NATURAL HAZARDS, VULNERABILITY AND PREVENTION OF NATURAL DISASTERS IN MIDDLE HIMALAYA, UTTARAKHAND

Dr Kuldeep Pareta [1], and Dr Madhu Joshi [2]

[1] Manager (Remote Sensing & GIS), [2] Senior Water Resources Engineer

DHI (India) Water & Environment Pvt. Ltd., 206, Ground Floor, Okhla Industrial Estate, Phase-III, New Delhi - 110020. India

Abstract:

Floods in The Himalayas have influenced the behaviour of rivers in Uttarakhand by changing the bank line, bed level and flow pattern of rivers in various stretches. Heavy downpour and subsequent devastating floods on 15th and 17th June 2013 in the various rivers of Uttarakhand led to heavy loss of lives and property. The event caused instability of the channel by shifting the banks. The main hazards in region related to the rivers are flooding, landslide, soil erosion, and river bank instability. Criteria to identify the vulnerable reaches is based on risk, exposure and hazards in that area.

The magnitude of risks due to flood hazards on various exposure along the riverbank is calculated based on qualitatively derived scores. Erosion rendered many locations along the banks vulnerable to economic and human loss. The extent and magnitude of risks have been assessed based on information of past events, rapid field assessments, current mitigation measures and interactions with the locals. The findings from these interactions, and secondary data based on geospatial analysis of bank line changes have been used in the identification of vulnerable reaches of the rivers. The shift in reaches are calculated by digitizing the bank line using satellite imageries of year 2005, 2010 and 2015. Susceptibility of banks and damages by high discharge along bank line are also studied. A fuller understanding will enable decision makers towards more efficient resources management for prevention and mitigation of flood events.

Key Words: Vulnerability, landslide, flood, bankline changes, Himalaya, and climate change.

About the Author:

Kuldeep Pareta

Madhu Joshi

Dr Kuldeep Pareta has obtained M.Sc. degree in Geography from Dr Hari Singh Gour University, Sagar (MP) in 2001, subsequently Ph.D. in Geomorphology, Hydro-Geology and Remote Sensing from same university in 2005. Presently, he is working as Manager (RS/GIS) in DHI (India) Water and Environment Pvt. Ltd., New Delhi, and has have over 17 years of R&D experience in the field of national resource management, geomorphology, hydro-geology, watershed modelling, and national disaster management. He has published over 60 research papers in various referred national and international journals, and four International books. He was conferred Prof. S.M. Ali Memorial Gold Medal in 2001 and MP Young Scientist award in the year 2004.

Dr Madhu Joshi is PhD from IIT-Delhi and having sound 20 years of experience in the Numerical Modeling of Coastal processes domain with focus on cyclones and their interaction with atmosphere, ocean currents, tides and waves. She has vast experience in the numerical modeling using POM-2D&3D, MITgcm, TELEMAC-2D&3D, MIKE 21 (Cyclone Model), IIT-D Surge Model SWAN, NGFS, NCUM, NIMO, RCM for CORDEX-6. She possesses good consultancy and research experience with more than 20 publications. She posses good scientific background having working experience with MoES and IIT Delhi, Hydraulic Research Wallingford India. Pvt. Ltd and RMSI Pvt. Ltd. Currently she is working as Sr. Water Resource Engineer in DHI India, one of the largest global modeling firms working in water and environment.

E mail ID: kupa@dhigroup.com / majo@dhigroup.com
Contact: +91-9871924338 / +91-9968887886

1. Introduction

The Himalayas are one of the youngest mountain ranges on earth. The uncertain climatic conditions, varying geology, steep slopes, rivers, highly variable altitudes, glaciers and high tectonic activity make the region inherently vulnerable to numerous types of hazards (Nadim et al. 2006). Landslides, debris flows, avalanches, flash floods, failure of high altitude natural and glacial lakes, extreme rainfall, earthquakes and rock falls cause widespread destruction in the area (Bajracharya and Mool, 2009 and Immerzeel et al 2010).

