UTTARAKHAND

Disaster Risk Assessment

VOLUME 1: Results and Methods

Final Project Report

CONTRACT DATASHEET

Under Contract for Consultant's Services

Lump Sum for

DISASTER RISK ASSESSMENT OF UTTARAKHAND

Project Name: Uttarakhand Disaster Recovery Project

Credit No: 5313-IN

Contract No. 01/UDRP/PIUTA&CBDRM/PMC/05

Between

Program Manager,

Project Implementation Unit TA & CBDRM

Uttarakhand Disaster Recovery Project (UDRP)

And

A Joint Venture of

M/s DHI Water & Environment (S) Pte Ltd., Singapore

M/s Asian Institute of Technology, Thailand

M/s Evaluacion de Riesgos Naturales, Mexico DF

Contract Initiated on 24th May 2016

QUALITY ASSURANCE DATASHEET

Project Title	Disaster Risk Assessment of Uttarakhand
Client	PIU (TA & CBDRM) of the Uttarakhand Recovery Project
Client Representative	Dr G. C. Joshi, Deputy Programme Manager
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DHI Project Reference	95800000
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Classification	**RESTRICTED**
Copyright	
Quality Assurance	This report has been prepared under the DHI Business Management System certified by Bureau Veritas to comply with ISO 9001 (Quality Management) and bizSAFE STAR.

FORWARD

We are in a state that must live with risk. It shapes our planning, policy, and development.

The need for good data and information to support the planning is vital. With financial support from the World Bank, the Uttarakhand State Government has engaged experts to complete a disaster risk assessment of the entire state so that it can understand the threat from natural hazards and the exposure of communities and critical infrastructure.

The project has assessed the threat and potential consequences of flooding (both fluvial and flash floods) earthquakes, landslides and industrial hazards in Uttarakhand. The project has developed a comprehensive inventory of data for hazards and assessed the likelihood and consequences of these hazards in future. This is the first attempt to develop an integrated disaster risk inventory for the state and is an important step to support our future decision-making and planning.

The key project outputs – A Digital Risk Data Base, Risk Atlas, exposure maps and open source tools - will benefit Uttarakhand as follows:

1. The DRDB will help each line department to update Annual District Disaster Management Plans and State Disaster Management Plans;
2. The disaster risk zones can be demarcated based on the available data and maps;
3. The project outputs will refine and realign the SOP (Standard Operational Procedures) during disaster preparedness and disaster response;
4. The DRDB, hazard mapping, modeling will help integration and teaming up of all line departments.

This is an important step in continuing journey for our administration. We are committed to improving our capacity to reduce risk in the short, mid, and long term. We are learning from the past to improve our risk based planning and development, and we are implementing technological solutions to help predict threats, manage responses, mitigate risk in our communities, and to protect our citizens.

I am pleased to commit this final report to you.

Shri Trivendra Singh Rawat

Chief Minister, December 2018

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ACKNOWLEDGEMENTS

The project team wishes to extend its gratitude for the support of Mr Amit Singh Negi, State Disaster Secretary, and the team in the PIU (TA & CBDRM) of the Uttarakhand Recovery Project.

Specifically, we wish to thank Mr Savin Bansal, Programme Manager, Dr G. C. Joshi, Deputy Programme Manager, and Mr C. Ravi Shankar (former Programme Manager) for their guidance, support, and interest in the work throughout. Dr G. C. Joshi and his technical team have developed an enduring template terms-of-reference for disaster risk assessments throughout India.

Our joint-venture team would not have succeeded with the support and commitment of risk management expert, Dr P. D. Mathur, and our local technical and operational counterparts. We are deeply grateful to this exceptional team. A special note of thanks to TESRA, who moblised so quickly to successfully complete the extensive field surveys.

We wish to thank the Technical Task Force (TTF) members, and specifically Dr M. L. Sharma, Dr Yogendra Singh, and the distinguished Vetting Agency members with whom we have formed a very constructive working relationship with our project team and their inputs have been invaluable over the course of the project.

We thank Dr Piyoosh Rautela of DMMC and his technical staff who so enthusiastically participated in the training and capacity-building programme. We trust that the tools, equipment, and data handed over to DMMC at the end of this project are of enduring value to the department.

Over the course of the project, we have collated large volumes of data from state level and district agencies. We are grateful to all of the nodal and administrative officers involved in the exchanges of information.

Finally, it is important that we acknowledge all the people we have interacted with through the many district level and divisional level workshops and who are deeply committed to improving risk management in the state. Your commitment and determination is admirable. *Keep pushing forward.*

The DRA Joint Venture Team

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ABBREVIATIONS & ACRONYMS

ADB	Asian Development Bank
AIT	Asian Institute of Technology
BIS	Bureau of Indian Standards
BOQ	Bill of Quantities
CBDRM	Community Based Disaster Risk Management
CRED	Centre for Research on the Epidemiology of Disasters
CWC	Central Water Commission
DDMO	District Disaster Management Office(r)
DEM	Digital Elevation Model
DI	Department of Industries
DIC	District Industries Centre
DMMC	Disaster Mitigation and Management Centre
DOT	Department of Tourism
DPGR	Decadal Population Growth Rate
DPR	Detailed Project Report
DRA	Disaster Risk Assessment
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EIA	Environmental Impact Assessment
EQ	Earthquake
FF	Flash Floods
GFCC	Ganga Flood Control Commission
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information System
GMPE	Ground Motion Prediction
GMPM	Ground Motion Prediction Model
GoI	Government of India
GovUK	Government of Uttarakhand
GSDP	Gross State Domestic Product
HAND	Height Above Nearest Drainage
HD	Hydrodynamic
HWL	High Water Level
IDA	International Development Agency
IIRS	Indian Institute of Remote Sensing
IMD	Indian Meteorological Department
JAXA	Japan Aerospace Exploration Agency
JV	Joint Venture
LS	Landslide

LWL	Low Water Level
MMI	Modified Mercalli Intensity Scale
MoFFCC	Ministry of Environment, Forest and Climate Change
MoWR	Ministry of Water Resources
MTZ	Maximum Threat Zone
NA	Not Applicable
NDMA	National Disaster Management Authority
NDRF	National Disaster Response Force
NGO	Non-Governmental Organisation
NICMAR	National Institute of Construction Management & Allied Research
NIDM	National Institute of Disaster Management
NIH	National Institute of Hydrology, Roorkee
NRSC	National Remote Sensing Centre
NWA	National Water Academy
NWP	Numerical Weather Prediction
PGA	Peak Ground Acceleration
PI	Pollution Index
PMU	Project Management Unit
PRA	Probabilistic Risk Assessment
PWD	Public Works Department
RR	Rainfall-Runoff
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SRTM	Shuttle Radar Topography Mission
TA	Technical Assistance
TBC	To Be Confirmed
TBD	To Be Decided or To Be Determined
TRMM	Tropical Rainfall Measuring Mission
TTF	Technical Task Force
TZ	Threat Zone
UDRP	Uttarakhand Disaster Recovery Project
UJVNL	Uttarakhand Jal Vidyut Nigam Limited
UNISDR	United Nations Office for Disaster Risk Reduction
USAC	Uttarakhand Space Application Centre
USDMA	Uttarakhand State Disaster Management Authority
USGS	United States Geological Survey
WB	World Bank
WIHG	Wadia Institute of Himalayan Geology
WSS	Water Supply and Sewerage

EXECUTIVE SUMMARY

Disaster Risk Assessment of Uttarakhand

EXECUTIVE SUMMARY

THE PROJECT

The Disaster Risk Assessment of Uttarakhand was commissioned under the Uttarakhand Disaster Recovery Project in 2016 and concluded on the 31st January 2019.

DHI Water & Environment (DHI) lead the team with key experts participating from ERN Mexico and Asian Institute of Technology (AIT). The consortium also collaborated tightly with the Earth Observatory Singapore, TESRA Engineers and Architects (India), and Prestels Engineers (India).

The project is the first attempt to quantify the risk and expected losses (economic and human) associated with earthquakes and flooding across the entire state. In addition, the project assessed the exposure of infrastructure and people to landslides, flash floods, and industrial hazards.

The results of the assessment are reported at state, district, and block level.

KEY OUTPUTS

The key outputs of the project include:

1. Data, including:
    - Comprehensive data on hazards, exposure, and risk for the entire state for all hazard classes, and
    - Improved inventories of infrastructure and demographic data.
2. State Atlas of Risk
3. Disaster Risk Assessment Toolkit, including
    - R-CAPRA Probabilistic Risk Assessment Platform
    - Online Risk Database for data exchange and reporting
    - Hazard Modelling Software, including R-CRISIS and MIKE Flood
4. Hotspot Risk Reduction Strategies:
    - 5 x Strategic Plans for **Urban** Risk “Hotspots”
    - 5 x Strategic Plans for **Rural** Risk “Hotspots”
    - 4 x Strategic Plans for **Tourism** Risk “Hotspots”
5. Comprehensive Training and Capacity Building Package

The report is submitted in four (4) volumes.

The content of each volume is summarised as follows:

VOLUME 1

- Introduction to the Project
- Methods for Modelling Hazards and Risk
- Summary of Results
- Introduction to Risk Hotspots
- Overview of the Risk Tool Kit Deployed Under the Study
- Recommendations for Improving Risk Assessment Over Time

VOLUME 2

Fourteen standalone Hotspot Risk Reduction Strategies for

- Five (5) Urban
- Five (5) Rural, and
- Four (4) Tourism

locations where the USDMA can focus mitigation and risk reduction activities with a discernible positive impact.

VOLUME 3

The comprehensive state-wide ***Atlas of Risk***, which is a product that the Joint Venture has developed to supplement the main study outputs and to help district level authorities understand their exposure, vulnerability, and risk at District and Block Level.

VOLUME 4

Appendices with field and workshop report, training materials, and other important supporting material.

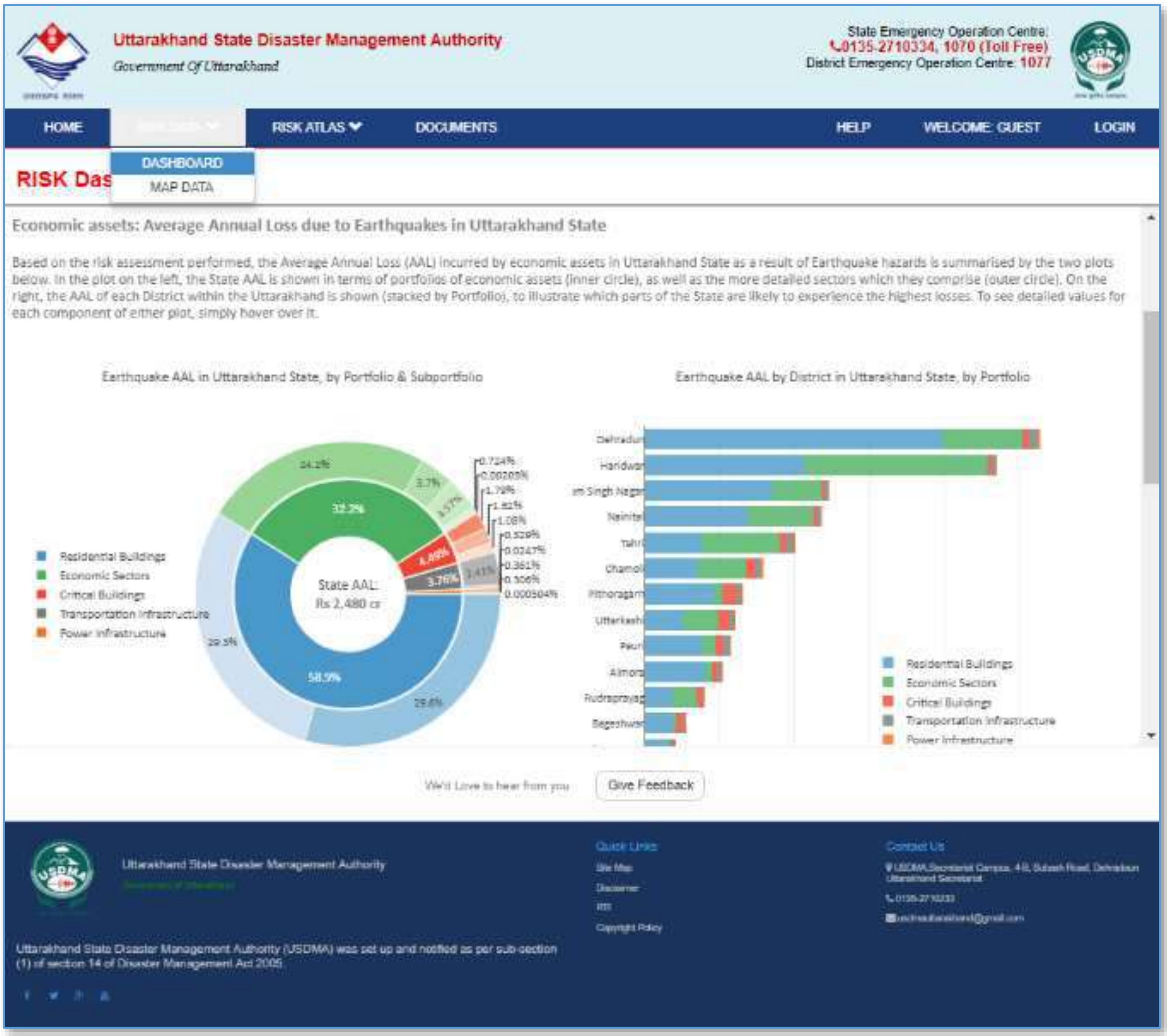
The full report set is available to download from the USDMA website (www.usdma.uk.gov.in).

Our DRA JV experts view this as a strong first step towards embedding risk based planning in to the disaster risk reduction in Uttarakhand. This collection of tools and resources will now require a concerted effort on behalf of the GovUk to maintain them and to improve them continuously.

RISK & EXPOSURE RESULTS

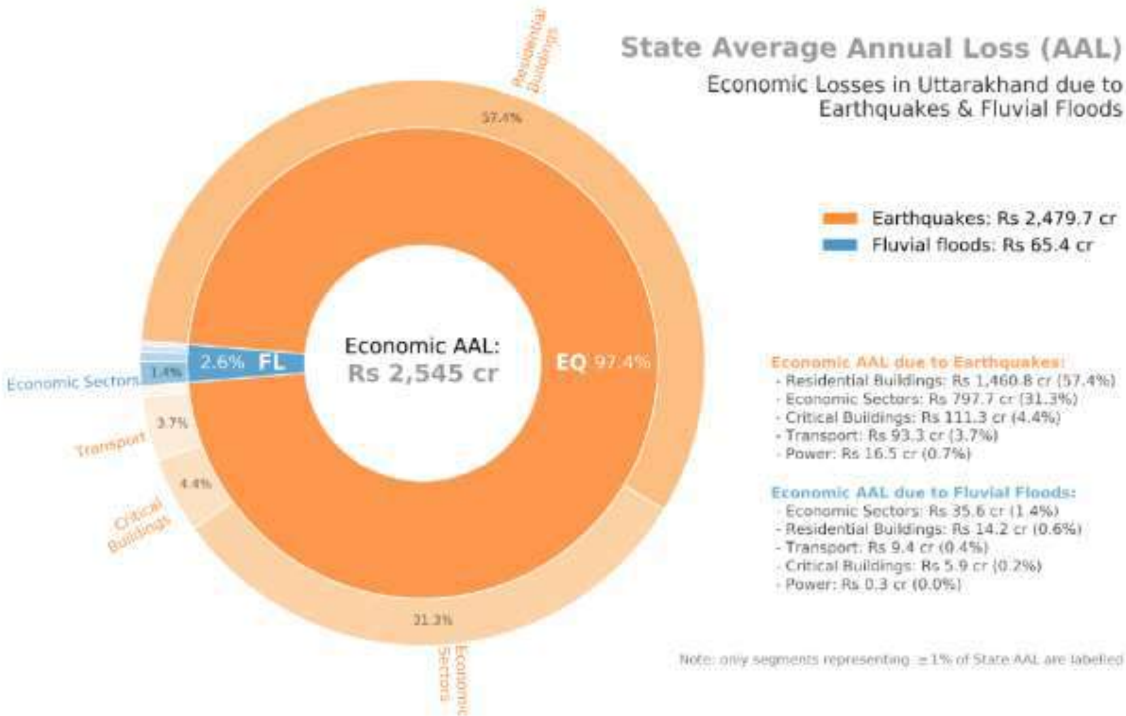
An online dashboard of risk available via the USDMA website provides a summary of the Average Annual Losses (AAL), Probable Maximum Losses (PML), and exposure for the state and individual district and blocks for each portfolio.

