Remote Sensing Data and GIS Application for Landslides Mapping: A Case Study from India

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 Vol. 28/2018, 1-13

ABSTRACT: Landslide is a major hydrogeological hazard that affects large parts of Himalayan area of Uttarakhand state in India. The developments in Geo-spatial technologies have opened the doors for detailed and accurate assessment of landslide prone area. This paper deals with a use of temporal remote sensing data and geographical information systems for landslide mapping. Six categories of controlling factors for landslides i.e. slope gradient, aspect, lithology, land use land cover (LULC), drainage density, lineament density are defined in this study. Normalized Difference Vegetation Index (NDVI) has been generated to identify the vegetated and non-vegetated area. During the study, it is clearly revealed that a total number of about 695 landslides spots covering an area of 2.30 sq. km. were mapped from Landsat-OLI-TRS image of 2015 whereas a total number of 157 landslides covering an area of 1.60 sq. km. were mapped from Landsat-ETM+ image of the year 2005. This study is valuable for hazard zonation, mitigation purpose and regional planning in the Himalayan area.

KEY WORDS: Landslide, remote sensing, GIS, Landsat, NDVI, Himalaya.

1. Introduction

Landslides are one of the major natural hazards that account for hundreds of lives besides enormous damage to properties and blocking the communication links every year (Onagh et. al., 2012a and 2012b) and referred to as significant geomorphic processes which usually form an important landscaping aspect in humid tropical mountain surroundings (Thomas, 2001). In such areas, landslide susceptibility mapping is very essential to delineate the landslide prone area. Landslide inventory maps show locations and also features of landslides that have moved in the past although usually do not show the mechanism that triggered them. Therefore, inventory maps provide useful information about the spatial distribution of locations of existing landslides and the potential for future landslides. Recently, landslide susceptibility mapping has been made possible due to the accessibility and variety of remote sensing data and thematic layers as causative factors data using GIS. The spatial and temporal thematic information derived from remote sensing, thematic maps and ground-based information needs to be integrated. Preparation of a landslide inventory relies on the main assumptions (Guzzetti et. al., 2012) i.e. landslide events leave visible marks on the territory, hence visual image interpretation of (stereoscopic) aerial photographs, satellite images, or digital representations of the topographic surface may help the recognition process. Accurate detection of the location of landslides is very significant for probabilistic landslide hazard study. The applications of remote sensing methods are used to find noteworthy and cost-effective information on landslides (Rai et. al., 2014).

Predicting hazardous events like landslides are particularly difficult because no laboratory exists that can preliminarily measures the necessary variables, refine the techniques, and apply the results (Dattilo and Spezzano, 2003). Most of the terrain in mountainous areas has been subjected to slope failure at least once, under the influence of a variety of causative factors and triggered by events such as earthquakes or extreme rainfall. With reference to their impact on society, landslides can be considered as high frequency natural hazard as compared to other natural calamities like earthquakes, floods and volcanic eruptions. Mitigation of landslides disasters can be successful only when detailed knowledge is obtained about the expected frequency, character, and magnitude of mass movement in the area. Landslide inventory mapping is the simple method in which the landslide events are recorded for their location and dimension (Dai and Lee, 2001; Dai et. al., 2002; Fall et. al., 2006).

Many researchers have evaluated landslide hazard using GIS (Gokceoglu and Aksoy, 1996; Burton and Bathurst, 1998; Larsen and Torres-Sanchez, 1998; Nagarajan et. al., 1998; Turrini and Visintainer, 1998; Jibson et. al., 2000; Dai et. al., 2001; Pandey and Dubey, 2002; Pandey et. al., 2005; Lineback Gritzner et. al., 2001; Lee et. al., 2002; Saha et. al., 2002; Onagh et; al., 2012a and 2012b, Rai et. al., 2014).

