# Multi-Hazard Risk Zonation Based on Functions Responsible for Hazards Like Landslides, Floods, Forest Fires and Earthquakes in Mandakini Valley

**Seema Joshi, J. K. Garg, Amarjeet Kaur**

*Abstract: The Himalayas are considered youngest mountain on Earth. Region is highly vulnerable to hazards because of tectonic activity, steep slopes, highly variable altitudes and uncertain climatic conditions. As a result, key hazards experienced in the region are earthquakes, landslides, forest fires, snow/ice avalanches, flash floods and extreme rainfall events which lead to great losses to human lives and property every year. The aim of study is to find most vulnerable area in terms of multi-hazards as per UNISDR guidelines. Here, GIS based techniques were used for disaster risk assessment towards various hazards and then integrating vulnerable areas with demography to perform detailed multi-hazard zonation of the area. Various Geo-spatial and statistical techniques were used in analysis of different types of disaster risk, determining the factors affecting incidents and in preparation of multi-hazard risk maps. The work involved the qualitative study, through in depth scientific observations, study available models for early warnings, develop models using sample data and generate multi-hazard vulnerability of study area. Using advanced geo-spatial techniques, Hazard Zonation maps were generated for different hazards in the Study Area. These maps were overlaid with Socio-economic and Demographic Profile of the habitations in the study area and multi-hazard risk assessment maps were generated. On the basis of complete geo-spatial analytics and scientific models, it was derived that 74 + villages are highly prone to various disaster. Scripts were written to automate various processes. Results were verified and validated during field visits.*

*Keywords: GIS, Hazard Risk Zonation, Landslides, Floods, Fires, Earthquake*

## I. INTRODUCTION

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The Himalayas are considered youngest mountain on Earth and are tectonically active. Region is highly vulnerable to hazards because of tectonic activity, steep slopes, highly variable altitudes and uncertain climatic conditions. As a result, key hazards experienced in the region are earthquakes, landslides, forest fires, snow/ice avalanches, flash floods and extreme rainfall events which lead to great losses to human lives and property every year.

As stated in UNISDR, there is no such thing as a "natural disaster", it is only "natural hazards". Disasters often follow natural hazards. Although damage to property cannot be avoided, loss of life can be prevented if disasters can be managed much more effectively by implementing efficient disaster warning systems, evacuation procedures and use of integrated GIS, Space, IT & communication technologies. The first step towards reducing disaster is to correctly analyze the potential risk and identify measures that can prevent, mitigate / prepare for emergencies.

Several Research Studies were made in the past where hazard Risk vulnerabilities were identified and zonation was performed for different hazards individually. Most of these studies have focused on causative analysis of disaster post disaster is experienced. Many a times, it was observed that one hazard triggers another hazard also. Further, with non-availability of multi-hazards vulnerabilities awareness, huge losses towards life and property were incurred.

Hence, there is a key requirement to identify vulnerabilities under various hazards and perform multi-hazards risk assessment to suggest measures to manage these multi-hazards efficiently.

## II. STUDY AREA

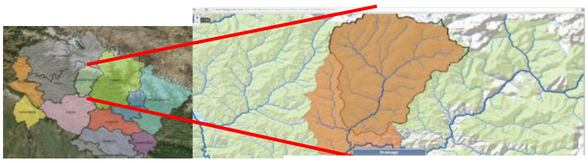
In the recent past, the statet of Uttarakhand has witnessed a number of geo-hazards leading to various disasters. It is vulnerable to small ecological changes and hence any small disturbance in mountain ecosystem triggers a disaster. Mandakini Valley by virtue of its geographical setting, is one of the most disaster prone areas in the state.

**Mandakini River Valley,** administratively, lies in Rudraprayag district of Uttarakhand State, covering an area of about 1982 sq. km lies between lat. 30° 12" 58.132' – 30° 48" 27.642' N and long. 79° 2" 58.649' – 79° 2" 0.952'

E. Mandakini is a branch of the Alaknanda River and originates from the Chorabari Glacier near Kedarnath in Uttarakhand, India and joins Alaknanda at Rudraprayag.

For the purpose of this paper, Rudraprayag District of Uttarakhand was selected as most of the district is falling under catchment of Mandakini River as shown in Fig.1.

For study sites, cities/habitations adjoining Mandakini River were selected enrouting from Rudraprayag to Guptkashi. For multi-hazard vulnerability assessment, entire Mandakini Valley was considered.



(a) Rudraprayag District (b) Mandakini Catchment

**Fig. 1.Study Area**

## III. APPROACH & METHODOLOGY

This study aims at finding the most vulnerable areas in terms of multi-hazards by incorporating qualitative & quantitative techniques of disaster risk assessment as per **UNISDR** guidelines. The key objective of the study was to perform hazard assessment using Geo-spatial technologies, and generate multi-hazard zonation of the area, which can be used for building Disaster Risk Resiliency in this study area. Various GIS tools like ArcGIS, ArcHydro, HECRAS, HECHMS, SINMAP etc. were used for extensive geo-spatial analysis. Various Geo-statistical techniques were also used for identifying different types of disaster risk, determining the key factors responsible for hazard incidents..

The work involved the qualitative study, through in depth scientific observations of the study area, collect and integrate base data and feeds available through multiple sources, study scientific models for hazard assessment, develop and test models using sample data and generate various hazard vulnerability maps of the study area. All this information together with demographic profile was used to generate multi-hazard zonation maps. A complete process flow is depicted in Fig 2

The first activity was to assess study area and identify sites which are highly vulnerable to hazard risks. A reconnaissance survey was conducted to assess various ecological, geological, geomorphological, physical and demographic features of the area. Study sites were identified considering vulnerabilities to various hazards, demographic profile, terrain, planned-unplanned settlements, hydro-geological features and historical hazards.

As huge secondary datasets were available through various national / global sources and Earth Observation techniques, the research had followed a combination of both primary and secondary data research approach. Hence, a number of Primary & Secondary data layers were collected for the entire Study Area and all information from multiple sources was integrated to generate Area Profile and Hazard Risk maps. Secondary data was also collected from a number of sources like Disaster Management & Mitigation Centre (DMMC), SoI, GSI, RGI, NASA, NOAA, USGS, ESRI etc.

