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Geographical Information System Based Landslide Probabilistic Model with Trivariate Approach - A case study in Sikkim Himalayas*

* **Prepared by L.P Sharma, National Informatics Centre, Nilanchal Patel, Department of Remote Sensing, Birla Institute of Technology, M.K.Ghosh, Department of Computer Science, Sikkim Manipal Institute of Technology, P.Debnath, College of Agriculture Engineering & Post Harvest Technology, India**

Geographical Information System Based Landslide Probabilistic Model with trivariate approach-A case study in Sikkim Himalayas.

L.P.Sharma[1], Nilanchal Patel[2], M.K.Ghosh[3], P.Debnath[4]

1. National Informatics Centre, Sikkim, India. (Corresponding Author: lp.sharma@nic.in)

2. Department of Remote Sensing, Birla Institute of Technology, Meshra, Ranchi, India.

3. Department of Computer Science, Sikkim Manipal Institute of Technology, Mazitar, Sikkim, India.

4. College of Agriculture Engineering & Post Harvest Technology, Ranipool, Sikkim, India

Abstract

Landslides like debris flow, mud slides and creeps are the devastating phenomenon in the state of Sikkim in India that has caused innumerable loss to lives and properties since ages. The purpose of this study was to categorize the land in the study area with respect to their vulnerability and susceptibility to landslides into different zones, for focused implementation of specific strategies for landslide reduction and loss prevention in the most vulnerable areas. The major parameters causing the landslide were identified based on past research and experts' opinion. The influencing soil parameters were soil depth, stoniness, hydraulic conductivity, soil drainage behavior, soil slope, soil erosion, surface texture and inner texture. Other parameters were lithology, slope, drainage network, and road network and land use pattern. The trigging factors are rainfall and anthropogenic interference like civil construction and deforestation. The input thematic maps on all the identified factors were collected from various sources and were integrated in Geographical Information System framework. A landslide inventory map was developed

based on the satellite data and a field survey. All the input layers were then overlaid in GIS environment, with all required attribute parameters from the input layers keeping intact in the final output layer. Landslide Information Value (LSIV) for a smallest polygon with in the study area was calculated based on the knowledge driven weights of the parameter and the data driven information (landslide density) due to each of the parameter variables. The value of LSIV ranged from 78 to 234 and was classified into three ranges based on histogram distribution of values that categorized the study area into least vulnerable, moderately vulnerable and the most vulnerable zones. On verification with the landslide inventory map we found that 11% of the landslides had occurred in the least vulnerable zone, 32% of the landslides had occurred in the moderately vulnerable zone and 57% of landslides had occurred in the most vulnerable zone. Highest percentage of landslides in the most vulnerable zone gives accuracy and conformation to our methodology.

Introduction.

Landslide is a major cause of disaster in the hilly region. In the state of Sikkim 3300 lives are recorded to have been lost causing a widespread state of terror in the mindset of the people when a prolonged monsoon triggered landslides in October 1968. Since then sporadic landslides in all parts of the state have disturbed and damaged lives and properties heavily. Mud slides and debris flows are usually the two types of landslides that have occurred due to heavy and prolonged downpour during the monsoon season. When ever such landslides have occurred, the manmade structures and natural resources stand no where against the fragile condition of the Himalayan ecosystem, ubiquity of weak geology and slope instability with average monsoon rainfall of 350mm per day risen up to 500 mm during cloud burst. There has been little effort put till date within and around the study area to scientifically assess the vulnerability with reference to the existing geo-technical information to predict the occurrence of such hazard that could help and support the disaster management authority to work towards disaster reduction strategies like early warning system, vacating of most vulnerable areas, stoppage of civil construction in the vulnerable areas, retrofitting of the structures lying in such areas and so on, and at the same time identifying safe zones for continuation of various sustainable development processes like industrialization and further urbanization. This Geographical Information System based study to delineate the study area into different categories with respect to its vulnerability and susceptibility to landslides is an attempt towards this goal. GIS based landslide vulnerability study have been attempted by many researchers and scientist in the past all across the globe (Jibson et al, 2000; Luzi et al,2000; Zhou et al 2002; Carro et al 2003, Lee 2007, Burrough and McDonnel, 1998, Miles et al. 1999, Siddle et al 1991, Lee et al 1991, Hutchinson and Chandler 1991, Hutchinson et al 1991, Morgan et al 1992, Carrara et al 1991. Logistic Regression Model was used for landslide mapping by Atkinson and Massari, 1998, S. Lee 2004, Ghosh et all 2006 along with Frequency Ratio Method (Lee et all 2006) and Information Value method (Ghosh et. all 2006). Fuzzy Gama method or Fuzzy Alzebric Function was used for landslide susceptibility modeling by Majid H. Tagestani (2007), Saro Lee (2003 & 2006), Ercanoglu and Gokceoglu (2002), Pistocchi et all (2002). Artificial Neural Network was used for landslide susceptibility study and modeling by Lee et all (2003, 2006), Gomez and Kauzoglu (2004) and Melchioree et all (2006). Bayesian Network was used for landslide probability study by Lau et all (2007) and Demoulin and Chung (2007). This study attempts to combine the experts' opinion or knowledge driven weights and the data driven evidence based information as landslide density to calculate the landslide information value on various parts of the study area.