This is an interactive a navigable dashboard. Graphs and tables are easily downloaded for reporting purposes.

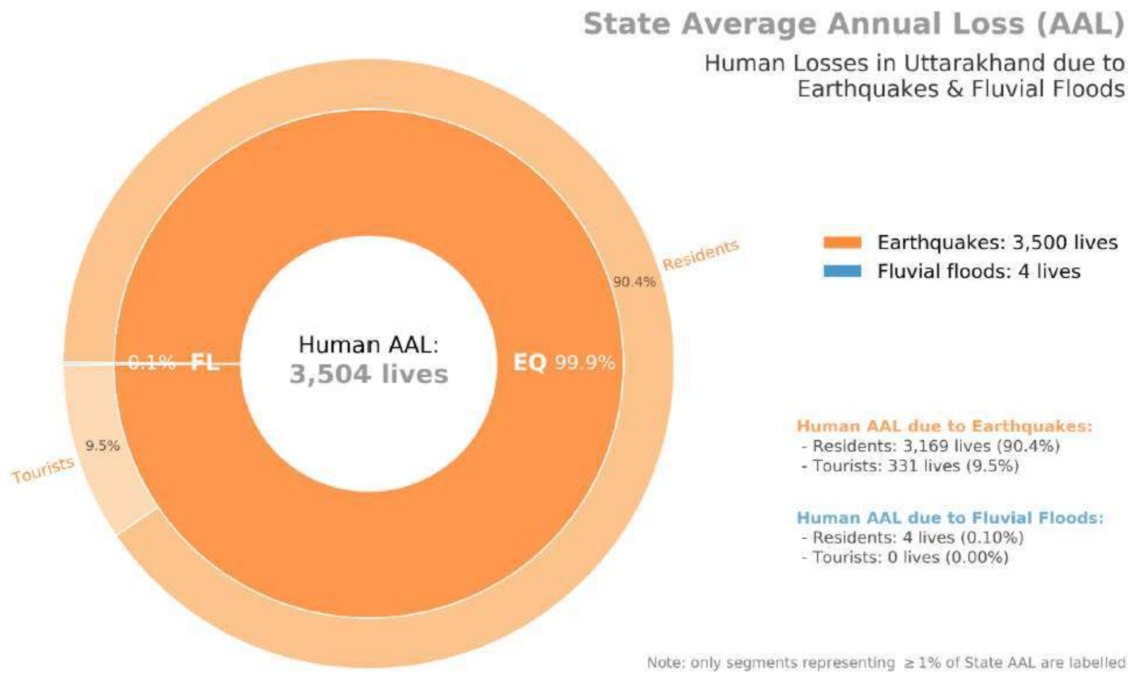


Earthquakes & Fluvial Floods

The combined Average Annual Losses (AAL) for specific infrastructure portfolios due to probabilistic flood and earthquake events is shown here. This is an indication of the expected losses in economic terms.

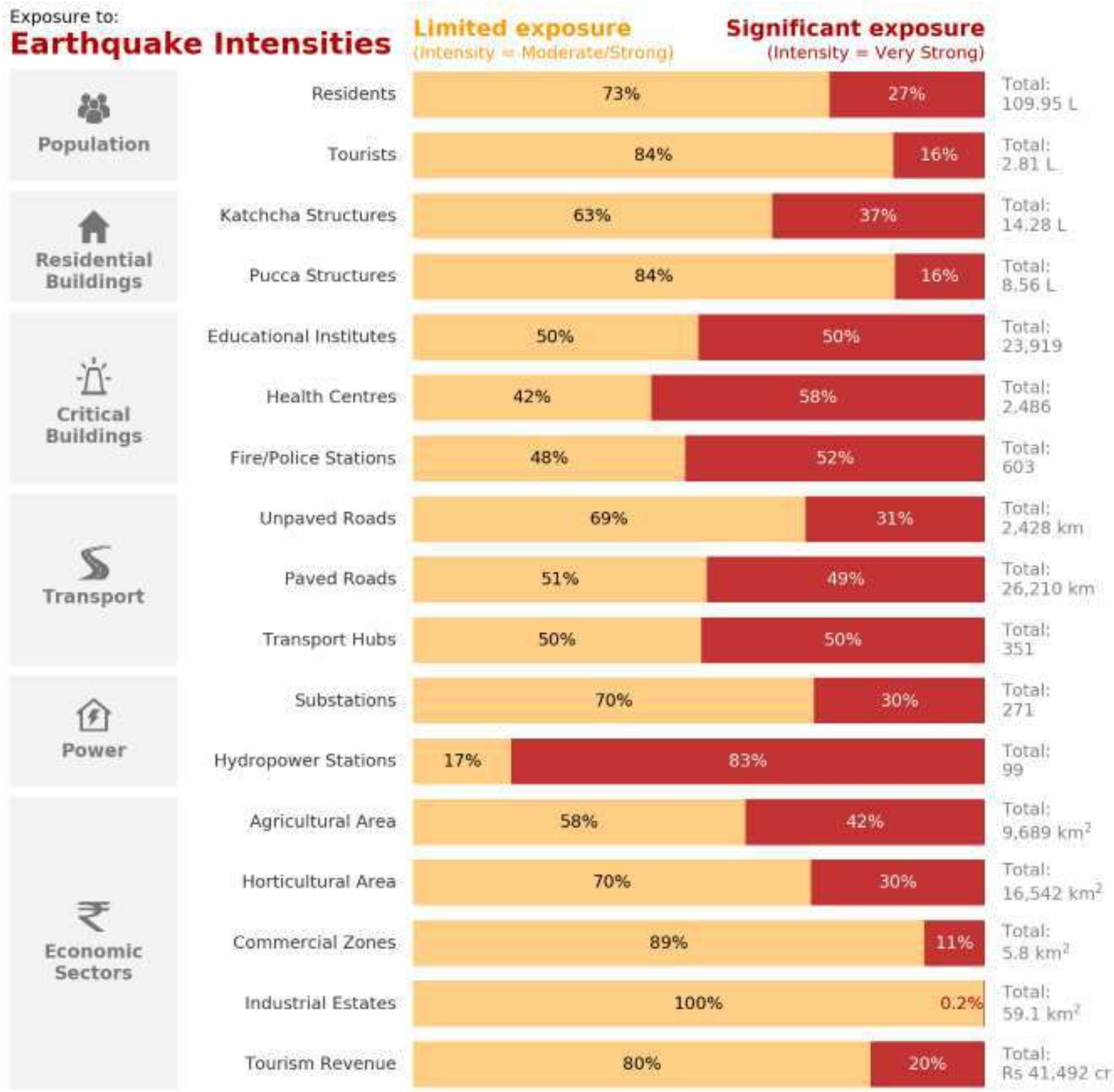


The combined expected human losses associated due to probabilistic flood and earthquake events is shown here.



The top four districts contributing most to the total expected losses for the state are (in order from highest to lowest): Dehradun, Haridwar, Udham Singh Nagar, and Nainital.

Earthquakes dominate the expected losses and the damage is, potentially, widespread. The following diagram summarises the exposure of critical infrastructure and people to earthquakes. It indicates that the portfolios most exposed to the Very Strong earthquakes are Hydropower Stations, Health Centers, Educational Institutes (incl. Schools), and Fire/Police Stations, and Transport Hubs.



Flash Floods

The exposure of infrastructure to flash flood risk is summarised as follows:

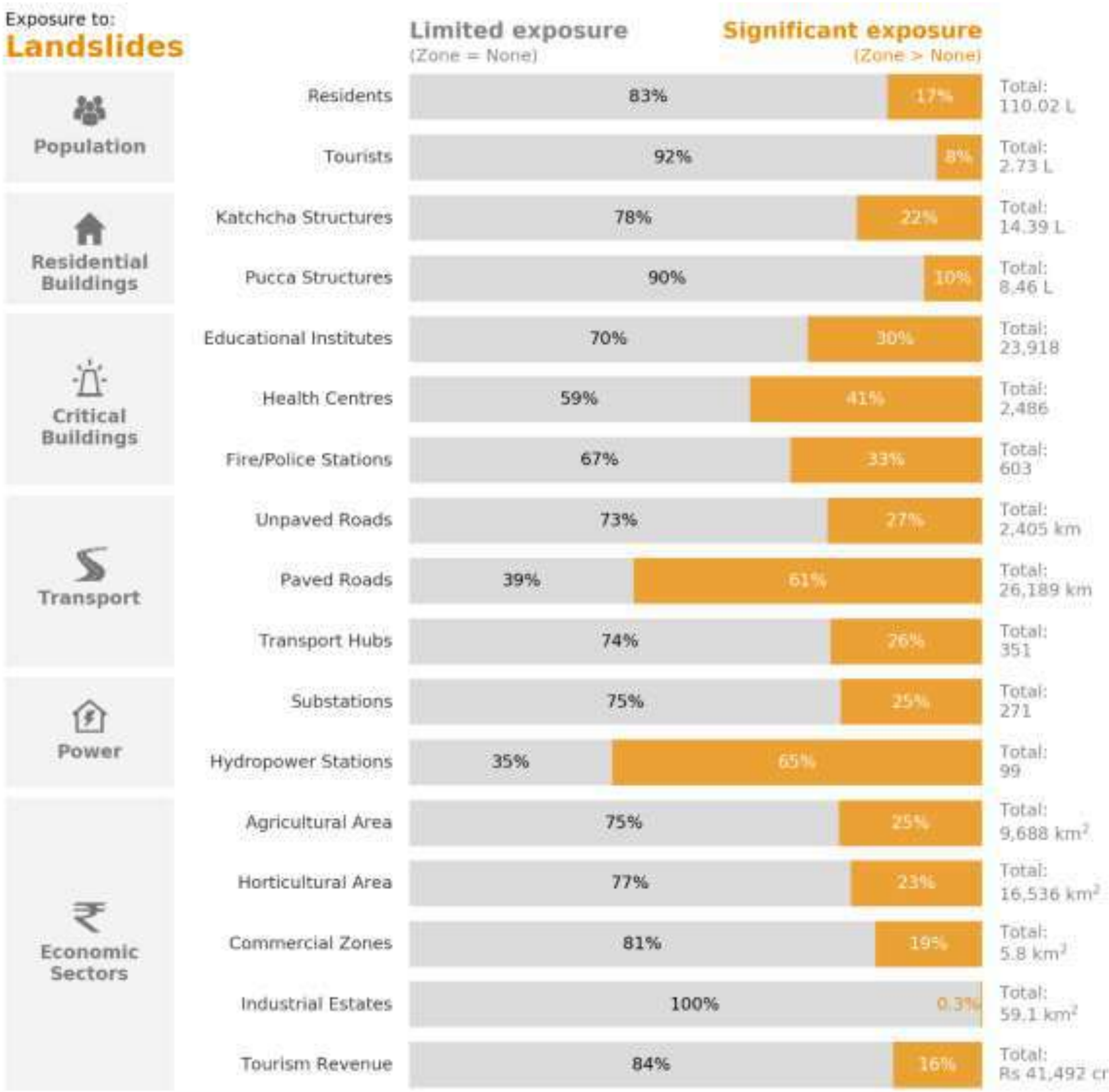
Exposure to:
Flash Floods

Sector	Asset	Limited exposure (Zone = Low)	Significant exposure (Zone > Low)	Total
Population	Residents	92%	8%	Total: 109.95 L
	Tourists	99%	1%	Total: 2.98 L
Residential Buildings	Katchcha Structures	100%	0.5%	Total: 14.39 L
	Pucca Structures	100%	0.3%	Total: 8.46 L
Critical Buildings	Educational Institutes	99%	0.9%	Total: 23,919
	Health Centres	98%	2%	Total: 2,486
	Fire/Police Stations	99%	1%	Total: 603
Transport	Unpaved Roads	98%	2%	Total: 2,425 km
	Paved Roads	99%	1%	Total: 26,208 km
	Transport Hubs	98%	2%	Total: 351
Power	Substations	99%	0.7%	Total: 271
	Hydropower Stations	60%	40%	Total: 99
Economic Sectors	Agricultural Area	99%	1%	Total: 9,689 km²
	Horticultural Area	99%	1%	Total: 16,540 km²
	Commercial Zones	100%	0.4%	Total: 5.8 km²
	Industrial Estates	100%	0.1%	Total: 59.1 km²
	Tourism Revenue	99%	1%	Total: Rs 41,492 cr

Most infrastructure and people are not routinely exposed to flash flood risk under a 100yr reoccurrence interval. However, flash floods can occur with localized and devastating consequences. Zonation to reduce exposure and early warning systems are effective mitigation measures.

Landslides

The following figure simply summarises the exposure of all portfolios to landslides. Roads and hydropower facilities are most exposed.



Industrial Hazards

- Most industrial facilities in Uttarakhand are light industry or pose no catastrophic threat. However, chronic pollution and illegal dumping remain a concern outside the scope of this assessment.
- There are 3 districts that are assessed to have facilities that pose most threat from potential industrial hazards; namely Udham Singh Nagar, Hardiwar and Dehradun.
- 23 industrial facilities are identified as hazardous in which 16 are in Udham Singh Nagar District, 1 in Dehradun District and the remaining 6 in Haridwar District.

- Most of these hazardous industries are located in the district of Udham Singh Nagar. There were 9 industries (~12%) who denied giving the data required for this study and it is unknown whether or not they use and/or store hazardous chemicals.
- It has been noted that Haridwar District is also under high risk because the industries present in these districts are situated in densely populated and constructed areas.
- The facility HRD 2 - Indane Bottling Plant, is located in Badrabadh Industrial Estate, which is situated in a very densely populated region thus some steps should be taken for the communities' safety.

KEY RECOMMENDATIONS

The state of Uttarakhand is rapidly changing and its risk profile is changing. Risk is dynamic. Therefore, the Government of Uttarakhand must invest in implementation of the recommendations arising from this study, and in the continuous improvement of the database and the upkeep of the Atlas in order that they remain relevant and useful for risk based planning and risk reduction.

Recommendations and strategies for risk reduction are grouped in to seven (7) priority areas.

1. Improvement of Capacity to Undertake and Apply Disaster Risk Assessment
2. Improvement of Disaster Risk Awareness & State Level Capacity for DRR
3. Enhancement of State Level DRM Policy and Planning
4. Reduction of Seismic & Landslide Threats to People & Infrastructure
5. Reduction of Fluvial and Flash Flood Threats to People & Infrastructure
6. Reduction of Social Vulnerability
7. Implementation of Strategies to Reduce Threats to Tourism Sector

Several critical and immediate steps are required in order to ensure successful implementation of the recommendations and applications of risk assessment in the state of Uttarakhand.

1. Implement a strong policy on disaster risk management and reduction, incorporating strong mitigation and planning requirements for municipal and district authorities.
2. Invest in Community Based Disaster Risk Management and amplify the activities building risk aware and resilient communities.
3. Ensure there is an annual update of the Atlas and Risk Profile of the state.

4. Secure commitments from line agencies to continually improve their asset inventories and data about their asset portfolios.
5. Build the recommendations arising from this study in to the state level and district level disaster risk management plans to strengthen the mid and long term mitigation plans.
6. Enhance the technical capacity of USDMA and DMMC to understand and apply risk assessments;
7. Continue to train line agencies and nodal officers in the application of risk based planning for mitigation of disaster risk;
8. Invest in the hotspot risk reduction strategies accompanying this report.

CHAPTER 1
Introduction

1 INTRODUCTION

The content of this report is guided by the Terms of Reference (ToR) of the study and captures the key outcomes of the project, whilst placing an emphasis on the hazard assessment methods as this is required under the ToR.

In this specific section of the report, we introduce the report structure, the project context and objectives, and we describe the overall approach taken for the DRA study.

This section of the report also provides an introduction of the State of Uttarakhand for readers unfamiliar with the project context. Since the focus of this report is on results and hazard assessment methods, the reader is referred to the Inception Report for further background information on the State.

1.1 OVERVIEW OF THE PROJECT

1.1.1 Objectives and Scope

Uttarakhand's sustainable development depends on the State Government's ability to implement effective disaster risk reduction strategies and measures in the long-term. Without effective DRR there can be no sustainable development, and Uttarakhand is a rapidly developing state[1] with ambitious economic goals.

