LHZ mapping on 10K scale of Mandakini valley, Rudra Prayag district, Uttarakhand - an earth observation technology

Goyal , Swati
Gupta , Peeyush
Intergraph SG & I India Pvt. Ltd.
Gurgaon, Haryana, India
swatigis23@gmail.com, peeyushgis@gmail.com

Abstract

Himalayan terrain is characterized by predominance of high relative relief. Inherent instability of hill slopes that is attributed to geological and tectonic set up of the terrain together with high relative relief and precipitation is often aggravated by the climate change and anthropogenic activities. Himalayas represent the fragile ecosystem, which is often manifested in recurring natural hazards like landslides. Landslide is a complex geological phenomenon which is triggered by interplaying of number of factors.

The fateful event that is considered to be the worst disaster of the recent centuries, Kedarnath devastation, on June 2013 was a multi day cloudburst event followed by landslide and flash flood. In 2013 monsoon was early to arrive and it caused massive devastation particularly in Mandakini valley.

The outcomes provide the privilege of removal of relief displacement so that all ground features are displayed in their true ground positions and hence it gives the accurate estimation which increases the accuracy of research work for which these are using as the inputs. Digital elevation model, Ortho images, merge product (High resolution satellite imageries), land use/land cover, slope, aspect, settlement, lineament, geology, structural set up, geomorphology have been prepared on 10 K scale. All the prepared layers have been correlated with landslide inventory data so as to generate the LHZ map on 10k scale using Statistical approach, Advance Digital Photogrammetry techniques, Image Processing, Ground Inventory in order to accurate assessment of the vulnerable Landslide Hazard area.

This research helps immensely in decentralized planning for disaster decision support system at Panchayat level using Earth Observation technology. This is a scientific approach through which the disaster managers/planners could effectively minimize the loss of human lives, property and natural resources.

Keywords: Relief displacement, Ecosystem, DEM, Ortho, Geomorphology, Digital Photogrammetry, LHZ map.

1. Introduction:

A. Himalaya vs disaster:

The Uttarakhand Himalaya that stretches between Kali Ganga in the east and Tons Yamuna with Himachal Pradesh in the west has nearly 10% of area covered with snow, ice and glaciers which are the perennial sources of water for four major river systems viz. Yamuna, Bhagirathi, Alaknanda and Kali. The Mandakini valley which is located in Higher Himalaya in Rudraprayag district of Uttarakhand has witnessed many glaciations for many decades due to its complex topography with steep slopes with glacerised basin in the north and fluvial terraces in the central and lower parts and rain-water, snow/ice melt fed high altitude lakes. A very prominent tectonic alignment i.e. Main Central Thrust (MCT) passes through this region which makes it more vulnerable to natural hazards. The landslides, earthquakes, rock-falls, debris flows, snow/ice avalanches, flash floods, failure of high altitude natural and glacial lakes and extreme rainfall events cause widespread hazards in the area that lead to great losses to human lives and property (WIHG Report, 2013).

B. Geospatial technique and landslide:

Landslides are one of the destructive geological processes which cause not only enormous damage to roads, bridges, and houses but also lead to loss of life. Entire landscapes can be dramatically reshaped by landslides with more gradual erosion processes. Hence, there is a need for landslide susceptibility mapping for identification of potential landslide areas. Landslides are the result of complex interaction among several factors, primarily involving geological, geomorphological and metrological factors. The spatial information related to these factors can be easily derived from remote sensing data, ground based information, and several other data sources. Remote Sensing and Geographic information systems (GIS) are very powerful tool for spatial data analysis. Efficient landslide hazard zonation mapping can be carried out by combining GIS with image processing capabilities. Uttarakhand state faced an excessive damage to life, infrastructure and natural resources during 16th and 17th June, 2013. Mandakini river valley in district Rudraprayag of the state experienced maximum destruction caused by rainfall, followed by cloudbursts and flash floods. The past history of the region indicates that Mandakini valley is prone to cloudburst and flash flood (Joshi, 2001).

C. Geology and geomorphology:

The area represents the complex and highly rugged topography characterized by moderate steep slopes that are intervened by narrow valleys. Fragile geology of the study area, nearness to Main Central Thrust (MCT), degradation process and torrential rain were responsible for triggering the process of landslides and flash flood. Landslide and flash flood affected the major towns and villages i.e., Kedarnath, Gauriya, Song Chatti, Ghindur Pani, Kanchula, Rambara, Linchori, Bheem Bali, Bhanu Chatti, Jungle Chatti, Gaurikund, Mundkatiya, Sonprayag, Rampur, Sitapur, Chaumashi, Kotma, Kalimath, Vidhyapith, Semi, Kund, Kakra, Bhiri, Chandrapuri, Augustyamuni, Tilwara, Rudraprayag and adjoining areas. The main shrine kedarnath is located above 20 -25 metres of Mandakini. The temple township is located on glacial outwash deposits. A landslide hazard zonation map having five different zones ranging from very low hazard zone to very high hazard zone was prepared with an objective to create reliable database for post-disaster management and for planning developmental activities in the district. The frequency of landslide in Garhwal Himalaya varies from one place to another, depending on the underlying structures, physiographic setting and anthropogenic changes taking place. Every year, the road network in this region sustains damages at hundreds of locations, due to incidence of landslides. Cloudburst is one of the natural disasters associated with the mass wasting triggering process in Himalaya. Several areas in Himalaya are severely damaged by cloudburst followed by debris flow and consequently the death of human and animal lives (Joshi, 1997).

D. Study Area:

Rudraprayag district of Uttarakhand state covering an area of about 1982.09 sq. Km lies between latitude 30^0 12'58.132 to $30^0$48'27.642 and longitude $79^0$2'58.649 to 79^0 2'0.952 (Figure 1). The district is bounded by Uttarkashi in the north, Chamoli in the east, Tehri Garhwal in the west and Pauri Garhwal on the south. The head quarter of the district is at Rudraprayag town comprises of three tehsils viz. Ukhimath, Rudraprayag and Jakholi and three development blocks viz. Ukhimath, Augustmuni and Jakholi. The climate in this region is mainly governed by monsoon. Mandakini is the major river of the district having many tributaries. The altitude of Mandakini river catchment extends from 670 m to 6000 m from m.s.l. Ukhimath area of this district is known as Cherapunji of Garhwal.