The climate in the mid-Himalayas consists of four distinct seasons - winter, pre-monsoon, monsoon and post-monsoon. 60% of the mean annual rainfall occurs during the summer monsoon (Rawat et al. 2015). Vohra (1981), suggests that the upper parts of the basin (Kedarnath area) receives equal amounts of precipitation during summer and winter monsoon.

Pre-monsoon rains between June 15 and 17, 2013 combined with melting of snow caused voluminous floods in the rivers of Uttarakhand and subsequently triggered widespread mud and landslides (Dobhal et al. 2013). Flash flooding and landslides killed more than 6000 people (Guha-Sapir et al. 2014), numerous roads and bridges were damaged, and at-least 30 hydropower plants were either destroyed or severely damaged (Sati and Gahalaut 2013). The destruction of roads and trekking routes left around 100,000 pilgrims and tourists stranded until military and civic authorities could complete evacuation efforts (Martha et al. 2014). Connectivity was disrupted across the state and vehicular traffic was disrupted along more than 2000 roads. About 150 bridges were damaged or washed off (Thakkar et al. 2013).

2. Data

Satellite remote sensing data, elevation data and hydro-meteorological data were used to assess the vulnerability in the rivers due to floods. Elevation data was obtained from Shuttle Radar Topography Mission (SRTM) and CartoSAT-1 Digital Elevation Model (CartoDEM), available at spatial resolution of 30 m. The same data has been used for slope mapping, drainage mapping, physiography and morphometric analysis. The details of the data sources are shown in Table 1.

The remote sensing data collected by Indian satellites from National Remote Sensing Centre (NRSC) was used to extract the morphological analysis, land use / land cover, soil, geology and geomorphic characteristics of the area. In-order-to enhance the display of the study area, images of LandSAT-7 and LandSAT-8 with low cloud content (spatial resolutions of 15 m) acquired on 2nd December, 2005 and on 26th September, 2015 were used. Additionally, IRS-P6 data (spatial resolutions of 23.5 m) captured on 5th November, 2010 was also used. Geological sample data was gathered during the field assessments of vulnerable reaches.

Table 1: List of the Data and Data Sources

S. No.	Data layer / maps	Sources
2.	Satellite Remote Sensing Data	LandSAT-7 ETM$^+$ (PAN shaped) satellite imagery (15 m) Global Land Cover Facility (GLCF), Earth Science Data Interface (ESDI), 2005
		ResourceSAT IRS-P6 LISS-III satellite Imagery (23.5 m) Indian Earth Observation, National Remote Sensing Centre (ISRO), 2010
		LandSAT-8 OLI (PAN shaped) satellite imagery (15 m) U.S. Geological Survey (USGS), Earth Explorer, 2015 & 2017
3.	Elevation Data	Shuttle Radar Topography Mission (SRTM) DEM Data (30 m) NASA, & USGS EROS Data Center, 2006
		CartoSAT-1 Digital Elevation Model (CartoDEM) Data (30 m) Indian Earth Observation, National Remote Sensing Centre (ISRO), 2010
4.	Land Use / Land Cover Map	Land use and land cover maps have been prepared at 1:50,000 scale by using multi-temporal satellite imagery

6.	Geological Map	District wise geological map (at 1: 250,000 Scale) data has been collected from GSI and updated through IRS-P6 LISS-III & LandSAT-8 OLI satellite data with limited field check.
7.	Geomorphological Map	Geomorphological map at 1:50,000 scale along with geological structures have been prepared using the IRS-P6 LISS-III data, LandSAT-8 OLI data, CartoSAT-1 DEM / SRTM-DEM data, and other ancillary data topographical map, geological map.
8.	Climatic Data	Indian Meteorological Department (IMD) station data for varying time periods depending upon their availability with IMD.

3. Climate and Extreme Rainfall

The climatic conditions in the study area are not uniform and vary according to the location, altitude, aspect and morphology. There is a large variation of relief from 362 m in south to more than 7,184 m in the north of the study area. It has been observed that for every 1,000 m ascent, there is a 6°C decrease in temperature (AHEC 2011). The details of temperature recorded at the meteorological observatories in the study area show that the highest temperature was 34°C and lowest 0°C. The slope aspect also plays an important role in determining the climate, as north facing slopes are much cooler and more damp when compared with south facing slope due to insolation effect. January is the coldest month after which the temperature begins to rise until June or July.