The Disaster Risk Assessment of Uttarakhand (DRA) was commissioned under the Uttarakhand Disaster Recovery Project in 2016 and concluded on the 31st January 2019.

The project has been funded by the World Bank and implemented under the Disaster Recovery Programme of Uttarakhand (UDRP). The UDRP itself was established to facilitate rapid and strong recovery after the devastating floods of 2013 and the DRA is one of several projects under this programme.

The implementation of the study was coordinated by the Project Implementation Unit (PIU) under UDRP and fully executed by a Joint Venture (DRA JV) comprising DHI Water & Environment (S) Pte Ltd, ERN International, and the Asian Institute of Technology (AIT). The DRA JV has collaborated

[1] Uttarakhand has ranked consistently in the top 4 fastest growing states in India since 2014 and is presently ranked as the second fastest growing state economy.

with local and international counterparts, including the Earth Observatory Singapore, TESRA, Prestels Engineers (India), Bindu Society, and Lime Agency Singapore to ensure the satisfactory and timely completion of this risk assessment.

The objective of this study has been to strengthen mid to long term planning and mitigation through helping the GovUk to “understand its risk”, a key goal under the Sendai Framework.

The study was comprised of six (6) components and each component has involved several key tasks. All components were tightly interrelated.

Component 1 collated, analysed and prepared all input data to facilitate hazard modelling executed in later steps. Component 2 delivered structural and socioeconomic data used to derive the vulnerability and exposure datasets required for the risk modelling. Component 3 made use of the collated data to deliver hazard related datasets generated by best-in-class hazard modelling tools. Component 4 dealt with the risk modelling and the quantification of risk and exposure across the state. In addition, Component 4 included the development of risk reduction strategies for “hot-spots” identified in Uttarakhand. Component 5 developed and delivered the IT solution required to store and share the data among agencies and public which is the DRDB (acronym for disaster risk database). Finally, Component 6 has focused on capacity building, engagement, and training of GovUk staff and the final project reporting.

Figure 1.1 depicts the study components and the tasks within each component.

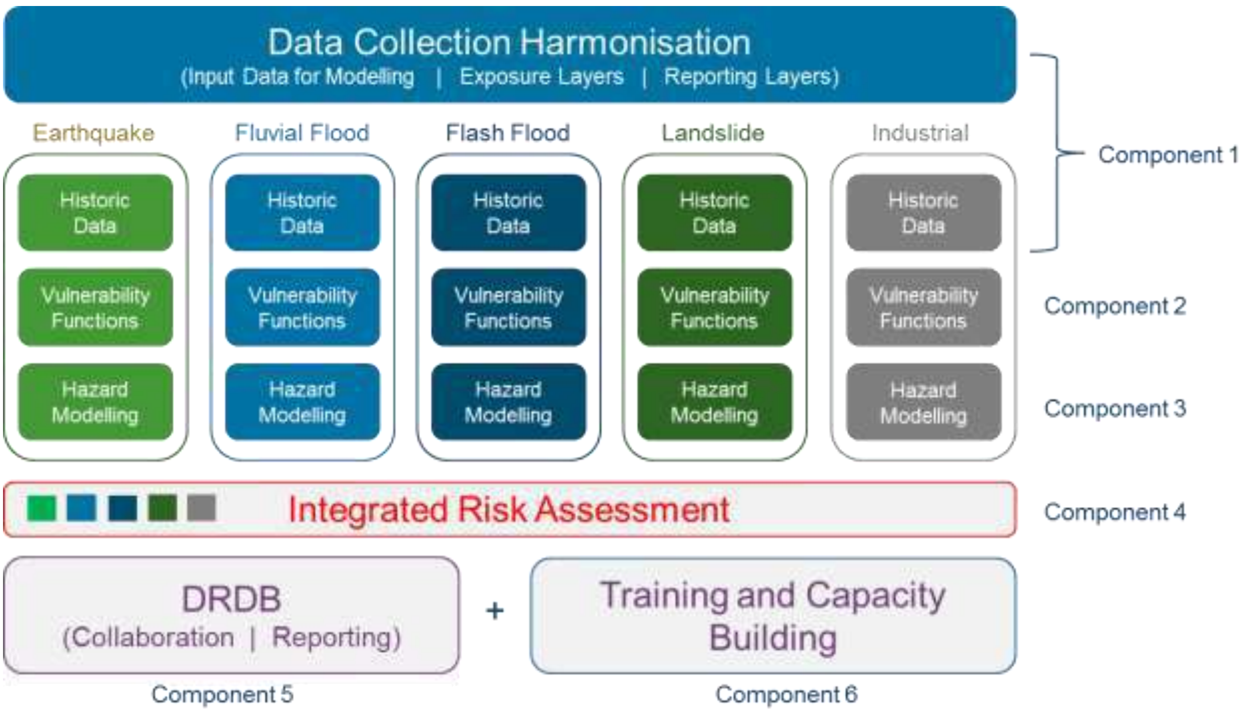


Figure 1.1: Components of the Disaster Risk Assessment Project

The DRA has set out to quantify the risk and exposure from five (5) types of hazard:

- Earthquakes;
- Fluvial Floods;
- Flash Floods;
- Landslides; and
- Industrial catastrophe[2].

For fluvial, or riverine, floods and for earthquakes, the exposure of infrastructure and people has been estimated and the total risk has been assessed probabilistically. The results are reported at block, district, and state level.

For flash floods, landslides, and industrial hazards it is not feasible to model the risk probabilistically. Instead, a deterministic approach has been taken and the exposure of infrastructure and people to these hazards has been estimated. The results are reported at block, district, and state level.

This overall approach is consistent with the terms of reference for the study.

An important overall objective has been to ensure that the process of risk assessment is ongoing and repeatable for USDMA and district level officers. Hence, the DRA JV has ensured the transfer of scalable and flexible tools that will help do this (for instance, CAPRA for risk computation and the Online Risk Database for exchange and communication of exposure data and results).

The key questions we are seeking to answer through this work are as follows.

- What hazards are most likely and severe?
- Where are people and infrastructure most exposed?
- Where and why are people and infrastructure most vulnerable?
- What human activity is increasing the likelihood or intensity of a hazard?
- What factors increase exposure and vulnerability?
- What can be done to manage these factors?
- What strategies can be committed to reduce risk?

[2] Chronic pollution in the vicinity of larger industrial facilities remains a concern but it was not under the scope of the DRA to assess this.

1.1.2 Schedule of Delivery

The core project work components were delivered in a timeframe of 26 months with an additional 2 months required for final contract closure. Figure 1.2 illustrates the schedule and the overlapping components.

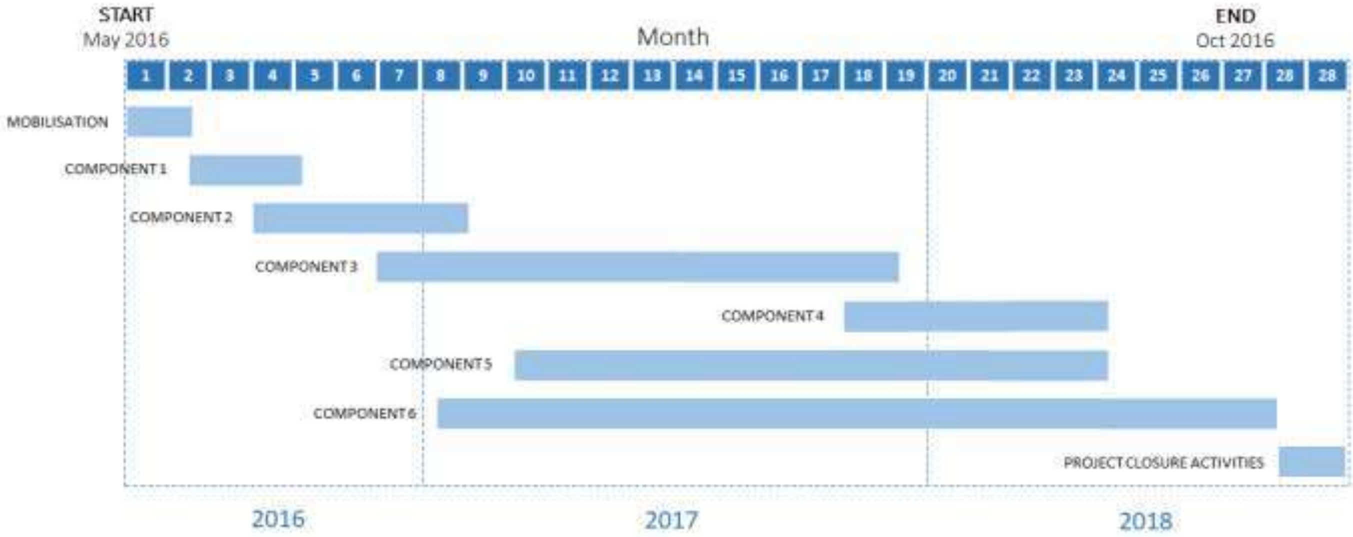


Figure 1.2: The DRA Project Schedule

1.1.3 About This Report

This report is the final output from the Disaster Risk Assessment of Uttarakhand (DRA) completed in January 2019.

It is written for risk management and planning practitioners in the Government of Uttarakhand (GovUk) and, specifically, the leadership of the Uttarakhand Stake Disaster Management Authority (USDMA). It also written for District Level Officers and staff on the "front line" of risk management.

The report is submitted in four (4) volumes.

The content of each volume is summarised as follows:

VOLUME 1

- Introduction to the Project
- Methods for Modelling Hazards and Risk
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locations where the USDMA can focus mitigation and risk reduction activities with a discernible positive impact.

VOLUME 3

A comprehensive state-wide ***Atlas of Risk***, which is a product that the Joint Venture has developed to supplement the main study outputs and to help district level authorities understand their exposure, vulnerability, and risk at District and Block Level.

VOLUME 4

Appendices with field and workshop report, training materials, and other important supporting material.

The report is available to download from the USDMA website (www.usdma.uk.gov.in).

Disclaimer

Whilst this study is a key aspect of disaster risk reduction, it is only the first step in a lengthy process of maturation of the state level risk planning management capacity. The outputs from this study facilitate long-term mitigation & planning and are not for engineering design purposes, real time monitoring or response planning.

1.1.4 Key Project Outputs

The key products arising from the project that are intended to have a lasting benefit in the state are:

1. A comprehensive inventory of all input datasets for the hazard models.
2. Statewide hazard maps for the entire state and reusable model outputs.
3. Greatly improved inventories of infrastructure, communities, and social vulnerability.
4. A “tool box” of software including CAPRA and a bespoke online portal for data exchange.
5. Statewide Atlas of Risk detailing exposure, vulnerability and risk to Block level.
6. Fourteen “Hotspot” risk reduction strategies.
7. Training materials.

Our DRA JV experts view this as a strong first step towards embedding risk based planning in to the disaster risk reduction in Uttarakhand. This collection of tools and resources will now require a concerted effort on behalf of the GovUk to maintain them and to improve them continuously.

1.1.5 Strategies for Project Success

The process of completing a multi-hazard risk assessment in a compressed timeframe has presented many challenges. However, the team adopted several strategies to ensure timely completion and to facilitate a positive outcome to the project programme. These include:

- Perform the components of the study in an overlapping and not in a truly linear programme.
- Deliver additional tools and resources beyond the terms of reference to empower the GovUk to repeat and refine the analyses on an ongoing basis (for instance, CAPRA, the Atlas of Risk, and training in the use of the hazard modelling tools).
- Engagement and awareness at the State (2 workshops), District (12 workshops), and Divisional (2 workshops) levels to validate collated data, preliminary findings, and to raise awareness of risk based planning and effective disaster risk reductions across the state.
- Engagement and alignment with Vetting Agency (IIT Roorkee) was essential to ensure that local domain expertise was codified in the models and approach conducted for the study. It was vital to ensure that the review process was collaborative and not adversarial, and we can confirm that this has been a successful aspect of the project.
- Local recruitment to build capacity and bolster geospatial data management and risk modelling functions. Six (6) local staff were engaged and based out of Dehradun.
- The DRA JV maintained strong local presence with a local office and training facility.
- To encourage effective handover of the tools and data, the DRA JV initiated Component 6 early and from the onset of the project. District Level workshops were initiated in month 4 and

training of USDMA began 12 months before project conclusion. Additionally, training opportunities have arisen given the local presence and we have capitalised on this opportunity to provide additional training beyond the initial requirement.

1.2 POST PROJECT ROAD MAP

The state of Uttarakhand is rapidly changing, and its risk profile is changing. Risk is dynamic. Therefore, the Government of Uttarakhand must invest in implementation of the recommendations arising from this study, and in the continuous improvement of the database and the upkeep of the Atlas in order that they remain relevant and useful for risk based planning and risk reduction.

Several critical steps are required in order to ensure successful implementation of the recommendations and applications of risk assessment in the state of Uttarakhand.

1. Implement a strong policy on disaster risk management and reduction, incorporating strong mitigation and planning requirements for municipal and district authorities.
2. Invest in Community Based Disaster Risk Management and amplify the activities building risk aware and resilient communities.
3. Ensure there is an annual update of the Atlas and Risk Profile of the state.
4. Secure commitments from line agencies to continually improve their asset inventories and data about their asset portfolios.
5. Build the recommendations arising from this study in to the state level and district level disaster risk management plans to strengthen the mid and long term mitigation plans.
6. Enhance the technical capacity of USDMA and DMMC to understand and apply risk assessments;
7. Continue to train line agencies and nodal officers in the application of risk based planning for mitigation of disaster risk;
8. Invest in the hotspot risk reduction strategies accompanying this report.

1.3 UNDERSTANDING RISK ASSESSMENT AND REDUCTION

1.3.1 What is Risk?

The risk posed by a specific hazard can be described as a function of the magnitude of the hazard, the vulnerability towards the hazard, and the exposure (severity) of the impact:

All dimensions of risk are highly variable in both space and time.

- Hazards: Quantitatively defined by the likely frequency of occurrence of different intensities for different areas, derived from historical data sets and covering events including earthquakes, landslides, flash floods and industrial hazards;
- Exposure: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses; with options for disaggregation of incidence by income level (i.e. impact on the poor), geographic area (i.e. to identify areas for urgent intervention), and sector (e.g. government/public, commercial/ industrial, residential); and
- Vulnerability: Quantitative and qualitative (proxy) measures of the damages and losses incurred to the exposed elements-at-risk (e.g. people, property, systems) by different intensities of the various hazards considered.

The relationship between these three aspects of understanding risk is illustrated in Figure 1.3.

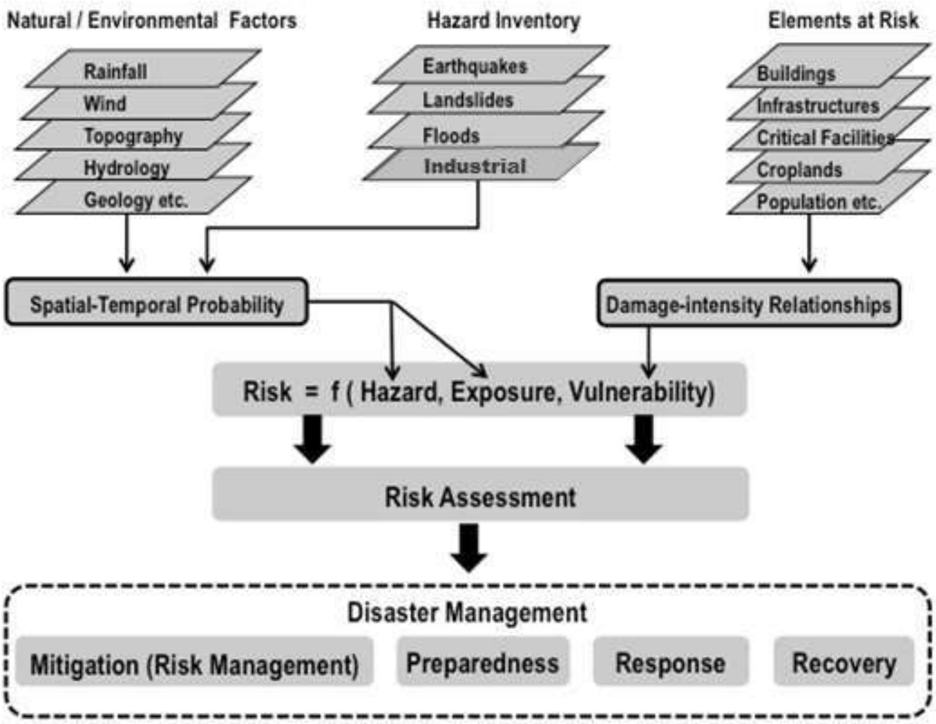


Figure 1.3: Framework for risk assessment, illustrating the relationship between hazard, exposure and vulnerability to derive risk

1.3.2 Probabilistic vs Deterministic Risk Assessment

> *While historical losses can explain the past, they do not necessarily provide a good guide to the future; most disasters that could happen have not happened yet*
>
> ***UNISDR, 2013***

Given the limitations in historic records, probabilistic risk assessment uses models underpinned by sound scientific and engineering knowledge to simulate those future catastrophes that are likely to occur. Probabilistic models recreate the intensity of a large number of synthetic events across a full spectrum of probabilities of occurrence. Uncertainty is factored in to the assessment and probabilistic models tend to produce a more realistic assessment of the over risk or expected losses.