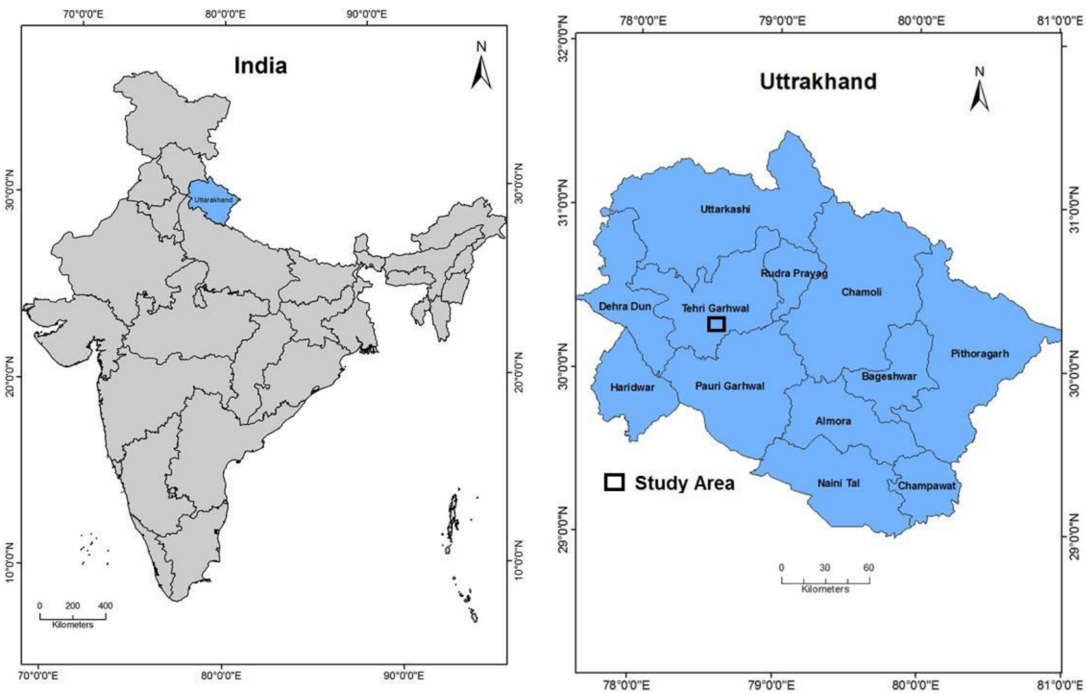

Figure 1 Location of the study area.

To forecast the future landslides in an area, comprehensive knowledge of causative factors of land sliding is necessary. Therefore to evaluate the change dynamics of landslides, analysis pertaining to past and present day landslides incidence over various terrain parameters need to be done.

In the present study landslides incidence over different selected terrain parameters i.e. lithology/geological, lineament density, land use land cover (LULC), slope etc. have been evaluated using GIS techniques based on mapping of landslides on Landsat images of the year 2005 and 2015. For landslide hazard zonation five relative classes, namely Very Low (VL), Low (L), Moderately (M), High (H) and Very High (VH) were considered in the study.

2. Study area

The area under study forms a part of Garhwal Himalayas and lies within longitude 78°13.5'-78°29.3' E and latitude 30°21.2' - 30° 34.6' N covering about 526.58 sq. km area in the state of Uttrakhand (Fig. 1). The Bhagirathi river, the main tributary of the Ganges river flows through the area on which Tehri dam is situated. The key townships in the area are New Tehri town and Chamba. The area receives heavy precipitation during the summer months between July and September and moderate rainfall during the winter months between Januarys to March. Elevation in the area ranges between 950 to 3850 m with respect to mean sea level and annual rainfall is approx. 1015.83 (mm). The area is transacted by a major National Highway connecting Uttarkashi and Gangotri in Uttarakhand state, India. The significant geomorphological feature in the study area comes under less dissected denudational hills whereas the minimum area is covered by River Terrace. It is interestingly seen that the Pratapnagar quartzite covers an area of about 64.21 sq.km, while Nagthat quartzite, Chandpur phyllites, Chandpur phyllites (schistose) and alluvium covers 33.24 sq.km., 217.34 sq.km. and 13.65 sq.km. respectively.