Study Area

The study area for this investigation i.e. **Sang Revenue Circle** in East District of Sikkim, India, comprises 15 (Fifteen) revenue villages namely Dung-Dung, Bhudang Thangshing, Khamdung, Byang Khamdong, Beng Sang, Namgaythang, Sirwani, Sakyong, Chisopani, Rabdang, Tshalumthang, Phegyong, Tirkutam, Nazitam, Martam lying from east longitude 88^o 26' 40.17" to 88^o 33' 42.35" and North Latitude of 27^o 13'48.85" to 27^o17'22.24" covering an area of around 36 square kilometers. Since 1968 there is a prominent landslide at *Sirwani Revenue Village* that blocks the road between *Singtam* and *Sirwani* every year during the monsoon season. The slide has spoiled around four acre of rich and fertile cultivable private land converting it to a muddy slide.

The area is typically hill slope and watershed of River Singtam and River Teesta (Figure 1) with elevation of the hill ranging from 340 meters at the river level to 2000 meters at the hill top as seen in the Digital Elevation Model (Figure 2a) with slope ranging from steep (45% to 60 %) to very steep slope (>60%)(Figure 2b). The rock formation in the area is mainly Chlorite, Phyllite and Schist with a less area having the Lingtse Gneiss group of rocks. The soil in the area is characterized by loamy to course loamy with high to low stoniness. The land cover pattern is dense forest, open forest, scrubland and cultivable land.

Data Used.

Spatial data in the state of Sikkim is available either with National Informatics Centre (NIC), GIS division or with the state remote sensing agency. Most of the thematic layers used in this study were used from NIC GIS data bank. The data prepared at low scale by the various national level agencies were upgraded to higher scale prior to the commencement of study at the state level with the help of various state level agencies with institutional mechanism. Table 1 shows list of thematic layers that were used along with their source and the original scale of digitization. Landslide inventory map was prepared from latest 2.5 m resolution cartoset panchromatic image augmented further by wikimapia multi-spectral image along with a field survey. Slope map was prepared from the digital elevation model of the study area.

Methodology.

All the input layers were brought to shape file format from geo-database or other vector formats. The attribute fields to carry the weights of the each parameter were identified, added and populated with respect to the varying parametric values. Slope map was derived from the Digital Elevation Model using the 3D-Analyst module of ArcGIS software. Landslide events map (Figured 4b) for the year 2007-2008 was digitized with screen digitization on Arcview GIS software from the high resolution satellite image and was augmented and verified further with field verifications. Road lines available as line layers were buffered at 40 meters on both sides and the drainage lines were buffered at 30 meters on both sides and converted to polygons for assessing their impacts on landslide susceptibility. All the input thematic layers were then brought to the single spatial reference and projection system (Figure 3). Errors that appeared due to change in projection system of some of the layers were cleaned and rectified to ensure that all the layers had end to end registration with the base map of the study area. The layers were then overlaid in Geomatica 10 overlay analysis software to get a single layered output. The output layer contained 9760 polygons with each polygon containing the weight of the all the parameters considered. At this stage 34 numbers of other variables were introduced and these fields named as x1 to x34 were added in the attribute table with the ArcCatalog module of the ArcGIS. These variables were basically to indicate the presence or absence of any particular parametric variable hence their value will be either 0 or 1. For example value of x1 will be one if deep soil is present in the polygon else its value will be zero. Similarly value of x34 will be one if land cover type is cultivable within in the polygon else its value will be zero. These values were then populated accordingly in group editing mode using selection queries and the editor module of the ArcGIS software. Landslide density was then calculated for each of these thirty four variables as ration of number of landslides to the total area in square kilometers where these variables prevail within the study area .Finally the Landslide Information Value (LSIV) is calculated for each polygon as sum of product of experts' based weights, landslide density and the Xn value of all the causative factors. It is obvious to deduce that higher the value of LSIV, higher the degree of landslide vulnerability. Hence based on the value of LSIV the geographical area is classified into Least Vulnerable, Moderately Vulnerable and Most Vulnerable Zones.