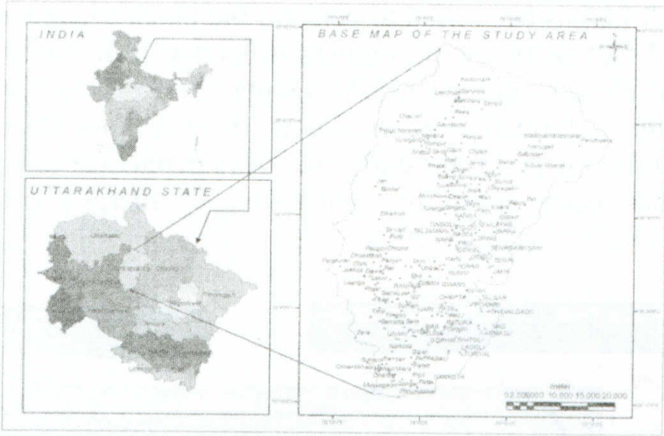


Figure 1 Location map of the study area

E. Data used:

The data used in this study were IRS-P6 (LISS IV) and IRS-P-5 (CARTOSAT-1) satellite data (Table 1), topographic maps of the Survey of India (1:25,000 and 1:50,000 scale), Carto DEM Chips (NRSC) and information from published geology map. The topographic maps, FCCs and NCCs of satellite data were used as the base maps for thematic layer generation and field data collection. Data pertaining to rock types, structural lineaments, slope, geomorphology, wasteland, land use, and landslides were collected for cross checking and improving the input data layers.

Table 1
Details of satellites data

Data	Resolution	Acq. Date	Event
LISS IV	5.8m	June 2011	Pre-event
LISS IV	5.8m	June 2013	Post-event
Catrosat 1	2.5	June 2011	Pre-event
Catrosat 1	2.5	June 2013	Post-event

(Source: Satellite data NRSC, Hyderabad)

2. Method and methodology:

The study is based upon independent field observations. ERDAS Imagine 14, LPS 14, ARC GIS 10.2.2, GEOM V1, HEC-RAS are used in the image processing, terrain generation, mapping, analysis and modelling. Study is divided into five part viz, DEM/ortho image generation, thematic mapping, LHZ mapping, cross section profile generation and rainfall and climate.

A. DEM/Ortho image Generation:

In this study latest Carto Dem Chips (Tile quality Validation, Source- NRSC, Hyderabad) used to generate DEM from Cartosat-1 stereo pairs. It is to be noted here that system corrected Rational Polynomial Coefficients (RPC) were used. Block triangulation have been performed using two stereo ortho kit products with RPC. Leica Photogrammetry Suite (LPS) 14.0 has been used to perform the block triangulation and block adjustment. It was found that accuracy of contours generated from Cartosat-1 stereo data was very accurate and close to ground height (Gupta, 2013). This Cartosat-1 stereo data can be used for height information generation at 10 m contour interval. The output product is DEM and Ortho image of the study area. Hyperspherical color space resolution merging technique has been apply for generation of merged product (Cartosat1 + LISS IV=Merged Product) (Gupta, 2012).

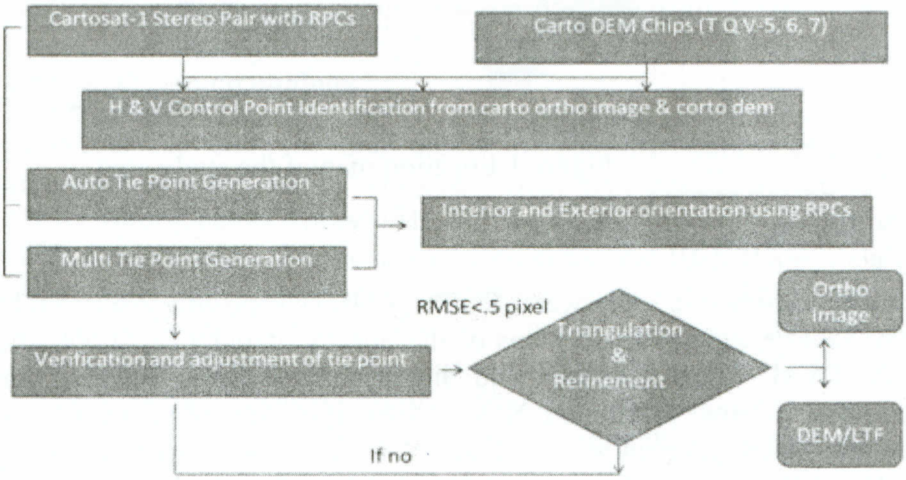


Figure 2 Flow Diagram of DEM/Ortho Image generation

B. Thematic mapping:

In this study Survey of India toposheets, Merge Product pre and post satellite data has been used. Extensive field surveys were also conducted in different phases for field check and identification of geology, geomorphology, land use/land cover, landslide, slope, aspects, drainage, lithology and lineament etc. The area is visited by the authors after all major disaster took place in Mandakini valley in the past.

Geological Setup of the region: Geological map of Mandakini Valley is shown in (Figure 3). Tectonically the Mandakini valley comprises of two separable major litho-stratigraphic units i.e. Garhwal Group and Central Crystalline Group. These groups are separated from each other by a major tectonic contact known as Main Central Thrust (MCT). This thrust contact is traceable in the area of Kund. This valley appears have undergone several phases of tectonic movements, which is depicted by local folds, faults and thrusts. The zone between Rudraprayag to Kund consists of quartz, slates, schists, crystalline limestone, dolomite, marble, gneiss and occasionally intruded by meta-volcanic of Garhwal Group. The upstream of Mandakini River from Kund to Kedarnath and Kund to Mandal, and beyond consists of various types of schists, gneisses, granites and amphibolites of Central Crystalline Group.