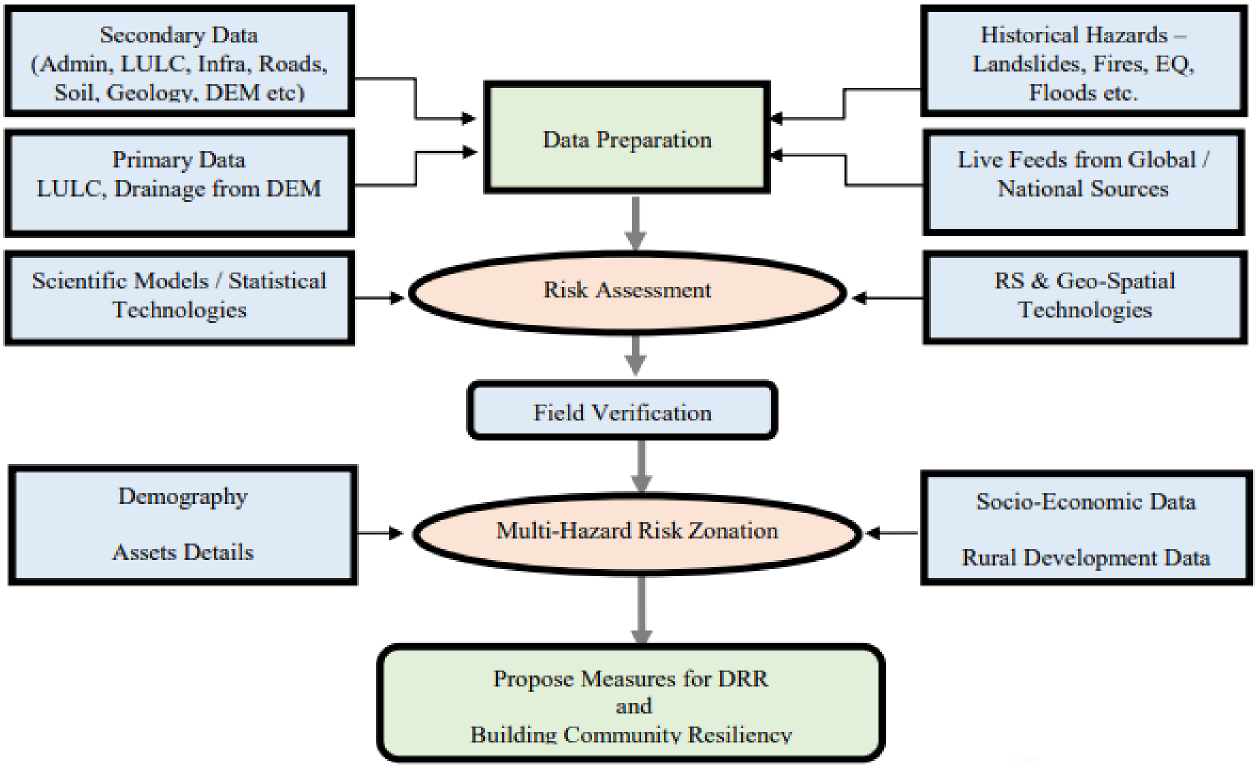



**Fig 2: Approach and Methodology – Block Diagram**

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Throughout the study, diverse sets of literature have been reviewed and suggested hazard related models were studied. These scientific models were evaluated and analyzed.

Output generated by these Models were compared with historical events like Kedarnath Disaster for accuracy assessment. In order to identify most suited model, sample time-series data was taken from historical disasters for necessary testing and comparison of results. Outputs generated under various hazards were further tested on ground with the help of field visits. During these field visits, results generated using different geo-spatial technical models were calibrated and verified against historical disasters.

As landslides is one of the pre-dominant major hazard which is responsible for triggering multi-hazards in the study area, various publications including reports from Geological Survey of India (GSI) were also referred to analyse and understand geotechnical structures and Landslides Susceptibility of the Study Area.

Using geo-spatial techniques, all these maps were then integrated with socio-economic and demographic profile of the habitations to generate risk assessment maps.

All these inputs were then integrated to generate Multi-Hazard Risk Zonation of the study area, which can be considered for necessary recommendation on building Disaster Risk Resiliency in the study area.

## IV. RESULTS & DISCUSSION

### A. Data Preparation

In order to prepare multi-hazard zonation map, a number of data layers were required, which were generated using primary and secondary sources. Following activities were performed and various outputs were generated, which were integrated to generate final results.

- **Primary Data Preparation - Establishment of river basin boundaries and preparation of base layers using ASTER DEM**

The ASTER Global Digital Elevation Model (ASTER DEM) is a joint product developed and made available to the public by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). It is generated from data collected from the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), a space borne earth observing optical instrument which provides elevation data. ASTER GDEM is an easy-to-use, highly accurate DEM (15 m resolution) covering all the land on earth, and available to all users regardless of size or location of their target areas. This data is extremely useful for advanced hydrology modelling, environmental monitoring etc.

In this study, ASTER GDEM was used to generate Drainage Network with 8 levels of Stream order along with other intermediate layers like River Catchment, Flow Direction, Flow Accumulation etc.

A GIS based model was designed using ArcGIS as shown in Fig. 3.1 to automate the process of generation of drainage network from DEM. This designed model can be used for generation of drainage network for any area or can be used for refinement of generated outputs to achieve better accuracy.

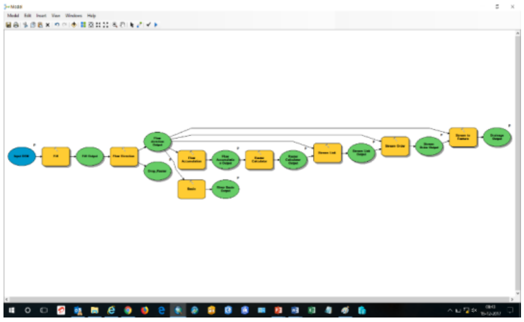
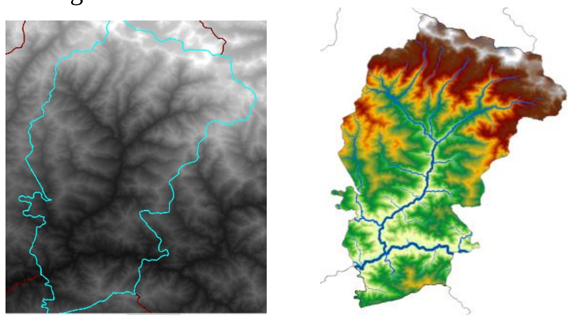


**Fig 3.1: Designing of Model to automate generation of Drainage Network from DEM**

ASTER DEM used and Drainage Network generated is shown in Fig. 3.2 below



(a) ASTER DEM (b) Generated Drainage Network

**Fig 3.2: Generation of Drainage from ASTER DEM**

Following data layers were also generated using ASTER DEM with the help of ArcGIS Platform:

- Slope Map (in Degrees) (Fig.3.3)
- Aspect Map (Surface Direction) (Fig.3.4)
- Hillshade (Considering 315 Azimuth and 45 Degree Altitude Angle of light source)
- Contours (Interval 5 mtr.)

