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Rapid Damage Assessment for the Mandakini Valley Flood using Pre & Post High Resolution Satellite Data in Uttarakhand State, India

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Abstracts

Mandakini River is an important branch of the Alaknanda River originates from the Chorabari Glacier near Kedarnath in Uttarakhand, India. Mandakini River turns ferocious during monsoon season often destroying various parts of national highway and many adjoining villages. Flash floods occur periodically in Mandakini Valley due to numerous factors including its complex topography and geological structures etc. The river has caused the 2013 Kedarnath floods in Uttarakhand state. In 16th and 17th June 2013, a multi-day cloudburst centred on the Uttarakhand state caused devastating floods and landslides in the country's worst natural disaster. One of the largest impacts appeared at Kedarnath, a Hindu shrine, which is an important pilgrimage destination. Most of the new established buildings and particularly the sangam (confluence) region at Rudraprayag was severely ruined in this flood. Besides, national highway, footpath, trekking routes, number of footbridges also got washed away completely. Many plants& vegetation cover that are food, fuel and fodder resources for locals had destroyed. In locales where larger volumes of sediment are flushed from beneath glaciers, they are responsible in creating outwash the area. To investigate damage assessment in the Mandakini valley, a GIS-based methodology has been developed for quantifying and spatially mapping the flood affected areas. The aim of this study was therefore to assess the impact of the 2013 flood on the infrastructures, road, settlement, forest and agricultural areas. This study used a satellite-based Remote Sensing and GIS method to investigate damage assessment in the Mandakini Valley in Uttarakhand, India.

Keywords: Mandakini valley, flash floods, damage assessment, Remote Sensing and GIS.

Introduction

Floods are the most destructive acts of nature and probably most devastating, wide spread and frequent. One of the major consequences of extreme meteorological conditions, especially intense precipitation, is flash flooding. Possible causal factors for flash floods include excessive rainfall, sudden release of water due to a dam breach or lake outburst (Hapuarachchi, Wang et al. 2011). In the realms of monsoon, river flooding is a recurrent natural phenomenon. Flash floods are extremely dangerous due to their unpredictability and rapid generation over a localized area. The occurrence of flash floods are rapid, generally within six hours of rainfall, and often accompanied by landslides, mudflows, bridge collapse, damage to buildings, and fatalities (Hapuarachchi, Wang et al. 2011) and consequent high river discharge damage infrastructures, crops and forest areas etc. World-wide flood damages to agriculture, houses and public utilities amount to enormous money each year in addition to the loss of precious human, cattle lives. For formulating any flood management strategy the first step is to identify the area most vulnerable to flooding.

Uttarakhand is no exception as far as floods are concerned. Severe floods occur almost every year in one part of the state or the other causing tremendous loss of life, large scale damage to property and untold misery to large number of people. Floods mostly occur in the state during June to September.

Ecologically sensitive region of Mandakini valley was washed away by floods triggered by heavy rains on June 16th & 17th flooded the catchment area of Mandakini River resulting in overflowing of channels which triggered erosion and subsequent silting up in the rivers. This resulted in huge volumes of water along with loose soil and debris from glacial moraines forming a slush which moved with unprecedented energy towards Kedarnath town and washed off its upper parts where Shankaracharya samadhi, Jal Nigam guest house and Bharat Seva Sangh Ashram are located. Similarly on downstream near Jangalchatti, Rambara Gaurikund and Sonprayag, infrastructures, houses and roads were collapsed completely.

