International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 9 (2018) pp. 6846-6854
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Application of Frequency Ratio Model for the Development of Landslide Susceptibility Mapping at Part of Uttarakhand State, India

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Abstract

Frequency Ratio model has been successfully applied as statistical approach for landslide susceptibility assessment in many regions all over the world. In the present study, a part of Uttarakhand Himalaya has been selected as a case study to apply the FR model for landslide susceptibility assessment and mapping. For this, landslide inventory map was firstly constructed with 276 landslide locations identified from various sources with the help of GIS technology. These landslide locations were then randomly split into two parts: (i) 70% landslide locations (for training process) and (ii) 30% landslide locations (for validation process). Presently, in total eleven landslide conditioning factors (slope, aspect, elevation, curvature, land use, geomorphology, depth material, slope forming material, distance to road, distance to river and rainfall) have been selected for analyzing the spatial relationship with landslide occurrences. Using training dataset, the FR model was then built to assess landslide susceptibility in the study area. Finally Landslide Density (LD) was used to validate performance of the FR model. Results indicated that FR model is an effective method for the landslide susceptibility assessment of hilly areas.

Keywords: Landslides; GIS, Frequency Ratio, Uttarakhand, India

INTRODUCTION

Landslide is a natural phenomenon which is described as a massive movement of materials (soils, rocks, organics, etc.) from up slope to down slope [1] causing loss of life and properties. Landslides usually occurs under different geo-environmental, geomorphological, geological and hydrological conditions depending on the characteristics of the study region . Landslides can have long-lasting effects on the environment. Major landslides can cause topographic changes especially in hilly areas and can change the river course and pattern. Landslides can destroy forest, wildlife habitat, remove productive soils from slopes and disrupt road traffic. Landslides can also cause tsunami, seiches, floods in some cases [2]. Landslides have environmental as well as socioeconomic costs affecting human populations.

Landslide susceptibility map is a useful tool in landslide hazard management. It shows degree of susceptibility of area to landslide occurrences. These maps can be generated based on the spatial prediction of landslides on the assumption that future landslides will occur under same conditions as in the past [3]. Therefore, landslide susceptibility can be assessed through evaluation of the spatial relationship between a set of conditioning factors and previous landslide occurrences. In recent years, many landslide susceptibility maps have been generated in many regions all over the world using Geographic Information System (GIS). Presently, statistical approach which is a subjective approach is the most popular for landslide susceptibility assessment. Many methods have been applied using this approach such as Frequency Ratio [4], Weights of Evidence [5], Logistic Regression [6]. Out of these methods, Frequency Ratio (FR) method is used widely for landslide susceptibility assessment with good performance [3].The main objective of the current study is to create landslide susceptibility map at a part of part of Uttarakhand Himalaya (India) using the FR model for landslide hazard management. Performance of the FR model was evaluated using Landslide Density Index (LDI).

DESCRIPTION OF THE STUDY AREA

The study area falls in parts of Pithoragarh and Bageshwar districts, and lies in the eastern part of Uttarakhand. The area is bounded between the latitudes N29°59′36″ and N29°45′12″ and longitudes E80°1′15″ and E80°14′02″ respectively (Fig. 1) occupying a total area of 561 sq. km. The area is hilly dissected by deep river valleys. Geologically metamorphic rocks (phyllite, shist, quartzite and dolomite) occupy major part of the area besides limestone and shale, and quaternary sediments (gravel and sand) in river valleys. Structurally the area is disturbed and rocks are folded and faulted.

