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Landslide Hazard assessment around Tehri Reservoir in the lesser Himalayas using Geoinformatics

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ABSTRACT

The role of reservoir in causing landslides and also in reactivating old landslides due to difference in hydraulic action has been very common around the world. The present study is an attempt to divide the area around Tehri reservoir into various landslide susceptible zones. The result obtained after superimposing the active landslide and landslide hazard zonation shows that there is strong correlation between these slides with high and very high landslides hazard zone area. On the whole it is clear that the density of landslides increases from very low to very high class. The quantative analysis of the data shows that more than 80% of the total landslide area existed in moderate and high hazard zone classified area. In spite of the scarcity of the data the hazard zonation assessment is helpful to mask out the area highly vulnerable to landslide which in turn is helpful for short-term and long-term plan before initiating any sort of development activities in the Tehri rim area.

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1.Introduction

Landslide is a common phenomenon throughout the world and can only be considered as a hazard when they have an impact on society or environment. Natural hazards like landslide, avalanches, floods and debris flow can result in enormous property damage and human casualty in mountainous areas. The role of reservoir in causing landslides and also in reactivating old landslides due to difference in hydraulic action has been very common around the world. The assessment of landslide hazard has become an important assignment for various interest groups comprising technocrats, planners and others mainly due to an increased awareness of the socio-economic significance of landslides (Devoli et al. 2007).Growing environmental concern in recent years has resulted in quantitative landslide hazard assessment studies (Alexander 2008;Carrara and Pike 2008).Landslides are a recurrent problem throughout most of Himalaya Region, where they cause extensive damage to property, and occasionally result in loss of life. In addition to its major objectives i.e. electricity, drinking water, irrigation facilities, fisheries, flood control and water sports, The Tehri Hydro electric project has been attracted International concern for its potentially harmful impact on environment and socio-economic instability to the surrounding area. There are about 85 reported localities of slope instability in the reservoir rim area taken under study. No doubt that problem of land subsidence is common in Tehri area for the last so many years but their frequency has been increase exponentially after the creation of huge Tehri reservoir. This can be attributed due to the periodic fluctuations of water level in Tehri reservoir which is about 45km toward Bhagirathi side and 19kms towards Bhilangana side. Some of the gather information which supports this statement is here under.

Jan 2008, (PTI) The Tehri dam, one of the largest dams in Asia, is once again in controversy, as its lake is posing threat to a number of adjacent villages in Uttarakhand. The houses in a number of adjacent villages have developed cracks. The villagers say that the cracks are because of the dam, but the local administration says that it is still investigating complains of the villagers. “Cracks have been seen in some places in the village and since the water level is receding, this area is under study. Once the investigation is over, some conclusion will be derived,” District Magistrate of Tehri. In 2010 the report submitted by the IIT Consortium, which includes the IIT-Roorkee to the National Ganga River Basin clearly mention that that the area under the influence of hydroelectric projects is suspected to undergo decline in its forest cover and experience enhanced landslides .Oct 31, 2011 (PTI) the survey conducted by Geological Survey of India (GSI) shows that over two dozen villages facing threat due to construction of a huge reservoir for 2400 MW Tehri hydropower project.

The construction of large number of dam in the recent times and their impact on the surrounding environment create lot of interest among the researcher to think on this line. In 1963 the catastrophic failure of the left bank slope occurred in Vajont Reservoir in Italy, which caused more than 2600 casualties (Müller, 1964). Schuster, 1979 & Millet et al., 1992 are of view that, the impoundment of reservoirs and the subsequent changes in the water level induced land sliding. In 2003 the reactivation of a landslide induced by the impoundment of the Three Gorges Reservoir (China) caused the loss of 24 lives in Qingjinagping village (Wang et al., 2004). In 2005 Wang et al. narrated that the Shuping landslide, 20 million m^3, was reactivated by the first impoundment of the Three Gorges Reservoir and led to the evacuation of the people living on the slope. The reactivation of Shuping slide due to reservoir impoundment has been monitored by GPS; extensometer and crack measurement for a period of six months, and it was proved that slope displacement is due to reservoir impoundment. The reactivation of the landslide forced a new relocation of the settlement (Deng et al., 2000;