Mandakini valley is seismically and ecologically very sensitive and fragile and even small disturbances (natural or anthropogenic) triggers changes that rapidly

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assumes dimension of the disaster. The upper reaches of Mandakini Valley are glaciated and are occupied by two glaciers i.e., Chaurabari and Companion. Mandakini valley shows, evidences of glaciation up to Rambara. The glaciation has witness of past debris in the form of moraines. The Kedar valley, in Quaternary period has faced large fluctuations of climate effecting glaciation due to the cooling. These climatic fluctuations are preserved as geomorphic signatures in the proglacial/supraglacial regimes of glaciers. The central crystalline rocks are well exposed in the Higher Himalaya of Kedarnath valley. The rocks of Central Crystalline Group form the oldest crystalline basement of the Himalaya, which shows fragile nature of this region. Geomorphology of the region shows that most of the villages here are located on the debris of old landslides. People have been settled here because of the availability of water and fertile lands. Presence of alder forest in this area indicates imprints of old landslide. The MCT, which demarcates the lesser Himalaya in the south and Himadri or Higher Himalaya towards north passes through south of Okhimath. The zone of MCT is a highly unstable domain nearly 5 to 20 km wide, and has highly sheared and pulverized rocks (Valdiya 1985). Majority of incidents of landslide are associated with this zone (Bhatt 1992, Kimothi et al., 1999).

The region has history of natural devastations i.e. various landslides and flash floods in the past. Landslide tragedy occurred in August 1998 around Madhyamaheshwar and the Kaliganga sub-watersheds in Okhimath Tehsil of Rudraprayag district has surpassed all the past records of calamity in this region (Kimothi et al.1996 & 1999). Other major landslides namely Phata landslide of 2001, Lwara slide in Basukedararea in 1992, Temriya slide, Chandrapuri slide are burning examples in Mandakini valley that have caused large-scale human tragedies, resources damage and associated environmental-social hazards. In year 2012 Okhimath area of Rudraprayag district has also witnessed unprecedented damage to the life and property, infrastructure, and landscape during September 13th to 16thdue to torrential rainfall and cloudburst occurrence.

Role of space technology in flood management

Geospatial technologies provide powerful capabilities for disaster/hazard planning, monitoring and mitigation. For the last two decades advancement in the field of remote sensing and geographic information system (GIS) has greatly facilitated the operation of flood mapping and flood risk assessment. It is evident that GIS has a great role to play in natural hazard management because natural hazards are multi-dimensional and the spatial component is inherent (Coppock, 1995). The main advantage of using GIS for flood management is that it not only generates a visualization of flooding but also creates potential to further analyze this product to estimate probable damage due to flood (Hausmann et al., 1998; Clark, 1998). Smith (1997) reviews the application of remote sensing for detecting river inundation, stage and discharge. Since then, the focus in this direction is shifting from flood boundary delineation to risk and damage assessment.

Satellites, by virtue of their remote sensing and data transmission capabilities to provide comprehensive multi-date and multi-spectral information on dynamic phenomena covering very large as well as small river basins, have been found to be admirably suited for mapping/monitoring and studying (i) flood inundated and drainage congested areas, (ii) extent of damages to crops, structures, transportation, bridges, forests etc. (iii) river configuration, silt deposits, shoals etc. and vulnerable areas of bank erosion (iv) watershed characteristics and land cover/land use in command areas and (v) hydrological and meteorological data transmission from data collection platforms. The flooded areas, which extend to several thousands of square kilometers, could be mapped very effectively using the satellite data. They are also useful in delineating the boundaries of flood prone zones. The multi temporal data from satellites are proved to be very valuable in the identification of the site ideal for taking up structural measures to control floods.

An attempt has been made in this study by using the Indian satellite data for the purpose of assessing the suitability of these data for a crude, rapid estimate of the damage for the 2013 Kedarnath disaster event. This study includes two aspects- 1) development of remote sensing as a tool of flood delineation, 2) assessment of the flood extent and damage. Remote sensing can effectively be used for mapping the flood-damaged areas. For mapping purposes, a pre-flood image and a peak flood image could be compared to delineate the inundated area.

Objectives

Viewing the significance of the space technology the present study has been carried out with following objectives:

- To define spatial extent of flood inundation.
- To evaluate impact of flooding on environmental concerns, assessment of damages in terms of Infrastructures, agriculture areas, forest areas etc.