Most of the rainfall in the study area occurs during the summer monsoon from June through October due to tropical storms and depressions originating from Bay of Bengal. The winter rains are brought by the western disturbances and summer rains by the summer monsoon winds. For all the seasonal regularity of monsoon winds and rainfall, local climates (over much of the area) are quite variable. At times the rainfall may arrive at the expected time bearing considerably diminished rainfall throughout the season and at times there will be unusually heavy rain leading to disastrous floods. The highest rainfall recorded at all the stations was in 2013.

Certain peculiar geomorphic features including cirque and funnel shaped valleys with high relative relief, dense forest cover, and average altitude exceeding 1500 m are considered to provide favourable conditions for cloud burst. Heavy localized rainfall is a natural phenomenon in the Himalayas and the frequency of such events is increasing due to climate change. Recent climate changes have had a significant impact on high mountain glacial environments. The unexpected heavy rainfall during this event combined with melting snow caused voluminous floods in the rivers and prompted widespread mud- and landslides in Uttarakhand.

4. Existing Infrastructure, Landslide and Glacier

Figure 1 is a composite image of the analysis area depicting the infrastructures, landslides and glaciers. Besides affecting the local population quite adversely, such a disaster severely disrupts the habitations, agricultural lands, forest, and other infrastructures along the rivers. Hence a vulnerability study is important for protection of the region. The high relief snow clad ranges of all river basins are located along the northern periphery of the basin. A very large number of glaciers exist above the snow line (Figure 1). The factors controlling the glacierization of an area include the height of ridges, the orientation of slopes and amount & type of precipitation in the area. According to Alternate Hydro Energy Center, (Jain et al 2008) Gangotri system is a cluster of glaciers comprising the main Gangotri glacier (length: 30.2 Km, width: 0.20-2.35 Km, area: 86.32 Sq. Km) as a trunk part of the system. Other major glaciers of the system are: Raktvarm (55.30 Sq. Km), Chaturangi (67.70 Sq. Km), Kirti (33.14 Sq. Km), Swachand (16.71 Sq. Km), Ghanohim (12.97 Sq. Km) and a few others (13.00 Sq. Km). Depth of these glaciers are about 200 m and the elevations vary from 4000-7000 m.

Landslides are mass wasting due to slope failures. It is downslope movement of rocks, soil and debris by the action of gravity. Several features of the basin make landslides a common occurrence such as the relationship between the rocks, characterized by multiple structural discontinuities, and the high relief slopes. Landslides on the roads disrupt communication routes. Similarly, landslides into the streams also pose major threats. The slid land masses cause blockades of river courses and subsequent breach of landslide dams increases the flooding potential of downstream reaches. Landslides also induce higher sediment loads into the rivers which can also have adverse impacts. Additionally, the following features of the basin make landslides a common occurrence in this river basin.