Calculation and Results.

The formula for calculation of Landslide Information Value (LSIV) for each of the polygons was deduced by us with the following analogy and presumption:

Suppose there are N numbers of potential factors with their expert based weights assigned as W_1, W_2,……to W_N affecting the slope instability considered with each of these potential factors having p numbers of variables values denoted as $P(W_1)$ to $P(W_n)$. Xi(w1) to Xi(Wn) with their values being either 0 or 1 denote the presence or absence of $p(W_1)$ to $p(W_n)$ variable value in each of the polygon. During the overlay analysis, suppose the total geographical area is divided into M number of polygons. Each of the polygon j (j=1,2,……..m) can be declared as stable or unstable based on their Landslide Information Value (LSIV): higher the value of LSIV more unstable the polygon j.

The Landslide Information Value for the j_{th} polygon was calculated as:

$$LSIV_j = W_{1j} \sum_{i(w1)=1}^{p(w1)} Xij(w1) LDij(w1) + W_{2j} \sum_{i(W2)=1}^{p(W2)} Xij(w1) LDij(w1)$$

$$+ \ldots\ldots\ldots\ldots\ldots W_{Nm} \sum_{i(Wn)=1}^{p(Wn)} Xim(Wn) LDim(Wn)$$

Where W_1, W_2,…….W_n are the expert based weights of the N^{th} identified parameters

$X_{ij(Wn)}$ is the variable value of I_{th} variable of the W_n parameter for J_{th} polygon.

$LD_{ij(Wn)}$ is the Landslide Density due to I_{th} variable of Wn Parameter for the J_{th} polygon

The Landslide Information Value for each of the polygons calculated with the above formula ranged from 78 to 328. A histogram distribution diagram was then used to classify LSIV values of polygons into three different ranges that categorized and delineated the study area into three different zones viz. least vulnerable zone, moderately vulnerable zone and the most vulnerable zone. The Least Vulnerable Zone with LSIV varying from 78 to 110 contained 1309 (13%) polygons with an area of 10.91(30%) sq km. The Moderately Vulnerable Zone with LSIV varying from 111 to 144 had 3800(39%) numbers of polygons with an area of 14.7(41%) sq km. The Most Vulnerable Zone had a total number of 4651(48%) polygons with an area of 10.66(29%) sq km (Table 1). A zonation map for the study area is produced on the basis of above classification that manifests these zones in three different colors (Figure 4a). We compared this result with the landslide event directory of the study are and found reasonable match between the prognostic models and the real events. The Least Vulnerable Zone witnessed a record of only 3 landslides in the last three years. The Moderately Vulnerable Zone had a record of 9 (32%) landslides as per the landslide inventory developed by us. The Most Vulnerable Zone recorded 16(57%) numbers of landslide events that brings a close proximity to real events versus the prediction.

Discussion & Conclusion

We calculated the Landslide Information Value (LSIV) for each of the polygon as a sum of the product of weight assigned for each of the causative factors, presence or absence of the variable of that factor and the landslide density calculated from the entire area where the said variable factor prevailed. The weights of the parameters were assigned in such a way that the higher value of the weight denoted greater instability. Hence it was obvious to understand that higher value of LSIV denoted a higher instability and landslide vulnerability. Looking at the statistics in the Most Vulnerable Zone, though the zone contained the highest numbers of polygons(4651) but the area under it is only 10.66 sq km and it contains the highest number of landslides which verifies and authenticates the methodology adopted in the study. Bar chart showing distribution of area in different vulnerable zones (Figure 5) depicts an almost equal distribution of area in all the zones with only the Moderately Vulnerable Zone having little larger (41%) geographical area. However the bar chart depicting number of landslides in each of the vulnerability zone demonstrated a constant increase in number of landslides and consequently the landslide density from Least Vulnerable Zone to the Most Vulnerable Zone (Figure 6). The most vulnerable zone with only 29% of the geographical area contained 57% of landslides giving very high accuracy to our zonation method. We found this method to be simple and highly accurate compared to any other method for landslide hazard zonation.

We were able to complete the Geographical Information System based landslide vulnerability study of around 37 sq. km. in hill area based on the spatial data with minimum field visit. The study was able to delineate and verify around 10 sq km of the study area as the most vulnerable where focused landslide reduction strategies need to be implemented. Such GIS based initiative in delineating the vulnerable areas will go a long way in helping the decision makers and land planners for site selection for developmental activities and for alerting and avoiding loss of lives and properties during landslide hazards through detailed response and mitigation plan both at pre and post disaster scenario.