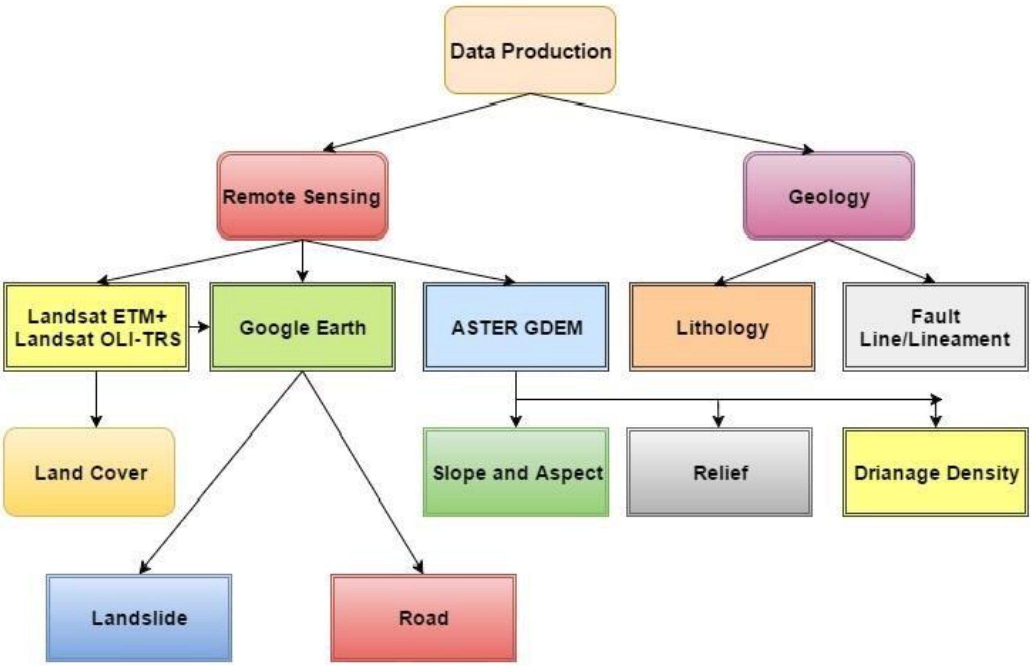

Figure 2 The elements and products of the study in data production process for Landslide mapping.

3. Data Used and Methods

In the present study, landslides mapping was done using satellite images of Landsat ETM + and OLI-TRS sensors acquired in October 2005 and October 2015 respectively.