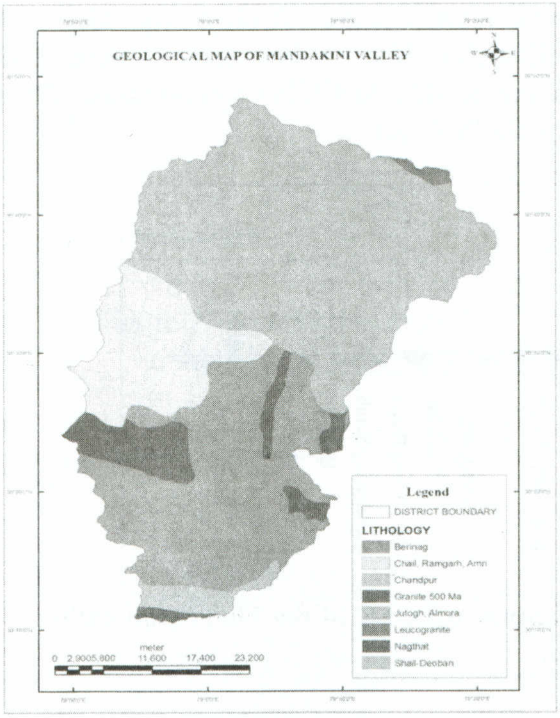


Figure 3 Geological map of the Mandakini valley

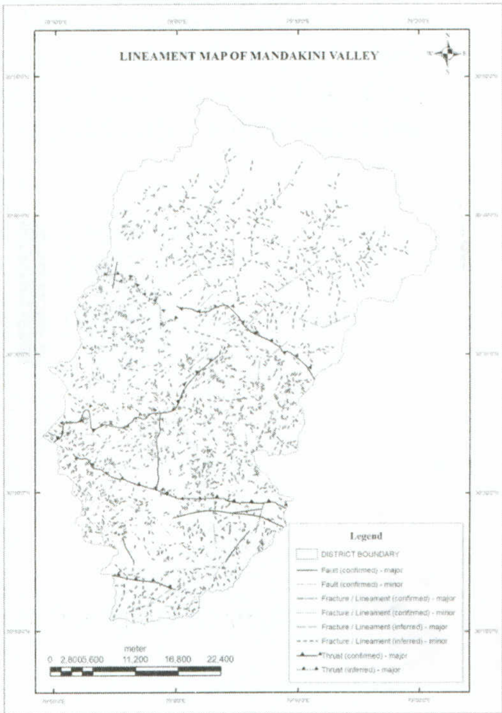


Figure 4 Structural map of the Mandakini valley

Remote sensing has proved to be a useful tool in lineament identification and mapping. Lineaments are linear or curvilinear structures on the earth surface; it depicts the weaker zone of bed rocks and is considered as secondary aquifer in hard rock regions. Lineaments in hilly terrain indicate joints, fractures, faults and other structural features of weakness (Figure 4) and therefore bear a direct relationship with the occurrence of landslides. A number of active landslides are located in the zones of faults and major lineaments in the area. The photo-lineament map was prepared using polygon mode in Arc GIS environment using high resolution ortho rectified merged product. The merged product is basis of Cartosat 1 and LISS IV imageries.

Land Use/Land Cover Pattern: In this catchment land use/land cover categories identified are forest, agricultural land, evergreen forest, alpine forest, grass land and barren land etc. Land use pattern is highly controlled by the underlying lithological types, topography and hydrology. Human settlements are mainly located in the shallow water zones or around the localities near to springs. Agricultural practices are mostly confined to areas of low relief. Forest are more frequent over steeper slopes than or moderate slopes (Figure 6). The Mandakini Valley of Rudraprayag district well forest covered area, most of the part of the valley covered non wasteland. The district very few places where degraded forest and degraded pasture in the region (Figure 7). Prominent fourteen classes of land use / land cover were identified in the study area. The land use and land cover area covered (Figure 5) i.e., Forest Evergreen/Semi Evergreen (945.80 km^2), Agricultural Land (339.28 km^2), Natural/Semi Natural Grassland & Grazing Land (190.51 km^2), Wastelands - Barren Rocky/Stony Waste (61.96 km^2), Forest - Scrub Forest (70.08 km^2), Snow Covered/Glacial Area (14.13 km^2), Water bodies - River/Stream-Dry (6.96 km^2), Tree Clad (74.92 km^2), Forest - Forest Blank (0.59 km^2), Wastelands - Scrub Land (4.31 km^2), Built Up (0.07 km^2), Forest - Deciduous (0.52 km^2), Permanent Snow (266.67 km^2) and Water bodies - River/Stream –Perennial (6.29 km^2).