In contrast, the deterministic approach typically models specific scenarios, where the input values are known and the outcome is observed. Both approaches have value.

1.3.3 Risk Management & Reduction

Risk management is the process through which risk is evaluated before strategies are introduced to manage and mitigate the threat (Smith and Petley, 2008).

As Crozier (2005) noted, the key drivers for the successful management of risk must be an awareness of threat, a sense of responsibility plus a belief that the threat can be managed or at least reduced. In an ideal world, the risk management procedure follows a clear set of priorities in which the highest levels of risk are addressed first. In order to develop such a priority list, a detailed quantitative risk assessment of all relevant factors and processes is required. This is a difficult task, not least because of the need to balance the relative significance of losses from high and low frequency events.

Risk management itself is often considered to be focused upon the prevention, mitigation and preparedness elements of this cycle, although the other elements are also important. Prevention, which forms part of this cycle, is only to a limited extent achievable.

The present project focuses on the aspect of pre-disaster protection of the risk reduction cycle. However, this does not mean the other half of the cycle will be completely neglected. Therefore, the basis of a risk management system will be developed that, in a later stage, may be expanded to act a basis for post-disaster recovery as well. For example, information generated for pre-disaster protection can be used (perhaps after adaptation) for pinpointing areas that most urgently require post-disaster recovery and for selection of effective and efficient post-recovery measures. Besides, due to the modular approach of the system, decision-making and action protocols for pre-disaster protection can be supplemented with protocols for post-disaster recovery.

As can be seen in Figure 1.4, pre-disaster protection consists of risk assessment, mitigation, preparedness and emergency plans.

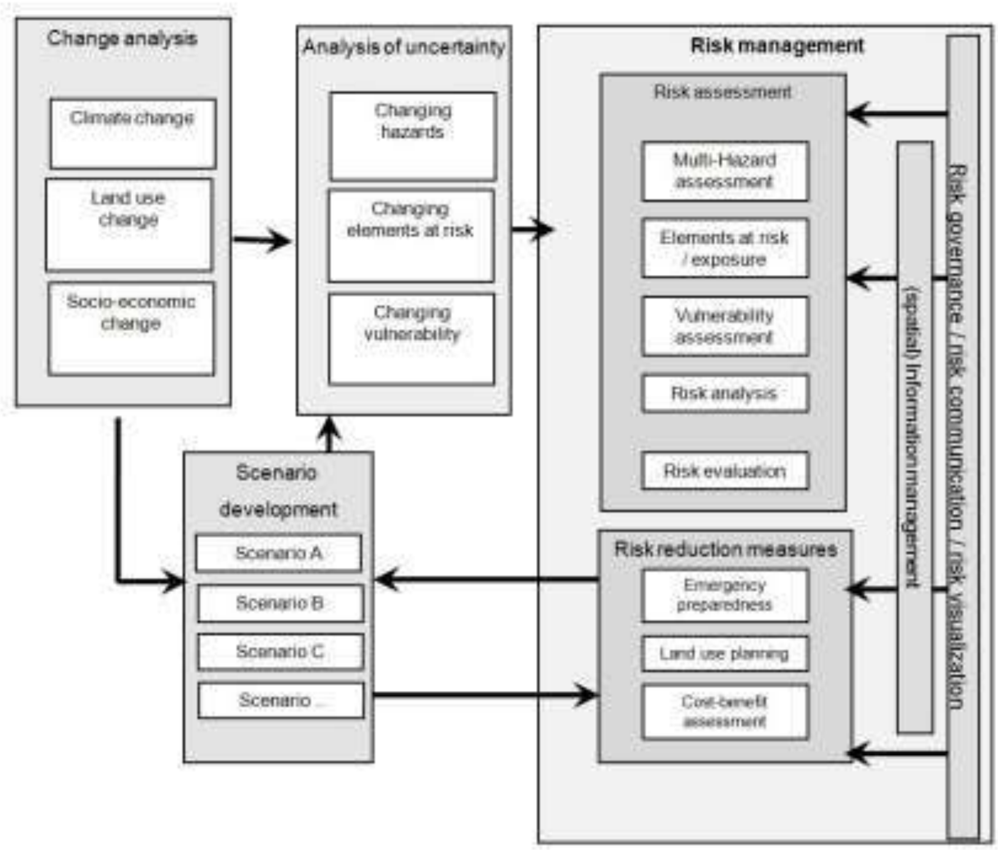


Figure 1.4: The reduction of risk through pre-disaster protection and post-disaster recovery activities. The time-scales needed for the activities shown may range from hours (emergency evacuation) to decades (rebuilding damaged infrastructure) (Source: Smith and Petley, 2008).

As shown above, the primary elements of pre-disaster protection are:

- Risk assessment: Involves the identification of a hazard, the accumulation of data and the preparation of loss estimates;
- Mitigation: Measures are taken in advance of disaster strikes, aimed at decreasing or eliminating the loss. Various long term measures, such as the construction of engineering works, insurance and land use planning are used;
- Preparedness: Reflects the extent to which a community is alert to disaster and covers short-term emergency planning, hazard warning and temporary evaluation procedures plus the stockpiling of supplies.

The capabilities of the risk assessment and associated management systems will allow for expansion in the future, to include, amongst others, functionalities facilitating other mitigation strategies, such as construction of engineering works, insurance schemes and land use planning.

In developing the methodology and approach for this project, the Consultant has been able to draw on its strong understanding and experience in Disaster Risk Management including hydrological studies, mapping, modelling and assessment in India and other parts of the world. The Consultant has a long involvement in water management and other related projects and provided services during different stages starting from project formulation to project construction and maintenance.

The Consultant's experience suggests there are two critical factors governing competence to successfully manage projects to achieve their objectives - the ability to identify key issues and the capacity to address them on a timely basis. This can only be done in conjunction with the Project Implementation Unit TA & CBDRM, Uttarakhand Disaster Recovery Project and other relevant stakeholders, and by ensuring that the lines of communication remain open. The approach and methodology adopted for the assignment has been geared towards the smooth execution of the scope of works specified in the RFP in systematic and sequential manners so that the man-power resources could be optimized and the project objectives could be achieved effectively. Special attention has been given to complex issues that formed constraints to the project in the earliest time, so that concerted efforts from various specialists and authorities could be utilised to resolve them in the shortest possible time.

There is a paradigm shift underway in disaster management (and the allocation of associated government/donor funding), both in India and worldwide, moving from a primary focus on response, recovery, and reconstruction to place a greater emphasis on disaster risk reduction (DRR) through effective mitigation and long term planning.

This shift requires a detailed and holistic assessment of the risks present in a given geographical and socio-economic context, which may then be used to inform a process of risk management and help reduce the impact of potential disasters in the future.

Holistic management of risk identifies actions to be taken to reduce the impact of extreme events before, during and after extreme events and include preventive technical/structural measures as well as a focus on socioeconomic aspects to reduce vulnerability to hazards. It is important to note that disaster risk management and management of climate change impacts share the same objectives, presenting a major challenge and opportunity to bridge current disaster risk management efforts with climate change adaptation measures.

Though risk assessment is not new in the region, a number of key constraints presently limit efficient Disaster Risk Management (DRM), including:

- Risk Assessment – Probabilistic risk assessment is typically executed through the simulation of a large catalogue of individual stochastic events. Thus the assessment is computationally heavy and technologies supporting efficient probabilistic risk assessment are new and not of widespread use. Novel tools are now available to efficiently execute a large number of scenario required to assess extreme events of low probability.

- Technical Data/Information Availability and Reliability - There are difficulties in the region collecting and using e.g. hydrological, health and disaster data. Many types of data to run comprehensive water resources modelling system are generally scarce. Owing to the concerted actions within the UDRP, data and assessments are made available ensuring adequate and reliable data to support the DRM.
- Experience in Planning Model Development and Use - There is limited comprehensive experience in fully developing and using Disaster Risk Modelling and planning tools. The lack of model development experience has led to models as “black boxes”, with some regional staff able to operate the models, but lacking in the knowledge and experience to maintain and upgrade the models after donor projects and funding have ended. With the UDRP, knowledge transfer through training is warranted ensuring sustainable establishment of DRM.
- Existing Institutional Structures and Coordination - There are limited developed institutional structures in the region for effective development, operation, and use of risk models. With our implementation of the UDRP collaboration with local institutions and transfer of transparent assessment tools will support the establishment of risk management across the society.
- Lack of Trained Personnel - Lack of trained staff, including the difficulty of retaining modelling and risk management staff after they have been adequately trained in model development and operations, is a perennial problem in the region. Continuation of the projects and political awareness of the need for DRM will ensure increased resilience towards disasters.
- Financial Resources - Financial resources provided through the World Bank are sufficient for an effective project implementation.

The successful implementation of the UDRP will close the currently existing gap in integrated disaster risk management that severely constrains the ability of Uttarakhand officials to make informed decisions about necessary investments in their country related to DRM. The UDRP project will develop and implement effective and modern risk management and risk communication systems, supporting informed investment planning and decision-making across all administrative levels.

1.3.4 Broad Responses to Risk

In theory, one of the best response to environmental hazard is avoidance. In practice, this is impossible due to the lack of influence of humans on large-scale physical processes and development pressures on land. Faced with such difficulties, loss acceptance is a common ‘negative option’, especially when limited resources exist. Loss acceptance occurs in different ways. Some people are unaware they live in a hazardous location and do nothing to reduce their risks. Others attach low priority to natural hazards compared to day-to-day domestic problems like inflation or unemployment while another factor is the limited scientific knowledge (Smith and Petley, 2008: 72).

The GovUK intends to raise its level of scientific knowledge and management institutions and processes in order to be better able to:

- Prioritise between various risk management strategies (see below) from an effectiveness and (economic) efficiency point of view;
- Respond to hazards in various stages. This means improving threat recognition, hazard evaluation, warning dissemination and public response (see further below).

Practical hazard-reducing adjustments fall into three broad groups:

- Mitigation – modify the loss burden. The most limited responses use a mix of humanitarian and economic principles to spread the financial burden beyond the immediate victims through disaster aid and insurance measures. These schemes are mainly loss-sharing devices but they can also be used to encourage loss-reducing responses in the future.
- Protection – modify the event. These responses rely on science and civil engineering to reduce the hazard by exerting (limited) control over the physical processes through structural measures (adjusting damaging events to people). The scales of intervention range from macro-protection (large-scale defences designed to protect whole communities) to micro-protection (strengthening individual buildings against hazardous stress).
- Adaptation – modify human vulnerability. These responses promote changes in human behaviour towards hazards (adjusting people to damaging events). In contrast to event modification, they are rooted in applied social science. Adaptation covers community preparedness programmes, forecasting and warning schemes and land-use planning.

By improving the scientific basis of risk management systems, the GovUk will be better able to optimize its mix of strategies (mitigation, protection and adaptation) in dealing with natural and man-made hazards.

1.4 STATE PROFILE

Uttarakhand, the 27th state of India, lies between 28.043’N to 31.027’N and 77.034’E to 81.002’E with a total geographical area of 53,484 sq. km. The state is a hilly state with hills covering an area of 46,035 sq. km (86.07%). The state is divided into two divisions, Kumaon and Garhwal and has 13 districts.

Uttarakhand's risk profile is one of expanding exposure and poorly understood vulnerabilities, and with a high susceptibility of major events like Earthquakes, Landslides, and Flash Floods.

A little less than half (46.24%) of the state's population lives in three plain districts of Haridwar, Dehradun and Udham Singh Nagar. The state is located in a geo-politically sensitive area with international boundaries facing Nepal in the east, and China (Tibet) on the north and north-east.

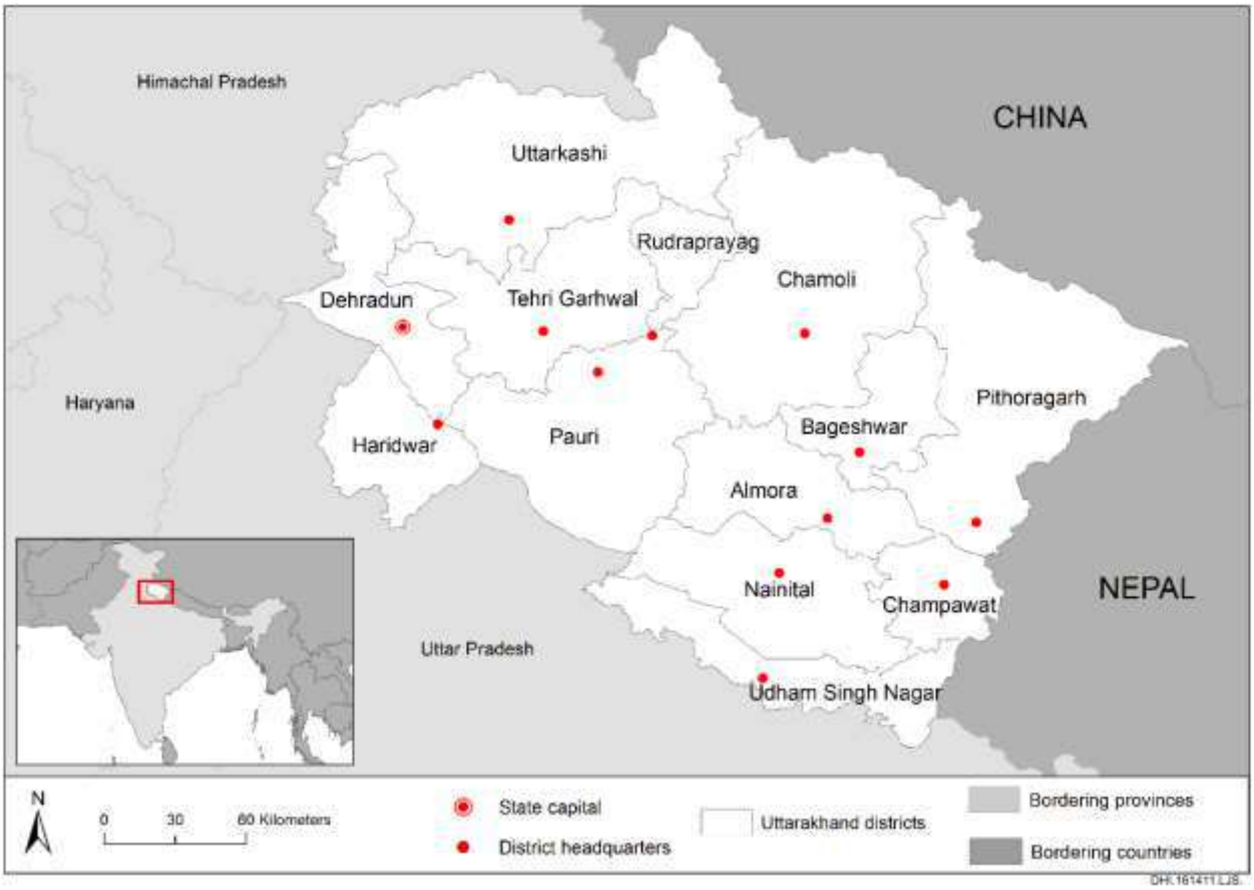


Figure 1-5: Geographical setting and district boundaries of Uttarakhand

On the other sides, the state is surrounded by the Indian states of Himachal Pradesh in the north-west hilly region and Uttar Pradesh in the southern plains.