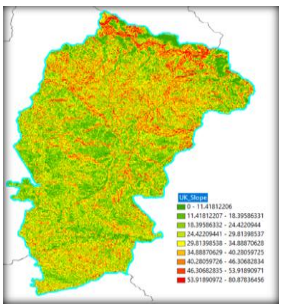


**Fig 3.3: Slope Map**

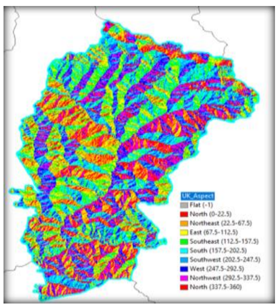


**Fig 3.4: Aspect Map**

- **Primary Data Preparation - Preparation of Land use / Land cover map**

The nationwide land use/land cover (LULC) map is generated by ISRO / Bhuvan using AWiFS data. This data is shared in the form of web services through ISRO / Bhuvan Portal. Framework was implemented for seamless access of these services. As LULC map service shared by ISRO was of year 2012 (Fig.3.5), latest Sentinel Satellite Imagery was used for preparation of LandUse / Landcover Map of year 2019 (Fig.3.6).

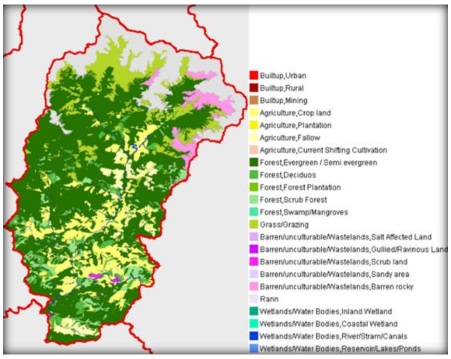



**Fig. 3.5: Landuse / Landcover Map (2011-12)**
**Source: ISRO / Bhuvan Portal**

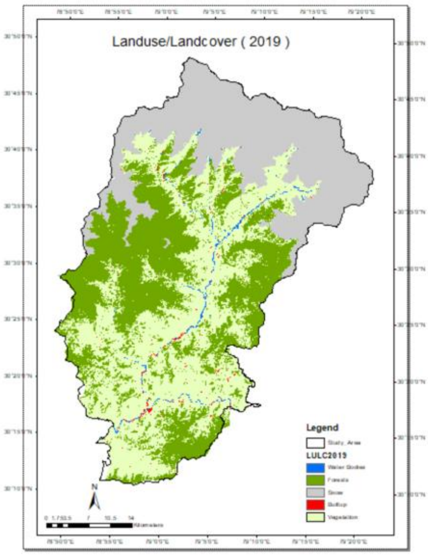



**Fig. 3.6: Landuse / Landcover Map (2019) generated using Sentinel data**

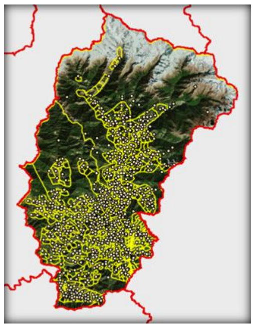
- **Secondary Data Collection and Integration**

For preparing detailed physiographic and geomorphologic profile of the area, a number of other related layers were required. Framework was created in ArcGIS Platform to access and use these layers available through various sources like ISRO/ Bhuvan, NASA, USGS etc. Other MIS attributes like Demography, Socio-Economic Profile of the Area, Historical Hazards were also collected from sources like Census of India, National Disaster Management Authority, Esri ArcGIS Online Cloud etc.

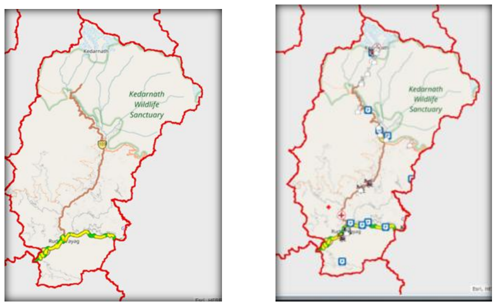
Required Secondary Data was collected from various sources and integrated to generate Hazard vulnerabilities:

- Administrative Boundaries covering Districts, Blocks, Villages, Settlements etc.
- Transportation Network – Highways, Roads, Streets and other connectivity
- Infrastructure like Schools, Hospitals, Banks, Facilities, etc.
- Social Amenities
- Land use / Land cover
- Hydrological Features
- Soil & Geology
- Historical Hazards
- Disaster Management related layers – Control Rooms, Evacuation Centers etc.
- Demography and Socio-economic Profile of Area

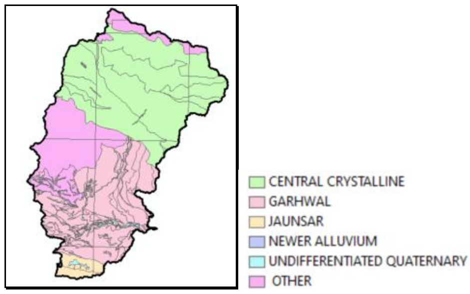
Sample data layers integrated from NRSC Bhuvan and GSI Portal are shown in Fig. 3.7 below



(a) Village Map




(b) Road Network (c) Critical Infrastructure
Source : Bhuvan, NRSC




(d) Lithology Source: GSI

**Fig. 3.7 Secondary Sample Data Layers**

## B. Hazard / Risk Assessment

For assessment of Geo-Hazard Risks & vulnerabilities, various Scientific models were studied for key hazards like Landslides, Earthquakes, Floods, Fires etc. and tested for the Study Area.