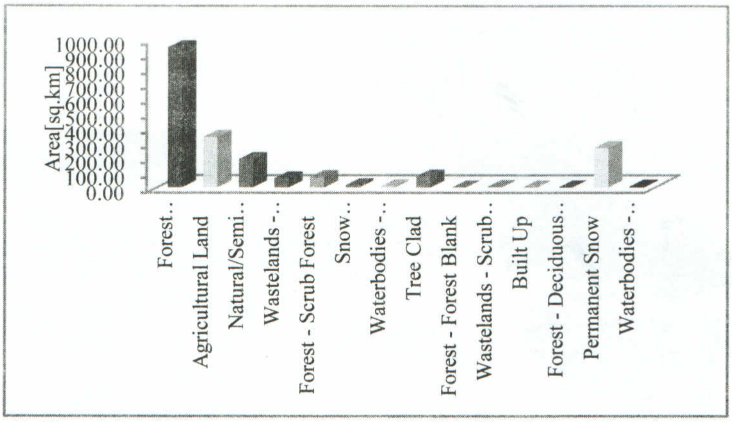


Figure 5 Graphical representations of LULC of the Mandakini valley

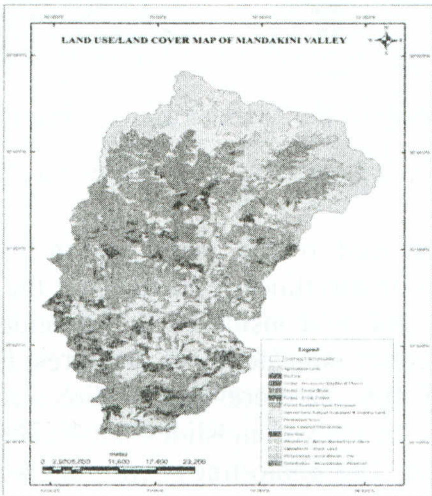


Figure 6 Land use map of the Mandakini valley

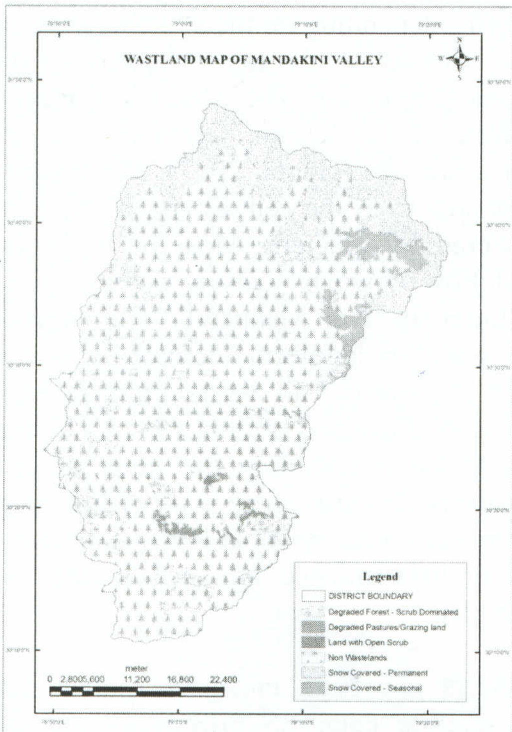


Figure 7 Wasteland map of the Mandakini valley

Figure 8 Drainage map of the Mandakini valley

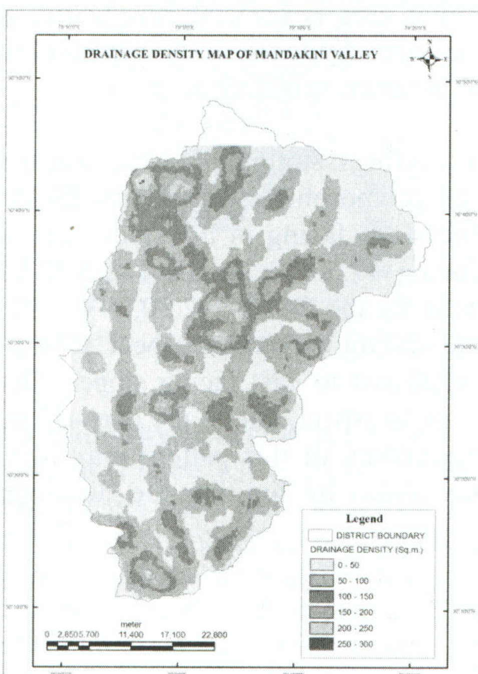


Figure 9 Drainage density of the Mandakini Valley

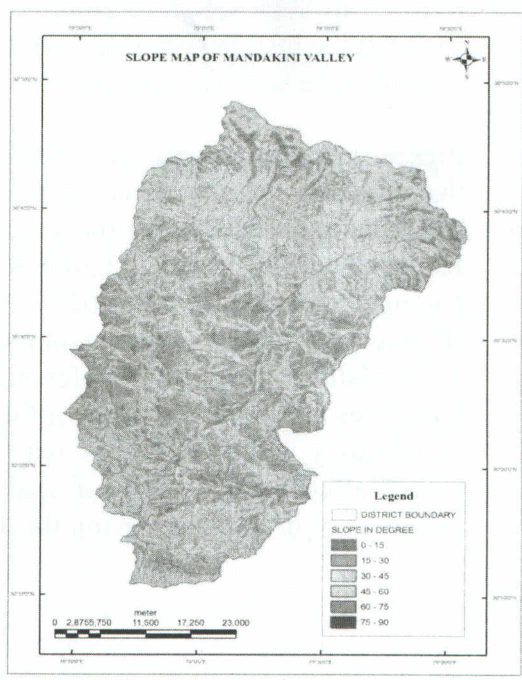


Figure 10 Slope map of the Mandakini valley

Drainage: The drainage of the study area derived from Carto DEM (10 m). The streams within a drainage basin form certain patterns, depending on the slope of land, underlying rock structure as well as the climatic conditions of the area. Majority of drainage is comprises of dendritic and radial patterns (Figure 8). The dendritic pattern develops where the river channel follows the slope of the terrain. Generally the drainage is controlled by underlying rocks and their structures (Gupta, 2013). Mandakini the main river passes through the area which originates from the central crystalline zone defined by high mountain ranges which is covered by glaciers. Most of the streams have originated from the higher altitudes and flow down by cutting deep gorges in lower altitude where they ultimately join with the main river Alaknanda. The drainage density is an important indicator of the linear scale of landform element in stream eroded topography and defines as the total length of stream of all orders/drainage area and may be an expression of the closeness of spacing of channels (Horton, 1932). The significance of drainage density is recognized as a factor determining the time travel by water (Schumm, 1956). The low drainage density is favoured in regions of highly permeable subsoil material, under dense vegetative cover where relief is low, while high drainage density is favoured in regions of weak or impermeable sub-surface materials, sparse vegetation and high mountain relief (Figure 9).

Physiography: Survey of India toposheets has been taken as spatial database on physiographic features along with the satellite data, RS GIS tools and the ground realities. The strike ridges and valleys are the result of geological structure and lithology. Likewise, steep scarps, peaks and mass wasted scree slopes are the result of denudational processes (Figure 10). Differential weathering and erosion of various rock types has resulted in such relief variation. The low relief area is basically consisting of weaker rocks like schist and phyllites, while quartzite, gneiss give rise to higher relief with sharp crested ridge because of relatively resistant to weathering and erosion.

Presence of steep scarps, deep narrow valleys, springs, straight course of streams suggest that the area is still in its youthful stage of geomorphic cycle. Carto DEM used for delineate slope aspect for the study area. The slope facing in the study area are: North Facing 337.5-22.50 NE 22.5-67.50, East Facing 67.5-112.50, SE 112.5-157.50, South Facing 157.5-202.50, SW 202.5 -247.50, West Facing 247.5-292.50, NW 292.5-337.50 (Figure 11). There is some association of land sliding with slope aspect, with a tendency for landslides to develop preferentially on southeast to east facing slopes. Deep seated landslides are less likely to be influenced by slope aspect, due to the over-riding controls of lithology and structure. A reasonable explanation of this pattern may be that slope aspect affects the density of shallow debris slides by limiting the development and thickness of drier slopes (Kimothi, 1999).