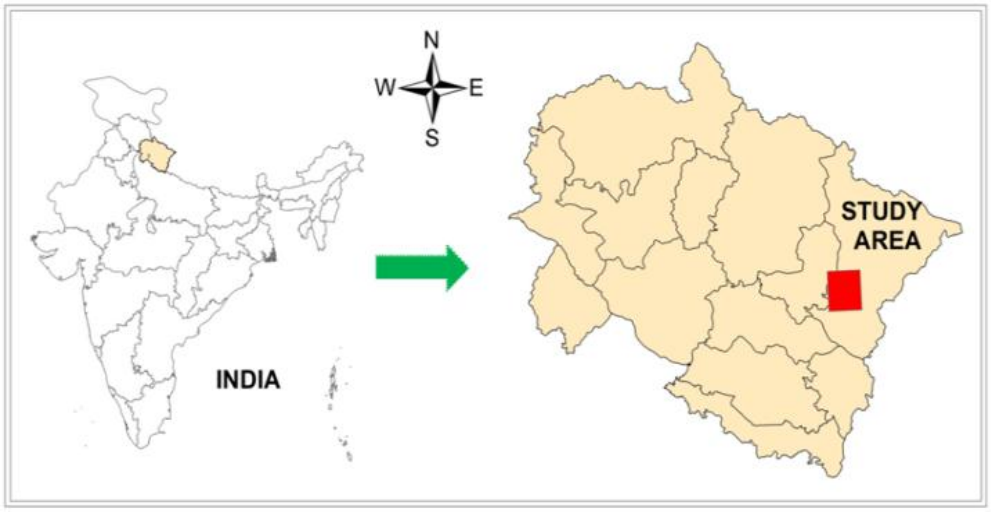


Figure 1. Location of the study area

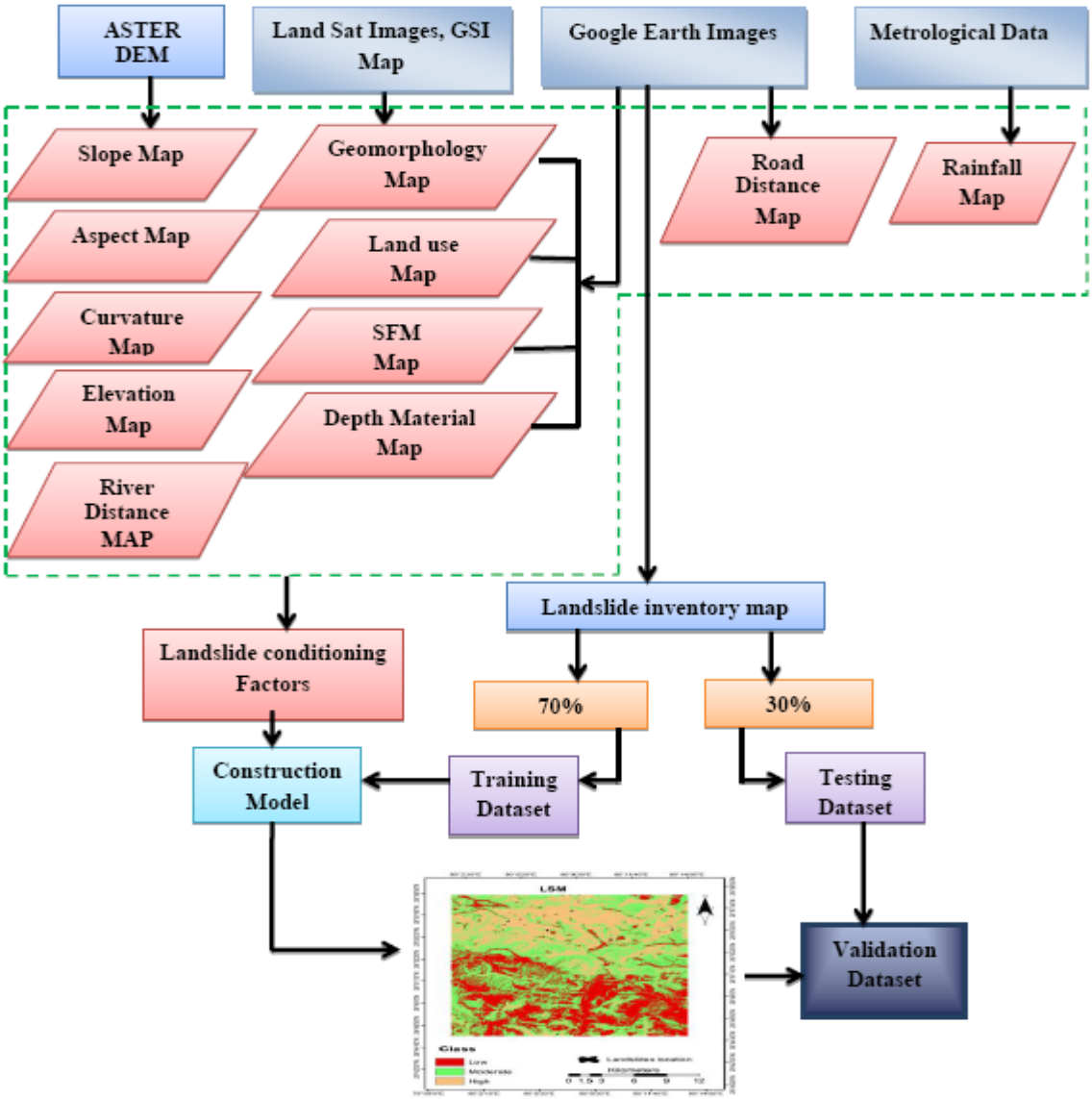


Figure 2. Methodology adopted in present study

METHODOLOGY

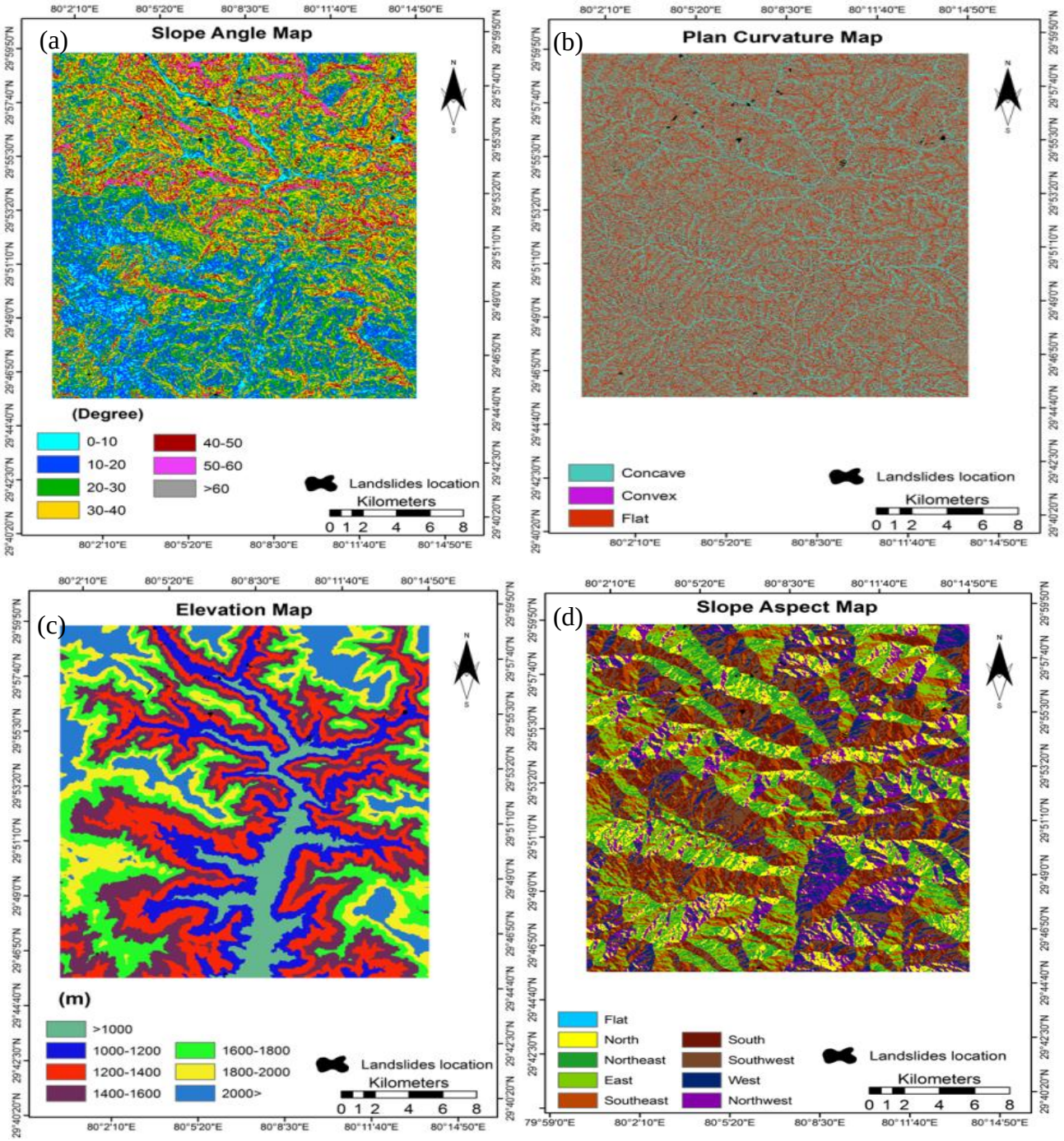
Development of landslide susceptibility in the present study area has been carried out in five main steps (Fig. 2): (1) data collection, (2) preparation of landslide inventory map, (3) determination of the landslide conditioning factors, (4) application of frequency ratio model (5) development of landslide susceptibility map, (6) Validation.