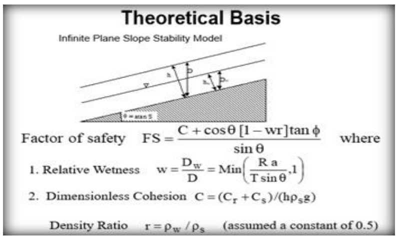
### a. Study of different scientific models – Landslides

Landslides are one of the major risks that brings losses both in terms of human lives and property. This geo-hazard is very common in study area. Geophysical phenomena like instability of slope, soil erosion, deforestation etc. are key triggering factors for landslides. For identification of vulnerable areas, preparation of Landslide Susceptibility Maps is required. These landslide susceptibility map help in identifying dangerous and high-risk areas, thereby enabling authorities to take measures to reduce the damage caused by landslide, if it were to happen in the near future.

In past, a number of methods were used for predictive mapping of landslide susceptibility. As land sliding is a result of complex interactions with several geo-environmental spatial factors, identification of any of the prevalent methods requires utmost care and prudence. Hence, various Scientific Models were tested for study area. ArcGIS software was used along with various datasets as required in respective models.

- **Landslide Susceptibility Mapping using SINMAP (Stability Index Mapping)**

SINMAP 2.0 (Stability Index Mapping) is an Esri ArcGIS plug-in that implements the computation and mapping of a slope stability index based upon geographic information, primarily digital elevation data. It helps in calculation of the stability index. SINMAP has its theoretical basis in the infinite plane slope stability model as per (1) with wetness (pore pressures) obtained from a topographically based steady state model of hydrology. Digital elevation model (DEM) methods were used to obtain the necessary input information (slope and specific catchment area). The methodology includes an interactive visual calibration that adjusts parameters while referring to observed landslides. The calibration involves adjustment of parameters so that the stability map "captures", a high proportion of observed landslides in regions with low stability index, while minimizing the extent of low stability regions and consequent alienation of terrain to regions where landslides have not been observed. Outputs generated by SINMAP were studied and overlaid with Study area for testing and analysing (Fig.3.8b)




$$FS = \frac{C + \cos\theta\,[1 - wr]\tan\phi}{\sin\theta}$$

$$w = \frac{D_w}{D} = \mathrm{Min}\left(\frac{R\,a}{T\sin\theta}, 1\right)$$

$$C = (C_r + C_s)/(h\rho_s g)$$

$$r = \rho_w / \rho_s$$

(1)

Theoretical Basis of SINMAP Model
Source: SINMAP User Manual

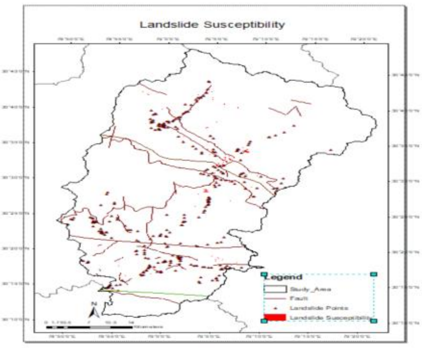



**Fig. 3.8a: Landslide Susceptibility Map using SINMAP**

- **Landslide Susceptibility Mapping based on Yules coefficient - Landslide Occurrence Favorability Score (LOFS)**

This method is an improved bi-variate statistical technique which uses landslide as a dependent variable to estimate the landslide susceptible areas.

A total of nine factor maps, viz., Slope, Aspect, Curvature and Drainage (derived from 30m ASTER DEM), Geomorphology and Landuse / Landcover (prepared using Digital Globe and SPOT images as base maps in ESRI Arc GIS), Slope Forming Material and Depth of Overburden (taken from GSI Geology map) and Structure (taken from NGLM data and GSI Geology map) were used to prepare map for susceptibility analysis. Besides these maps, Landslide Inventory Map was also used as base map in ESRI ArcGIS. All these 10 map layers were used for the assessment of factor class ratings, map weights and validation of the landslide susceptibility map (LSM) for the study area. Subsequently, the LSM maps were prepared in raster format by calculating the Landslide Occurrence Favorability Score (LOFS) for all factor classes of each geo-factor theme using ArcGIS. Finally, a susceptibility score map was calculated after adding LOFS values of all factor maps and normalizing it by its weight.

Success rate curve was used to subdivide the susceptibility scores into three classes of different landslide susceptibility (i.e., high, moderate and low). The cut-off boundaries are taken based on cumulative distribution of landslide percentage such that approx. 60% landslides are contained within high susceptibility, 30% in moderate and rest 10% in low susceptibility.

A detailed Workflow diagram to generate Landslide Susceptibility Map is shown as Fig.3.8b and the output generated using this Model is shown as Fig.3.8c

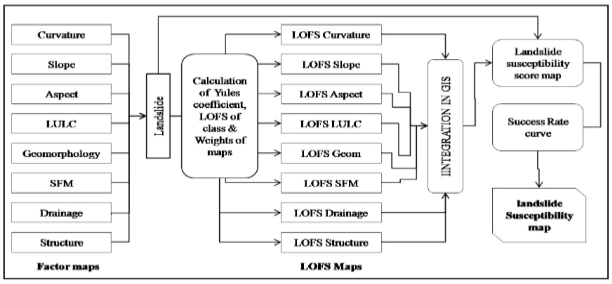



**Fig. 3.8b: Flow diagram showing the process for Landslide Susceptibility Mapping based on LOFS**

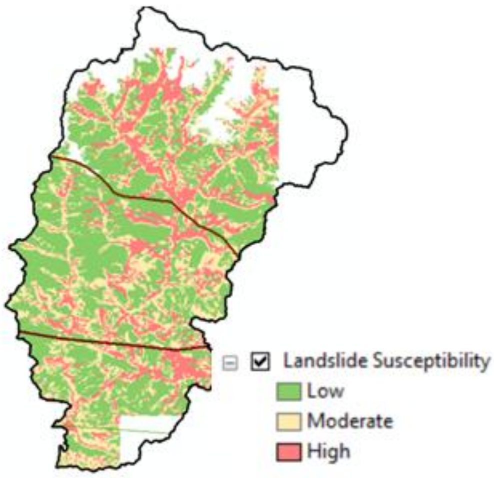



**Fig 3.8c: Landslide Susceptibility Map**

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- **Landslide Susceptibility Mapping using Probabilistic Certainty Factor**

Certainty factor (CF) is one of the commonly used probabilistic GIS model. Here, CF for each pixel is defined as change in certainty that a proposition is true from without the evidence to be given for each data layer. Certainty as function of probability is given below as (2)

$$CF = \begin{cases} \dfrac{ppa-pps}{ppa(1-pps)} & \text{if } ppa \geq pps \\ \dfrac{ppa-pps}{pps(1-ppa)} & \text{if } ppa < pps \end{cases} \quad (2)$$

Where CF is certainty factor. This ranges between -1 to 1. Positive values indicated an increase in certainty and negative value indicates decrease in certainty. Value 1 means it is very certain that landslide will happen and value -1 means landslide will not happen at all.