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Wu et al., 2001; Liuet al., 2004).Shengwen Q et al., in 2006, highlights the impact of reservoir inundation on reactivating a historical landslide, The Maoping landslide, the largest ancient landslide in Geheyan reservoir, with a volume of 23.5 million m3. April 2012(Times of India) it has been reported by the ministry of Land resources China that the number of landslides and other disasters has increased 70% since the water level in the China's Three Georges Dam rose to its maximum level in 2010.Ministry Official, told China National radio that another 100,000 may have to move away from the China's Three Georges Dam due to the risk of disastrous landslides and bank collapses around the reservoir.

2. Objectives of the study

The present study outlines the following objectives:

- To study the Temporal analysis of landslides around the Tehri rim before and after inundation.
- To analyse the Landslide hazard zone around the Tehri reservoir.

3. Study Area

Nested in the Garhwal Himalayas, Tehri dam is located between 30º 28' North and 78º 30' East, near the town of Old Tehri (submerged) in the Lesser Himalayan region of Uttarakhand in India. In order to see the impact of reservoir on the surrounding area a five kilometre buffer zone around the main reservoir has been created. Study area was delineated by high resolution data of Geo eye taken from Globe Earth and SOI Toposheets no. 53J/7 & 53J/11. The area selected for the present study is located between 30 º 20' to 30 º 29' 54'' N latitudes and 78 º 22' 30'' to 78 º 32' 50'' E longitudes. It covers an area of 201 sq kms. As per the Administrative setup is concern the area under study is the part of Jhakni Dhar and Pratab Nagar Block, Pratap Nagar Tehsil Headquarter and Tehri Garhwal District. The district headquarter is located at New Tehri Town since 1.4.1989, earlier Narendranagar was the district headquarter.

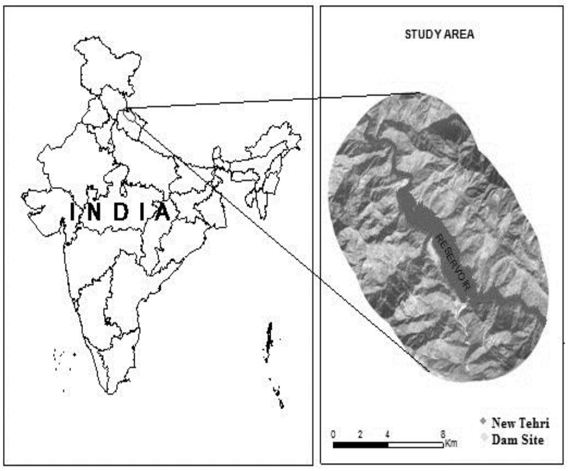


Figure 1. Location of Study Area.

3.1 Geology

The Dam is situated in Lesser Himalayan geo-tectonic block which is bounded by Main Central Thrust (MCT) in the north and Main Boundary Thrust (MBT) in the south. A prominent tectonic feature, Srinagar Thrust lies 5 Km north of the dam site and it crosses Bhagirathi at Nalupan and Bhilangana at Gadolia. Geology of the study area is defined by rocks of Chandpur Formation and Routgara Formation of Jaunsar Group and Deoban and Beringag Formation of Tejam Group. Chandpur Formation overlies the Nagthat and Blaini Formation of the Mussoorie Group (Negi, 1998).

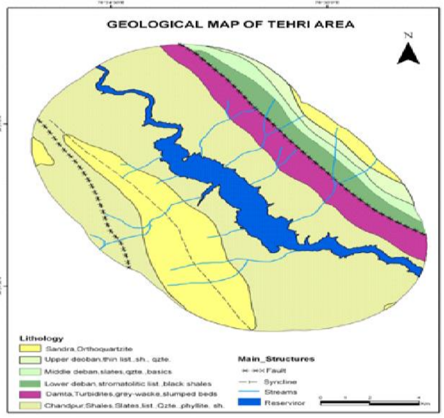


Figure 1. Geological Map of Tehri area.

The rock exposed in the Dam area is Chandpur phyllite, having variable proportions of argillaceous and arenaceous constituents. These rocks are classified into four sub-classes as Phyllitic Quartzite Massive (PQM), Quartzite Phyllite (QP) and Speared Phyllite (SP). Seismically the area falls in zone IV.