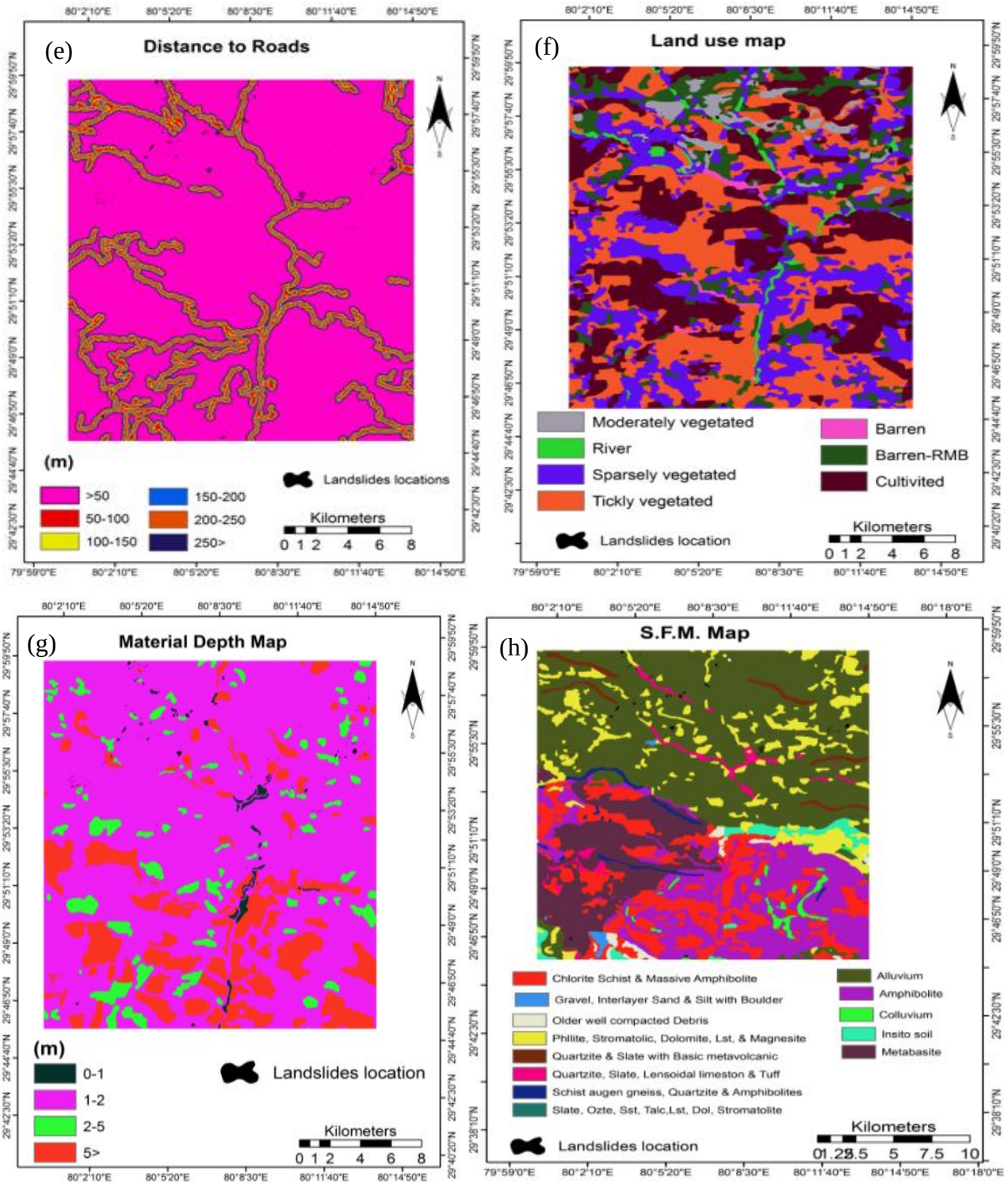
Data collection and analysis

The data for the development of landslide susceptibility map was collected and extracted from the Aster Digital Elevation Model (DEM), Land Sat Images, Geological Survey of India (GSI) reports and Google Earth images, and Indian Meteorological Department (IMD).

Preparation of landslide inventory map

Landslide inventory map was constructed with 276 landslide locations identified using interpretation of Google Earth images. These landslide locations were validated from historical landslide reports, and field data of GSI.