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Study area

Mandakini Valley

Location and Extent: Mandakini valley lies between 30.2 N to 30.7 N, 79 E to 79.4 E in Rudraprayag district. Rudraprayag is one of the districts in Uttarakhand which lies in awesome crests of the Himalayas. It is bounded on the north by Tehri Garhwal and Uttarkashi districts, on the north-east and east by Chamoli district, on the south by Garhwal and on the west by Tehri Garhwal district. The district headquarter is located at Rudraprayag town, and the district is spread over in an area of approximately 1895 sq. km. There are three tehsils and blocks namely- Ukhimath, Jakholi & Agastmuni having approx. 900 villages. Total population of the district according to 2011 census is 236857 persons, comprising of 111747 males and 125110 females with an average literacy rate of 82.09% higher than the national average of 79.63%, with male literacy of 94.97% and female literacy of 70.94%.

Figure 1. Study Area Map

The maximum of the total population lives in the rural areas or villages. The main source of the income of the people of the rural areas is agriculture and animal husbandry. Out of the total population about 91.9 percent lives in the rural areas and the remaining 8.9 percent lives in the urban areas. The total irrigated area in the district is about 2614 hectare and the total actual irrigated area is about 1239 hectare .The total irrigated area in the district is about 4427 hectare and the actual irrigated area is about 3021 hectare. Transportation facility is dependent upon roads and pathways. In remote areas transportation is done through pack animals like horses, ponies, she-goats etc. As the elevation of the district ranges from 800 m. to 8000 m. above sea level the climate of the district very largely depend on altitude. The winter season is from about mid-November to March. As most of the region is situated on the southern slopes of the outer Himalayas, monsoon currents can enter through the valley, the rainfall being heaviest in the monsoon from June to September.

Material & methodology

Data Used

Different type satellite images from different sources were used for this study (Table 1). Before disaster and during the disaster high resolution satellite images were used to determine the difference between flooding area and ordinary water body. The details of data set are given in the following table:

S. No.	Satellite Name	Resolution	Date of Acquisition	Pre and Post Event
1.	LISS IV & Cartosat Merged	2.5m	June 2011	Pre-event
2.	Resourcesat 1 AWiFS	58m	June 2012	Pre-event
3.	LISS IV & Cartosat Merged	2.5m	June 2013	Post-event

Source: *Satellite data sets were collected from NRSC, Hyderabad and Internet.*

Methodology

Geospatial data for rapid damage estimates, three general methodologies have emerged. These are the following:

1. **Direct damage assessment**: remote sensing is used to directly detect damaged buildings and other damaged assets resulting from the disaster. This can be done for all hazard types.
2. **Indirect damage estimation**: damage is estimated by deriving the hazard footprint and overlaying this on asset data for which the locations are mapped. This method assumes all assets within the hazard footprints are damaged and all assets outside the hazard footprint are not. This method is applicable to floods, landslides and tropical cyclones.
3. **Direct validation of government generated damage data**: If the above two methodologies are not possible for reasons such as lack of baseline spatial data, as a last resort, it would be possible to simply verify government generated data by imposing the government collated damage data on the post-event satellite/aerial data that shows the damage. This validation will be done visually. The caveat is that the government provided damage data must be spatially referenced that allows it to be overlaid on the post-event image. This again is applicable to all hazard types, as long as the government provided data is spatially referenced.

An indirect damage estimation method was used to map landslides and the inundation extents in Mandakini valley using Indian optical satellite data (LISS IV). For damage estimation, an assumption is made which is that the assets (identified from pre-event spatial baseline

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data) that fall within the hazard footprints are assumed damaged, and those outside the hazard footprints are not. No distinction is made of the different levels of damage likely to be found within the hazard footprints. The impact to the assets is assessed using a simple binary system, i.e. damaged or not damaged. The first step is to extract the hazard footprints from the post-event satellite/aerial data.

Extracting hazard event footprints

The extent of the flash flood/debris flows and the land slide scarp locations were mapped using visual interpretation using the Indian satellite data Cartosat 1 and LISS IV merged. False colour images were used to visually interpret these hazard footprints.

