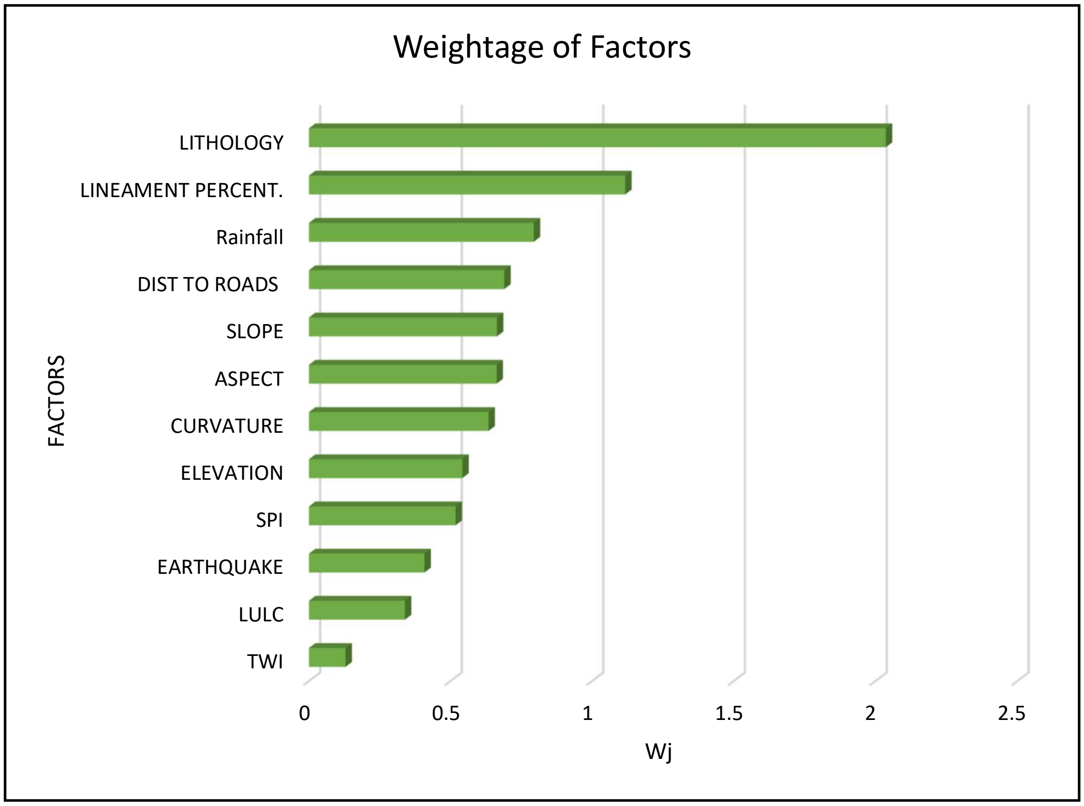

Fig 4.14. Dominance of factors inferred from SE approach

4.4.2 LSM Outcome

Fig. 4.15 shows the LSM created using SE approach. Map was created using Wj values obtained from calculations. Fig.4.16 represents the area distribution of landslide calculated in Table 4.8. Almost 45% of the landslides have occurred in the 'High' zone created by the SE approach for generation of LSM. Around 42% of the landslide area lies in 'Moderate' zone of Jammu and Kashmir as per the calculations and tabulations done in the table itself.