Uttarakhand is prone to natural hazards mainly caused by water, (floods, flash floods, heavy precipitation, avalanches, landslides, droughts, hail, lightning, GLOF), as well as cold waves and earthquakes. The recent calamity due to heavy downpour and subsequent devastating floods in various rivers on 16-17 June 2013 led to heavy losses of life and property. Unprecedented floods and landslides have rendered many locations along the riverbanks vulnerable to losses. Besides affecting the life of the people adversely, such calamities also disrupt habitations around the rivers that contribute significantly towards total national agricultural and industrial product value.

Subject to extremes of weather and the collision of the Indian tectonic plate into mainland Asia, Uttarakhand has proved a difficult home for countless generations of its people, who have nonetheless prized it for its beauty and unique culture. Also known as the "Abode of God", Hindu mythology is deeply rooted in this beautiful State. Every year, hundreds of thousands visit the famous holy sites of Badrinath, Kedarnath, Gangotri and Yamonitri; collectively known as *Char Dham*.

Other important pilgrimage centres include the river confluences at Vishnuprayag, Nandaprayag, Karnprayag, Rudraprayag and Devprayag. In addition, the mighty Ganges River plays a tremendous role in Hindu mythology, and Rishikesh and Haridwar attract many pilgrims to take a holy dip where the Ganges reaches the flood plains. Additionally, the areas around Mussoorie, Nainital, Kausani, Ranikhet, Almora and Lansdowne are home to a significant tourism industry.

Historically, traditional wisdom has enabled Uttarakhand to contribute to both religious and educational progress in the hands of gurus, and today boasts an excellent educational system with many important knowledge organisations such as IIT Roorkee, Forest Research Institute, Indian Institute of Remote Sensing, WADIA Institute of Himalayan Geology, Survey of India and G B Pant Institute of Himalayan Environment and Development.

Dehradun, the Capital of Uttarakhand, lies in the Dun Valley, in the watershed of the Ganga and Yamuna Rivers. The State has two Divisions, (Garhwal and Kumaun), comprising 13 districts and six major cities with populations over 100,000 people (see Figure 3-1). The whole state counts an overall population of about 10 million.

Uttarakhand is rich in natural resources, especially water and forests, with many glaciers, rivers, dense forests and snow-clad mountain peaks. Geographically, it extends over 53,483 sq. km with 93% of the territory being mountainous area and 64% covered by forest.

There is a large proportion of uncultivable land and fallow land in the hilly regions, and it is estimated that around 46.3% of the total area is cultivated. Of the total cultivable land available, (cultivable wastelands, other fallow lands, permanent pastures, grazing lands, and miscellaneous tree crops), it is estimated that about 12.5 % is not currently cultivated, (DMMC, 2014).

The resources of the state are limited as far as water and land are concerned. The Food Grain Production needs to be improved through scientific transformation and modernisation of agriculture. The contribution of agriculture to the state's domestic product is about 22.4% and the population dependent on agriculture for their livelihood is about 75-85 %. The contribution of Uttarakhand to the country's total food grain and sugarcane production is however negligible (DMMC, 2014).

The pattern of land ownership is quite different from the rest of India. Most Uttarakhand farmers are owner-cultivators and limited to family farms only, with tenant farming and sharecropping barely evident. As such, the zamindari system of big landholders is limited to the plains. It is thought that both geography and Pahari cultural heritage have played a role in maintaining traditionally more reasonable land distribution in Uttarakhand (UEAP, 2016).

Table 1.1: Key Demographic and Socio-economic Profile (Sources: DMMC website, 2014 and Census, 2011)

Item	Year	Value
Total population (Census) (in lakhs)	2011	101
Crude Birth Rate (SRS) '000 of Population	2007	19.7
Crude Death Rate (SRS) Per '000 of Population	2007	6.8
Infant Mortality Rate (SRS) '000 of Live Births	2009	41
Sex Ratio (Census) / '000 of males	2011	963
Male Literacy Rate (Census) (%)	2011	88.33
Female Literacy Rate (Census) (%)	2011	70.7
Sex Ratio (Census) / '000 of males (0-6 years)	2011	886
Population Density (per square kilometre)	2011	189
Decennial growth rate	2001-2011	19.17
Rural population (Census)	2011	7,025,583
Urban population (Census)	2011	3,049,338

The state of Uttarakhand is graced with a rich bio-diversity, which can be found in its forests. The State counts six national parks and six wildlife sanctuaries for the conservation of flora and fauna and it still maintains rich wildlife outside their protected areas. This added to the fact that, it has almost all major climatic zones, makes Uttarakhand a region open to a variety of commercial opportunities in horticulture, floriculture, agriculture and a vast tourism potential in adventure, leisure, and eco-tourism (UEAP, 2016; Invest Uttarakhand, 2016).

The State accounts with several areas having mineral deposits like sand, sandstone, limestone, marble, rock phosphate, dolomite, magnesite, copper, gypsum however extensive quarrying is not practiced in the state (UEAP, 2016).

With most of the industries being forest-based, there is however, a number of small scale industries (44,809 providing employment to more than 208,846 persons), heavy and medium industries (nearly 2000 with an investment of Rs 20,000 crores employing (in 2013) 5 lakh persons) and around 55,000 handicraft units in the state (UEAP, 2016; Invest Uttarakhand, 2016; Directorate of Economics and Statistics, 2014).

It is also important to underline its higher level of literacy over the national average, which in a short span of its existence has emerged as a significant destination for investments in manufacturing industry, tourism and infrastructure. The Government of Uttarakhand has undertaken several policy measures and incentives in order to encourage inflow of investment in the main three sectors of its economy; agriculture, industry and services (Invest Uttarakhand, 2016).

1.4.1 State Administration

The Uttarakhand state is comprised of two regions and 13 districts. The Governance in Uttarakhand is entrusted to the following units and agencies:

Table 1.2: Administrative Arrangement in Uttarakhand (Source: Uttarakhand at a Glance 2014-15, Directorate of Economics and Statistics, Govt. of Uttarakhand)

Administrative Units	Year	Unit	Units
Divisions	2014	No	2
Districts	2014	No	13
Tehsils	2014	No	98
Development Blocks	2014	No	95
Nyaya Panchats	2014	No	670
Gram Panchayat	2014	No	7555
Census Villages	2011	No	16793
Inhabited villages including forest settlements	2011	No	15745
Un-inhabited villages	2011	No	1048
Municipal Corporations	2014	No	6
Nagar Palika Parishads	2014	No	31
Nagar Panchayats	2014	No	41
Cantonment Boards	2011	No	9
Census Towns	2011	No	41
Industrial Townships	2011	No	2
Development Authority	2014	No	6

1.4.2 Population Demographics

The state has a population of 100.86 lakh as per 2011 census. The population density is 189 persons per km², lower than the national average of 324 persons per km². 69.76% population lives in rural areas and remaining in urban areas. The gender ratio is 963 females per 1000 males, more than the national level figure of 940.

The total population of more than 10 million inhabitants is distributed heterogeneously across the state. Uttarakhand state ranks as the 20th most populated state in India comprising of 0.83% of the country's population. Compared to the India national average, Uttarakhand performs better in terms of population density, gender ratio and literacy. 20.9% of the population belongs to scheduled castes or tribes.

Table 1.3: Population Characteristics. Figures in bracket are percentage to total value (Source: Census, 2011)

Measure or Indicator	Unit	2011 Census	
		Uttarakhand	India
Geographical Area	Sq Km	53,483 (1.83%)	3,287,469 (100%)
Population	No	10,086,292 (0.83%)	1,210,854,977 (100%)
Female Population	No	4,948,519 (49.48%)	587,584,719 (100%)
Male Population	No	5,137,773 (51.38%)	623,270,258 (100%)
Urban Population	No	3,049,338 (30.55%)	377,106,125 (31.16%)
Rural Population	No	7,025,583 (69.45%)	83,308,768 (68.84%)
Decadal Growth	%	18.81	17.64
Scheduled Caste Population	%	17.90	16.20
Scheduled Tribe Population	%	3	8.20
Density	Per sq km	189	382
Gender Ratio	Females per 1000 males	963	940
Literacy	%	79.63	74.04

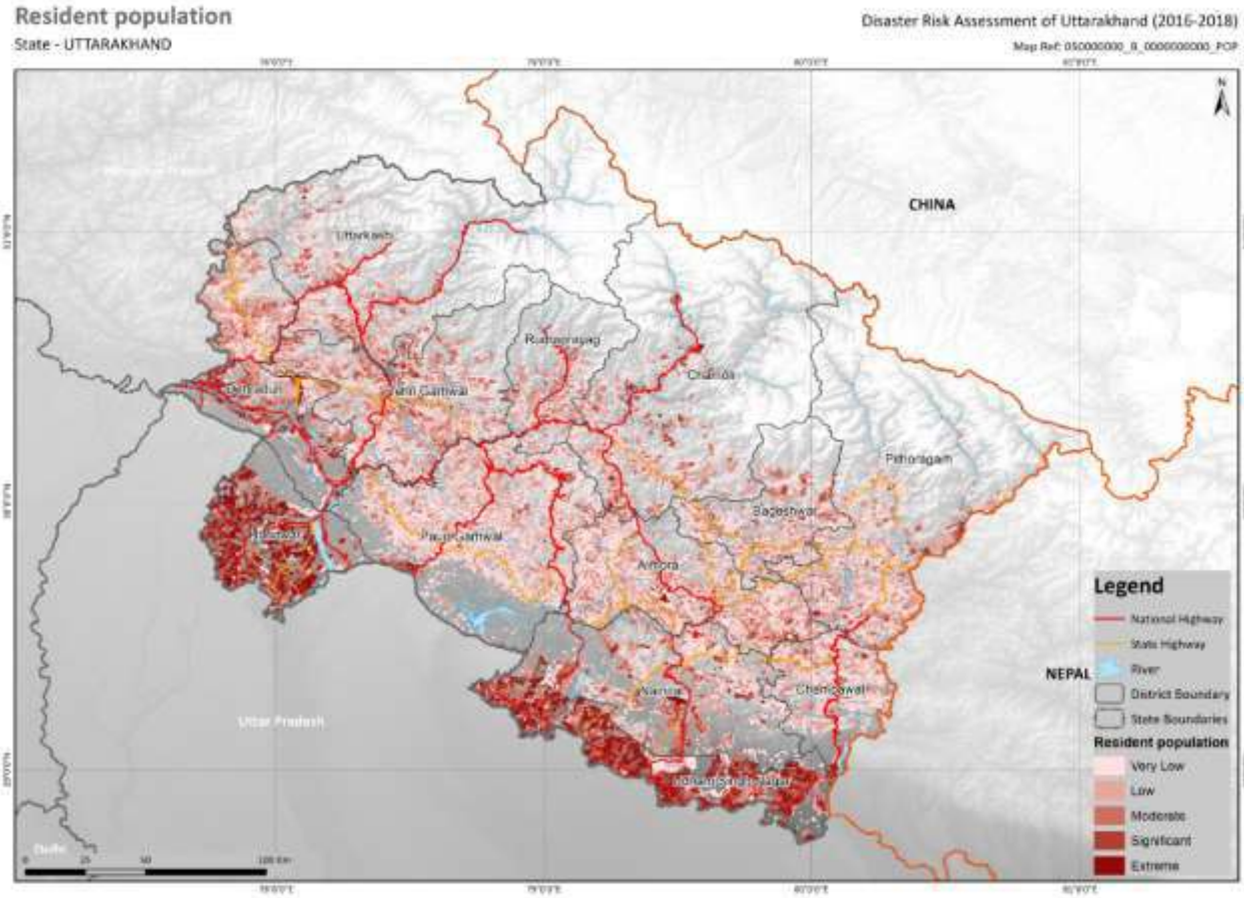


Figure 1.6: Resident Population Density across Uttarakhand (Source: DRA JV).

The decadal growth rate of population in Uttarakhand during 2001-2011 was 19.17% against national average of 17.64%. The trend of decadal population growth during 1901 to 2011 is by large aligned with trend of national average with exception in 1921. During 1921, there was fall in decadal population growth rate whereas in 1981 it was slightly higher than the national average.

The density of population varies from 41 persons per sq km in Uttarkashi to 817 persons per sq km in Hardwar. In the Almora and Garhwal districts decadal population growth rate (DPGR) is now negative. Today, 51.91% of the state population is concentrated in 3 districts - Hardwar, Udham Singh Nagar and Dehradun.

Table 1.4: District wise Demography Indicators (Source: Census, 2011)

District	Number of households	Population	% of state	% female	Female per 1000 males	Literacy Rate %	Density No/km²	DPGR % 2001-2011
Uttarkashi	67,602	330,086	3.27	48.9	959	76.00	41	11.75
Chamoli	88,964	391,605	3.88	50.5	1021	83.5	49	5.6
Rudraprayag	53,542	242,285	2.40	52.8	1120	82.1	119	4.14
Tehri Garhwal	132,714	618,931	6.14	51.9	1078	75.1	169	1.83
Dehradun	347,001	1,696,694	16.82	47.4	902	85.2	550	32.48
Garhwal	161,778	687,271	6.81	52.5	1103	82.6	129	-1.51
Pithoragarh	114,730	483,439	4.79	50.5	1021	82.9	69	5.13
Bageshwar	58,046	259,898	2.58	52.2	1093	80.7	116	5.13
Almora	140,577	622,506	6.17	53.3	1142	81.1	198	-1.73
Champawat	53,953	259,648	2.57	49.5	981	80.7	147	15.49
Nainital	191,383	954,605	9.46	48.3	933	84.9	225	25.2
Udham Singh Nagar	308,581	1,648,902	16.35	47.9	919	74.4	648	33.4
Hardwar	338,104	1,890,422	18.74	46.8	879	74.6	817	33.16
Uttarakhand	2,056,975	10,086,292	100	49.1	963	79.63	189	19.17

Important to note:

- Female Headed households: As per 2011 census, 342,185 households out of total 2,056,975 households in the state or 16.63% households are headed by females.
- 2011 Census reported that 1.85 lakh persons are disabled in the Uttarakhand state. It is 1.84% of the total population.
- As per 2011 census, religious break up of population indicates that there were 83.0% Hindus, 14.0% are Muslims, 0.37% are Christians, 2.34% Sikhs, Buddhist 0.15%, Jains 0.09% and other and religion not state were 0.13%.
- Scheduled Caste population is 18.93% where Scheduled Tribe were 2.92%.
- The child gender ratio (Population 0-6 age group) was 890 females per 1000 males indicating that a large fraction of the population is migrating or otherwise escape the statistics.

In total, 69.76% of the population lives in rural areas in Uttarakhand. The rural population is concentrated in the nine hilly districts whereas the urban population predominate in Dehradun and is proportionately significant in Haridwar, Udham Singh Nagar and Nainital.