Certainty factor that is being used here is data driven where different layers of information were integrated in the model to generate Certainty Factor. Here, Certainty factor was carried out for each layer based on historical landslide inventory. Block Diagram to generate CF values for all layers is shown in Fig. 3.8d. Final CF was generated using (2) by combining CF of all input layers. This CF raster was classified based upon Table I and final Landslide Susceptibility Map was generated as shown in Fig. 3.8e

**Table I: Classification for Certainty Factor (CF)**

| Sl. no. | Description | Susceptibility class | Range of certainty factor |
|---|---|---|---|
| 1 | Very low certainty–stable | Very low | −1–0.5 |
| 2 | Low certainty–moderately stable | Low | −0.5–0.05 |
| 3 | Uncertain | Uncertain | −0.05–0.05 |
| 4 | High certainty–moderate instability | High | 0.05–0.5 |
| 5 | Very high certainty–high instability | Very high | 0.5–1 |

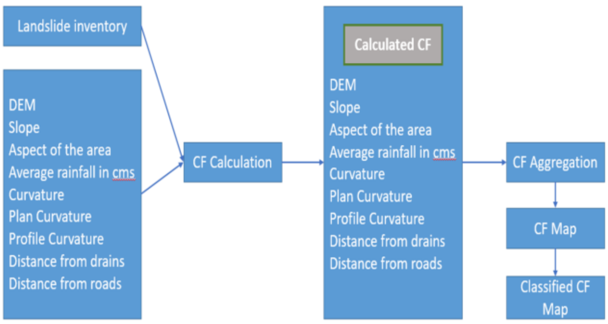


**Fig. 3.8d Block Diagram for calculating CF of Layers**

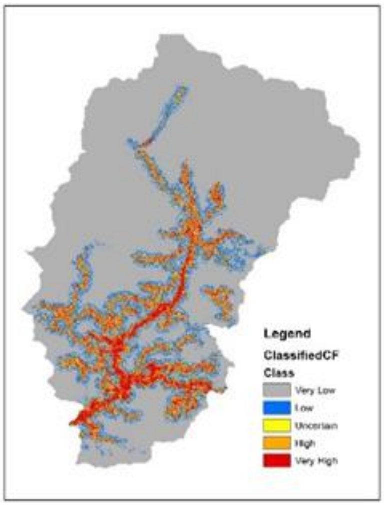


**Fig. 3.8e: Landslide Susceptibility Map using Probabilistic Certainty Factor**

Historical data of landslides was also collected from key Organizations like Geological Survey of India, NRSC Bhuvan, NDMA and Gobal sources like NASA, Pacific Disaster Center, Earth Networks etc. and Model outputs were compared.

It was observed that **Probabilistic Certainty Factor Method** for landslide susceptibility mapping generated very close results as verified during field visits.

### b. Study of different Scientific Models – Floods

In study area, another key hazard observed is floods. These floods and flash floods result in disaster events leading to huge losses towards life and property. In order to identify areas vulnerable to these floods hazard, various hydrological models were studied in order to use for assessment of vulnerabilities towards floods. For this purpose, most commonly used GIS tools were used to perform hydrological analysis and generate Model to carry out Rainfall-Runoff analysis for flood risk vulnerability.

Following GIS tools, software and data layers were used

- ArcGIS
- ArcHydro tools(ArcGIS Spatial Analyst extension)
- Hec-HMS 5.0
- Hec-GeoHMS (extension for ArcGIS)
- Data used – TRMM 2 years daily average, DEM, LULC, HSG, other base layers

Using ArcGIS and above tools, a detailed Model was designed to perform Hydrological analysis of the study area and identify areas vulnerable to flood inundation. The process flow diagram is shown in Fig. 3.9a below for Hydrologic and Hydraulic modelling and generating map of areas going to be inundated in case of any flood event in the Study Area.

Output were generated using Rainfall-Runoff model using integrated ArcHydro / HEC RAS / HEC HMS Models for the Study Area is shown in Fig. 3.9b.

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Information about historical floods was collected from different organizations like DMMC, NDMA, DMMC, NRSC, FEMA and output generated by developed Model were compared with historical Kedarnath Flood Hazard.
As shown in Fig. 3.9c, it was observed that results were well aligned with outputs generated by NRSC, ISRO Flood Inundation Maps. Using same model, Flood Zone was generated to depict floods vulnerability in entire Study Area