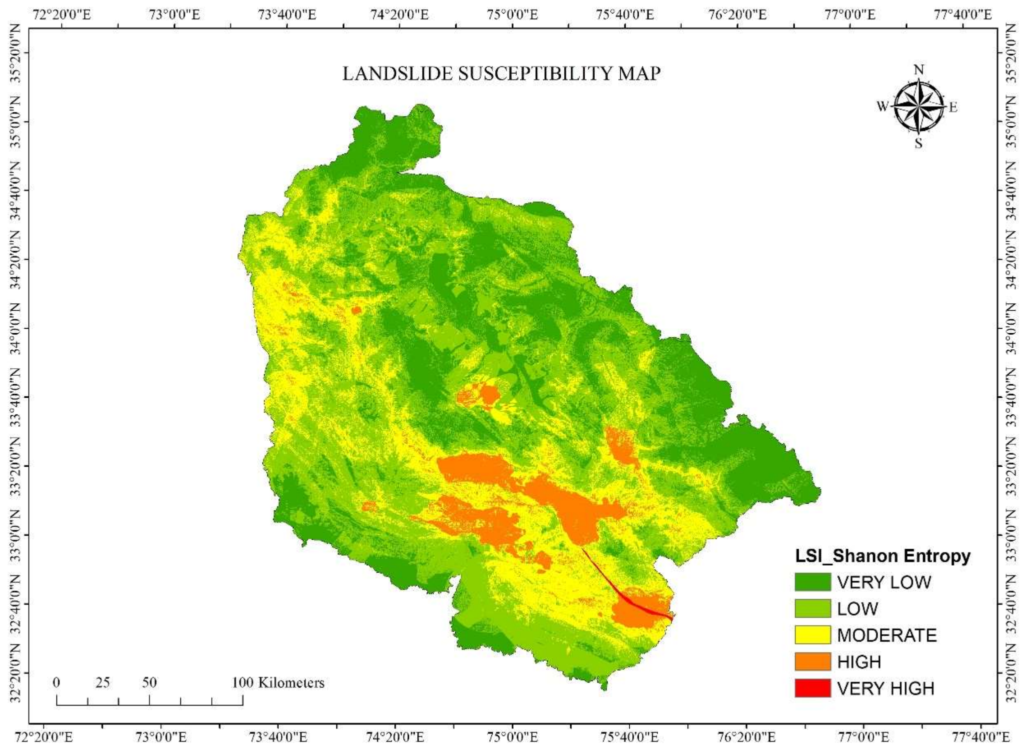

Fig 4.15. LSM using SE approach

Table 4.8. Landslide percentage area using SE approach.

Method Used	Zone	Class Pixel	%age Class Pixel	Landslide Pixel	%age Landslide Pixel
Shannon Entropy	Very Low	16654015	28.12158	10800	1.630435
	Low	25197068	42.54759	59400	8.967391
	Moderate	13090510	22.10454	279000	42.11957
	High	4197220	7.087396	299700	45.24457
	Very High	82089	0.138614	13500	2.038043

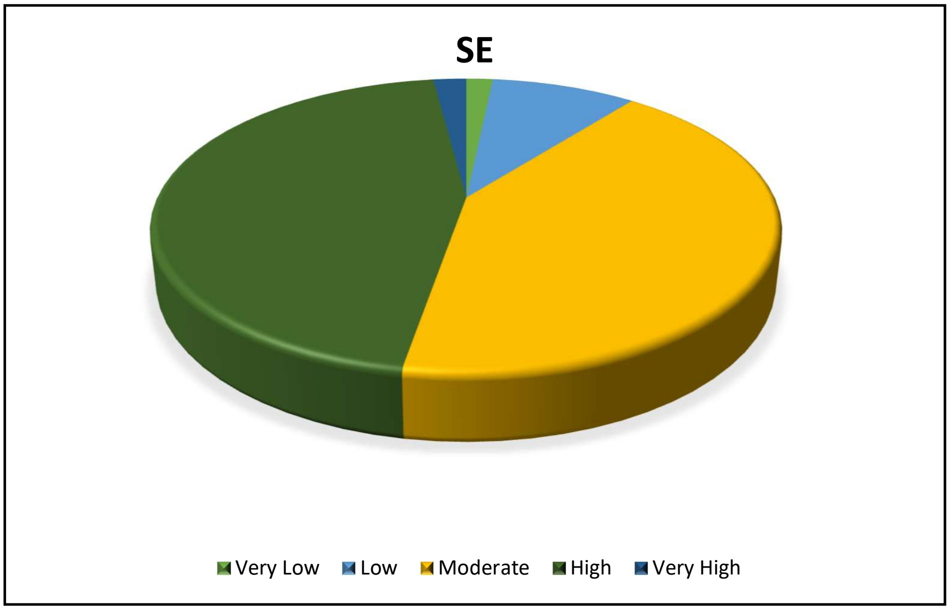

Fig 4.16. Landslide zone distribution as per SE

4.4.3 Validation Results

Accuracy check shows SRC of 87.5% and 87.2% result for PRC as shown in Fig. 4.17 and Fig. 4.18 respectively.