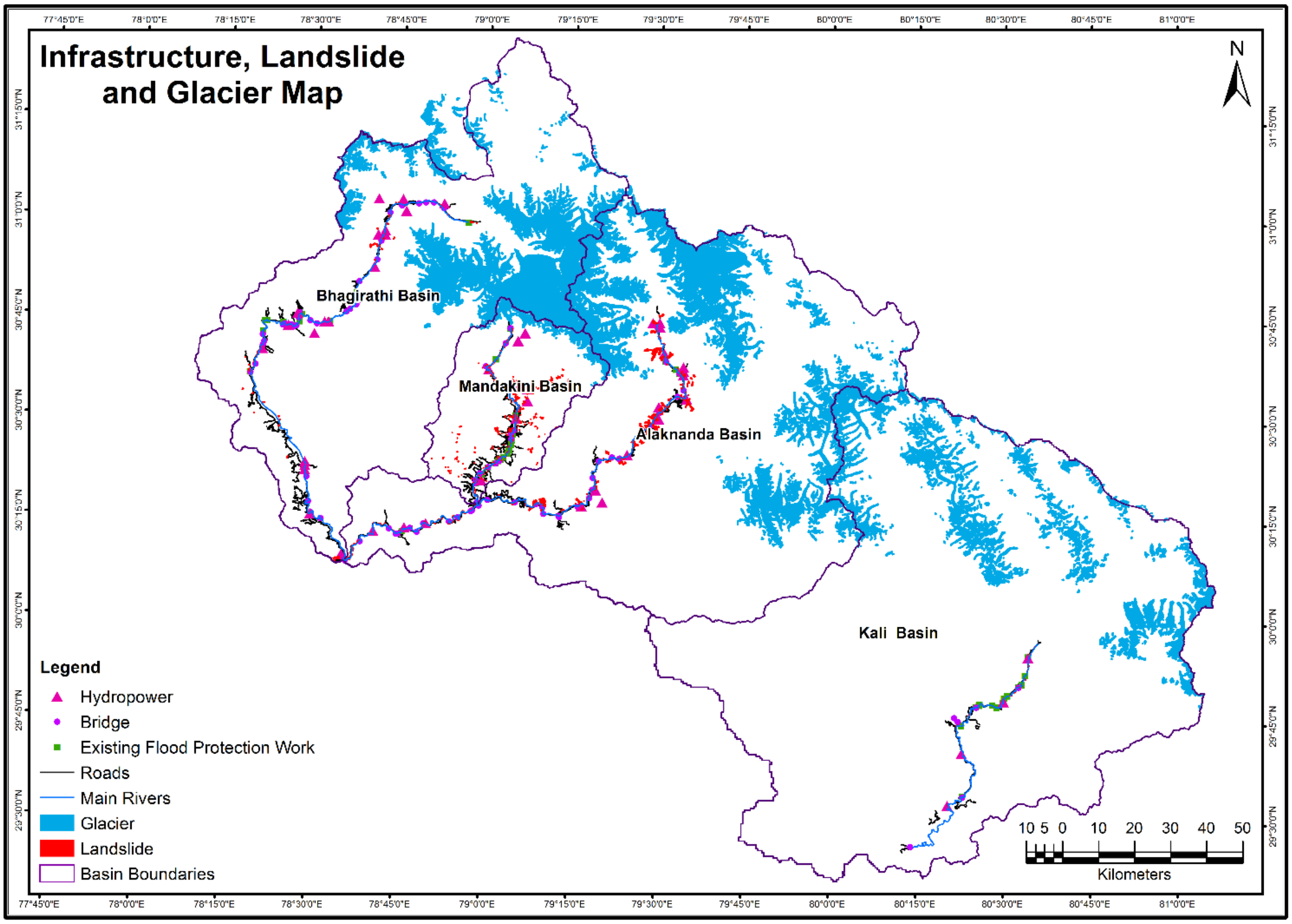

Figure 1: Existing Infrastructure, Landslide and Glacier Map of Study Area

5. Geology

The geological mapping consists of a sequence of activities executed on the field, with the purpose of collecting the maximum information about the geological constitution of a specific area. Several scientific papers concerning different geological aspects like structural geology, lithostratigraphy, geomorphology, slope instability, seismic hazard of the area, have been collected and critically reviewed and relevant information incorporated into the final map. Notable studies which have contributed to diverse geological aspects of the study area are: Auden JB (1934), Gansser A (1964), Verma RK et al (1970), Krishnaswamy VS (1982), Dhingra D et al (2004), Celerier J et al (2009) and many more.

The area is mostly composed of banded Central Crystalline; Martoli Group; Granitoid of Amritpur, Almora, Chamoli and Chandrapuri; Rautgara (formations of Garhwal Group). The bedrock outcrops are severely weathered on the ground surface. No geologic event is recognized in recent years. Therefore, geologic features are divided into two parts: hard part and soft part. Erosion due to river and landslide in soft rock parts at Rautgara (Formations of Garhwal Group), Granitoid of Amritpur, Almora, Chamoli and Chandrapuri, and Bhilangana Fromation has been recorded.