Table 1.5: District wise Rural and Urban population; number of villages and towns (Source: Census, 2011)

District	Area in sq km	Population			No of villages	No of towns
		Total	Rural	Urban		
Uttarkashi	8,016	330,086	305,781	24,305	707	3
Chamoli	8,030	391,605	332,209	59,396	1,246	6
Rudraprayag	1,984	242,285	232,360	9,925	688	2
Tehri Garhwal	3,642	618,931	548,792	70,139	1,862	7
Dehradun	3,088	1,696,694	754,753	941,941	748	22
Garhwal	5,329	687,271	574,568	112,703	3,473	9
Pithoragarh	7,090	483,439	413,834	69,605	1,675	3
Bageshwar	2,241	259,898	250,819	9,079	947	1
Almora	3,144	622,506	560,192	62,314	2,289	5
Champawat	1,766	259,648	221,305	38,343	717	4
Nainital	4,251	954,605	582,871	371,734	1,141	11
Udham Singh Nagar	2,542	1,648,902	1,062,142	586,760	688	19
Hardwar	2,360	1,890,422	1,197,328	693,094	612	24
Uttarakhand	53,483	10,086,292	7,036,954	3,049,338	16,793	116

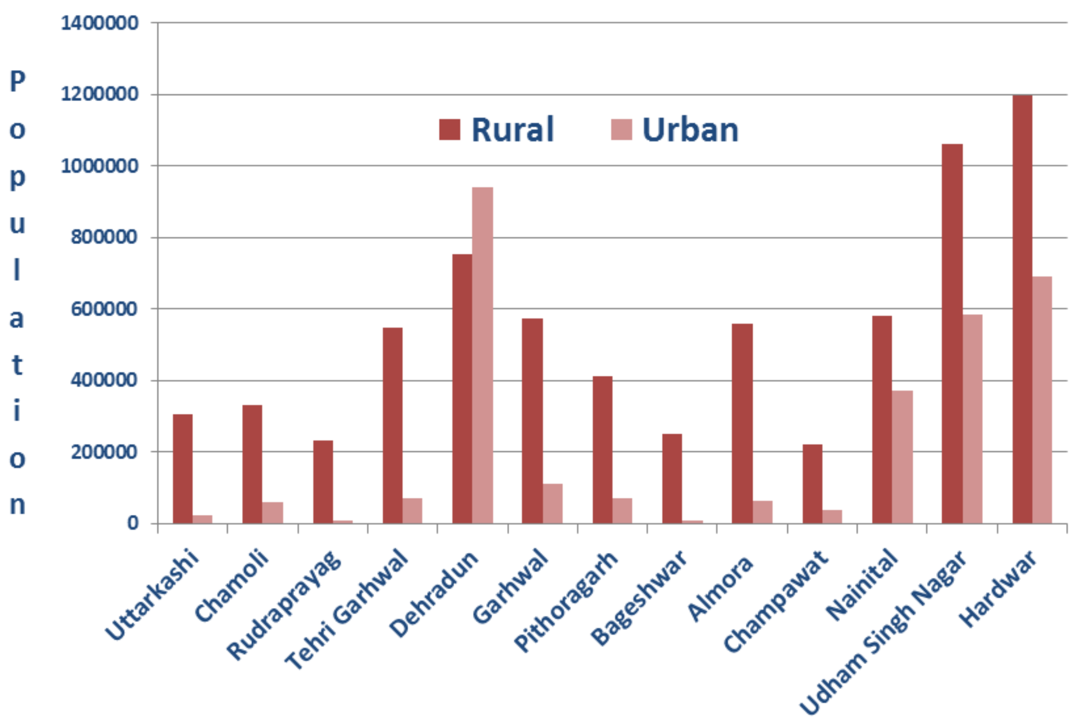


Figure 1.7: District wise rural and urban population in Uttarakhand 2011 (Source: District Census Handbook, 2011)

1.4.3 Land Use

The state has varied terrain, major portion of which is mountainous with high alpine areas to the Sub-tropical and Tropical regions.

More than two third of area is under forest and agriculture and allied activities are restricted to 23.6% area.

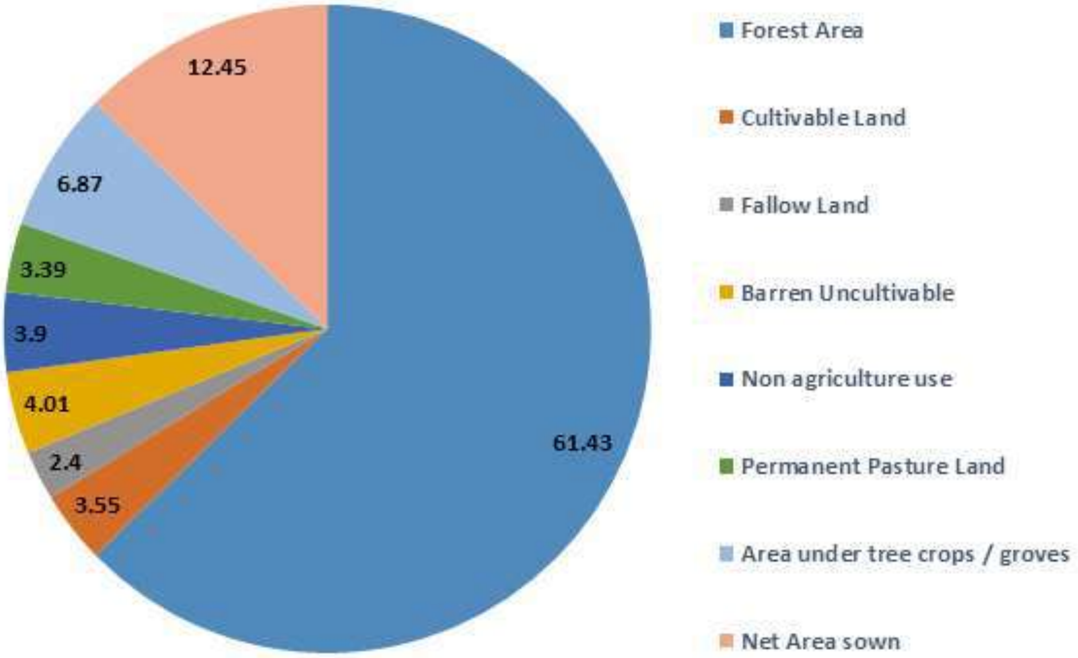


Figure 1.8: Land Use in Percentage in Uttarakhand State 2013-14 (Source: Uttarakhand State Level Annual Plan 2013-14)

The major resource of the state is its forests covering 70% of the geographical area with rich biodiversity. Uttarakhand state is bestowed with rich natural resources, having abundant water resources, glaciers and dense forests.

The state has almost all major climatic zones making it suitable for commercial activities such as horticulture. 69% of population from rural area mainly depends on agriculture for their livelihood.

1.4.4 Occupation Profile

As per 2011 census, the working population is 3,872,275 or 38.39% of the total population. The remaining population that is 61.68% is dependent on the working population. The dependency ratio is therefore 2.61. The sector distribution of occupation indicates that 52.28% of workers are engaged in other economic activities (tertiary or service), 36.43% of the working population is engaged in cultivation and another 8.6% as agriculture labour. Hence, a total of 45% of the working population are engaged in the primary sector which includes agriculture, agriculture labour, mining, fishing, horticulture, etc.

Uttarakhand is characterized by rural agricultural dominance. 69.76% of the population lives in rural areas and 44.49% of the working population was engaged in agriculture in 2011.

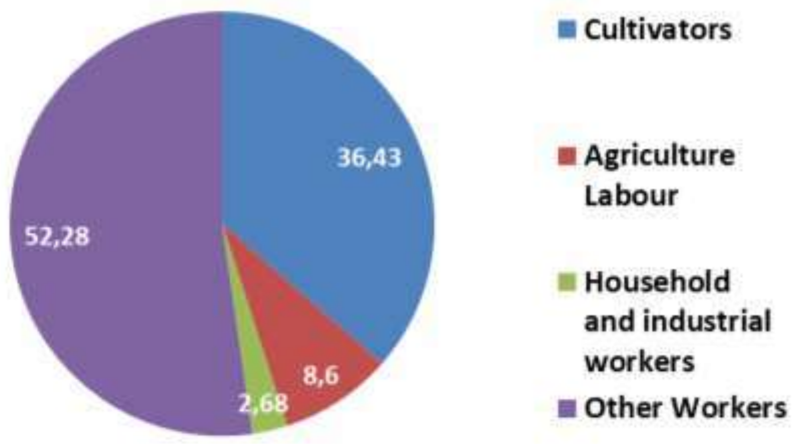


Figure 1.9: Workforce Engagement 2011 indicating 38% of the population are working (Source: Census, 2011)

1.4.5 Economy

Here the economic profile of the state is summarised. The reader is referred to Appendix E for the comprehensive economic assessment of the state that has been undertaken as a sub-component of this study. The baseline economic assessment has been critical to enable the team to estimate exposure and risk to key economic sectors.

The Gross State Domestic Product of Uttarakhand has been progressively increasing since 2004-05. The GSDP has grown by three fold in the decade 2004-2013. The contribution to the GSDP of Hardwar, Udham Singh Nagar, Dehradun and Nainital is more than two to three folds of contribution of any other districts. It is reflected in the following illustrations in Figure 1.11 and **Error! Reference source not found.**.

During 2013-14, per capita income was Rs1.03 lakh in Uttarakhand state as per figures released by the Directorate of Economics and Statistics against national per capita income of Rs. 74,380/-

The per capita income of the state was Rs 92,191 in 2012-13. The state has demonstrated a steady growth in Per Capita Net State Domestic product as is evident from the following Figure 3-38.

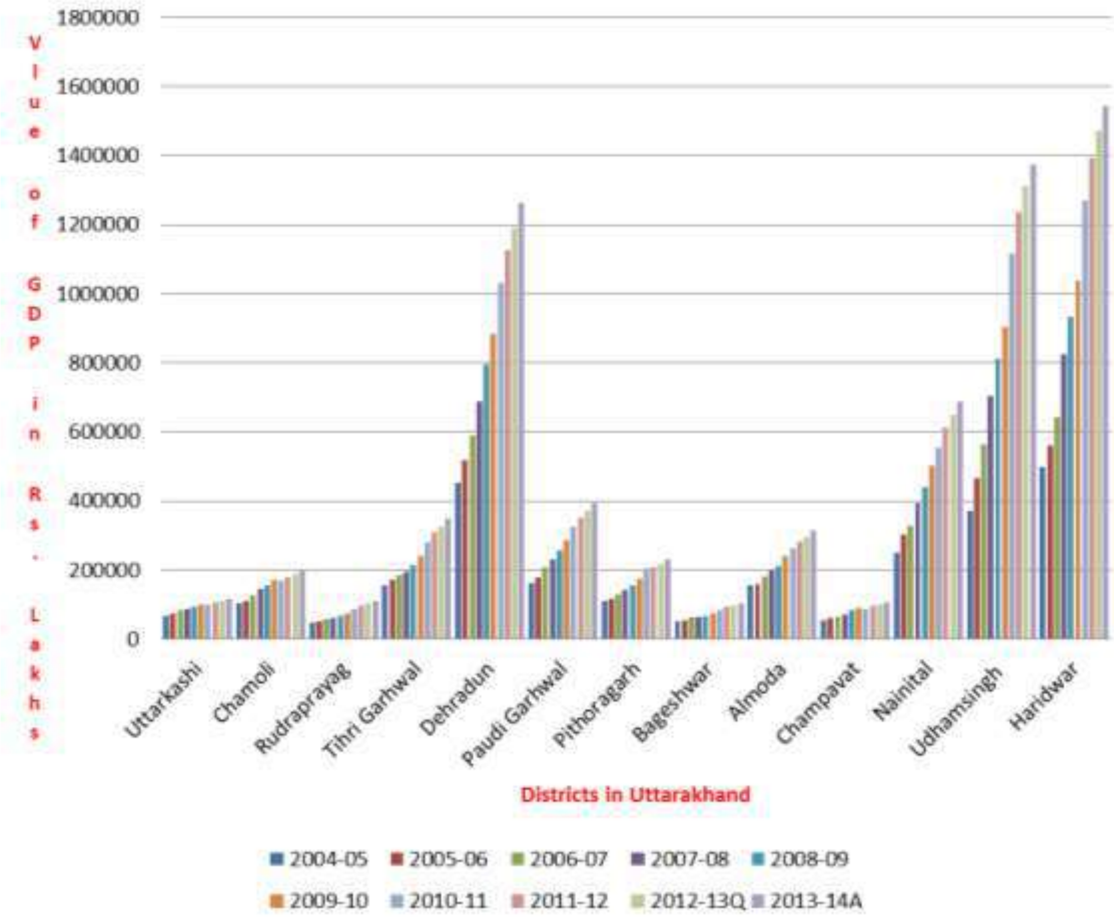


Figure 1.10: Gross Domestic product per district (Source: data.gov.in)

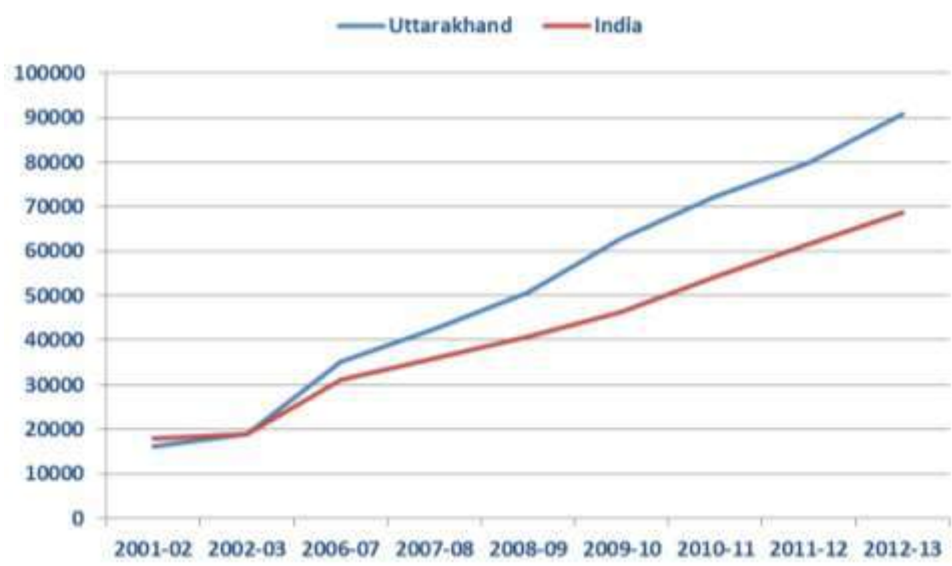


Figure 1.11: Net State Domestic Product at current prices (year 2013-2014). In 2013-2014 the NSDP rose to RS. 118,798 (Source: data.gov.in)

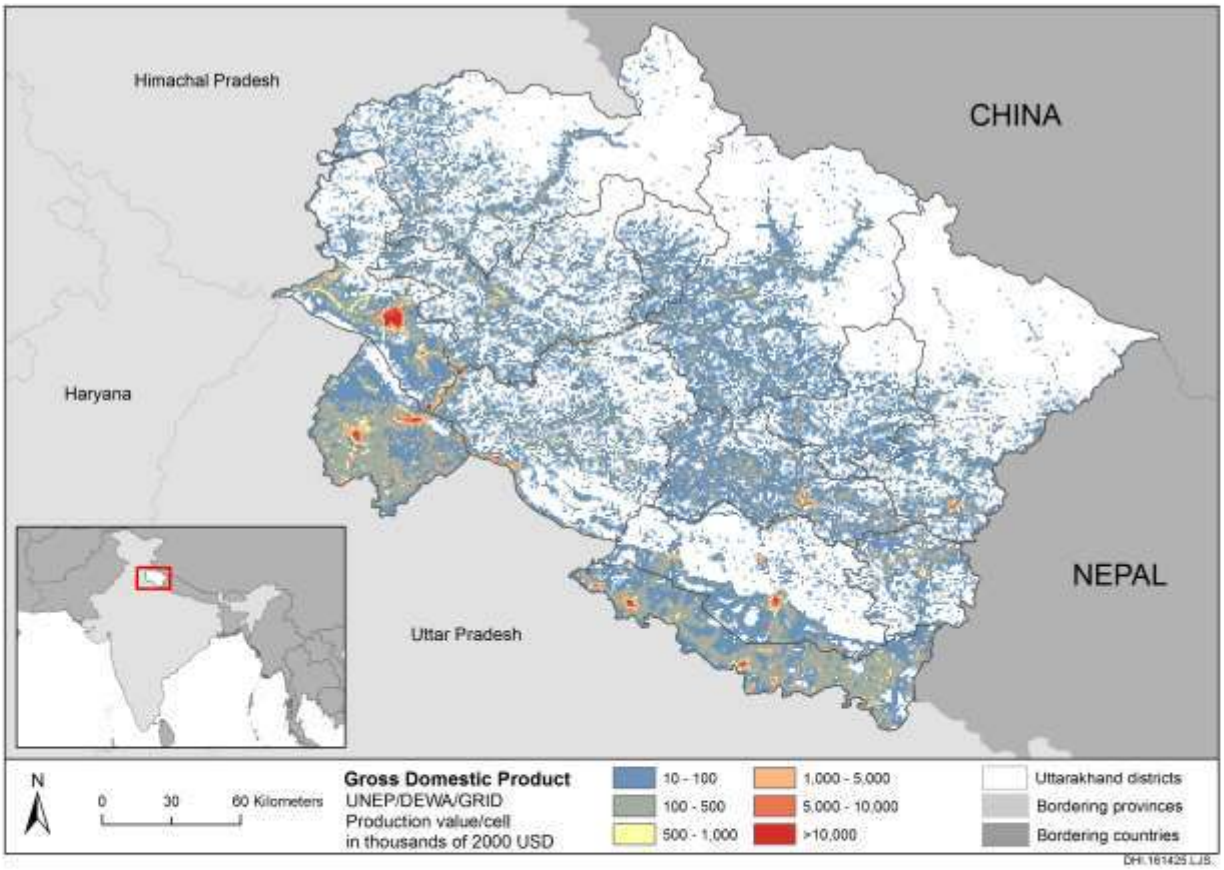


Figure 1.12: Gross Domestic Product distribution in Uttarakhand (Source: UNEP-GRID)

61.57% of the Uttarakhand population resides in Haridwar, Dehradun, Udham Singh Nagar and Nainital. These four districts combined also contribute more than 50% of the total GSDP of the state.