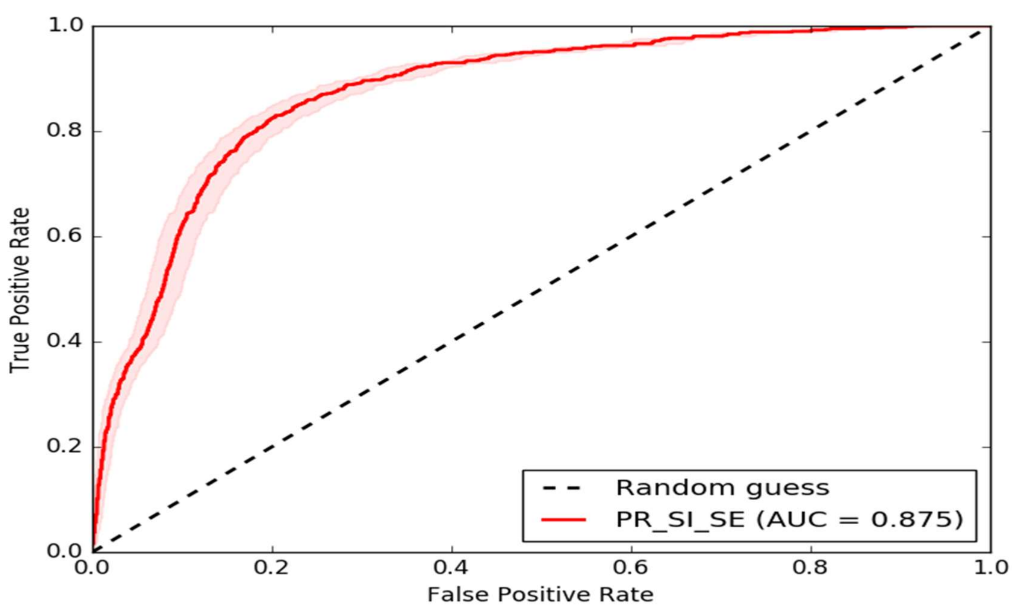

Fig. 4.17. SRC using SE

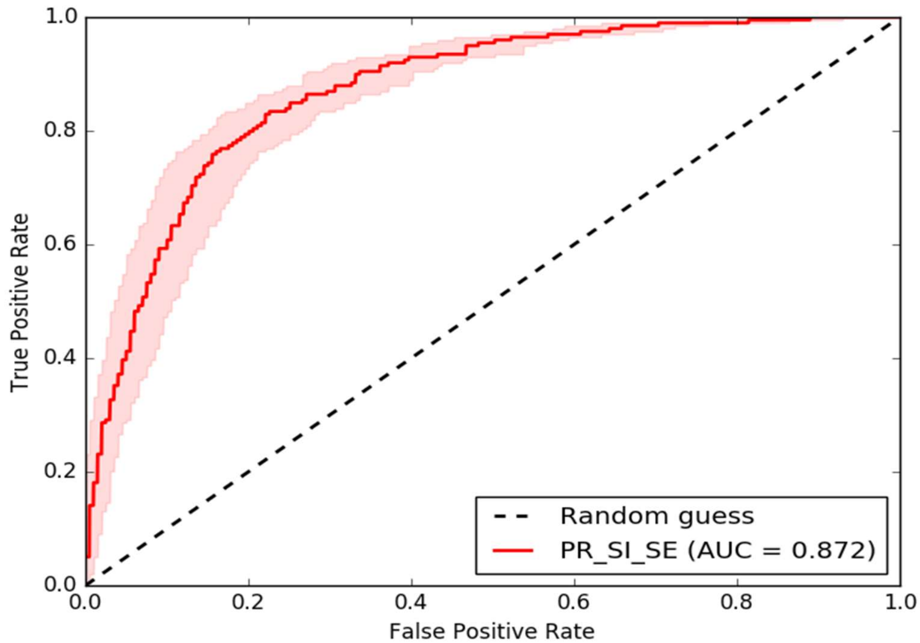

Fig. 4.18. PRC using SE

4.5. Comparative Study

The results obtained show varied distribution of landslide area in different categories of zonation created for the models used as in Fig. 4.19.