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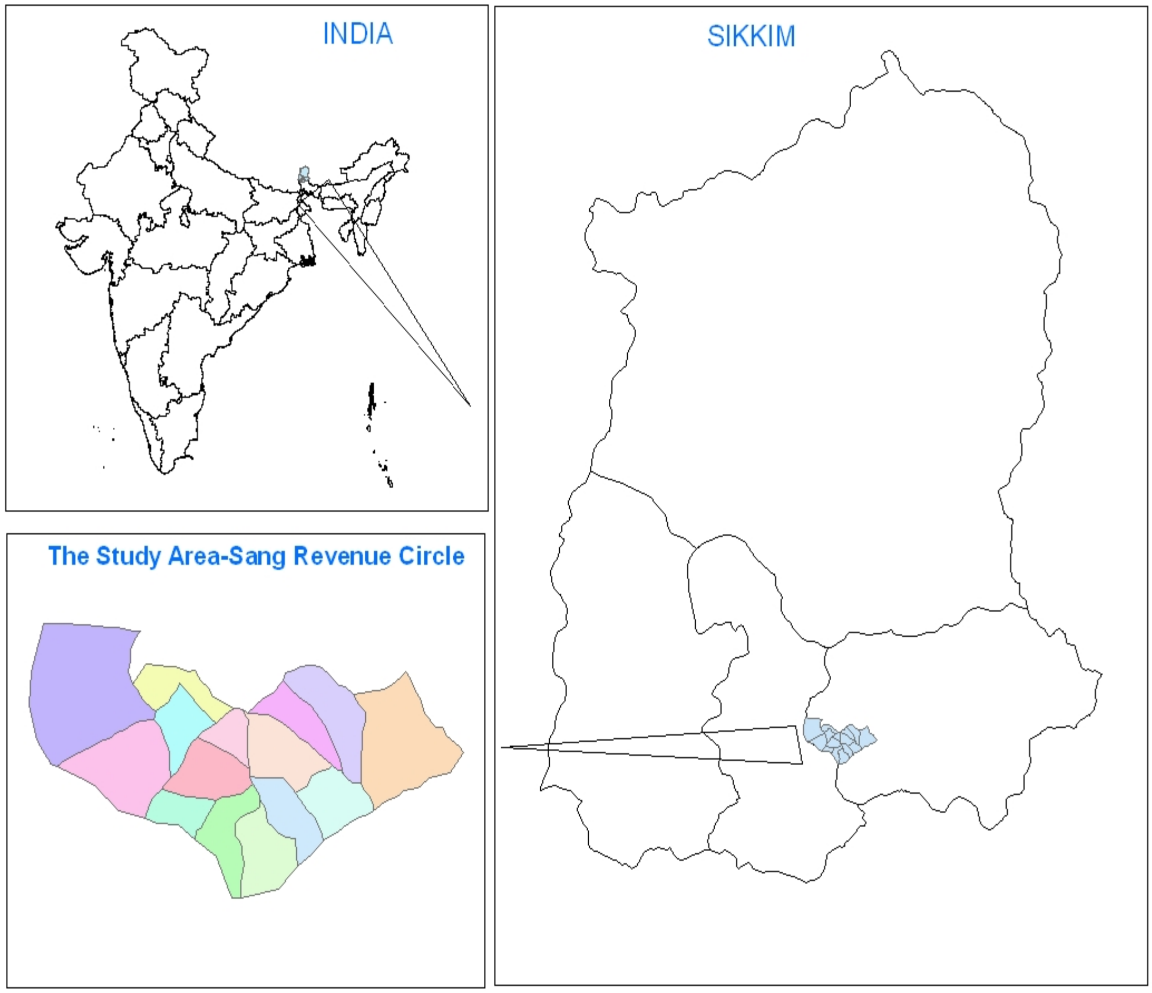