4. Materials and Method

For analyzing the landslide susceptibility mapping around the Tehri area the following data has been used.

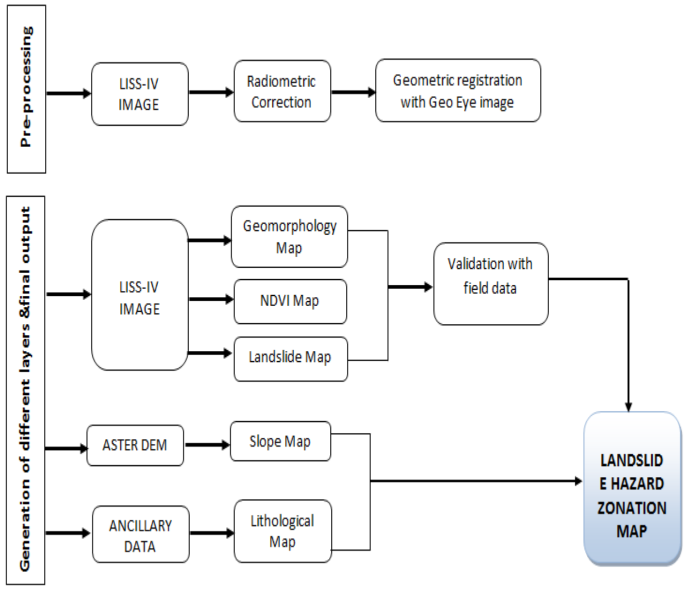
IRS LISS IV satellite imagery of IRS P6 (LISS IV) for two period of time i.e. 26th, Feb, 2005(before inundation) and 28th April, 2010(after inundation) has been used. Aster 30m Dem has been use in the present study for studying the general slope condition. A survey of India Topographic sheet number 53 J/7 &J11 depicts the area of interest (study area) has been used in the study for better field surveys and location information.

High resolution Geoeye satellite imagery with 1.65m resolution taken from Google earth was used for detailed understanding and preparation of the field plans and identification of Landslide bodies.

Field data is used for identifying active landslide and the validation of Landslide susceptibility area.

4.1 Methodology

The overall methodology used in the present study is summarised below: -



4.2 Pre-processing of Satellite Data

Accurate geometric registration of satellite data to a common spatial framework is a principal requirement for image analysis involving multiple satellite images (Prenzel and Treitz, 2004). In this study, Topographic Map and the Geo eye image of the study area has been used as a reference for the geometric correction of LISS IV time-series images, using second order polynomial. During geometric correction, uniform projection (UTM) and datum (WGS84) were maintained. The maximum RMS error after the transformation was less than 3 pixels, and can be considered satisfactory given the problems of image registration in mountainous areas.

5. Preparation of Thematic Layers and its Integration

5.1 Landslide Map

After demarcating the study area on the geoeye images, map showing landslides was prepared. Preliminarily this map was used for conducting field survey. Later on this map was updated by using LISS IV images of 2005, 2010 and field data and is used for further analysis. After the field work a point map showing the location of different active landslides around the rim of Tehri reservoir has been prepared from GPS field data.

5.2 Geomorphology Map

The pre-processed LISS IV image has been used for the creation of Geomorphology map. Visual interpretation technique has been used for the creation of geomorphologic map. Geomorphologically the area under study is broadly divided into four parts i.e Highly Dissected Hills, Moderately Dissected Hills, Low Dissected Hills and River Terraces.

5.3 Geology Map

The geological map of the study area has been created form the existing Preliminary geological map of the eastern Kumaon Himalayas prepared by J.Rupke and R. P. Sharma. Tehri area shows six lithological units and two main structures (see fig.2).

5.4 Slope Map

From the Aster 30mt DEM, slope map has been generated using the surface analysis tool of Arc GIS. The whole area is divided into eight slope zones.