Geomorphology: The Mandakini Valley of Rudraprayag district is mountainous forming part of Westerns Himalayas. It is characterized by Himalayan topography.with a series of crisscross ridges and ravines. The altitude varies from 570 to 6930 m above msl. The Mandakini valley has moderate dissected hill and Valley to Highly dissected valley as well as large number of denudational hill in the region (Figure 12). The State's climatic condition is determined almost exclusively by the difference in altitudes. Most of the rivers and streams in this area are in the boulder stage and have not attained a permanent regime even before entering the plains. Urbanization in the road vicinity and also in the catchment areas is one of the major causes inducing unstable conditions, especially surface scour and thereby allowing water to percolate and create pore pressure conditions that cause movement of large scale debris creating blockage. The drainage basin of the present area is fan-shaped and has a greater run-off rate.

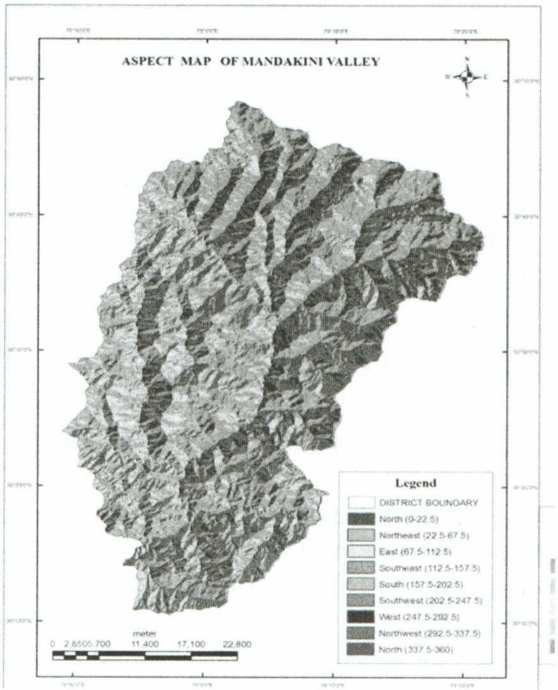


Figure 11 Aspect map of the Mandakini valley

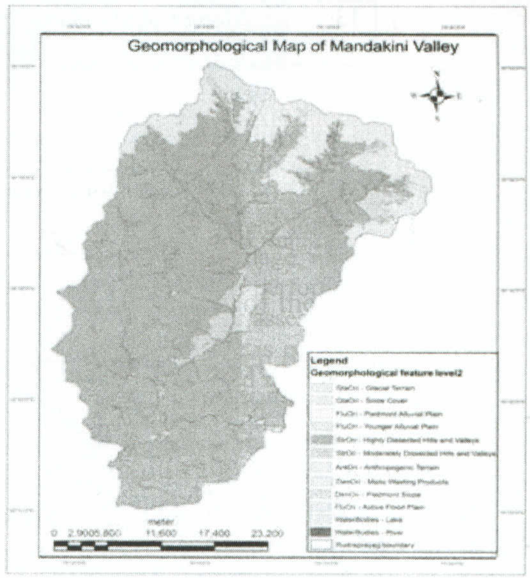


Figure 12 Geomorphological map of Mandakini valley

Landslide Inventory: Based on pre and post satellite data analysis nearly 290 landslides delineate (Figure 13) from (Pre image) and 1665 landslides delineate (Figure 14) from (Post image) have been identified in the Mandakini Valley. Frequencies of maximum landslides were observed between Kedarnath and Gaurikund route corridor most of them triggered due to June 2013 excessive rainfall event and has caused loss of lives and property from Kedarnath to Gaurikund in the downstream areas. The exiting 14 km pedestrian route as well as road network also damage by landslides. Inventory of landslides in different stretch along the Mandakini Valley up to Rudraprayag is elaborates in Table 2 (Figure 14). Fragile geology of major, minor fractures/lineaments in the area, nearness to MCT, slope degradation process and torrential rain were responsible for triggering process of landslides and flash flood in the area (Gupta, 2012).

Table 2
Details of landslide inventory in the Mandakini Valley

S. No.	Name of Place/River /Stream	Pre Image	Post Image
1	Kedarnath to Gaurikund	40	168
2	Along Vasuki Ganga to Sonprayag	20	86
3	Sonpryag to Narayankoti	10	83
4	Along Kali Ganga to Kotmaheshwari	50	62
5	Along Madhmeshwer Ganga to Kotmaheshwari	20	122
6	Along Markanda Ganga to Nanugad	15	156
7	Khuna to Narayankoti (Kalimath)	15	37
8	Narayankoti to Masta	20	3
9	Nala to Kund	25	173
10	Kund to Rudraprayag	15	296
11	Along Lastar Gad to Bhimali	10	136
12	Chamshil to Rudraprayag	40	230
13	Along Bhardari Gad- Nagaon	10	113
Total		**290**	**1665**

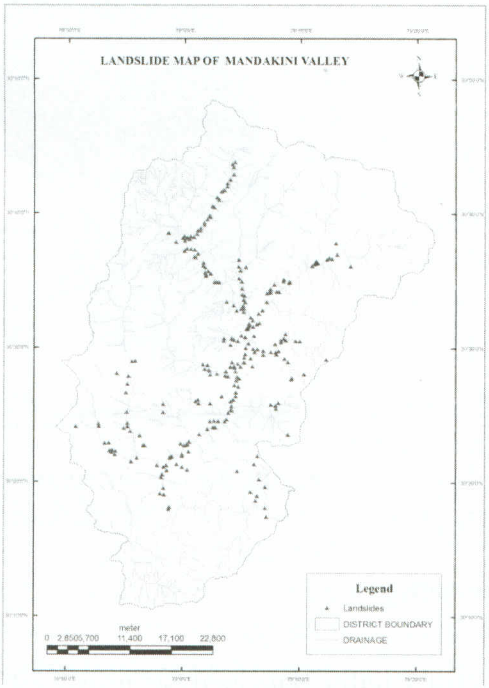


Figure13 Landslide map (2011) of the Mandakini Valley

Figure14 Landslide map (2013) of the Mandakini Valley

C. LHZ mapping using bivariate statistical model:

Statistical index method (Van Westen, 1997) has been utilized for landslide hazard zonation mapping whereby all the thematic layers (geomorphology, lithology, slope, aspect, proximity to fault, drainage density, density of lineament, and land use / land cover) are correlated with the landslide map (2013) so as to decide upon the weight value of each and every parameter class of the individual thematic layers (Gupta, 2012). The individual weight values are defined as the natural logarithm of the mass wastage density in the class divided by the mass wastage density in the entire map. Weighted map have thus been prepared for each theme layer and these have been integrated to prepare the hazard map (Gupta, 2013). The hazard map so prepared categories the area in five hazard categories viz. very high hazard zone, high hazard zone, moderate hazard zone, low hazard zone and very low hazard zone.