Figure 1. Study Area-Sang Revenue Circle

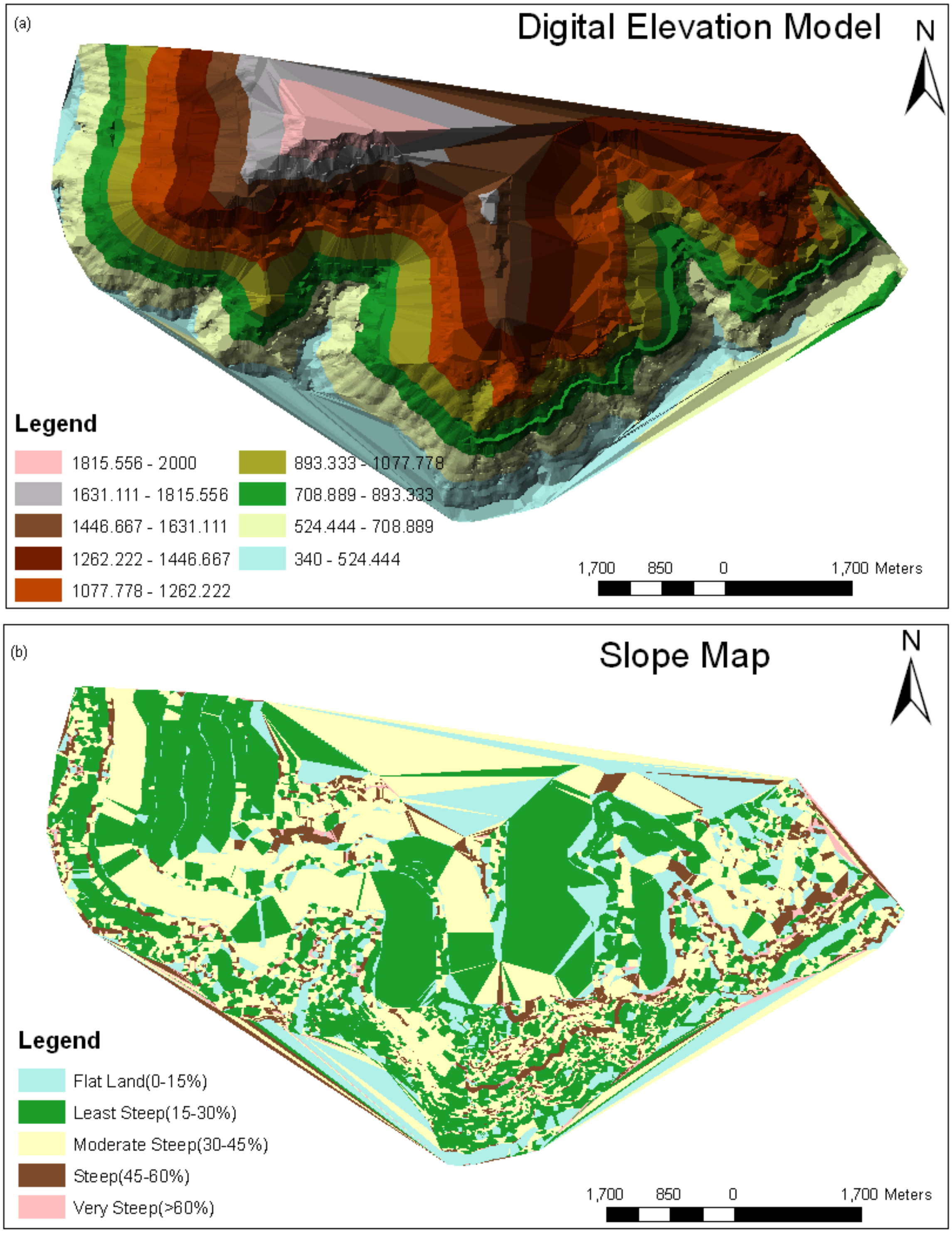

Figure 2. (a) Digital Elevation Model of Study Area (b) Slope Map

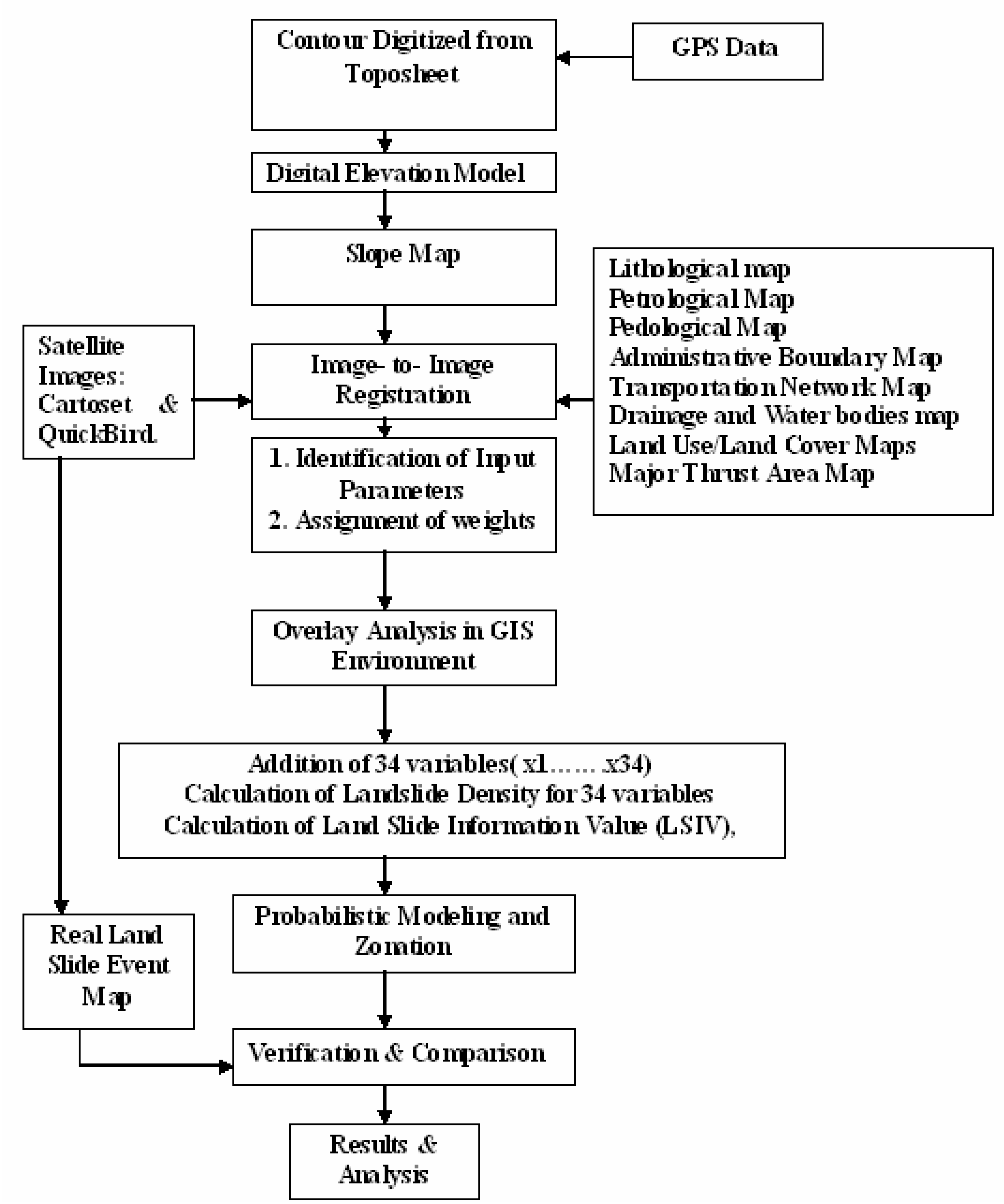

Figure 3. Methodology Flowchart

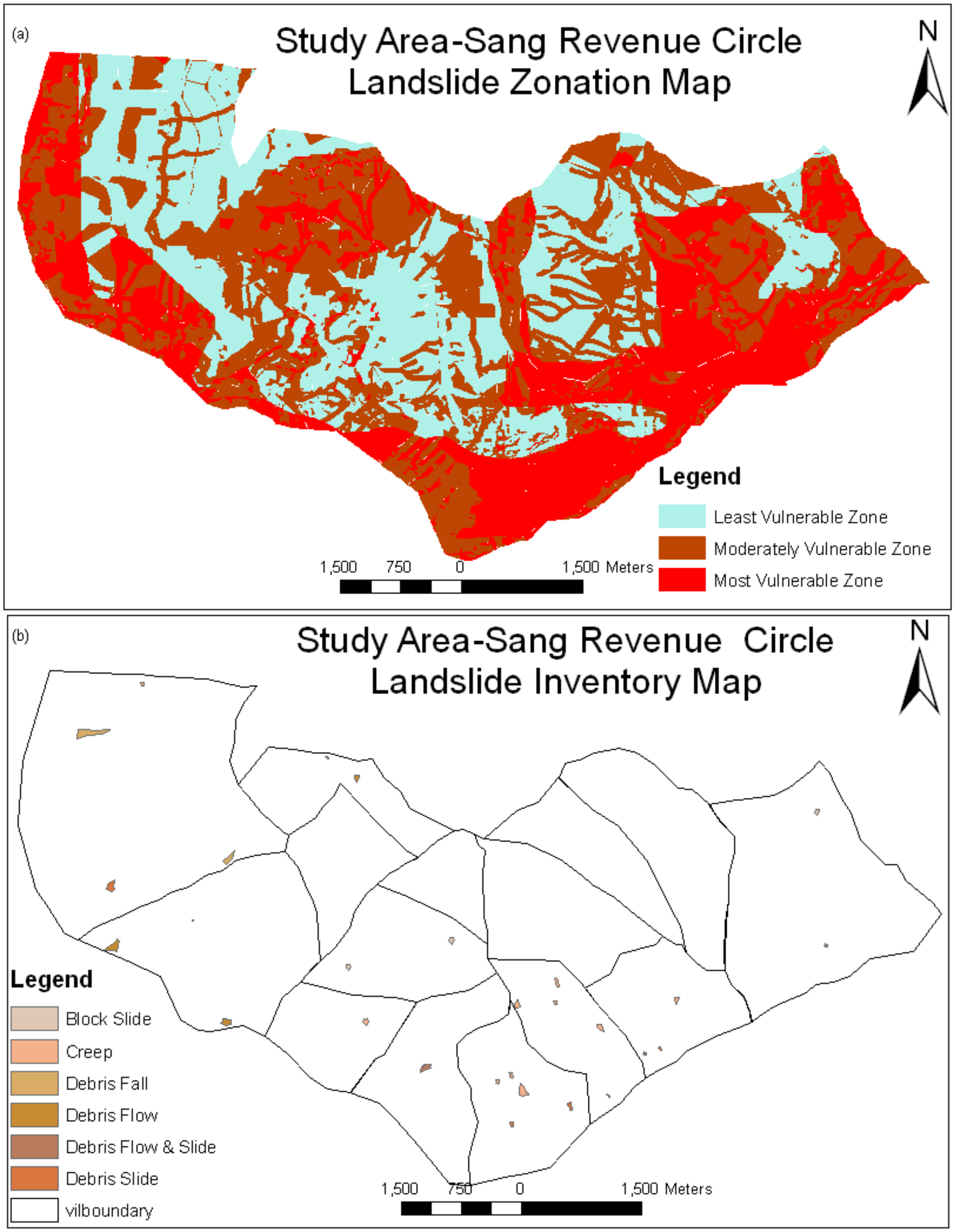

Figure 4. (a) Zonation Map (b) Landslide Event Map

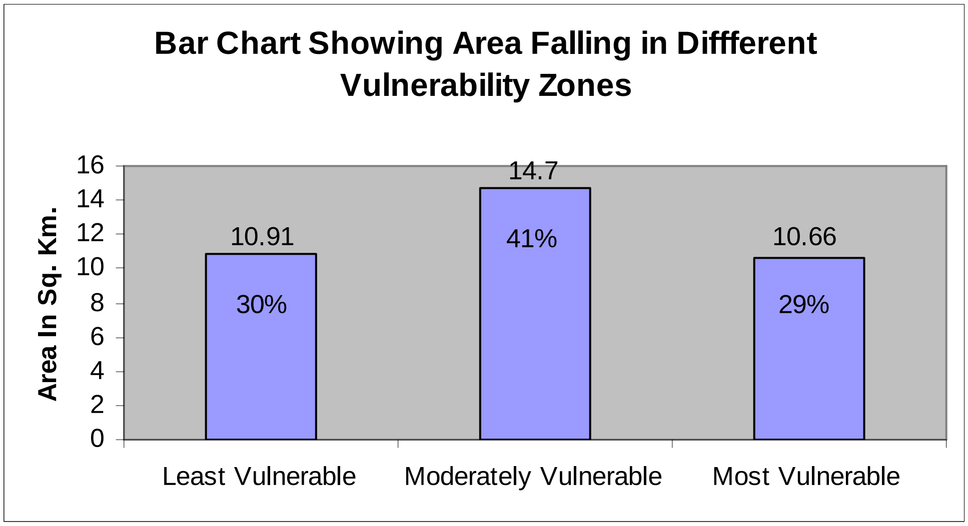

Figure 5. Bar Chart Showing Area falling in Each Vulnerability Zone

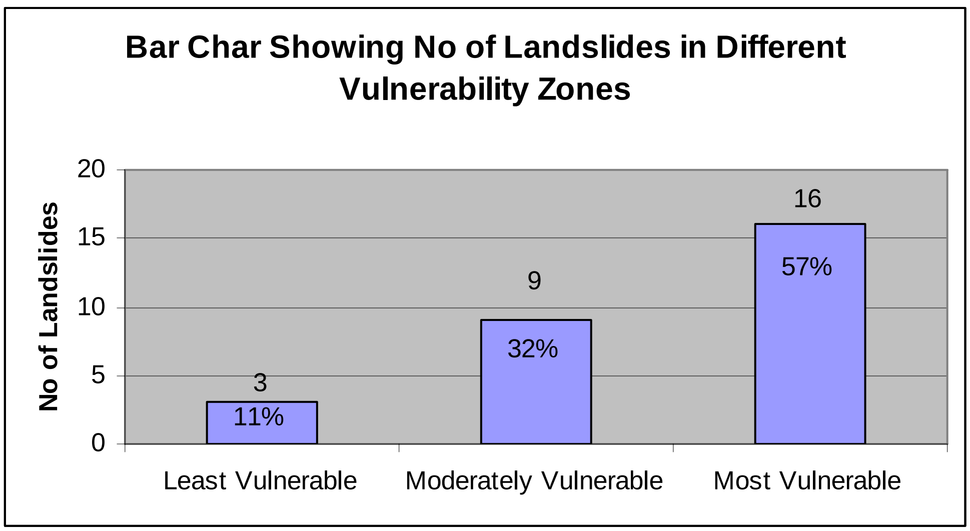

Figure 6. Bar Chart showing number of landslides in each Vulnerability Zone

Table 1. List of Data Used in the Study

Sl. No.	Name of Thematic Layers	Original Map Scale	Data Source
1	Slope Map	1:50,000	DEM/50k Topographic Map
2	Land Use & Forest Map	1:50,000	NIC-GIS Databank
3	Geological Map	1:50,000	Geological Survey of India.
4	Soil Map	1:250,000	NIC-GIS/NBSS&LUP
5	Road Map	1:50,000	NIC-GIS Databank
6	Drainage Map	1:50,000	Digitized from Topographic Map