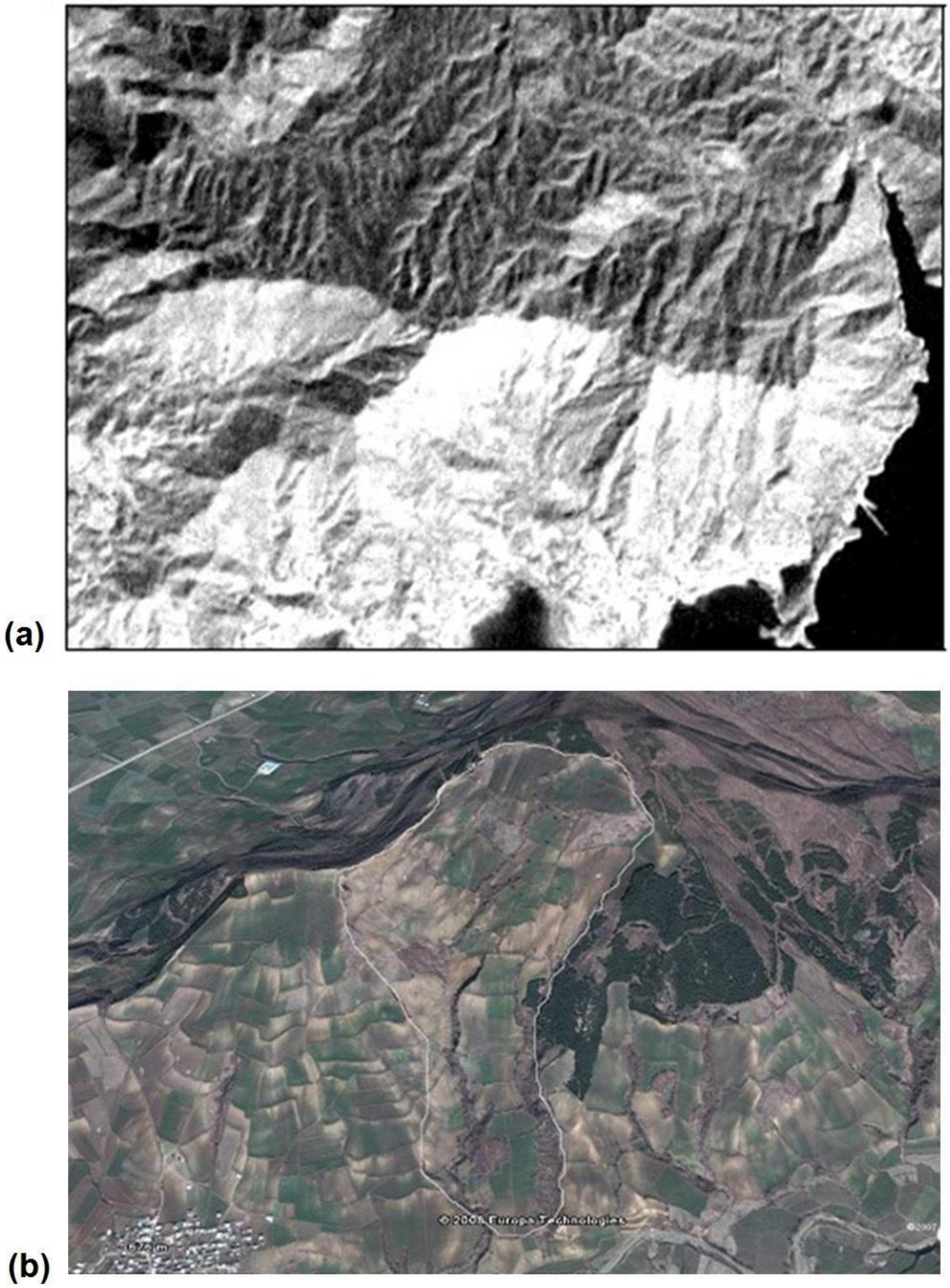

Figure 3 (a) A view of NDVI image showing healthy vegetation (bright white tonal areas); and (b).

ASTER-GDEM is also used in this study. Use of Digital Elevation Model (DEM) is of immense importance in landslide hazard assessment. Several thematic data layers such as slope angle, slope aspect, lineaments, drainage, ridges etc. can be extracted from DEM with good resolution. The basic image interpretation keys like shape, size, texture, contrast and morphological expression were used as important parameters for the mapping of landslides. The spatial resolution of the Landsat ETM+ image is 28.5m, which enable mapping of large landslide prone area. The similarity of tones over landslides and built up are made it difficult to discriminate between them at number of locations where landslides occur in the vicinity of build up lands. Therefore, image enhancement techniques were used to enhance landslides from built-up and agriculture lands by creating Principal Component Images (PCA) in ERDAS imagine software. The PCA-1 image shows good discrimination between landslide, vegetation and built-up land due to change in texture between these LULC classes.

ERDAS Imagine-10 was used for image processing of Landsat ETM + and OLI-TRS images in lineament analysis, NDVI and land use land cover (LULC) classification. ARC GIS-10.3 and Global Mapper were used for data acquisition, analysis and presentation of the final research results. The thematic layers of all predictive factors and existing landslides were prepared in GIS platform. Mainly DEM based derivates and field data were used to prepare data layers of predictive factors.