LHZ MAPPING USING BIVARIATE STATISTICAL MODEL

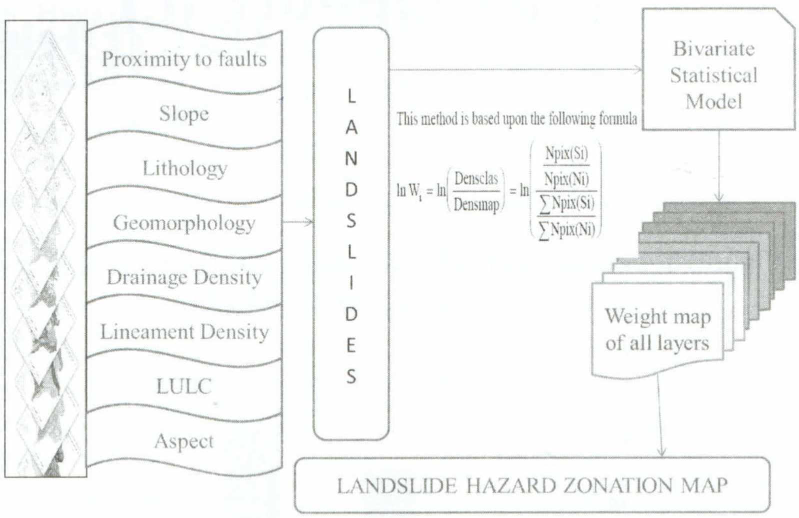


Figure 15 LHZ Mapping of the Study Area

D. Rainfall and climate:

The climate in this region is mainly governed by monsoon. The altitude of this valley extends from 570 m to 6930 m (snow covered area). The high peaks more than 3000 m in this catchment are covered by perpetual snow. Below this altitude snow last for three months in winter and temperature falls below freezing points. Rainy season is restricted between mid-June and mid-September and receives >60% rains of mean annual rainfall of about 1734 mm. Around the study area the maximum rainfall recorded at Ukhimath i.e., 2257 mm and minimum at Rudraprayag 1210 mm (Dobhal, 2013). On 16th and 17th June 2013, heavy rains together with moraine dammed lake (Chorabari Lake) burst caused flooding of Saraswati and Mandakini Rivers in Rudraprayag district of Uttarakhand (Dobhal, 2013).

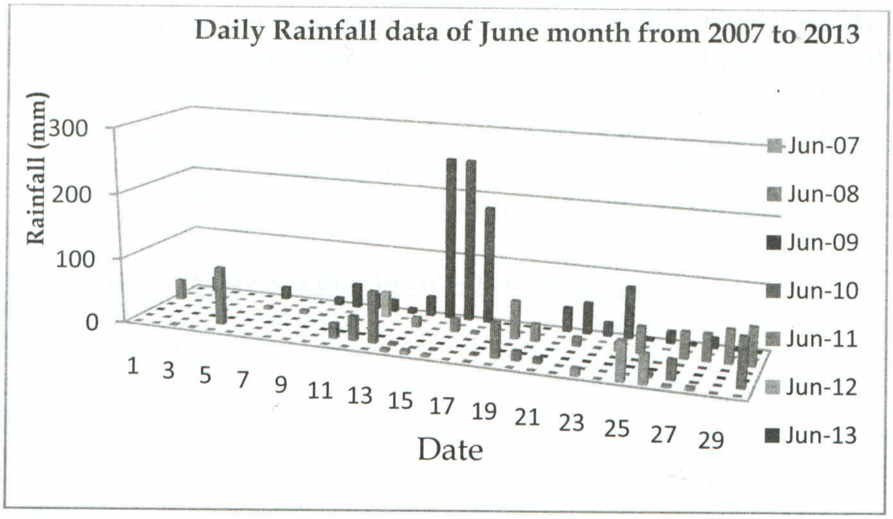


Figure16 Average Rainfall distribution (2007-2013) in Mandakini valley (Courtesy: LANCO)

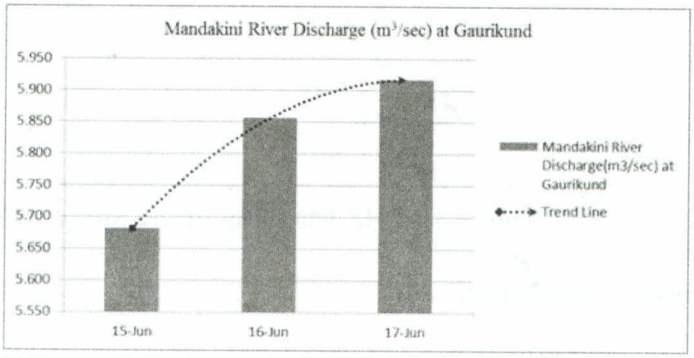


Figure17 Run off discharge in Mandakini valley (Curtsey: LANCO)

It was observed that the antecedent rainfall saturated the area and suddenly exceeds the limit on 15th to 17th June, 2013 (680 mm) more than average rainfall 2007 to 2012 (17.23 mm) of the area, which is one of the reasons for activation of landslides and flash flood in the Mandakini valley (Figure 18) (USAC, 2013). Runoff discharge data collected at Gaurikund in Mandakini River which is also indicating that Antecedent Rainfall (15th to 17th June, 2013) suddenly exceed its limit and overflow of rivers during 15th June 5.682 m3/sec to 5.917 m3/sec on 17th June, 2013 (Lanco Mandakini Hydro Energy Pvt. Ltd.) which has led to Flash Flood into downstream areas (Figure 19).