(e)
Distance to Roads
(m)
>50
50-100
100-150
150-200
200-250
250>
Landslides locations
Kilometers
0 1 2 4 6 8
(f)
Land use map
Moderately vegetated
River
Sparsely vegetated
Tickly vegetated
Barren
Barren-RMB
Cultivited
Landslides location
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0 1 2 4 6 8
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Material Depth Map
(m)
0-1
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5>
Landslides location
Kilometers
0 1 2 4 6 8
(h)
S.F.M. Map
Chlorite Schist & Massive Amphibolite
Gravel, Interlayer Sand & Silt with Boulder
Older well compacted Debris
Phllite, Stromatolic, Dolomite, Lst, & Magnesite
Quartzite & Slate with Basic metavolcanic
Quartzite, Slate, Lensoidal limeston & Tuff
Schist augen gneiss, Quartzite & Amphibolites
Slate, Ozte, Sst, Talc,Lst, Dol, Stromatolite
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Metabasite
Landslides location
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0 1.25 2.5 5 7.5 10

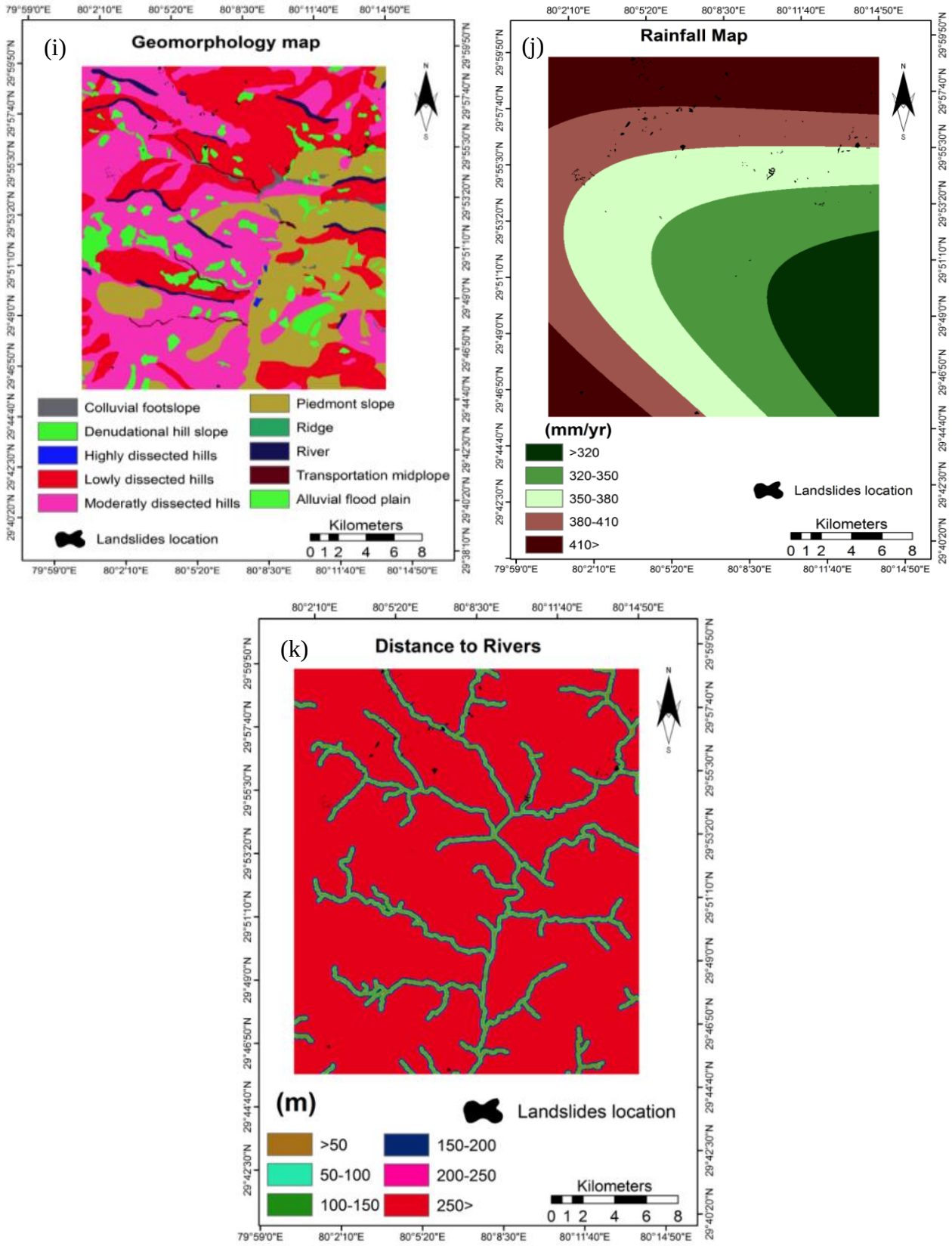

Figure 3. Landslide affecting factor maps :(a) slope angle map, (b) curvature map, (c) elevation map, (d) slope aspect map, (e) Distance to river map :(f) land use map, (g) depth material map, (h) SFM map, (i) Geomorphology map, (j) rainfall map, (k) distance to road map.