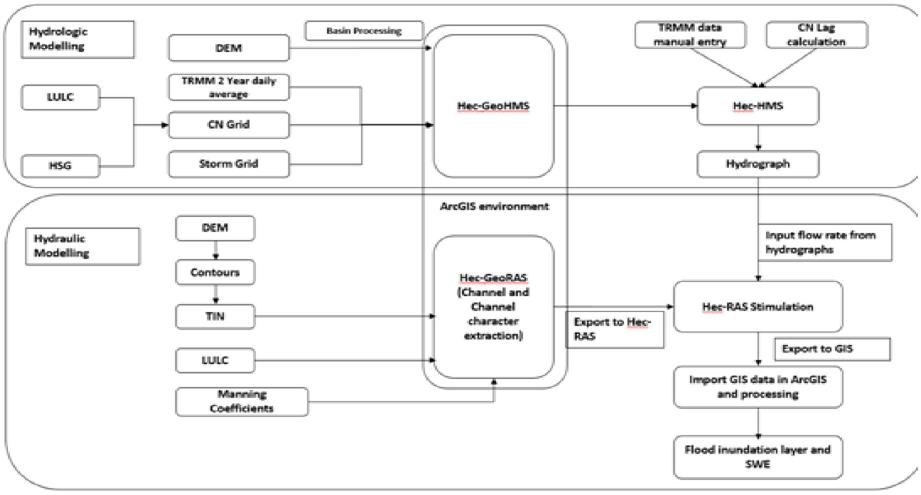



**Fig. 3.9a: Block Diagram of Hydrological Model for Floods vulnerability as shown in Fig. 3.9d**

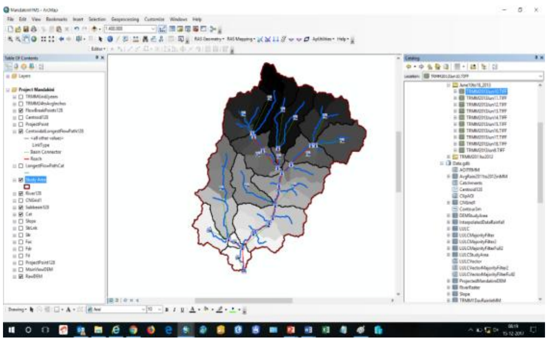


**Fig. 3.9b: Rainfall Run-off Modelling**

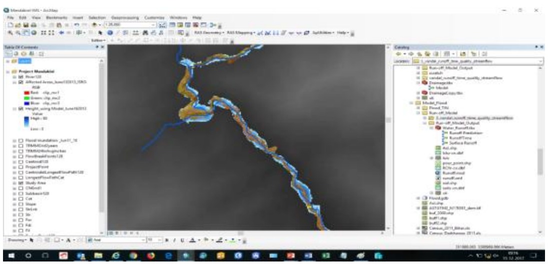


**Fig. 3.9c: Comparison of Results with Historical Flood**

**Fig. 3.9d: Flood Zonation**

### C. Study of different Scientific Models – Earthquakes

Earthquakes pose significant risk to mankind all over the world. Uttarakhand, being at tectonic plate, is highly vulnerable to seismic activity.

The USGS Earthquake Hazards Program of the U.S. Geological Survey (USGS), which is part of the National Earthquake Hazards Reduction Program (NEHRP) led by the National Institute of Standards and Technology (NIST), provides Earth sciences information and products for earthquake loss reduction. With historical data, it was assessed that several million earthquakes occur in the world each year, which mostly go undetected because they occur in remote areas or have very small magnitudes.

To analyze areas prone to Earthquake Hazard, complete time-series data from year 2001 onwards was extracted from USGS Site for the Study Area and integrated for assessment of hazard vulnerability of the area. In addition, Earthquake Data was collected from other sources like NASA, PDC and NDMA. Live Feeds from USGS were also integrated and overlaid on study area. Hotspot Analysis was performed to generate vulnerability maps as shown in Fig.3.10.

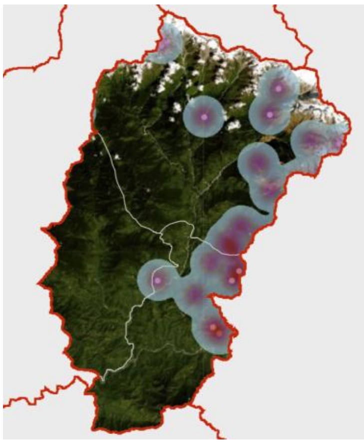


**Fig. 3.10: Earthquake Hot Spots / Hazard Zone Data Source : USGS, NASA**

### d. Study of different Scientific Models – Fires

MODIS Global Fires is a product of NASA's Earth Observing System Data and Information System (EOSDIS), part of NASA's Earth Science Data. EOSDIS integrates remote sensing and GIS technologies to deliver global MODIS hotspot/fire locations to natural resource managers and other stakeholders around the World. Historical Data was integrated from MODIS Satellite & NASA FIRMS live feeds for the Study area as shown in Fig.3.11a . Additional details like Burn Index available through NASA was also integrated as shown in Fig. 3.11b. All inputs were integrated to demarcate vulnerable areas. Live Feeds from MODIS were also integrated and results were compared with historical Fires.

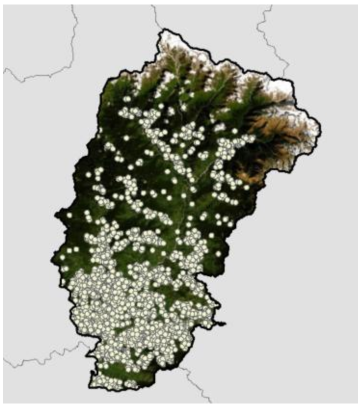


Fig. 3.11a: Fire Hazard events

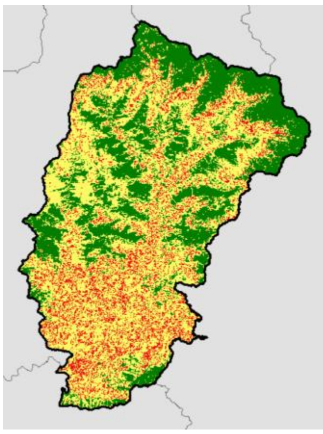


**Fig. 3.11b: Fire Burn Index**

### e. Study of different Scientific Models – Climate Change

Live feeds from A-16 Koppen-Geiger were integrated and results were compared with historical hazards. This time enabled service of world depicts global trends in observed climate and projected climate change scenarios. Time series data for the extended period 1901-2100 was anlysed to study the impact on study area.

### f. Study of different Scientific Models – Cloud Bursts

A number of Research Papers were explored and Models were evaluated. Since relevant required data was not available for the study area, this category of hazard was not included and is recommended for further studies.

### C. Field Verification

After demarcation of Hazard prone areas, Field visits were undertaken in the study area during pre-monsoon and post-monsoon periods to assess impact of monsoons and calibrate results generated using different models. For study sites, outcrops along the main highway running parallel to Mandakini River from Rudraprayag to the township of Guptkashi were studied in high resolution and details such as lithology, structures, land use, vegetation and slopes were noted and integrated for analysis. In addition to study and assess area profile, the key objective was to observe key vulnerabilities of the area and factors responsible for various hazards. All collected data from Primary & Secondary Sources was integrated with Historical Data of hazards in past collected for different hazards in the area as shown in Fig. 3.12. Hazard data collected during field visits using GPS with geotagged images was also integrated with existing map layers. This data generated using current observations during field study was compared with results generated. Various Hot Spot layers were generated which were used in performing multi-hazard vulnerabilities.