To supplement the visually interpreted information, the difference between the Normalized Differential Vegetation Index (NDVI) of the pre- and post-event LISS VI images were derived. NDVI is a well-established methodology to detect vegetation in a multispectral image. The assumption here is that if the pre-event image used was taken in the same season as the post-event, the changes seen in the NDVI between the two images can be attributed to the flood and landslides/debris flows from the event. The results should be interpreted with caution, with the limitations of this NDVI method in mind. One issue to consider is that the changes in NDVI may not always have been caused by landslides or inundation but simply the difference in the agricultural planting cycle.

Flood extent, landslides and River channel were extracted from post disaster high resolution satellite images. Various thematic layers i.e. road network, drainage system, village locations etc. were delineated from pre-event satellite images. To get various categories of Land use, post event satellite image was classified into different classes using unsupervised classification. One of the most important issues in the context of an object oriented classification is the accurate segmentation of the input images. For each segment, information an average Normalized Difference Vegetation Index (NDVI), built-up, agriculture land and Water bodies, etc. was derived. This information was used to develop suitable classification algorithms for individual land cover classes. Image objects were linked to class objects and each classification link stored the membership value of the image object to the linked class. Similar way, NDVI of pre and post event satellite images was subtracted to determine the changes between two times and this information was used to assess the various aspects of damages in Mandakini Valley. Land use/land cover map on 1:50 k Scale was used to find out the changes in various land use classes. Occurred damage statistics was calculated for results and discussion using ArcGIS using overly technique. GPS points and field informations were also used to validate the results.

Spatial baseline datasets used for the damage estimation: Three spatial baseline datasets were used for the Uttarakhand damage estimation: Land use land cover (LULC) data, Road network data and location of villages. These were each used to estimate the damage in the following sectors: agriculture, transportation and housing. A short description of the datasets is provided below:

Land use/land cover (LULC) data: Land use/land cover map generated for entire Uttarakhand state using three season (Kharif, Rabi and Zaid) satellite data LISS-III (23.5 m spatial resolution) for the year 2011 & 2012 has a standard set of 38 land use/land cover classes. This information is updated every five years.

Road network data: Road network data has been produced for the whole state by digitizing Cartosat 1 and LISS IV merged satellite data from 2011. The two datasets were merged to create a seamless cloud free cover of the state. The road network is digitized at 1:10,000 scale. The roads are classified into 4 categories i.e. National Highway, District Road, Village Road (Pucca) & Village Road (Kuccha).

Population (census) data and corresponding revenue village boundaries: In Uttarakhand, the administrative levels are defined as follows: State, District, Blocks, Tehsils and Revenue villages. Revenue villages can contain more than one hamlet. The unit of reporting for census population data is the revenue village. It is also the unit for administrative management and community program planning. For the district of Rudraprayag, there are approximately 900 revenue villages, and 16000 in Uttarakhand as a whole. The boundaries for the revenue villages are defined by the Survey of India, the national mapping agency.

Forestry data: The same LULC data used for Agriculture was again used to estimate the damage to the forests.

Damage estimation methodology

Population (as a proxy for housing)

The proportion of population likely to have been affected was estimated by overlaying the hazard footprints over the revenue village boundaries and estimating the proportion of land covered by the hazard footprint in each of the revenue village boundaries. Since the population of the revenue village boundary is known from the census, the percentage of land affected

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within each village was multiplied by the known population of the village, identified in the census.

Settlement- The hazard footprints were overlaid on the settlement layer and the settlements that overlapped were measured as affected.

Roads - The hazard footprints were overlaid on the road network vectors and the intersected lengths measured to estimate the length of road affected.

Agriculture- The hazard footprints were overlaid on the agricultural portion of the LULC data. The proportion of cultivated land affected was estimated as the intersected areas.

Forestry- The forestry cover map was overlaid on the hazard footprints. Areas that overlapped were estimated as damaged.