Landslide conditioning factors

Landslide conditioning factors such as (slope angle, slope aspect, elevation, curvature, land use, geomorphology, depth material, slope forming material, and rainfall) have been taken into account to evaluate the spatial relationship between them and landslide occurrences in the study area. Slope angle map, slope aspect map, elevation map, curvature map, and distance to river have been constructed using aster DEM (Digital elevation model) (Fig. 3a, b, c, d, e). Land use map, depth material map, SFM map, geomorphology map have been constructed using land sat image and Google images (Fig. 3f, g, h, i). Rainfall map has been generated based on spline interpolation method using meteorological data (Fig. 3i).and finally distance to road map has been constructed by Google images (Fig. 3j).

Application of Frequency Ratio for Landslide Susceptibility Mapping

Frequency Ratio (FR) is a statistic approach that has been applied to evaluate landslide susceptibility in this study. The FR model is an observation-based approach for the preparation of landslide susceptibility maps [3]. For construction of FRM landslide conditioning factors and training data set were used. The mathematical representation of FR is as follows [3]:

$$FR = \frac{N_i^p / N}{N_i^{lp} / N^l} \quad (1)$$

Where N_i^p is the number of pixels in each landslide conditioning factor class, N is the number of all pixels in total the study area. N_i^{lp} is the number of landslide pixels in each landslide conditioning factor class, N^l is the number of all landslide pixels in total the study area (Table 1).

Table 1 Landslide conditioning factors and its Frequency Ratio values

Data layers	Class	Pixels	% Class Pixels	Landslide pixels	% Landslide Pixels	FR
Slope aspect	Flat (-1)	16	0.003	0	0.000	0.000
	North (0-22.5 and 337.5-360)	74691	11.974	19	3.310	0.276
	North-east (22.5-67.5)	76986	12.342	41	7.143	0.579
	East (67.5-112.5)	73378	11.764	100	17.422	1.481
	South-east (112.5-157.5)	81870	13.125	165	28.746	2.190
	South (157.5-202.5)	93080	14.922	140	24.390	1.634
	South-west (202.5-247.5)	87938	14.098	83	14.460	1.026
	West 247.5-292.5)	66851	10.717	12	2.091	0.195
	North-west (292.5-337.5)	68956	11.055	14	2.439	0.221
Curvature	Concave (<-0.05)	305530	49	340	59.233	1.209
	Flat (-0.05-0.05)	20060	3	11	1.916	0.596
	Convex (<0.05)	298176	48	223	38.850	0.813
Elevation(m)	725-1000	45684	7	37	6.446	0.880
	1000-1200	89631	14	214	37.282	2.595
	1200-1400	126107	20	186	32.404	1.603
	1400-1600	127655	20	103	17.944	0.877
	1600-1800	104338	17	31	5.401	0.323
	1800-2000	72879	12	0	0.000	0.000
	2000-2651	57472	9	3	0.523	0.057
Slope angle (degree)	0-10	40667	6.5196	5	0.871	0.134
	10-20	146786	23.53	62	10.801	0.459
	20-30	188967	30.294	150	26.132	0.863
	30-40	15841	25.400	260	45.296	1.783
	40-50	71085	11.396	83	14.460	1.269
	50-60	17819	2.8567	14	2.439	0.854
	60>	1	0.0002	0	0.000	0.000
Depth material	>5	502	1	3	0.523	0.774
	0-1	57082	77	539	93.902	1.222
	1-2	4810	6	17	2.962	0.457
	2-5	11902	16	15	2.613	0.163