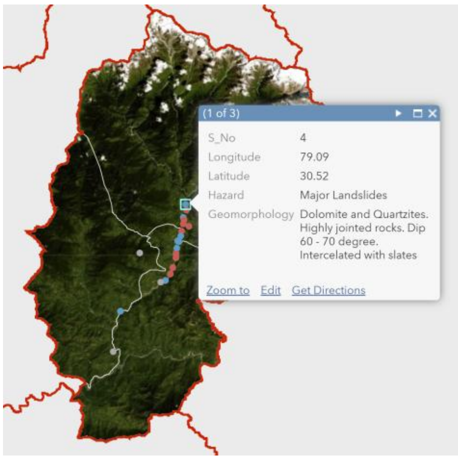


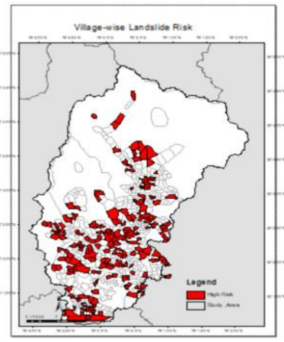

**Fig. 3.12: Field Data Collection along Mandakini River**

Re-visits were planned for two consecutive years to study Pre and post-monsoonal impact on the vulnerabilities, and to verify accuracy of outcomes generated using various Scientific Models. These field vists helped in re-assessment of the study area from multi-hazard vulnerability perspective.

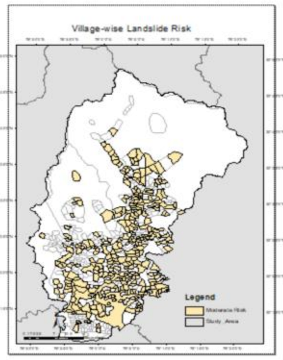
## D. Hazard Risk Zonation

### *a. Landslide Risk Zonation*

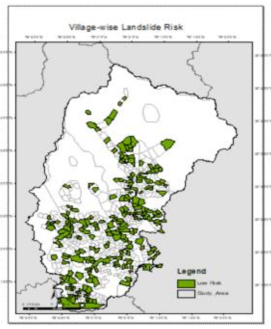
Outputs generated using Landslide Susceptibility Mapping generated based on Probabilistic Certainty Factor Modelling. were integrated with demography of the area. Villages were categorized as villages prone to High Landslide Risk, Moderate Risk and Low Risk as shown in Fig 3.13. It was observed that around 215 villages are affected with approx. 6.47 % area falling under High Risk as shown in Table II.




*(a) High Landslides Risk*




*(b) Moderate Landslides Risk*




*(c) Low Landslides Risk*

**Fig 3.13: Villages prone to Landslides Risk**

**Table II: Landslide Risk Zonation**

| Hazard Impact | Total Villages Affected | Total Area (Sq.km.) | Total Area of Affected Villages under Risk (%) | Total Affected Population |
|---|---|---|---|---|
| High | 215 | 16.42 | 6.47 | 92092 |
| Moderate | 329 | 32.53 | 7.63 | 117376 |
| Low | 231 | 18.69 | 6.83 | 92092 |
| Total | 605 | 93.32 | 3.70 | 216166 |

### *b. Floods Hazard Zonation*

Village-wise Flood Risk assessment was performed by overlaying Flood Inundation Zone generated using GIS based Hydrological / Hydraulic Modelling as shown in Fig. 3.14. This Flood Zone is overlaid with Village Layer integrated with Demography to demarcate Villages affected by Flood Hazard. Villages at High Risk of Flood Hazard are shown in Fig 3.15 below. It is found that around 95 villages are highly prone to Flood Hazards with around 18% area is directly affected as shown in Table III

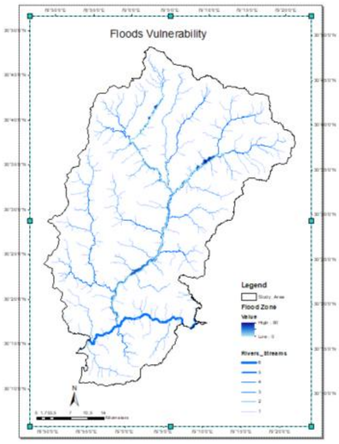



**Fig 3.14: Flood Zonation**

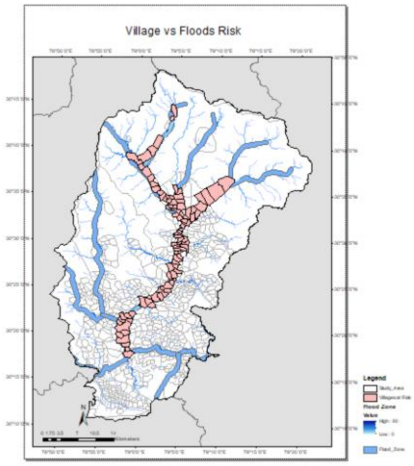



**Fig 3.15: Villages at Floods Risk**

**Table III: Floods Risk Zonation**

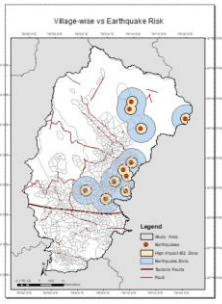
| Flood Hazard Impact Assessment | Value |
|---|---|
| Total Villages | 95 |
| Total Population | 41827 |
| Total Households | 8762 |
| Total Area (Sq.Km.) | 1528.56 |
| Total Flood Prone Area (Sq.Km.) | 276.37 |
| Percentage Area Affected ( % ) | 18.08 |
| Villages with Percentage Affected Area > 20 % | 28 |
| Villages with Percentage Affected Area > 50 % | 1 |

### *c. Earthquakes Risk Zonation*

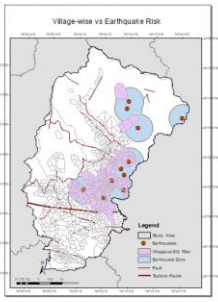
As per assessment of historical Earthquakes and Live feeds from USGS & NASA, it was observed that study area has experienced few critical earthquakes in the past as shown in Figure 3.16a.

Shake Maps were also integrated for the assessment and hot spots were generated as shown in Fig. 3.16b-c. Using ArcGIS, Village map integrated with Demography was overlaid to identify Villages prone to Earthquake Hazards as shown in Fig. 3.16d. It is observed that around 83 Villages with around 24800 Population are prone to high Earthquake Hazard Risk.