In association with the early monsoon onset, during the peak summer tourist and pilgrimage season, heavy to extremely heavy rainfall was reported all over the state during 16th to 18th June 2013. This caused flash floods in the tributaries in the upper catchments of the Ganga and Yamuna rivers over this region, resulting in widespread loss of human life and property. The network of rain gauges of India Meteorological Department (IMD) and the Uttarakhand government, numerical models and remote observation sources such as satellites and radars captured this widespread heavy rainfall episode (Kotal, 2014).

E. Results and discussion:

Combining all the controlling parameters and by giving different weightage value for all the themes, the final landslide hazard zonation (LHZ) map is prepared and categorised into 'Very High', 'High', 'Moderate', 'Low' and 'Very Low' hazard zones (Figure 18). The output map is generated on a scale of 1: 10,000. Various hazard classes described in detail are as following:

a. **Very High Hazard Zone:** Geologically, this zone is highly unstable and is at a constant threat from landslides, especially during and after an intense spell of rain. This is so, because, the area forms steep slopes with loose and unconsolidated materials, and include areas where evidence of active or past landslips were observed. Besides, it also includes those areas which are located near faults and tectonically weak zones. This zone is manifested on the surface by subsidence of the land as noticed in many parts of Rudraprayag district (Rautela, 2014). It further includes areas where road cutting and other human activities are actively undertaken. Therefore, the Very High Hazard Zone is found pre-dominantly in settlement areas. This zone is more prevalent in the southern and eastern parts of the district. It constitutes an area of about 118.31 sq. km and forms 5.96% of the total study area. Since the Very High Hazard Zone is considered highly susceptible to landslides, it is recommended that no human induced activity be undertaken in this zone. Such areas have to be entirely avoided for settlement or other developmental purposes and preferably left out for regeneration of natural vegetation to attain natural stability in due course of time. Zone as seen in many of the villages and towns i.e. Gauriya, Song Chatti, Ghindur Pani, Kanchula, Rambara, Linchori, Jungle Chatti, Gaurikund, etc.

b. **High Hazard Zone:** It mainly includes areas where the probability of sliding debris is at a high risk due to weathered rock and soil debris. It covers an area of steep slopes which when disturbed are prone to landslides. Most of the pre-existing landslides fall within this category. This rendered them susceptible to slide along the slope. Significant instability may occur during and after an intense spell of rain within this zone. Several lineaments, fractured zones and fault planes also traverse the high hazard zone. This zone occupies 451.66 sq. km which is 22.78% of the total area. The High Hazard Zone is also geologically unstable, and slope failure of any kind may be triggered particularly after heavy rain.

c. **Moderate Hazard Zone:** This zone comprises the areas that have moderately dense vegetation, moderate slope angle and relatively compact and hard rocks. It is generally considered stable, as long as its present status is maintained. Although this zone may include areas that have steep slopes, the orientation of the rock bed and absence of overlying loose debris and human activity make them less hazardous. The Moderate Hazard Zone is well distributed within the study area. Several parts of the human settlement also come under this zone. This zone covers almost half of the entire study area - about 334.39 sq. km. which is 16.87 % of the total study area.

d. **Low Hazard Zone:** This zone includes areas where the combination of various controlling parameters is generally unlikely to adversely influence the slope stability. Vegetation is relatively dense, the slope angles are generally low, about 30 degrees or below. Large part of this zone prominently lies over hard and compact rock type. Flat lands and areas having gentle slope degrees fall under this zone. It spreads over an area of about 425.90 sq. km. and occupies 21.48 % of the total study area.

e. **Very Low Hazard Zone:** This zone generally includes valley fill and other flat lands. Playgrounds are prominent features within this zone. As such, it is assumed to be free from present and future landslide hazard. The dip and slope angles of the rocks are fairly low. Although the lithology may comprise of soft rocks and overlying soil debris in some areas, the chance of slope failure is minimized by low slope angle. This zone extends over an area of about 651.82 sq. km. and forms 32.88% of the total area.

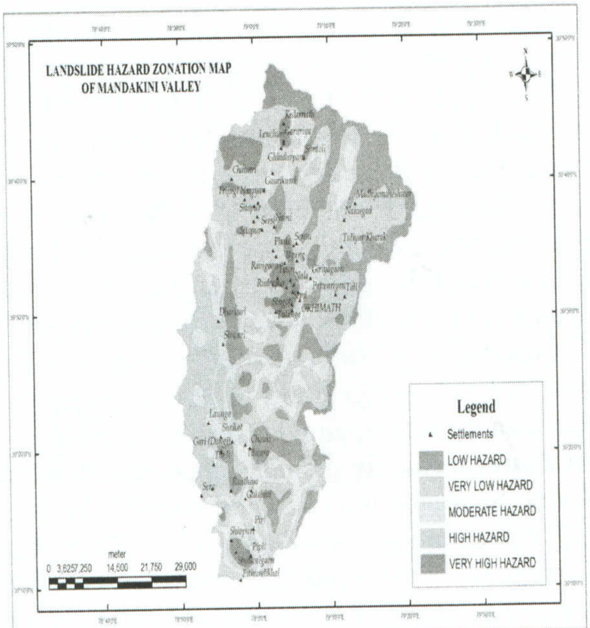
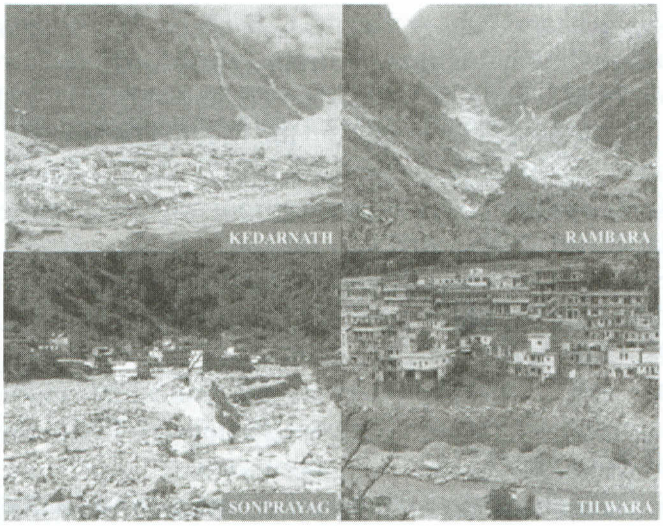