Table 1. Slope zones of Tehri area

Slope Zones	Slope in Degree
Zone - I	0-15
Zone – II	15-25
Zone - III	25-30
Zone - IV	30-35
Zone - V	35-40
Zone - VI	40-45
Zone – VII	45-60
Zone - VIII	60>

5.5 NDVI Map

LISS IV image of 2010 has been used for the calculation of NDVI. The value of the (NDVI) ranges from (-0.726619 to 0.746799) which is further reclassify into five classes. Higher value (+ive) of NDVI show denser vegetation, very low value (-ive) depicts barren areas, active landslides areas and water bodies whereas moderate value shows fallow and exposed surface.

5.6 Data Integration

Data integration is the process of making different data sets compatible with each other, so that they can reasonably be displayed on the same map and so that their relationships can sensibly be analysed (Rhind et al.)There are number of methods employed for data integration. For the present study Index Overlay method has been used keeping in view the objective and heterogeneity of the study area. Index overlay a multiple layer integration method in which weights are assigned to different layers according to their importance. There are two types of index overlay models binary index overlay model and multiclass index overlay model. Multiclass index overlay model is used in this project and the scores for the classes are given between 1 to10 while weights for the maps are given between1 to 8, the weight and score assigned to each class according to their importance to the Landslide. The basic criterion used for assigning weights to all the classes is depended on simple criteria that, higher the area prone to landslide higher will be the weight/score. The scores and weights given to the various classes and maps are as follows:

Table 2. Weights and score assigned to different classes / layers.

Layer	Weight	Class	Score	Normalised Weight
Slope	8	0-15(in Degree)	1	1.25
		15-25	2	2.5
		25-30	3	3.75
		30-35	4	5
		35-40	5	6.25
		40-45	6	7.5
		45-60	7	8.75
		60>	8	10
Geology	7	Sandra,Orthoquartzite	5	8.33
		Upper Deoban, thin list,sh, qzte.	3	5
		Middle Deoban, slate, qzte.	4	6.67
		Lower Deoban, stromatolitic list.	2	3.33
		Damta,Turbidities, grey-wackes.	1	1.67
		Chandpur, shale, phyllite.	6	10
Geomorphology	4	Highly dissected hills	2	5
		Low Dissected hills	3	7.5
		Moderate Dissected hills	4	10
		River terraces	1	2.5
NDVI	5	Very low	5	10
		Low	4	8
		Moderate	3	6
		High	2	4
		Very high	1	2

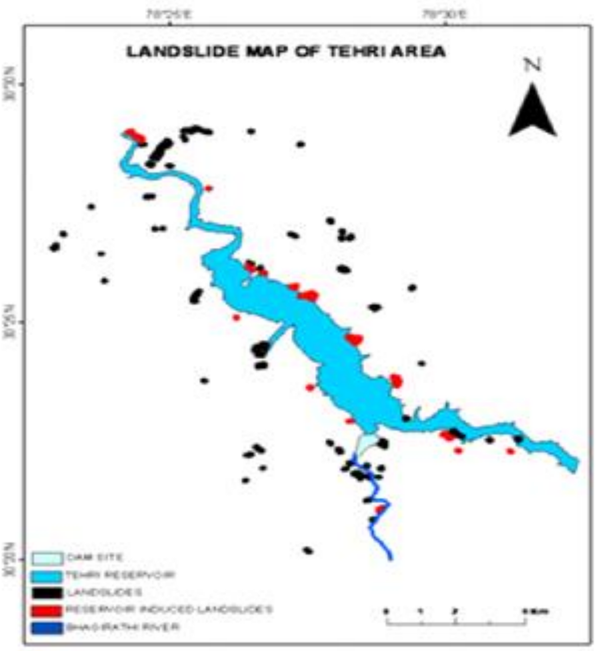


Figure 3. Map showing landslies around Tehri Reservoir.

6. Results and Discussion

The landslide inventory map created in 2005 is used as a base map in examining the reservoir induced landslide. The landslide map of 2010 has been prepared by using LISS IV data which is updated by the field data of 2012. In May, 2012 a detail field study, focusing on the areas very near to the outer limit of the reservoir has been conducted in order to identify the reservoir induced landslides.