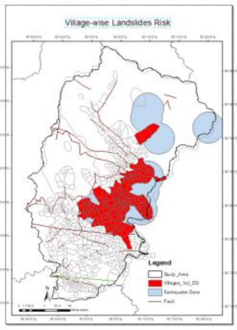

(a)




*(b)*




*(c )*




(d)

**Fig 3.16 – Villages affected by Earthquake Hazard EQ Data Source : USGS / NASA**

**Table IV: Floods Risk Zonation**

| Earthquake Hazard Impact Assessment | Value |
|---|---|
| Total Vulnerable Villages | 83 |
| Total Population | 24800 |
| Total Households | 5599 |
| Total Village Area (Sq.Km.) | 1548.29 |
| Total EQ Impact Area (Sq.Km.) | 1317.20 |

### *d. Fire Risk Zonation*

To perform Fire Risk in the Study area, Live feeds were integrated from MODIS Satellite & NASA FIRMS. Historical Fire incidents for duration 2002 – 2019 were also collected from Forest Survey of India and Uttarakhand State Disaster Management Authority. It was observed that during last 20 years, 545 Fire incidents were reported, which were distributed in the Study area as shown in Fig. 3.17. This Fire incident layer was overlaid on village boundary to assess villages affected or are within close proximity to Fire prone areas. Around 80 Villages are found to be in close proximity to these Forest Fire incidents as shown in Fig. 3.18

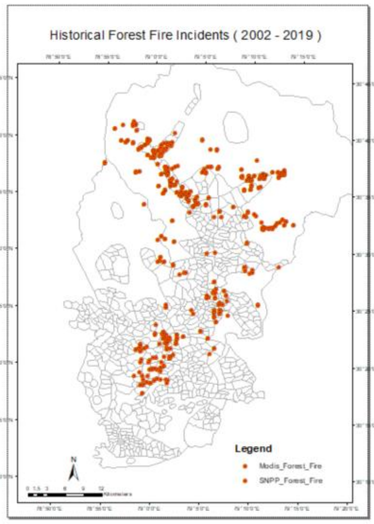



**Fig. 3.17 Historical Fire Incidents**

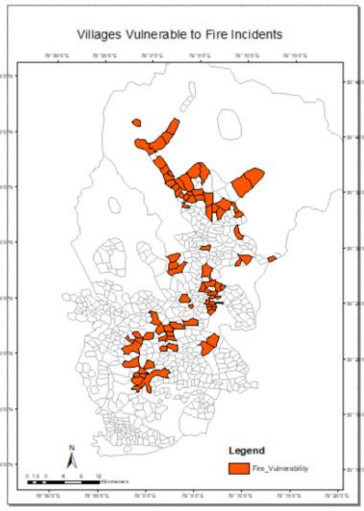



**Fig. 3.17 – Historical Fire Hazard Incidents**

**Table V: Forest Fire Risk Zonation**

| Fire Hazard Impact Assessment | Value |
|---|---|
| Total Fire Incident ( 2002 – 2019) | 545 |
| Total Vulnerable Villages | 80 |
| Total Population | 39058 |
| Total Households | 8546 |
| Total Village Area (Sq.Km.) | 202.83 |
| Total Forest Beats | 29 |

### E. Multi- Hazard Risk Zonation

All layers generated for various Hazards were integrated to perform multi-hazard analysis. It was observed that out of 695 Villages, 74 villages as shown in Fig. 3.18 with total Population of 75245 as per Census of India are highly vulnerable for various hazards as per Table VI. These villages are primarily clustered and are adjoining to River Catchment. These Villages may be considered under Multi-Hazards.

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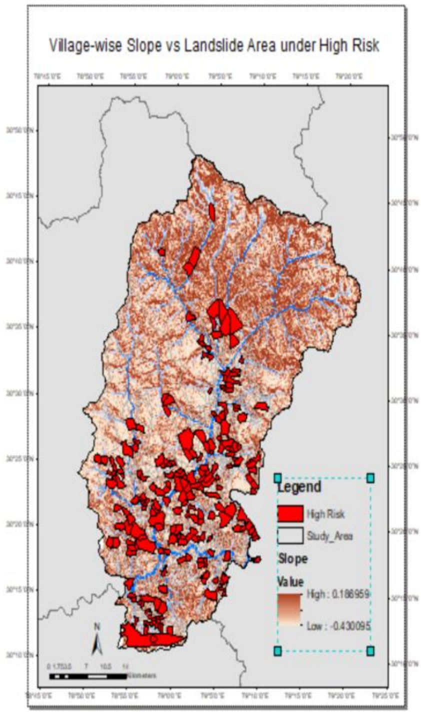


**Fig 3.18 – Villages prone to Multi-Hazard Risk**

**Table VI: Forest Fire Risk Zonation**

| **Multi-Hazard Impact Assessment** | **Value** |
|---|---|
| Total Vulnerable Villages | 74 |
| Total Population | 31709 |
| Total Households | 6965 |
| Total Village Area under Hazards (Sq.Km.) | 160.8 9 |

## V. CONCLUSION & RECOMMENDATION

a. Though various Geo-spatial & Geo-statistical Analysis and comparing results with field observations, it was observed that **74 + villages are highly prone to various disaster.**

b. The key Hazards observed are primarily Landslides, Floods, Fires and Earthquakes

c. Landslides, which is prominent hazard in the study area, leads to various multi-hazards, at time with catastrophic effect. These are primarily because of unstable slopes, fragile geology. Major landslide hazards were triggered because of degraded areas in steep slopes, facing south facing Aspect. Incidents adjoining to rivers and water bodies are primarily due to toe-cutting. Additionally, unplanned constructions of buildings are also a major contributor to Landslides.

d. It was observed that floods are primarily triggered because of Cloud Bursts, heavy rainfall and Landslides.

e. Fires Hazards are observed in lower part of Study Area with few instances of incidents in higher altitudes. Fires are primarily seasonal (in the months of March – June) and are human induced because of agricultural activities, vegetation type and increase in depth of water table. At high altitudes, Fires are primarily because of lightening.

f. Although Himalayas are highly vulnerable to Earthquakes, eastern part of the Study area is found to be vulnerable for Earthquake Hazard.

g. During Field visits, it was observed that very few mitigation measures has been implemented in the Study Area. There were instances, where constructions were allowed in the Flood Zone. It was observed that near Guptkashi, right at Main Central Thrust (MCT), buildings were constructed, which were tilted because of Land unstability.

h. It is highly recommended that Government should prepare and enforce Disaster Management Plans in the Study Area, with proper planning & monitoring mechanism.

i. It is further recommended to leverage integrated Geo-spatial technology Platform integrated with measures for early warnings, in order to ensure effective Disaster Management and Mitigation towards various Hazards.

j. Finally, it is highly critical to build Disaster awareness among communities, primarily in those villages which are highly prone to multi-hazards.

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