Geomorphology	Alluvial flood plain	463	0.6232	1	0.174	0.280
	Colluvium foot slop	3632	4.8886	96	16.725	3.421
	Denudation hill slope	73	0.0983	1	0.174	1.773
	Highly dissected hills	22448	30.214	302	52.613	1.741
	Lowly dissected hills	28435	38.272	166	28.920	0.756
	Moderately dissected hills	15085	20.303	5	0.871	0.043
	Piedmont slop	58	0.0781	0	0.000	0.000
	Ridge	1538	2.0701	0	0.000	0.000
	River	389	0.5236	3	0.523	0.998
	Transportation mid slope	2175	2.9275	0	0.000	0.000
Land use	Barren	2296	3.0903	252	43.902	14.20
	Barren (RBM)	1241	1.6703	4	0.697	0.417
	Cultivated land	18270	24.590	88	15.331	0.623
	Moderately vegetated	24024	32.335	79	13.763	0.426
	River	548	0.7376	0	0.000	0.000
	Sparsely vegetated	8573	11.539	146	25.436	2.204
	Tickly vegetated	19344	26.036	5	0.871	0.033
SFM	Slate,Qzte, sst, Talc, Dol, Stormatolite	31574	42.500	499	86.934	2.045
	Schist AugenGneiss,Qzte,&Amphibolites	11787	15.866	37	6.446	0.406
	Insitu soil	9999	13.459	0	0.000	0.000
	Amphibolite	700	0.9422	2	0.348	0.370
	Gravel, interlayered sand and silt with boulder	214	0.2881	0	0.000	0.000
	Phyllite, Stromatolitic Dolomite, Lst and Magnesite	1142	1.5372	0	0.000	0.000
	Qzte, & slate with basic metavolcanics	8792	11.834	0	0.000	0.000
	Quartzite, slate, Lensoidal Lst and tuff	570	0.7673	2		0.000
	Colluvium	6592	8.8732	25	4.355	0.491
	Older, well compacted Debris	939	1.2639	0	0.000	0.000
	Metabasite	1290	1.7364	9	1.568	0.903
	Alluvium	641	0.8628	0	0.000	0.000
	Chlorite schist and massive Amphibolites	51	0.0686	0	86.934	2.045
Distance to river(m)	0_50	2934	3.9491	21	3.659	0.926
	50-100	2822	3.7983	59	10.279	2.706
	100_150	2782	3.7445	58	10.105	2.699
	150_200	2690	3.6207	53	9.233	2.550
	200_250	2669	3.5924	54	9.408	2.619
	250>	60399	81.295	329	57.317	0.705
Distance to road (m)	0_50	4213	5.6706	37	6.446	1.137
	50_100	3687	4.9626	16	2.787	0.562
	100_150	3384	4.5548	2	0.348	0.076
	150_200	3124	4.2048	2	0.348	0.083
	200_250	2885	3.8831	4	0.697	0.179
	250>	57003	76.724	513	89.373	1.165
Rainfall (mm)	<320	82534	13.231	0	0.000	0.000
	320-350	141637	22.706	12	2.091	0.092
	350-380	156866	25.148	111.000	19.338	0.769
	380-410	124276	19.923	345.000	60.105	3.017
	>410	118453	18.990	106.000	18.467	0.972

Landslide susceptibility mapping

Landslide susceptibility map has been constructed by calculating and classifying Landslide Susceptibility Indexes (LSI) for whole study area. LSI indicates the degree of susceptibility of area to landslide occurrences. Areas with smaller LSI indicate less susceptibility to landslide occurrence. LSI has been calculated based on the FR values that have been determined in training process (Table1). The calculation of LSI is shown in Eq. (2) [3]:

$$LSI = \sum_{i=1}^{11} FR_i \quad (2)$$

The above formula consist the summation of eleven factors, (slope, elevation, aspect, curvature, geomorphology, land use, depth material, SFM, distance to river, distance to road, and rainfall map). The calculated Development of Landslide Susceptibility Index (DLSI) values ranges from (2.618 to 17.910) (Fig. 4) The map has been classified into three classes: Low, Moderate and High.