Google earth imagery and National Geographic Organization topographic maps on a scale of 1:50,000 of the study area were used to digitize landslide, land cover types, boundaries and other features such as roads, etc. Landsat data is used for visual interpretation for delineation of landslides. It is observed that due to coarse spatial resolution (28.5m) of the Landsat image, a number of small landslides in the area were not very well interpreted.

Landsat data has visual, near-infrared and mid-infrared bands. Mid-infrared bands (Band 5 and Band 7) are sensitive to canopy moisture content and may be linked to vegetation type and canopy structure and are useful to establishing vegetation indices that identify burned or stressed vegetation (Bannari et. al., 1995; Fraser et. al., 2000). NDVI is also estimated in this study.

The formula for producing NDVI using LANDSAT bands is as follow:

$$NDVI = (Band\ 4 - Band\ 3)/(Band\ 4 + Band\ 3) \qquad (1)$$

NDVI values range from -1 to +1, with higher values indicating denservegetation. The higher the NDVI value, the denser the vegetation (Rai et. al. 2012; Rai et. al. 2013; Singh and Rai, 2017). A number of thematic features based on specific parameters which are related to the occurrence of landslides, viz. slope, aspect, lithology, land use land cover etc. have been used. The elements and products of the study in data production process for Landslide mapping is given in the Fig. 2. The existing location and distribution of landslides in the study area during 2005 and 2015 are shown in Fig. 4a.

4. Results and Discussion

The study of landslides from two different periods using satellite imagery is very useful in understanding the change in spatial distribution pattern of landslide occurrences over a period of time. By comparative study of landslide distribution in temporal data one can understand the landslides dynamics as well as the relationship between changing landslides incidence with reference to the different terrain parameters. Apart from this, the effect of human activity on triggering of landslides can also be evaluated by studying landslides dynamics with reference to human activities like road network, infrastructure development and land conversion for agricultural activity.

To study the temporal changes in landslides, remote sensing images of Landsat ETM+ sensors for the year of 2005 and 2015 have been used in the present study. The total area of landslides mapped from Landsat OLI-TRS image of 2015 was 2.30 sq. km in comparison to 1.60 sq. km of landslide area mapped from Landsat ETM+ satellite image of 2005. In terms of landslide incidence the number of landslides in area increased from 157 during 2005 to 695 in 2015 indicating 77.41% increase in landslide incidence during 2005 to 2015.

The number of landslides identified during 2005 and 2015 were analyzed with reference to mapped topographic parameters in the area. The percent wise changes of landslide incidence during 10 years have been calculated to understand the intensity of landslides incidence over numerous landslide inducing landscape parameters.

Lithology is a key parameter conditioning landslide occurrence because different lithologic units have different sensitivities to active geomorphological processes such as landslides (Carrara et. al., 1991). It is seeming that in all the lithological units there is a substantial increase in landslide incidence over a period of about 10 years (Table 1). Four rock formations (i.e. Nagthat quartzite, Chandpur Phyllites, Alluvium Deposit, Pratapnagar Quartzite) show a decadal increase of more than 80% except Blaini Bolder Bed (50%), Bhelunta limestone (54.76%), Bhainga Slate (66.66%) and Chandpur phyllites (77.57%). Alluvium has witnessed an increase in landslides incidence possibly due to construction on new transportation network in the mountainous areas and due to this soft material activated landslides in every rainy season.

NDVI image generated using equations (1) is presented in the Fig. 3a. Healthy vegetation shows higher values in the NDVI image, but from the index values, it is difficult to discriminate between healthy vegetation and the disturbed vegetation types (Fig. 2a).