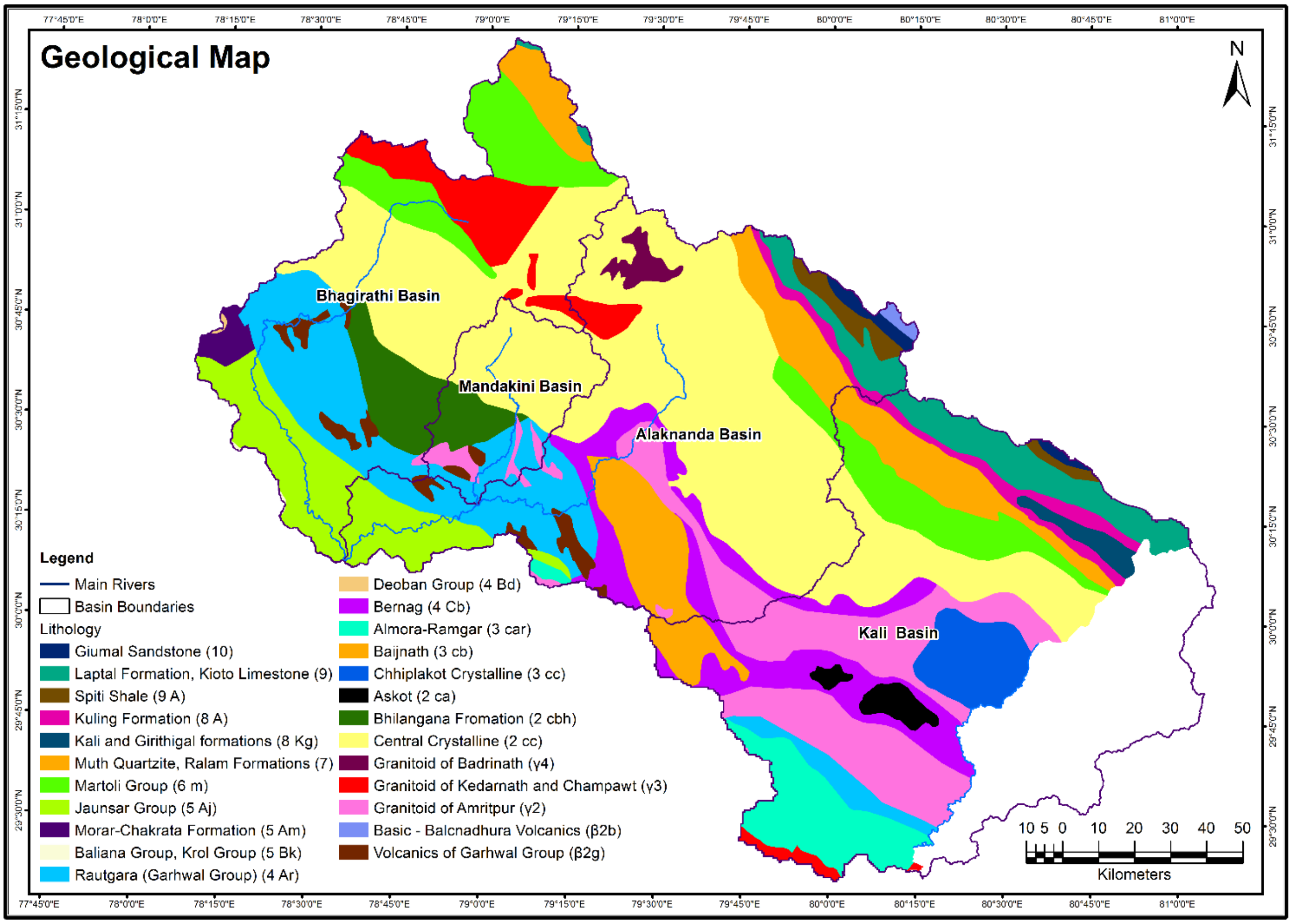

Figure 2: Geological Map of Study Area

6. Hazards, Risks and Exposure

The screening process for identification of vulnerable reaches is based on the hazards present along a river reach, the level of risk of those hazards, and the level of exposure of the population and the infrastructure to the hazards. Fluvial geomorphology has approached flood hazard analysis from different angles detailed in Table 2.