Results and discussion

The hazard footprint vector files were overlaid on asset data for the following sectors; affected villages, transportation networks (namely roads and bridges), agriculture and forest. The results for each of these sectors are described below:

Effect of cloud cover in the post-event image

It must be noted that the post-event LISS IV image used for the extraction of the hazard event footprints has 20% cloud cover. The ground features under the clouds are obscured from the view of the satellite sensors. Taking this into account, it may be justified to inflate the damage figures below by an extra 20%, assuming a similar distribution of damage in the areas covered by cloud. The numbers reported below are the original figures, without any inflation applied to them.

Number of villages affected (proxy for proportion of housing damage)

Of the 968 villages in the district, approximately 200-230 are within the hazard footprints.

Table 1. Block wise distribution of affected Villages

S.No.	Block Name	Affected Villages	
		Min.	Max.
1	Agastmuni	100	144
2	Jakholi	34	44
3	Ukhimath	69	71
	Total	**203**	**259**

Transportation

The total road length for all road types found in the Uttarakhand Spatial Data Infrastructure database (1:10,000) for the district of Rudraprayag is 1,643 km, of which approximately 230 km falls within the hazard event footprints.

Table 2. Distribution of affected Roads

	Roads		
S.No.	Road Type	Affected Area (Km)	
		Min.	Max.
1	National Highway	56.42	87.41
2	District Road	37.44	46.72
3	Village Road	134.58	269.92
	Total	**228.44**	**404.05**

Table 3. Distribution of Bridges/ Cross drainage structures affected

	Bridges		
S.No.	Block Name	Affected Bridges/Cross Drainage Structures	
		Min.	Max.
1	Agastmuni	174	347
2	Jakholi	65	100
3	Ukhimath	72	96
	Total	**311**	**543**

Agriculture

The total cultivated area in the land use-land cover data (2011-12) derived from LISS III data is approximately 300 km^2, of which 46 km^2 is estimated to have been impacted.

Table 4. Distribution of affected Agricultural land

S.No.	Crop Type	Affected Area (ha)	
		Min.	Max.
1	Kharif Crop	2267.25	4346.14
2	Rabi Crop	356.15	527.44
3	Two crop area	945.93	1748.07
4	Zaid Crop	26.41	35.36
5	Current Fallow	1100.34	1386.61
	Total	**4696.08**	**8043.61**

Forestry

The LULC layer shows the total area of forest affected in the district to be approximately 80 km^2.

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Table 5. Distribution of affected Forest cover

S.No.	Forest Type	Affected Area (ha)	
		Min.	**Max.**
1	Forest-Evergreen / Semi Evergreen-Dense	4118.49	12240.81
2	Forest-Evergreen / Semi Evergreen-Open	1332.78	4004.44
3	Forest-Scrub Forest	448.55	1515.11
4	Natural/Semi natural grassland & Grazing land-Alpine/Sub alpine	1330.95	2345.19
5	Natural/Semi natural grassland & Grazing land-Temperate/Sub tropical	31.71	63.79
6	Tree Clad Area/Open	697.48	1820.27
	Total	**7959.96**	**21989.60**