Land use is also one of the key factors responsible for the occurrence of landslides, since, barren slopes are more prone to landslides. The study area were classified in crop land, degraded forest, dense forest, forest blank area, open forest, built-up area, scrub land (Fig. 4b and Table 2). LULC of the study area is shown in the Fig. 4b. In contrast, vegetative areas tend to reduce the action of climatic agents such as rain, etc., thereby preventing the erosion due to the natural anchorage provided by the tree roots and, thus, are less prone to landslides (Gray and Leiser, 1982; Dahal et. al., 2008). Those area where growth of natural vegetation is vital in influencing slope stability due to better bonding of the slope material. Thus, slopes gradient with dense vegetative cover should be less prone to the occurrence of landslides incidence than barren slopes, while all other parameters remain constant. Majority of the LULC classes have observed an increase in landslide incidence by more than 50% except dense (33.33%) and degraded forest (50 %). It is interesting to note that only one incidence of landslide is identified in scrub land in 2015 whereas the highest increase is observed over agricultural lands (82.66%). High increase of landslide incidence in agricultural areas could be attributed to human interferences, low foliage cover and high sheet erosion during heavy rainfall time periods.

Lineaments signifying the faults, fractures, shear zones, etc., are the utmost noticeable structural interpretations on the remote sensing data and also control the occurrence and movements of ground water in hard rock terrain. A lineament map was prepared by visual interpretation of the Landsat data by identifying the fractures and fault lines (Fig. 4d). Using lineament data, the lineament density were calculated. From the calculation, it was recognized that the majority of the study area falls under very low lineament density category followed by low, medium density, high and very high. High and very high lineament density are seen as small patches, which are distributed mostly along the foothills of the study area. The lineament density is categorized in to five classes i.e. very high, high, moderate, low and very low as show in the Fig. 4c and Table 3. Decadal percent increase of landslide is also shown in the Table 3. The calculation shows that about 80.76% decadal percent increase of landslide in the low lineament density area changes of landslide while 50% landslide occurrences were seen in the high and very high landslide density zone. Slightly, high landslides occurrence corresponds to thrust fault type of lineament as revealed by higher landslide density in the zone of thrusts in the study area. Plate 1 shows the field photgraph of landslide incidences in Uttarakhand Himalayan region.

During the study, it is very well interpreted through remote sensing data that the geomorphic units i.e. dissected structural, river terrace hills were observed more than 88% decadal percent increase in landslide occurrence except in dissected denudational hills. Landslide incidence in structural hills with hard rocky terrain has increased perhaps due to excessive human interferences and road constructions in the area. Deforestation is also an improtant cause of land slide incidences in the study area.

Values of drainage density (Dd) show the stages of geomorphic development of concerned area. Lower values designate old stage and higher values specify early mature to youth stage of geomorphic development. Usually, low 'Dd' is found in regions of highly resistant or highly permeable subsoil materials, under dense vegetation cover and low relief. And high 'Dd' is preferred in regions of weak or impermeable surface materials, sparse vegetation and mountain relief. It is to observed that the very low and low 'Dd' were seen more landslides incidence i.e. 87.34% and 84.49% respectively whereas high 'Dd' classes have shown only about 38.63% increase. Very high and high 'Dd' corresponds to hard rock topography in high altitude with high terrain dissection due to more drainage cutting across the topography hence not being targeted for road network expansion, therefore have less increase in landsides incidence. On the contrasting, low 'Dd' shows more sheet flows, more saturated top soil cover which moves down slopes throughout heavy rainfall time periods. In area which have intense gully erosions on both down and up slope of the road cut side retaining wall construction is required after clearing the rocks and debris fallen on the road, besides, proper drainage on the upper slope sections must be provided.