1.4.6 Migration

In Uttarakhand, migration is higher among educated than those with little or no education. Men migrate largely to seek employment opportunities while women migrate when they get married.

Table 1.6: Percentage of migrants to total population 2001 (Source: NSDC, 2013)

% of migrants	Uttarakhand	India	Remarks
to total population (2001)	36.2	30.6	Same magnitude of migration from HP, Sikkim and JK is reported

Table 1.7 Percentage of distribution of reasons for migration by gender for duration 0-9 years 2001 (Source: NSDC, 2013)

Particulars	Work	Education	Marriage	Family	Others
Total	19.9	4.3	35.4	31.5	8.9
Male	45.7	7.9	0.6	32.3	13.5
Female	3.2	2.0	58.0	30.9	5.9

While migrants from rural areas largely engage in self-employment, the urban migrants generally engage in salaried job.

Table 1.8: Percentage distribution of the streams of migration 0-9 years 2001 (Source: NSDC, 2013)

Stream of Migration	Uttarakhand (%)	India (%)
Intra District	44.7	55.00
Inter District	19.3	27.1
Interstate	33.3	17.1
International	2.7	0.8

Migrants from urban areas migrate longer duration or permanently while migrants from rural areas return to their native place after few years or migrate during lean period in their native place. Those who migrate do contribute to the state economy as the families spend more money on household expenditure, investments and repay their debts wherever required. Migration is highest in the hilly districts since most people migrate to the plains to seek seasonal employment

Table 1.9: District wise ranks for migrants per 1000 persons, 2001 (Source: NSDC, 2013)

District	Migrants per 1000 persons	Rank
Paudi Garhwal	115	1
Bageshwar	96	2
Chamoli	90	3
Tehri Garhwal	89	4
Uttarkash	89	5
Almora	83	6

1.4.7 Poverty Indices

Poverty prevails in area under snow, glaciers, remote, hilly and inaccessible areas. As per Hunger project studies held in 2011, in Uttarakhand. 39.6% population was living below poverty line. (40.8% in rural and 36.5% in urban).

1.4.8 Human Development Indices

The Human development Index (HDI) for Uttarakhand state was 0.467 as against 0.490 for national HDI as appeared in the Uttarakhand Annual Plan 2013-14.

1.4.9 Education

As per census 2011, the literacy rate of Uttarakhand stands 79.60%, which is higher than the national average of 74%. Uttarakhand is well known for its boarding schools and is home to a number of technical education institutes. There are 107 colleges, 13 universities, 3 Deemed universities, and the reputed IIT in Roorkee.

Table 1.10: Infrastructure details, 2012 (Source: Directorate of Economics and Statistics Uttarakhand)

Education Infrastructure	No.
Junior Basic	23,420
Senior Basic	15,507
High School /Intermediate	3,256
Colleges	116
Universities Central, state,	16
Deemed Universities	4
Industrial Training Institute	161
Polytechnics	52
IIT	1

1.4.10 Health and Medical Facilities

As of March 2011, the state had 256 PHCs, 59 CHCs, 13 District level hospitals, 8193 beds in Government hospitals with reach across the state. Crude Death Rate is 6.1 per 1,000 persons in 2013 in the state against the national average of 7.3. It is high in rural area with 6.4 per 1,000 persons against 4.8 per 1,000 persons in urban areas.

Infant Mortality Rate: During 2013, infant mortality rate was 32 per 1,000 of live births and thereby lower than national average of 50. It is high in rural area with 34 per 1,000 of live birth against 22 per 1,000 of live births in urban area in the state.

As per National Sample Survey Organization's Survey No. 69/1.2 Key Indicators of drinking water, sanitation and housing conditions in India, the following was the situation in Uttarakhand in 2012.

Table 1.11: Drinking Water, Sanitation, Drainage and Housing Condition Indicators; Uttarakhand (Source: NSS – 69th Survey on Drinking Water, Sanitation, Drainage and Housing Conditions 2012)

Indicator	Unit	Rural	Urban
Households having sufficient source of drinking water	No of Households per 1000 households	928	999
Households having improved source of drinking water	No of Households per 1000 households	877	900
Households having drinking water within premises	No of Households per 1,000 households	546	858
Distance that Household members have to travel to reach principle source of drinking water	Distance <0.2km	291	124
	Distance 0.2 km to 0.5 km	118	8
Average Time spend b household members to fetch water	Minutes	25	13
Households treating drinking water by any method	No of Households per 1,000 households	198	407
Households without bathroom facilities	No of Households per 1,000 households	205	24
Households without Latrine facilities	No of Households per 1,000 households	197	16
Households living in a pucca house	No of Households per 1,000 households	970	991
Average Floor Area of dwelling	Sq M	39.13	43.13
Households with separate kitchen	No of Households per 1,000 households	765	772
Households with separate room for married couple	No of Households per 1,000 households	610	772
Households with improved drainage facility	No of Households per 1,000 households	425	890
Households with garbage disposal facility	No of Households per 1,000 households	262	912
Households staying for 10 or more years in non-notified slums	No of Households per 1,000 households		789

1.4.11 Transportation

Uttarakhand has a road network comprising of National and State Highways, District Roads, and Rural roads all maintained by Public Works Department, Border Road Organization. The total road network has currently a length of 39,766.93 km corresponding to a road density of 134.50 km per 100 km^2 of geographical area in the state. Hereby, the road network density is considerably higher than the national averaged road network density of 108 km per 100 km^2.

Table 1.12: Road Network in Uttarakhand State (Source: Uttarakhand at a Glance 2014-15)

Agency	Type of Roads	Road length (Km)
Public Works Department	National Highways	1,375
	State Highways	3,782
	District Major Road	3,289
	Other District Roads	2,985
	Rural Roads	16,177
	Local Village Road	790
Border Road	Border Roads	1,281
Local Body Roads	District Panchayat	807
	Urban Local Bodies	2,356
Others	Irrigation Dept	741
	Cane Dev. Dept	850
	Forest Dept	3,270
	PMGSY-UMP	2,060
	Total Length	39,766

There are 345 kms of railway and it is limited to plains as 90% of the state is hilly terrain area. Uttarakhand has plans to increase the share of railway for cargo and passenger transport by having railway placed at strategic locations to reduce the transportation cost for industrial development including tourism. The state has the only one civil airport at Dehradun for domestic air travel services.

There are two key airports and a number of smaller airfields throughout the state. Jolly Grant airport in Dehradun is the primary airport in Uttarakhand. Pant Nagar airport is located in the Kumaon region of Uttarakhand. Other smaller airfields in Uttarakhand are situated in Gauchar, Bharkot as well as Naini Saini in Pithoragarh district.

1.4.12 Telecommunication Services

There are 2,719 post offices and 473 telephone exchanges across 13 districts as well as 5,275 Public Call offices. There are 195,855 no of individual and institutional telephone connections and from one of ten mobile phone providers (BSNL only) 902,096. This illustrates that mobile phone use has penetrated into essentially all homes of Uttarakhand.

1.4.13 Tourism

The number of tourist visitors is increasing i.e. in 2013-14, 225.25 lakh Indian and 1.10 lakh foreigners visited Uttarakhand. There are 327 marketed tourist destinations in the state across all the districts. The tourist inflow in national parks and wild life sanctuaries is reported at 273,297 Indian and 10,764 foreign tourists.

The figure below indicates the relative density of tourists per annum across the state.

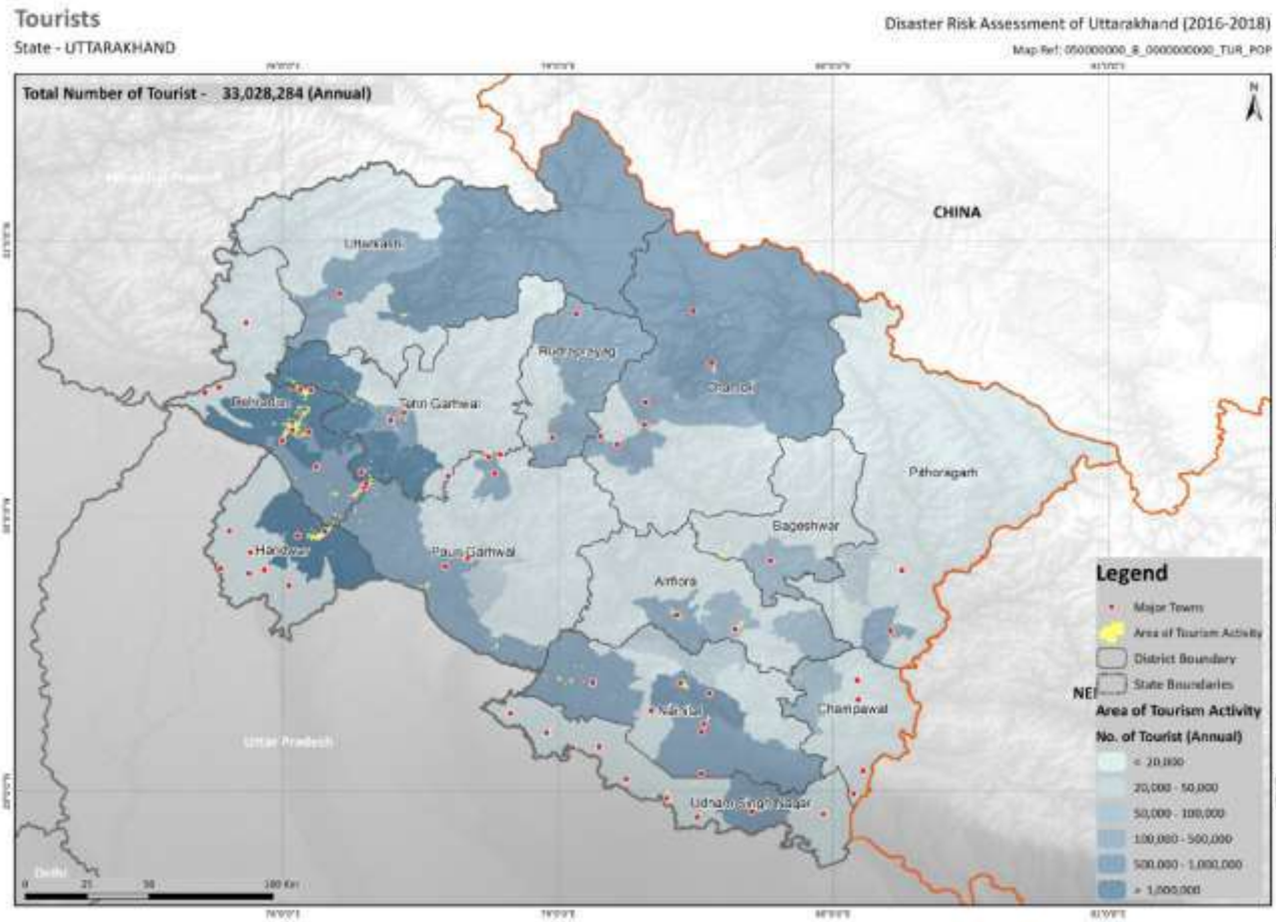


Figure 1.13: Estimated Annual Distribution of Tourists across Uttarakhand

1.4.14 Acts, Regulations & Guidelines WRT Disaster Risk Management

The following acts and guidelines set the context for the hotspot risk mitigation strategies and are pertinent in shaping the mandated response, recovery, mitigation, and planning activities for the state level government and its regional subsidiaries.

National level Acts & Plans

- National DM Act 2005
- National DM Policy 2009
- Compendium of laws on DM 2015
- National DM Plan 2016

National Guidelines by NDMA

- Guidelines on School Safety Policy 2016

- Guidelines on Hospital safety 2016
- Guidelines on Minimum Standards of Relief
- Guidelines on management of Earthquake 2007
- Guidelines on Management of Floods 2008
- Guidelines on Management of Urban Flooding 2010
- Guidelines on Management of Landslides & Snow Avalanches 2009
- Guidelines on Medical Preparedness & Mass Casualty Management
- Guidelines on incident Response System 2010
- Guidelines on seismic Retrofitting of Deficient Buildings & Structures 2014

National Guidelines under GoI UNDP DRM Program

- Model Guidelines for Development and Building Construction including Safety provisions for natural Hazards in Rural Areas – 2008
- Proposed Amendments in Town & Country Planning Legislations, including:
  - Regulations for Land Use Zoning
  - Additional Provisions in Development Control Regulations for Safety & Additional Provisions in Building Regulations/ Byelaws for Structural safety in Natural Hazards Zones of India – Vol-1(A)- for Municipal Councils - 2007

Uttarakhand State Acts/ Guidelines/ Regulations

- The Uttarakhand Building Byelaws & regulations – 2011 (Amendment 2016)
- The Uttarakhand Urban & Country Planning & Development Act 1973
- The Uttarakhand Flood Plain Zoning Act 2013

1.4.15 Relevant Bylaws and Regulations

It is pertinent to mention here that just after the creation of the State of Uttarakhand in 2000 all byelaws & regulations were adopted from the state of Uttar Pradesh. These byelaws and regulations were applied as per provisions of following Acts under Uttarakhand Adaptation and Modifications Order 2006.

- Section 5 of Uttar Pradesh (Construction work regularisation) Act 1958.
- Section 57 of Uttarakhand Town & Country planning & Development Act, 1973 (Amended Act, 2013).
- Section 50 of Uttar Pradesh Special Area Development Authority Act 1986.

The Uttarakhand Building Bye Laws & Regulations 2011 (Amendment 2016) provides all the guidelines for the construction in urban as well as in the rural areas of the State (Table 1.13). The Chapter VI, section 6.1 of the Act talks about the safety related provision from earthquakes and fire etc while section 6.3 of Chapter VI provides relevant code for structural safety in natural hazardous areas.

As per the Act "all parts of the Uttarakhand State falls under Zone 4 & 5. Therefore, the mentioned provisions in the record and other relevant guidelines of the Indian National Building Code in Appendix IV for development of important structural facilities would be followed for new buildings under every zone essentially".

The present act & regulations provide all sufficient guidelines and norms for the construction in the region, however due to lack of implementation and non-compliance of the rules and regulations, constructions are going on without a proper authority and/or technical expertise.

Table 1.13: Codal Provisions in Uttarakhand

For General Structural Safety	For Earthquake Protection
• IS: 456:2000 “Code of Practice for Plain and Reinforced Concrete • IS: 800-1984 “Code of Practice for General Construction in Steel • IS 875 (Part 2):1987 Design loads (other than earthquake) for buildings and structures Part2 Imposed Loads • IS 875 (Part 3):1987 Design loads (other than earthquake) for buildings and structures Part 3 Wind Loads • IS 875 (Part 5):1987 Design loads (other than earthquake) for buildings and structures Part 5 special loads and load combination • IS: 883:1966 “Code of Practice for Design of Structural Timber in Building	• IS: 1893-2002 "Criteria for Earthquake Resistant Design of Structures (Fifth Revision)" • IS:13920-1993 "Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces - Code of Practice" • IS:4326-1993 "Earthquake Resistant Design and Construction of Buildings - Code of Practice (Second Revision)" • IS:13828-1993 "Improving Earthquake Resistance of Low Strength Masonry Buildings - Guidelines" • IS:13827-1993 "Improving Earthquake Resistance of Earthen Buildings - Guidelines", • IS:13935-1993 "Repair and Seismic Strengthening of Buildings - Guidelines • Improving Earthquake Resistance of Buildings- Guidelines" by Expert Group, Government of

For General Structural Safety	For Earthquake Protection
• IS: 1904:1987 "Code of Practice for Structural Safety of Buildings: Foundation" • IS1905:1987 "Code of Practice for Structural Safety of Buildings: Masonry Walls	India, Ministry of Urban Affairs & Employment, published by Building Materials & Technology Promotion Council, 1998. • The National Building Code of India -2005. For location of the building in hazard prone area of earthquakes, cyclone or wind storms and floods, reference may be made to the following: • Vulnerability Atlas of India, by Expert Group, Government of India, Ministry of Urban Affairs & Employment, published by Building Materials & Technology Promotion Council, 1997.

1.4.16 Historic Hazard Profile

Historically, hazards have resulted in disasters, causing losses of property, natural resources assets, and human lives. The most significant natural hazards in Uttarakhand are Earthquakes, Floods, Flash Floods and Landslides, and these are the focus of this study. In addition, increased industrialization may have led to an increase in industrial hazards. This risk study is, therefore, focusing on these five hazards.