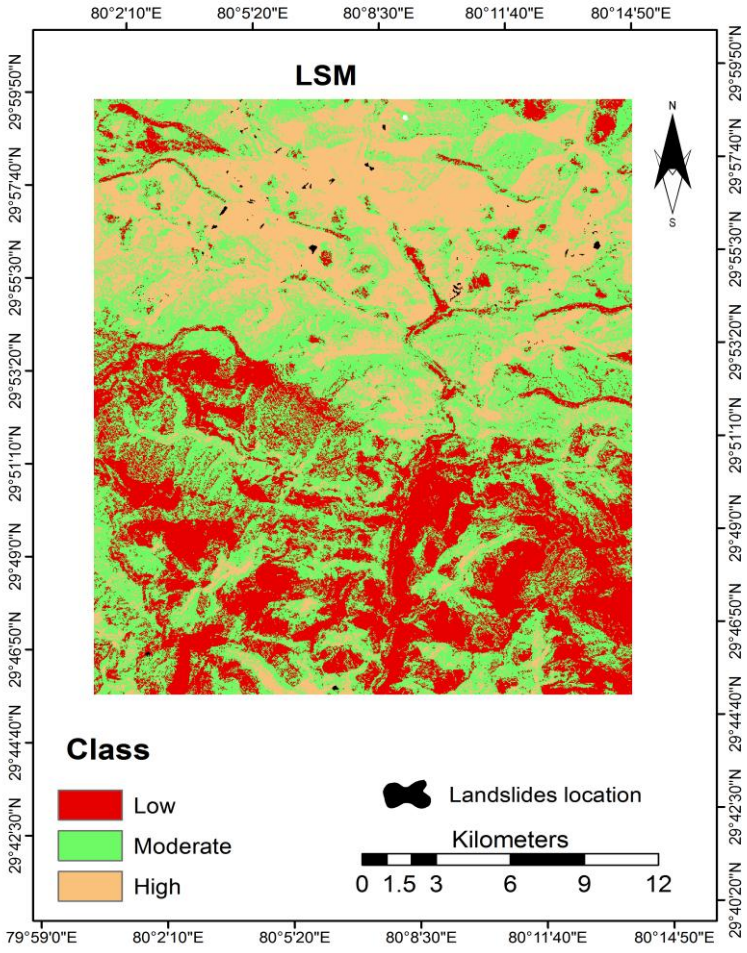

Figure 4. Landslide susceptibility map of the study area using the FR model

Validation of Frequency Ratio Model

The performance of the FR model was evaluated using the Landslide Density Index (LDI). For validation, landslide area which has not been used for the construction of model is generally considered as the future landslide area. In this study, all landslides (polygons) were divided into two parts (70% for modeling and 30% for validation). Landslide Density (LD) Index was used to validate the model which is a ratio between the percentage of landslide pixels and the percentage of class pixels in each class on landslide susceptibility map (Pham etal. 2016). The calculation result of LDI is shown in Table 2.

Table 2 The performance of the FR model using LD

Class	LSI	% Pixels	%Landslide	Landslide Density
Low	2.433-7.91	28.5	7.06	0.248
Moderate	7.91-10.44	27.88	12.27	0.44
High	10.44-15.4	43.66	80.67	1.85

RESULT AND CONCLUSIONS

Landslide susceptibility assessment at a part of Uttarakhand Himalaya, India has been carried out using Frequency Ratio (FR) model considering socioeconomic dimension of landslides. Landslides can cause destruction of land resources, forest, agriculture, fisheries, communication, industries and pollution of drinking water. Therefore, development of landslide susceptibility map is desirable for the proper development and management of landslide prone areas. In view of this, a total of 276 landslide locations were utilized to construct landslide inventory map. Eleven landslide conditioning factors (slope angle, slope aspect, elevation, curvature, land use, geomorphology, depth material, SFM, distance to river, distance to road and rainfall) were taken into consideration for evaluation of the spatial relationship between these factors and landslide occurrences. The performance of the FR model was validated by Landslide Density Index. The result shows that Low, Moderate and High values of landslide susceptibility map are comparable with the Landslide Density Index. The study confirmed that the FR model is an effective method for landslide susceptibility assessment of hilly and mountainous areas for landslide hazard management.

ACKNOWLEDGEMENT

The first author is thankful to the ICCR, Government of India for providing financial assistance for carrying out this research. Second author is thankful to the BISAG for providing financial assistance. Authors are also thankful to the Director, Bhaskaracharya Institute for Space Applications and Geoinformatics (BISAG), DST, GOG, Gandhinagar for providing facilities for this research project.

REFERENCES

[1] Guzzetti, Fausto, et al. "Probabilistic landslide hazard assessment at the basin scale." Geomorphology 72.1-4 (2005): 272-299

[2] Geertsema, M., Highland, L., Vaugeouis, L., 2009. Environmental impact of landslides, Landslides–Disaster Risk Reduction. Springer, pp. 589-607.

[3] Pham BT, Tien Bui D, Prakash, I, Dholakia M (2015) Landslide susceptibility assessment at a part of Uttarakhand Himalaya, India using GIS–based statistical approach of frequency ratio method International Journal of Engineering Research and Technology 4:338-344

[4] Regmi AD, Devkota KC, Yoshida K, Pradhan B, Pourghasemi HR, Kumamoto T, Akgun A (2014) Application of frequency ratio, statistical index, and weights-of-evidence models and their comparison in landslide susceptibility mapping in Central Nepal Himalaya Arabian Journal of Geosciences 7:725-742

[5] Regmi NR, Giardino JR, Vitek JD (2010) Modeling susceptibility to landslides using the weight of evidence approach: Western Colorado, USA Geomorphology 115:172-187

[6] Ohlmacher, G.C., Davis, J.C., 2003. Using multiple logistic regression and GIS technology to predict landslide hazard in northeast Kansas, USA. Engineering geology, 69, 331-343.