The slope angle was measured the key parameter of the slope constancy (Lee and Min, 2001); it was normally used in preparing landslide susceptibility analyses (Anbalagan, 1992; Pachauri et. al., 1998; Saha et. al., 2002; Yalcin, 2008) as the shear stress increases with progressive inclination. During the analysis, it is shown that the highest landslide incidence is identified over very high slope category (85.71%) and less in low slope category (52.58%). About 80.10% increase in the landslide has seen in very low slope category during 10 years which specifies human interest to very low and low gradient area for LULC changes for agricultural practices and building construction in the area (Table 5). Slope gradient classes of the study area are shown in the Fig. 4e. Like slope, aspect is one of the significant parameters in preparing landslide susceptibility maps (Carrara et. al., 1999; Guzetti et. al., 1999; Saha et. al., 2002; Cevik and Topal, 2003; Ercanoglu et. al., 2004; Lee et. al., 2004; Lee, 2005; Yalcin, 2008). North (N), North-West (NW), East (E), South-East (SE) aspect were observed more landslide occurrences (>82%) whereas North-East (NE), South (S), South-West (SW) & West (W) aspects were relatively low increase in landslides rate (<82%). In the study area, majority of the elevation categories have noticed decadal percent increase in landslide incidence by more than 85% except in the case of relief class <950m (70.10%) and 1850m -2150m (63.15%).

Table 1 Changes of Landslides (2005-2015) for Lithology.

Lithology	Landslides (2015)	Landslides (2005)	Increase in Landslide Area (%) from 2005-2015
Blaini Bolder Bed	4	2	50.00
Nagthat quartzite	123	24	82.48
Chandpur Phyllites	68	14	84.40
Bhelunta Limestone	42	19	54.76
Alluvium Deposit	20	3	85.00
Pratapnagar Quartzite	157	31	80.25
Bhainga Slate	9	3	66.66
Chandpur Phyllites	272	61	77.57

Table 2 Changes of Landslides (2005-2015) for LULC

LULC	Landslides (2015)	Landslides (2005)	Increase in Landslide Area (%) from 2005-2015
Open Forest	149	47	68.45
Forest Blank	18	8	55.55
Dense Forest	18	12	33.33
Degraded Forest	2	1	50.00
Built-up area	11	3	72.72
Crop land	496	86	82.66
Scrub Land	1	0	100

Table 3 Changes of Landslides (2005-2015) for Lineament Density

Lineament Density	No. of Landslides (2015)	No. of Landslides (2005)	Increase in Landslide Area (%) from 2005-2015
Very Low	259	54	80.70
Low	286	64	77.62
Moderate	124	27	76.37
High	20	10	50.00
Very High	4	2	50.00

Table 4 Changes of Landslides (2005-2015) for Drainage Density

Drainage Density	No. of Landslides (2015)	No. of Landslides (2005)	Increase in Landslide Area (%) from 2005-2015
Very Low	79	10	87.34
Low	329	51	84.49
Moderate	242	68	71.90
High	44	27	38.63
Very High	1	1	0.0

Table 5 Changes of Landslides (2005-2015) for Slope/gradient category

Slope	No. of Landslides (2015)	No. of Landslides (2005)	Increase in Landslide Area (%) from 2005-2015
Very Low	196	39	80.10
Low	116	55	52.58

Slope	No. of Landslides (2015)	No. of Landslides (2005)	Increase in Landslide Area (%) from 2005-2015
Moderate	302	46	84.76
High	53	13	75.47
Very High	28	4	85.71