7	Topographic Map	1:25000	Rural Management Dev. Department, Govt. of Sikkim.
8	Cartoset Pan Image	2.5 m Res.	NRSA
9	Quick Bird Image	60 cm Res.	Wikimapia
10	Landslide Events Map	1:10,000	Digitized from cartoset/ wikimapia verified with field survey.

Table 2. Table showing number of polygons, area and number of landslides in different vulnerability zones.

LSIV	No. of Polygons	Area(Sq. Km)	No. of Landslides	Vulnerability Zones
78-110	1309(13%)	10.91(30%)	3(11%)	Least Vulnerable
111-144	3800(39%)	14.7(41%)	9(32%)	Moderately Vulnerable
145-328	4651(48%)	10.66(29%)	16(57%)	Most Vulnerable
	9760(100%)	36.27(100%)	28(100%)	

About The Others:

Shri L.P.Sharma has B.Tech. in Electronics and Communication Engineering with masters in computer science and is perusing Ph.D. in spatial analysis. He has been working in National Informatics Centre since 1993 and is presently Scientist-D and Principal System Analyst at Geo-Informatics Cell, National Informatics Centre, Sikkim State unit Gangtok. He can be reached at lp.sharma@nic.in

Dr. Nilanchal Patel *is Professor in the Department of Remote Sensing in Birla Institute of Technology, Mesra, Ranchi, Jharkhand, India. His research areas include Environmental Remote Sensing, Digital Image Processing, Natural Resources Management, Landscape Ecology, GIS, Morphometric Analysis, LUCC, Biomass and NPP Estimation. He can be reached at npatelrsgis@yahoo.co.in*

Dr. M.K.Ghose *is the Professor and Head of the Department of Computer Science & Engineering at Sikkim Manipal. Institute of Technology, Mazitar, Sikkim, India. Prior to this, Dr. Ghose worked in the internationally reputed R & D organisation ISRO – during 1981 to 1994 at Vikram Sarabhai Space Centre, ISRO, Trivandrum in the areas of Mission simulation and Quality & Reliability Analysis of ISRO Launch vehicles and Satellite systems and during 1995 to 2006 at Regional Remote Sensing Service Centre, ISRO, IIT Campus, Kharagpur in the areas of RS & GIS techniques for the natural resources management. Dr. Ghose has conducted quite a number of Seminars, Workshop and Training programmes in the above areas and published around 27 technical papers in various national and international journals in addition to presentation/ publication in several international/ national conferences. He can be reached at headcse.smit@gmail.com*

Dr. P .Debnath has BSc. (Agri.) from Cental Agricultural University (CAU), MSc(Agri) and Ph.D. in Soil Science from Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur, Nadia, West Bengal. Since 2006, he is Assistant Professor in the Dept. of Agricultural Chemistry and Soil Science, College of Agricultural Engineering and Post Harvest Technology (CAU), Ranipool, Gangtok, Sikkim. He can be reached at kanupran@yahoo.co.in