Table 2: Cause of River Morphological Hazard and Flood Hazard

Hazard	Cause
River Morphological Hazard	
Bank Erosion	Increased hydraulic forces in the vicinity of the river bank
	Weaker bank materials properties or geotechnical characteristics of the banks.
	Configuration of the bank.
Bed Scour	High flows with strong velocities
Aggradation of bed level	Higher sediments load than the sediment transport capacity of a river reach.
Narrowing of waterways	Caused by blocking of channel due to landslides, unusual deposition, constrictions imposed due to occupation of land by human activities.
Meandering of rivers	The meandering of rivers along a reach is the main cause of erosion of banks at high floods. Bed and bank scours occur at sharp meanders. Landslides depositing debris in the river bed aggravate the

	impacts of meandering rivers, causing sharp shifting of the river course and migration of rivers towards lands and settlements.
Flood Hazard	
	Flash floods generated due to sudden heavy rainfall, including cloudbursts in parts of the catchment. Discharge higher than the conveyance capacity of a river reach. Temporary blocking of river due to landslides. Glacier lake outburst floods (GLOF) generated in catchments at higher elevations.
Landslide	
	Landslides directly related to erosion of river banks, caused mainly by toe erosion. Landslides due to construction of roads, with debris falling into the river. Landslides away from the river above the road towards hillside terraces, but ultimately affecting the river flow due the falling debris.

Level of risk is identified based on direct and indirect impacts of the hazards to the exposed elements. Impact is estimated based on exposure to human losses, socio-economic losses, and environmental losses. If the hazard is due to the river, score is one and if hazard is not due to the river then the score is zero. Risk is calculated by multiplication of hazard, exposure and impacts. If score is more the four risks will be high and if score is one or less than one, then risk will be low. Exposure refers to people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses. While the literature and common usage often mistakenly combine exposure and vulnerability, they are distinct. Exposure is a necessary, but not sufficient, determinant of risk. Following exposures are considered under the present study.

- Human population (rural as well as urban) residing near the river bank, which is exposed to hazard or affected earlier
- Infrastructure includes roads, bridges, hydropower stations, irrigation systems, human settlements, health care facilities and places of religious importance.
- Agricultural land
- Tourism spots
- Defense establishments

7. Vulnerability and Risk Analysis

Risk on the vulnerable reaches along the four rivers are assessed based on hazard, exposure, and impacts due to hazard. If multiple hazards are present, the score is assigned to three and if a single hazard is present the score is two or one depending on whether the hazard is river or other than river respectively. If exposure is more than one and settlement is one of them the score is three. If the only exposure is settlement, then the score is one. If the exposure is road or agriculture land, the score is one. If the impact is due to the river, score is one and if impact is not due to the river then the score is zero. Risk is calculated by multiplication of hazard, exposure and impacts. If score is more than four, risk will be high and if score is one or less than one then risk will be low. Calculations of quantitative measures of the risk along the reaches are based on following methods.

Risk= Hazard x Exposure x Impact

Calculations:
If score is >4, Risk is high
If score is >1 and <= 4, risk is medium
If score is < =1, risk is low.

Risk is low or medium high if score is 1, it means protection work completed. If score is zero it means that no protection measures provided at that particular reach and risk is high. If total risk is high and hazard is not due to river, those locations will be not considered in the final list.

Table 3: Calculation of the Risk

	Score	Descriptions
Hazard		
If multi hazard	3	If hazard is due to river
If single hazard	2	If hazard is due to river
If single hazard	1	If hazard is due to landslide or other than river
Exposure		
If exposure is more than one	3	If road, agricultural land associated with settlement or only settlement
If settlement	3	
If road	2	
If agricultural land	1	
Impact due to		
If due to river	1	
If not due to river	0	
Special case	Populated town: Uttarkashi, Srinagar and Dharchula Kasba etc.	Populated and important towns

8. Problems Encountered in the Vulnerable Reaches

The rivers experienced extreme floods in the year 2013 due to heavy rainfall within 72 hours on 16th and 17th June 2013. It developed adverse conditions for river hydraulics and sediments transportation. Following morphological changes at various river reaches occurred.