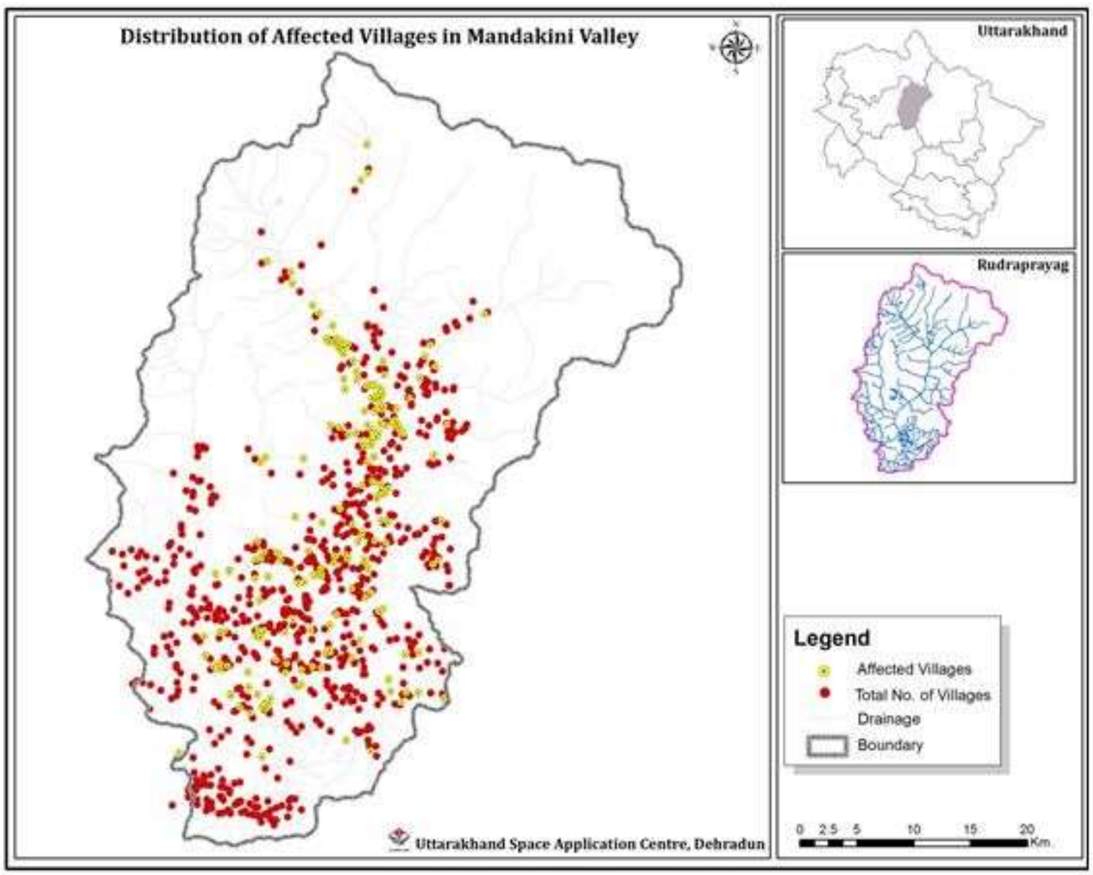

Figure 2. Map showing distribution of affected villages in Mandakini valley

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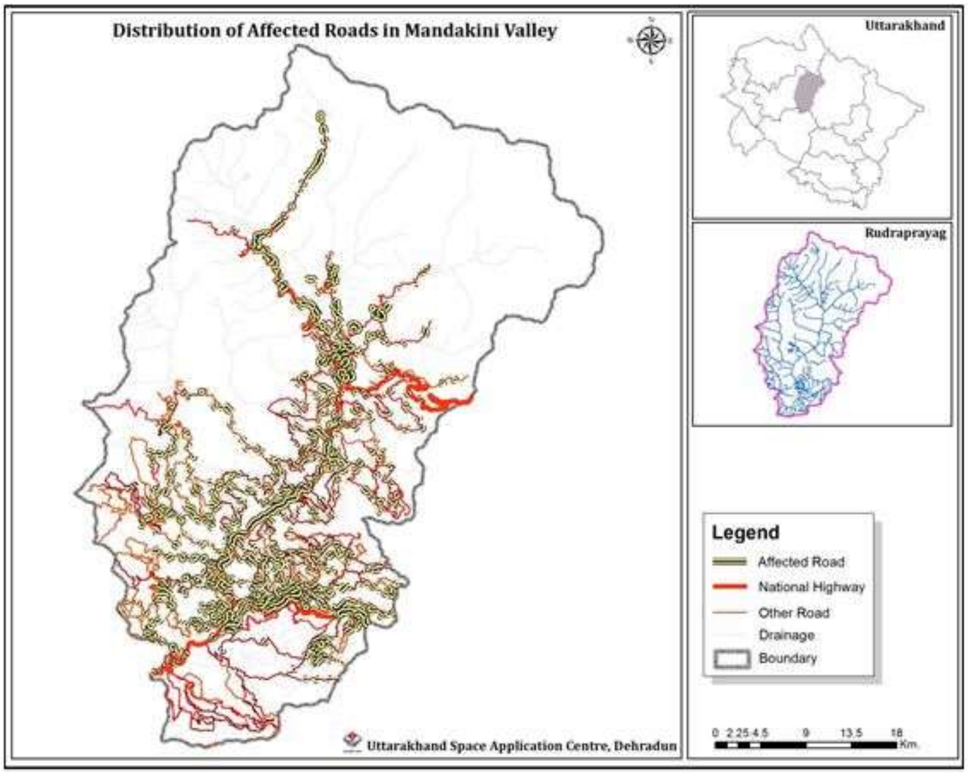