The comparative study of 2005 and 2012 landslide map shows that there are eighteen number of reservoir induced landside present in the study area. Out of these, eight landslides are newly reported and rest ten slides show an increase in its dimension. This situation in the rim area is may be attributed due to the change in the hydraulic condition.

6.1 Landslide Hazard Zonation

By integrating four different layers in raster format representing simple ordinal number we get the landslide hazard map which is further divided into five classes i.e very low, low moderate, high and very high.

Table 3. Area under different landslide hazard zones.

Hazard Class	Area(Sq Kms)	Percentage
Very Low (Zone-1)	17.24	8.58
Low (Zone-2)	58.75	29.23
Moderate (Zone-3)	54.64	27.19
High (Zone-4)	57.44	28.58
Very High (Zone-5)	12.85	6.39

It has been clear from the table.3 that very high and very low zones shares less than 10 percent of the total landslide area each. However rest of the three zones shares area between 25 to 30 percent. The reservoir and the surrounding small river terraces constitute the zone 1 i.e very low of the study area. Whereas most of the upstream part of the study area having steep slope constitue the very high zone.

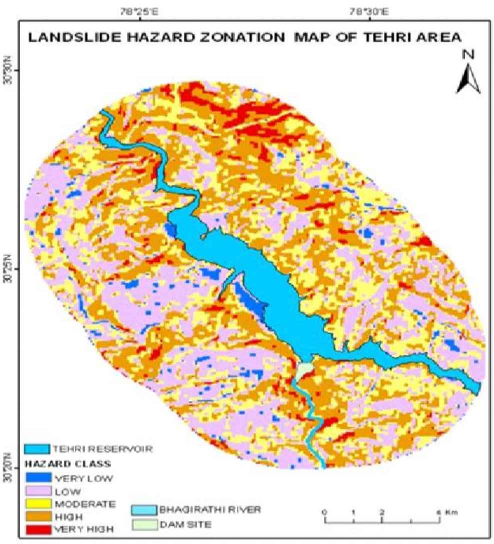


Figure 4. Landslide Hazard Zonation map of Tehri Area

6.2 Validation

The final assessment of landslide hazard has been made by comparing figure 3 with figure 4 which shows the existing landslides in the Tehri area. The result obtained from this comparison shows a good correlation between the existing landslides and high to very high hazard classes. The boundaries of the active landslides when superimposed on the hazard zone map shows a strong correlation between these slides with high and very high landslides hazard zone area. On the whole it is clear that the density of landslides increases from very low to very high class.

Table 4. Concentration of landslides in different Landslide hazard zone.

S. No	Hazard Zone	Hazard Zone Area (Sq mt)	Landslide Area (Sq mt.)	% as per hazard zones ($*10^{-4}$)
1	Very Low	17240000	17	0.98
2	Low	58750000	161	2.74
3	Moderate	54640000	293	5.36
4	High	57440000	393	6.84
5	Very High	12850000	187	14.55

The comparative study of table 5 and 6 shows that the percentage of hazard zone area is high in Low class but the concentration of landslide area is more in high zone. The quantative analysis of the data shows that more than 80% of the total landslide area existed in moderate and high hazard zone classified area.

7. Conclusion

The inundation of the reservoir was started in Oct, 2005 and it reaches upto the level of 785Mts in 2006.After its inundation lot of instabilities in terms of slide and subsidence has been experienced around the Rim Area. In spite of the scarcity of the data the result has shown persuasive achievement in the delineation of area under study into various zones susceptible to landslide around the Tehri reservoir. This work is helpful to mask out the area highly vulnerable to landslide which in turn causes insecurity to the nearby settlements.

Tehri dam is surrounded by slopes that are steep and unstable occurring of landslides due to rains, have been common there for a long time. Since the inundation of the reservoir, their frequency has grown exponentially and moreover it also causes the reactivation of the old slides. The temporal analysis of landslides around Tehri reservoir shows that there are eighteen number of reservoir induced landside present in the study area. Out of these, eight landslides are newly reported and rest ten slides show an increase in its dimension.This happened due to periodic changes in the water level which in turn causes small and progressive slides closer to the reservoir and makes the upper slopes vulnerable. In this connection the present work very righty point out the need for short-term and long-term plan before initiating any sort of development activities in the Tehri rim area.

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