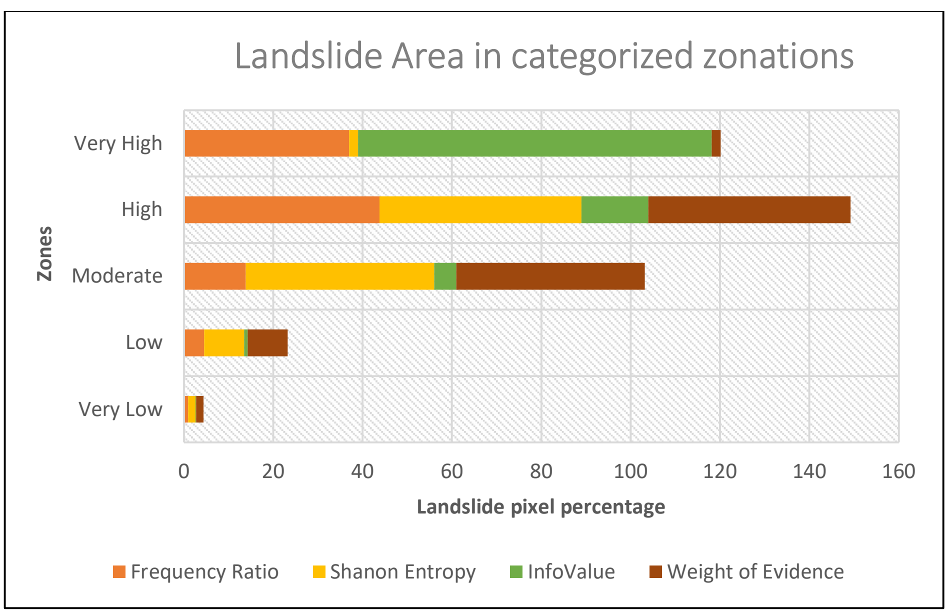

Fig. 4.19. Comparison of landslide area for different methods

Fig. 4.20 and Fig. 4.21 show the SRC and PRC for the models used. The most accurate model can be used further and analysed for causative factors.

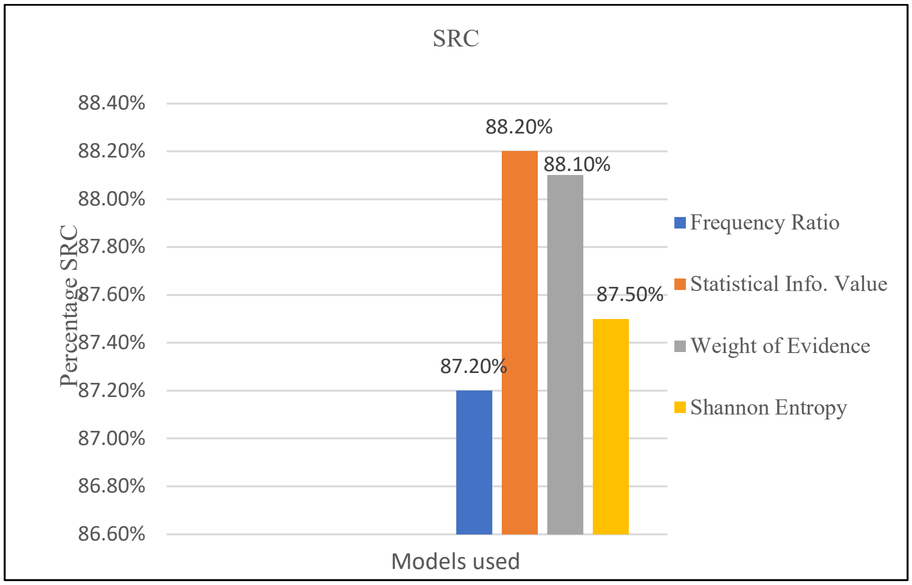

Fig. 4.20. Comparison of SRC for different methods

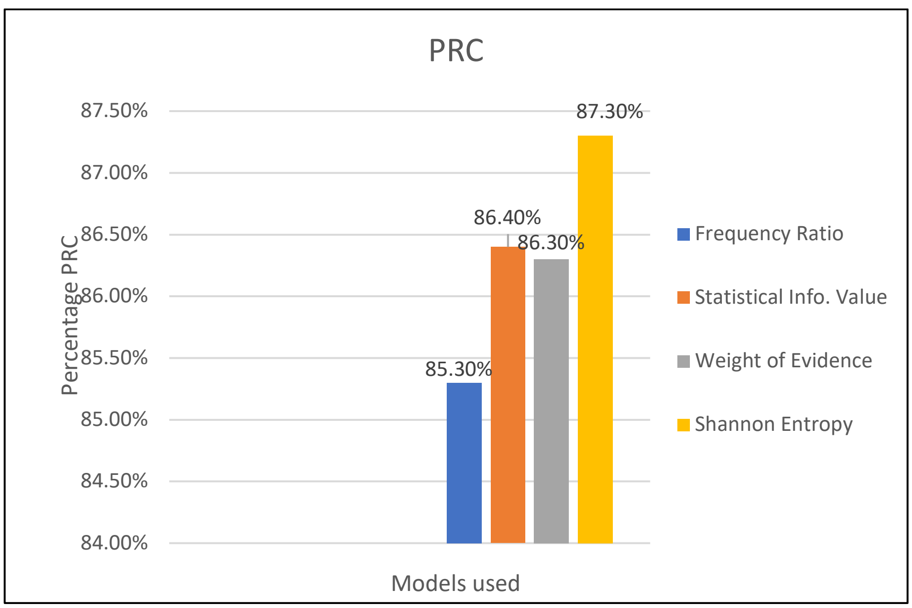

Fig. 4.21. Comparison of PRC for different methods

CHAPTER 5

CONCLUSION

5.1. Conclusion

It is very evident that landslide has proved to be detrimental to property and lives. Thus understanding the causative factors and its hazard zonation becomes a part of vigilance. The results obtained conclude that:

- Jammu & Kashmir is very prone to landslides as majority of the land area lies in 'high' to 'very high' zone for the models used.
- SIV approach gives highest accuracy of 88.2%. Other approaches also give similar accuracies ranging from 87.2% to 88.1%.
- SE model gives the highest prediction rate of 87.3% yet SIV is also challenging the former with good prediction rate of 86.4%.
- FR and SE models give specific weightages to the factors considered, thus it can ne inferred that lithology, lineament percentage, rainfall, elevation and distance to roads are the most influential factors for triggering landslides in Jammu and Kashmir area.
- Though SIV method has highest accuracy yet the major contributing factors for landslide can be detected from FR and SE approaches.
- Sedimentary formations in lithology and lineament percentage of 0.1% to 0.4% exists in the area which are under 'high' to 'very high' category of LSM.
- Ramban, Udhampur, Doda & Reasi are areas most susceptible to landslides as evident from LSMs obtained. This can also be attributed to the fact that these areas have National Highway 44 been passed through, thus making distance to roads one of the crucial factors. This only all weather road connecting J&K with rest of India gets blocked due to frequent landslides, thus affecting lives and economy.

Application of different models of FR, SIV, WoE and SE can assist in predicting landslide prone areas and its mitigation. Prior detection of hazard can lead to appraisal of precautionary measures thus saving lives and property.

5.2. Recommendations

The research has been carried out to best of knowledge and the data available, yet some improvisations can be done to make the LSMs more reliable and for better understanding of causative factors. Some of the improvisations can be done as under:

- Earthquake as a factor can be intrigued more, and connection of landslide with peak ground accelerations can be found using other approaches available.
- Due to restriction of data for the area, factors such as geology and agricultural index could not be considered, but if accessed, it can improve the LSM generation.
- Different sources for DEM can be used for data collection for better resolution and proper mapping of the landslide prone areas.
- Machine learning based approaches can be used instead of bi-variate approaches for more accurate predictions and success rates.
- Stability analysis of the area which is most vulnerable to landslides can be carried out with proper testing thus giving an insight of the cohesion and friction angle present and consequently stabilization measures can be carried out.

5.3. Future Scope

One of the most crucial tools available to natural hazard experts today is landslide susceptibility mapping, which assists in determining a region's susceptibility to slope failures, consequently preventing the expense of field investigation and offering the local authorities with prepared susceptibility maps for improved and meticulous landslide management work. Forecasting landslide prone areas and their mitigation can be aided by the application of models such as FR, SIV, SE, and WoE. The consideration of proactive measures can save individuals and assets if hazard is anticipated prior. LSM can assist construction firms and highway authorities for execution of work which turns out to be safe for lives and property.

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CONFERENCES

1. Acceptance mail of conference 1 received on Feb 25 ,2023.

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Poornima University, Jaipur_ETMDR-2023_March 02-04, 2023_Paper acceptance_Paper Code: CE-005

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Greetings!!!

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Authors: Sheikh Romana, Raju Sarkar

Paper Title: Landslide Susceptibility Mapping of Jammu & Kashmir using GIS-based Frequency Ratio and Information Value approach

Herewith, we are pleased to inform you that your draft paper mentioned above has been accepted by the 4th International Conference on Emerging Trends in Multi-Disciplinary Research "ETMDR-2023" which will be held on March 02-04, 2023 at Poornima University, Jaipur (Rajasthan) (India) and the final paper after revision and formatting will be published in the Proceedings of ETMDR-2023 with ISBN.

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Author Name : Sheikh Romana

Co-Author Name : Raju Sarkar

Institution : Delhi Technological University, India

Dear Sheikh Romana,

Congratulations !

The scientific reviewing committee is pleased to inform your article "**Landslide Susceptibility Mapping Using Four Statistical Probabilistic Models for Doda District of Jammu & Kashmir, India**" is accepted for at " **IC-ESSU-2023** " on **30th & 31st March-2023 at Manila, Philippines** . The Paper has been accepted after our double-blind peer review process and plagiarism check.

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