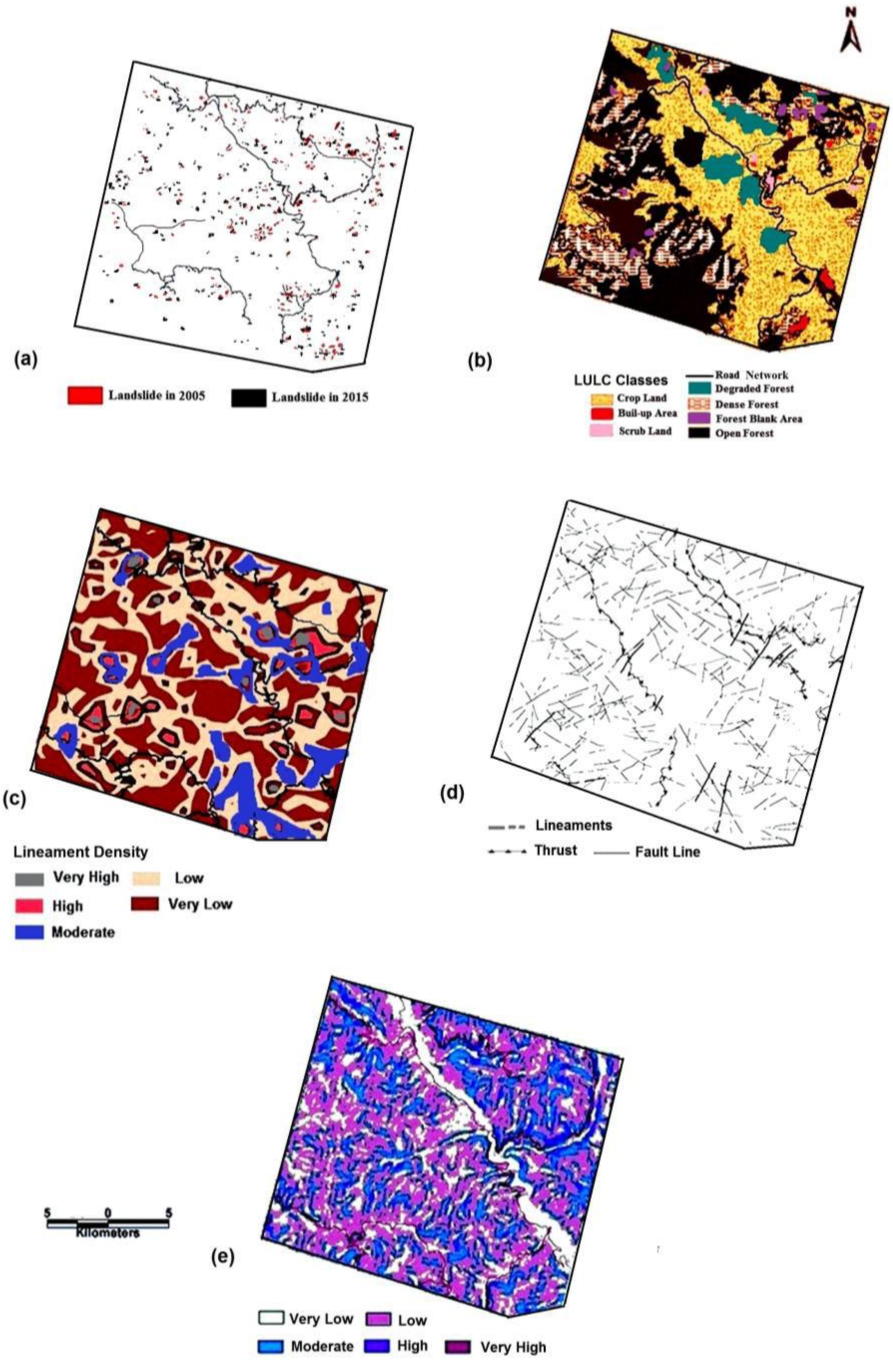

Figure 4 Selected Input thematic layers of study area: **(a)** Landslide inventory map, **(b)** LULC map, **(c)** Lineament density, **(d)** Lineament map and **(e)** Slope gradient map.

Plate 1 View of Landslides in the study area.

5. Conclusions

Landslides in mountainous areas cause enormous loss of life and property every year. The frequently occurring landslides have damaged the road sections, bridges and farmlands. In such areas, landslide susceptibility mapping is very essential to delineate the landslide prone area. The results of landslide susceptibility index revealed that the most important parameters in the occurrence of landslides were slope, aspect, and lithology and drainage density, LULC map. These parameters have higher landslide susceptibility index than the other parameters. Remotely sensed data are able to represent disturbed vegetation, denuded hill slopes, and shallow landslides in natural topography. The impacts of landslides on people and structures can be minimized by total avoidance of landslide hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity. Landslide mapping and hazard maps through remote sensing are of great help to planners and engineers for selecting appropriate locations to implement developments. These outcomes can be used as basic input to help slope management and appropriate land use planning in the high mountainous region.

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