Figure 3. Map showing distribution of affected roads in Mandakini valley

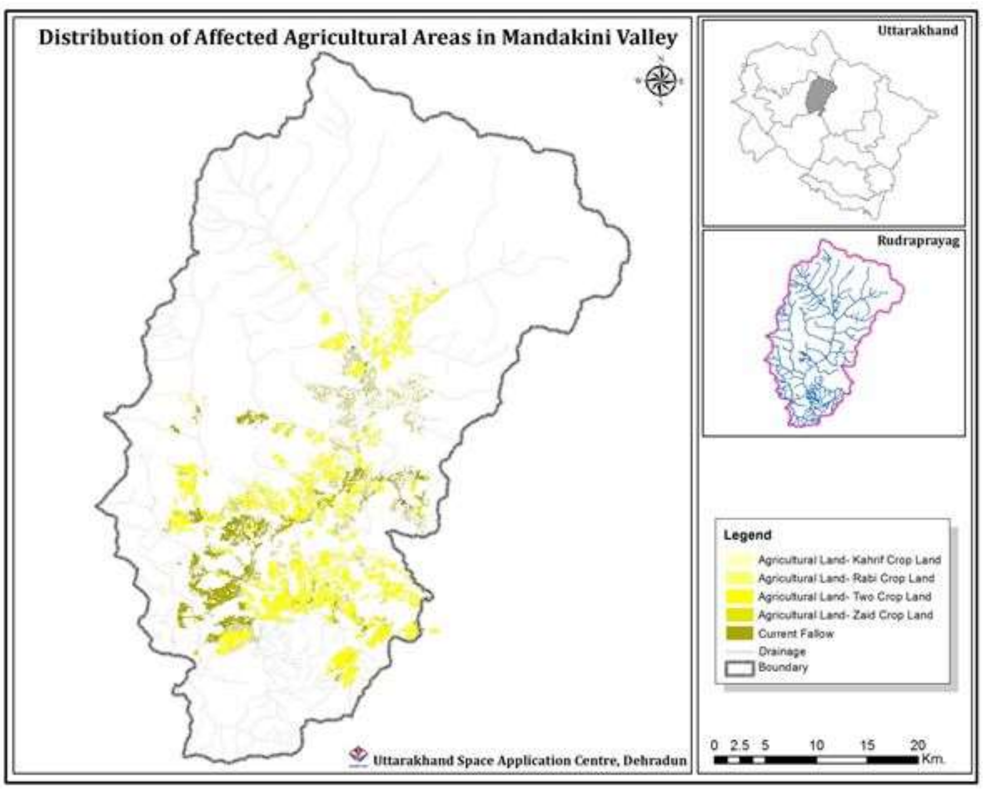

Figure 4. Map showing distribution of affected agricultural areas in Mandakini valley