Figure 18 Landslide Hazard Zonation map of Mandakini Valley

3. Conclusions:

The methodology for landslide hazard zonation mapping using bivariate statistical model presented here involves the generation of thematic data layers, spatial data integration, and validation of results. In the present study, remote sensing/Image Processing and GIS is extensively used. Advance photogrammetry technique used for DEM and Ortho image generation. The merging of multispectral and panchromatic satellite data greatly improved the quality of terrain features in the image. Application of GIS is finding immensely useful for thematic data layer generation and for their spatial data analysis, which involved complex operations. The bivariate statistical model was improved by evaluating and optimizing the results. The landslide hazard zonation map divides the area into different zones corresponding to five relative hazard zonation classes. The High Hazard Zone is also geologically unstable, and slope failure of any kind may be triggered particularly after heavy rain. As such, allocation and execution of major housing structures and other projects within this zone should be discouraged. A forestation scheme should be implemented in this zone. The results are validated on the basis of landslide distribution in the area during field study. It may be noted that as seismic activity and continuous heavy rainfall can reduce the slope stability, it is recommended not to disturb the natural drainage, and at the same time, slope modification should be avoided as far as possible. Further, future land use activity has to be properly planned so as to maintain its present status. The landslide hazard zonation map can help in decision making, while implementing a development project in the terrain. It is always better to avoid the highly hazard zone but, if not possible, corrective measures must be worked out to minimize the probability of landslide occurrences (Photograph 1).



Photograph 1 Photo showing disaster devastation in Kedarnath, Rambara, Sonprayag and Tilwara

References:

1. Dobhal, D. P., Gupta, A.K., Mehta, M., Khandelwal, D.D., "Kedarnath disaster: facts and plausible causes. Current Science", Vol. 105,issue 2, pp. 171-174, 2013.
2. Gupta, Peeyush and Uniyal, Swati. "Landslides and Flash Floods Caused By Extreme Rainfall Events/Cloud Bursts in Uttarkashi District of Uttarakhand", Journal of South Asia Disaster Studies. JSADS, in press.
3. Gupta, Peeyush and Kimothi. M.M., "Generation of Digital Elevation Model using Photogrammetry approach for Haridwar Distric, Uttarakhand," Proc. National Seminar on Status of Environment and biodiversity: RIO + 20 and role of space technology, 2-3 Nov, G.K. University, Haridwar,2012
4. Gupta, Peeyush and Kimothi. M.M., "Slope instability and Landslide hazard zonation mapping of the area around Nainital," Proc. National symposium on Space technology for food & environment security & annual conventions of Indian society of remote sensing & Indian society of geomatics, 5-7 Dec, ICAR, New Delhi, 2012

5. Gupta, Peeyush and Uniyal, Swati. "LHZ mapping of the area around Nainital using bivariate statistical analysis. International Journal of Advance Technology & Engineering Research. IJATER,Vol.3, Issue 1.Jan 2013.ISSN No.2250-3536.
6. Gupta, Peeyush and Kimothi. M.M. "Block Adjustment technique, processing & geometric quality assessment of cartosat-1 for Uttarakhand Himalayan terrain," International Journal of Advancement in Remote Sensing, GIS and Geography. IJARSGG.Vol.1, No. 1. (2013) 49-60.ISSN No. 2321-8355.
7. Horton, R.E. Drainage basin characteristics. Trans. Am. Geophys. Union 13, 1932, pp. 350-360.
8. Joshi. V. and Kumar, K.," Cloudburst: a natural calamity-a case study from Garhwal Himalaya, U.P.J. Indian Build. Congress," Vol. 4, issue 1, pp.207-219, 1997
9. Joshi. V., Naithani. A.K. & Negi G.C.S," Study of Landslides in Mandakini river valley, Garwhal-Himalaya, India," GAIA, 16, pp. 87-95, 2001
10. Kimothi. M.M., Garg. J.K., Joshi. V, Semwal. R.L, Pahari. R., and Juyal, N, "Slope activation and its impact on the Madhyameshwar and Kaliganga sub-watersheds, Ukhimath, using IRS-1C/1D data," Scientific Report, SAC/RES A/FLPG-FED/SR/04/99, published from Space Application Centre (ISRO), Ahmedabad, pp. 1-38, 1999.
11. Kotal. S.D, Roy. S.S. and Roy. B, "Catastrophic heavy rainfall episode over Uttarakhand during 16-18 June 2013, observational aspects. Current science, Vol. 107, issue 2, pp. 234-245, 2014.
12. Naithani, A.K, "Morphotectonics and landslide problems in area between Kedarnath and Okhimath, Garhwal Himalaya" Ph.D. thesis, science Fac. HNB Garwhal Univ., 1997, 200. (Unpublished)
13. Rautela, Piyoosh et al, "Geological Investigations in Rudraprayag District with special reference to mass instability," DMMC Book, pp. 1-117, 2014
14. Schumm, S.A, "Evolution of drainage system and slope in badlands of Perth Amboy, New Jersey. Bull. Geol. Sc. Am, Vol. 67, pp.597-46, 1956.
15. USAC, "Satellite based observations of devastating caused by torrential rainfall on 16th & 17th June 2013 in Kedarnath Dham and Mandakini Valley of Rudraprayag District," Scientific report- USAC/SR/02/2013, 2013.
16. Van Westen, C.J, "Deterministic Landslide Hazard Zonation, ILWIS Application guide," International Institute of Aerospace Survey and Earth Sciences, En-schede, The Netherlands, pp. 85- 98, 1997.
17. WIHG, 2013, "A Report on Kedarnath Devastation. December 2013"
18. Joshi. V. and Kumar. K, "Extreme rainfall events and associated natural hazards in Alaknanda valley, Indian Himalayan region". Journal of Mountain science, Vol. 3, pp. 228-236, 2006.
19. NRSA. Landslide hazard Zonation Mapping in the Himalayas of Uttaranchal and Himachal Pradesh states using remote Sensing and GIS techniques. ATLAS 2001. National Remote Sensing Agency, Dept. of Space, Govt. of India, Hyderabad.
20. Joshi. V. and Negi. G.C.S., "Analysis of long term weather data from Garhwal Himalaya." ENVIS Bull., Vol. 3, issue 1-2, pp. 63- 64.