- Straightening of river meanders
- Accentuation of meanders at their apex points
- Shifting of channels
- Due to thorough saturation of soils, the stability of the slopes of river banks had been seriously disturbed and severe bank erosions took place at numerous locations
- High sediment loads deposited by the rivers at every probable place of comparatively slack flows, resulting in high HFL and high pressure on banks.

The changes brought to the rivers have made identification of vulnerable reaches problematic at many locations.

9. Critically Vulnerable Reaches

Settlements, roads, forests, agricultural lands and other infrastructure are exposed to river hazards. Based on the analysis given in Table 2 and Table 3, the vulnerability has been identified through field visits and interaction with local people. Risk on the vulnerable reaches along the four rivers are assessed based on hazard, exposure, and impacts due to hazard. Many vulnerable reaches were identified based on hazard, exposure and impacts due to factors like river or landslide. Vulnerability and associated risk at above mentioned eight locations has been listed in table 4.

Table 4: Risks on Vulnerable Reaches before Emplacement of Protection Work

S. No.	River Basin	Location	Exposure and Description of Hazard	Vulnerability	Risk
1	Bhagirathi	Jyoti	Agriculture Land: Landslide above the road and toe erosion below the road may affect the vehicular traffic and obstruct the pilgrimage.	Landslide and toe erosion	Medium
2		Uttarkashi	Settlement:	Debris deposition, flooding	High

			Debris deposition, flooding due to the barrage situated within the town, toe cutting on both banks are main hazards.		
3	Mandakini	Sitapur	Agriculture Land: Toe erosion and direct cutting of the right bank led the loss of agricultural land.	Toe erosion and debris deposition	Medium
4		Tehsil Area Rudraprayag	Settlement: Slope failure and bank erosion at the bend is the main hazard to Tehsil area.	Bank erosion	High
5	Alaknanda	Khiru Village	Settlement: Toe cutting by high shear stress is the major cause of bank failure. There is the possibility of sediment deposition to block the flow of Alkananda from the heavy silt laden flow of Khiru Nala which hits the Alaknanda almost perpendicularly on the right bank. This can divert the Alkanada flow toward the village by shifting of the bank.	Flow from tributary is directly hitting the settlement	High
6		Deolibagad	Settlement: The hazards are flooding of the low lying village on the left bank and gravity failure of bank associated with toe erosion.	Settlement existing on the flood plain	High
7	Kali River	Gothi Village	Settlement: The hazard is bank failure due to by toe erosion, removal of material from bank.	Settlement endangered due to toe erosion	High
8		Jhulaghat	Settlement: Major hazard at this location is bank erosion at right bank and landslide at left bank.	Settlement is on the eroding bank of river	High

10. Conclusions

The Uttarakhand June 2013 disaster had potential regional and global significance in term of vulnerability assessment. The high-mountain glaciated areas heavy rainfall and rapid melting of ice due to continuous rising air temperatures, have increased the potential for danger from dammed lake outburst floods to the human population and infrastructure.

This paper describes the meteorological and morphological characteristics of Uttarakhand river basins (Alaknanda, Bhagirathi, Mandakini and Kali), which can influence the river morphology. This will give detailed knowledge of the basin and the behaviour of the rivers. All data collected, onsite detailed work combined with satellite information and knowledge acquired from the available literature contribute to understanding the geology and geomorphology of the study area. River basins focusing on rainfall, topography, drainage pattern, soil, landslide, and exiting infrastructure in relation to vulnerability of the region are discussed in detail.

A detailed description and methodology to identify the critical vulnerable reaches along the river which are associated with the river morphology in the region is given. Bank line changes and river bar delineation have been obtained using high resolution satellite data through GIS for the years 2005, 2010 and 2015. This manual will be of great use to policy makers and rural or villages planners in preparing proper village plans, slope stability plan, disaster management plan and in prevention of natural hazards and manmade hazards. The manual will also be useful to drainage designers to plan the layout of drains and potential hydro projects and in planning of other infrastructure facilities like roads, national parks, reserve forest and Government Plans.

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