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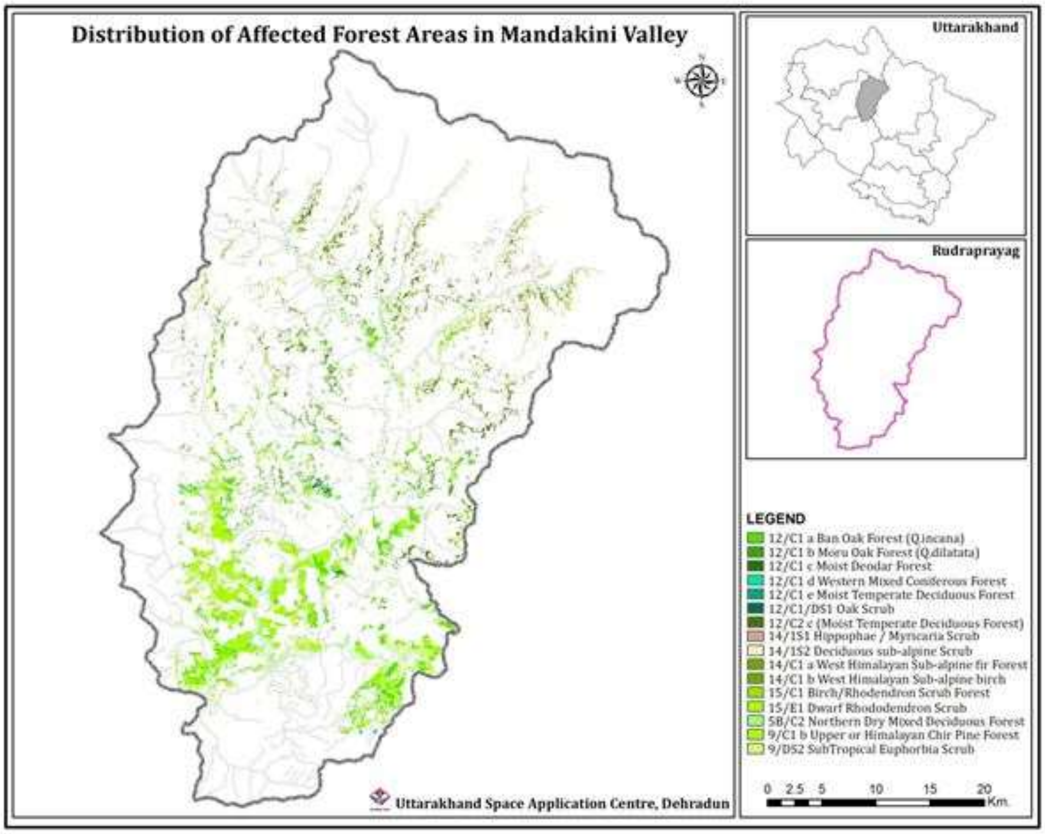

Figure 5. Map showing distribution of affected forest areas in Mandakini valley

Conclusion

- Space technology can play an important role in providing valuable information particularly useful in the flood assessment, mitigation and preparedness phases of floods besides weather monitoring and effective communication for early warning and management of the floods. From the technology point of view, it is not an exaggeration to say that it is already possible to use the latest existing technologies to come up with rapid assessments.
- NDVI is a well-established methodology to detect vegetation in a multispectral image.
- Analysis shows that the estimated number of resources affected are:
  - Affected villages- 203 (min) and 259 (max)
  - Affected Road- 228 kms (min) and 404kms (max)
  - Affected bridges- 311 (min) and 543 (max)
  - Affected agricultural land- 4696 ha (min) and 8044 ha (max)
  - Affected forest area- 7959 ha (min) and 21989 ha (max)
- Some of the conditions required to be met for a good spatial data-based assessments are; a strategy in place before an event happens that ensures the rapid acquisition of the post-event images that covers the entire affected area, pre-event images ideally from the same season in the immediate previous years or immediately prior to the event, highly detailed spatial baseline datasets that show the location of the key assets on the ground as well as the population distribution, dedicated man power for the duration of the assessment to be able to process the large amount of data, as well as an impact assessment methodology.

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