This section will briefly summarise our preliminary understanding of Uttarakhand's risk profile, in terms of the various hazards faced, the exposed populations and assets, and their vulnerability to these hazards.

It is noted that this section is not intended to present new information and rather shares findings from some of the excellent official reports already produced (such as NIDM 2014) as well as journal articles and news reports.

Especially in recent years, Uttarakhand has become known for the increasing frequency and intensity of disasters caused by a wide range of natural and (to a much lesser extent) industrial hazards. The state is especially prone to geological hazards, such as earthquakes and landslides, as it falls in the highest seismic risk zone in the country, but also experiences frequent floods, epidemics, fires, hailstorms, lightning, road accidents, etc. In the following sections, a wide range of hazards will be briefly introduced, with a particular focus on the hazards under investigation in this project. Additional details are provided in the relevant methodology sections later in the report.

As discussed above, throughout its history, the state of Uttarakhand has been subject to a varied and intense range of natural hazard events. While many of these are unaccounted for in the historical record, (given the frequency of chronic, low-intensity events, such as minor landslides), a summary of the major events for each hazard type is provided in Table 1.14.

Table 1.14: Summary of Relevant Historical Hazard Events in Uttarakhand

Hazard	Earthquakes [1]	Landslides [2]	Floods / Flashfloods [3]	Cloudburst [4]
Number of events	65 from 1803-2013 11 with magnitude > 6.0 Ritcher	29 major events from 1867-2013	28 major events from 1989 -2013	9 major events from 2002-2016
Casualties	-	>5400 since 1998	More than 6500 from 1989-2013 (~5700[5] only from June 2013 floods)	155

Sources: [1] Setendra (2003) | [2] NDMA (2009) | [3] SEOC (2011) | [4] UAEP (2016) [5] CBS news

1.5 DEFINING VULNERABILITY

Vulnerability describes the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. The disaster vulnerability of an area is determined by its social, physical, environmental and economic settings, which can make the land and its people susceptible to the impact of disasters. This may be related to the weaknesses in their capacity to understand, withstand and respond to hazards, and/or to bounce back after the disaster. Poor socio-economic conditions, either due to loss of environmental sustainability or degradation of natural resources, and inadequate avenues of alternative livelihood and prospects of local economic development, along with marginalization, non-access to goods and services, illiteracy and ignorance, govern people's preparedness and capacity to withstand a disaster.

Poverty and deprivation, with lack of economic base to sustain and maintain safe housing and occupations extensively contribute to the vulnerability of the people. Lack of resources and capacity leads to poor settlements in hazardous and more vulnerable areas. However, changing livelihood choices, increased social aspirations and wish for increased earnings has also increased unsafe construction of hotels and other tourism amenities in hazard prone locations along roads and rivers.

1.5.1 Development vs Vulnerability

Vulnerability or susceptibility of a physical region or its society to natural hazards is essentially the result of the prevailing conditions, which are often the consequences of the development pattern and practices. Therefore, the development practices play a very important role in determining the vulnerability of a society or land to natural hazards. Development and disaster have a very close and multi-dimensional relationship. The relationship between disaster and development is very clearly visible in the Uttarakhand region. After the formation of the State, developmental activities have been speeded up considerably. Roads, buildings, hydropower energy projects, tourist related infrastructure and, sand and stone collection from river channels are the main developmental activities, which influence the vulnerability of landscapes and local communities to natural hazards.

There is no doubt that the region needs economic growth. But this development cannot come at the cost of the environment. It will only make the already risk-prone and ecologically fragile region more vulnerable and development more “deadly”. We also know that climate change will exacerbate the vulnerability of this already fragile ecosystem.

The Uttarakhand tragedy offers a valuable opportunity to reframe the contours of the (development) debate. It is not really about environment versus development; it is about environment versus reckless growth built on non-adherence to rules, regulations, guidelines and experts’ recommendations. This, in effect, derails development in the long-term.

In order to determine the vulnerability means, to find out what would happen if a certain event affected people at risk. The pragmatic approach for vulnerability assessment will take into account the specific scenario having many dimensions to comprises of physical, social, economic, environmental, institutional and human factors. There would be a challenge to quantify and qualify these vulnerability indices in the absolute terms.

1.5.2 Vulnerability Scenario in Uttarakhand

Uttarakhand has been primarily an agricultural State where more than 75% of the population has been dependent on the agriculture sector including horticulture and animal husbandry for their livelihood. The economic condition of population in general is not very good. It is a critical attribute increasing vulnerability of the people, which pushes them to move and settle in more vulnerable areas. Lack of road connectivity, irrigation facilities, food storage facilities, marketing/credit institutions in the rural hilly areas of the State also increases vulnerability of the people during disaster (DMMC Report, 2015).

Different valleys in Himalayan region have typical geological, seismic, lithological and hydrological susceptibilities that are always ready to welcome such a potent trigger for banging the valleys. Susceptibilities of different valleys, villages and entities, e.g. roads, buildings, dams, etc., against different kinds of hazards are also important factors to understand the sequence of physical events and their potential to create and intensify the emergency situations.

1.5.3 Physical Vulnerability – Building Structures

Much research in Himalayan region points towards developmental activities and loss of forest cover as the major destabilizing factors acting to increase the vulnerability in the region at large. In the event of flood, landslide and earthquake, poor housing structures result in more damage and loss of lives.

Design specifications of houses as well as material used for construction, particularly for making roofs and walls, have a direct bearing on the vulnerability of houses to common disasters like earthquake, landslides and floods. As per the vulnerability Atlas of India, about 56% of the houses in the State are constructed using mud, un-burnt brick walls and stone walls; 37.9% using burnt brick walls; and 2.1% of concrete and wood walls. The majority of these houses consisting of mud, un-burnt/burnt brick walls and stone walls are highly vulnerable and likely to be severely damaged or even collapse during moderate intensity earthquake, landslide and food.

Most recent constructions in the urban areas in the hills thus consist of poorly designed/ constructed buildings. The older buildings, even if constructed in compliance with relevant standards at that time, might well not comply with the more stringent specifications of the latest standards. Assessment of the present condition of the structures is thus highly pertinent as this is intended to pave way for effective and timely mitigation planning through appropriate structural and non-structural interventions.

Further, the old construction practices and local material used for the buildings makes the houses here more vulnerable to earthquakes. Therefore, the identification of the building types and their categorisation on the basis of building type and material used is essential to mitigate the impact of such earthquakes over these areas (Table 1.15).

The Government of Uttarakhand has initiated an ongoing Rapid Visual Screening Survey of government buildings across all districts (see Table 1.16), and initial results from five districts reveals that nearly 80% buildings are unsafe as per building structure criteria. The unsafe status of the building structure is further qualified on the margin scale of bad, very bad and very worst.

Table 1.15: Categorisation of building material and house types (Source: Vulnerability Atlas of India)

#	Building Material Type	Wall Type	Roof Type
A	Building in field stone, rural structures,	A1: Mud wall	a) All roof sloping
		A2: Unburned brick wall	a) Sloping roof
			b) Flat roof

	unburnt brick houses, clay houses	A3: Stone wall	a) Sloping roof
			b) Flat roof
B	Ordinary brick building: building of the large block and pre-fabricated type, half-timbered structures, building in natural hewn stone		a) Sloping roof
			b) Flat roof
C	Reinforced building, well-built wooden structures	C1: Concrete wall	a) Sloping roof
			b) Flat roof
		C2: Wood wall	All roofs
		C2: Ekra wall	All roofs
X	Other types of houses	X1: GI & other material sheet	All roofs
		X2: Bamboo, thatched grass, etc	All roofs

Table 1.16: Present Status of Government Buildings in the Districts (Source: Source: Uttarakhand Disaster Recovery Initiative)

Districts	Total Number of Buildings	Surveyed/ Ranked	Safe	Unsafe
Bageshwar	254	183	27	156
Chamoli	888	295	60	235
Pithoragarh	593	178	24	154
Rudraprayag	615	274	92	182
Uttarkashi	746	407	84	323
Source: http://ukdisasterrecovery.in/rvs/index.php				

The reasons could be that these buildings are aged and unmaintained buildings that became unsafe or they were never properly constructed. Poor construction could be due to lack of suitably qualified technical manpower in these areas, lack of awareness regarding multi-hazard threat in the region and non-compliance of latest building regulations & codal provisions by the local government officials, construction agencies and individuals.

Another factor that worsens the vulnerabilities of local population is the increasing tendency of adopting non-sustainable modern technologies for house constructions, especially in hazardous areas. Cost of constructing such buildings in hilly areas put local people under enormous economic pressure and makes the households more vulnerable during extreme events.

In hilly region, generally the type of house construction varies from mud or stone or burned brick walls, with flat roofs consisting of wooden joists, earthen or lime concrete topping or various types of slabs and, others having pitched roofs consisting of thatch or tiled roof and bamboo construction etc. Various combinations of all such local materials are also prevalent. In addition, as modern technologies the constructions with brick masonry, stone masonry and even RCC frame are also being done along the major roads where the extent, type, form and height of buildings vary.

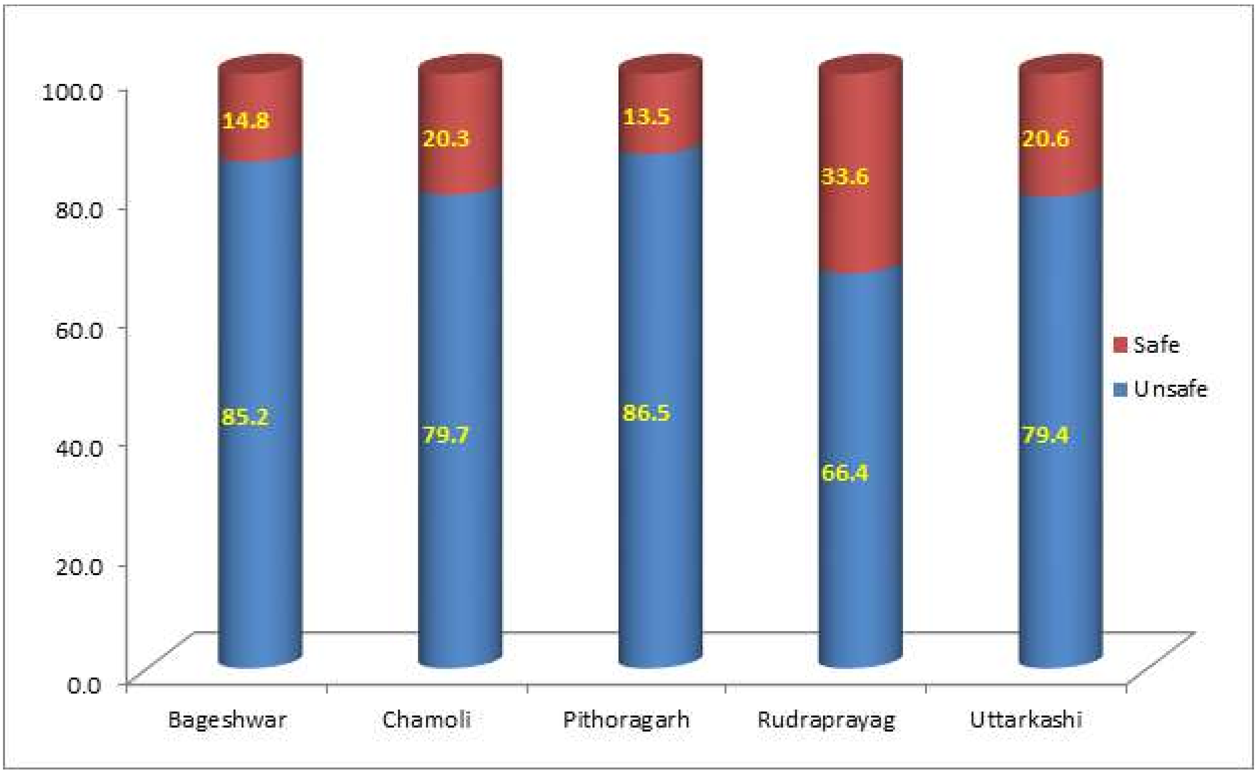


Figure 1.14: Preliminary Results Showing the Proportion of Safe and Unsafe Government Buildings in 5 Districts (Source: Uttarakhand Disaster Recovery Initiative)

The DRA Project Team captured some of building construction practices during the field visits.

The faulty building construction practices in the region is responsible for a very high vulnerability towards disaster. In the event of flood, landslide and earthquake, poor housing structure results in more damage and loss of lives. Due to population outburst and unavailability of suitable land, people are forced to live on more unstable and highly vulnerable slopes. Most of the habitation in the region is situated on the old landslide debris or loose material.

1) Multi-floor Building in the high land slide zone,

2) Constructing the Plinth level at steep slope- use of RCC Beams and Columns

3) Brick House with RCC Roof/ Floor without Columns at Corner, can suffer corner damage and collapse of walls

4) Erecting RCC Structure at River Bed

Figure 1.15: Selected Present Building Construction Practices – Increasing Vulnerability

This has been taken as one of the key consideration while devising the vulnerability indicators for this assessment study. It is a widely accepted fact that "Earthquake does not kill people but the buildings do" and in Uttarakhand this would be true if a quake hits before the buildings and cities have improved structures. The majority of deaths and injuries in earthquake incidences are caused by trauma post collapse of buildings and other man-made structures.

Vulnerability assessment should be performed at household level, and then aggregated to a group of people, community, and state in relation to different types of hazardous phenomena. The identification of the building types and their categorization, is essential to mitigate the impact of hazards.

<table>
<tr><th colspan="2">Selected Present Building Construction Practices – High Vulnerability</th></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">House/ Building construction in Urban/ Town Area</td></tr>
<tr><td></td><td></td></tr>
<tr><td>1) Multi-floor Building in the high land slide zone</td><td>2) Constructing the Plinth level at steep slope- use of RCC Beams and Columns</td></tr>
<tr><td></td><td></td></tr>
<tr><td>3) Brick House with RCC Roof/ Floor without Columns at Corner, can suffer corner damage and collapse of walls</td><td>4) Common Building Typologies in Hillside Areas</td></tr>
</table>

Figure 1.16: Illustration of current building practice

Once the vulnerability is assessed, standards, regulations and programs to raise awareness need to be determined with the ultimate goal to reduce existing vulnerabilities. An effective action to decrease vulnerability is to develop and enforce regulations on building methodology and materials. These regulations have to be made stringent and enforced to promote sustainable development. Punitive actions, fixing accountability and other adequate measures need to be in place to discourage unsafe building construction practices while involving insurance and financial institutional mechanism.

Faulty building construction practices in the region are making it more vulnerable and prone to disaster. In the event of flood, landslide and earthquake, poor housing structure results in more damage and loss of lives.

1.5.4 Socio-Economical and Environmental Vulnerability

Impact of modernity and efforts to extend the development models of plains, into the hilly region have made the social and economic life of mountain communities vulnerable. The vulnerability of people/ community or region is inseparably linked to the social, cultural and economic processes developing there and the agricultural and ecological transformation of the region. The great Himalayan Mountains are of enormous value for the ecosystem services and potential and the Uttarakhand region represents one of the most fragile, vulnerable and economically challenged ecosystem. It is an acknowledged phenomenon that vulnerabilities are created, they are the product of social development or faulty development, and they reflect deficits, shortages or disruptions within socio-economic development.

The emerging crisis can be minimized by indigenous knowledge based and modern technological interventions. To safeguard against accelerated degradation and improve the living standard of hill people, there is need to address hill specific issues through systematic and effective integration of the ecosystem service and development, highland and lowland linkages etc. The ever-present threat from devastating landslides, earthquake, flood etc. remains a reality putting the opportunities of the progeny in jeopardy without a replicable and hill specific development policy. In order to assess disaster risk, it is important to comprehend the issues and concerns of the community/ regions in the Uttarakhand state (Table 3-10).

Table 1.17: Issues and Concerns for Community Regions in Uttarakhand

Issue	Concern
Environmental: Revival of traditional customs, sacred forest, dedicated memorial forests and agro-eco based land use.	General absence of environment friendly development and conservation efforts. Over exploitation of vegetation. Lack of soil conservation and water harvesting with protected drainage systems and safe disposal of water.

Issue	Concern
	Environment sensitive resource conservation and utilization; diversified integrated farming systems with dominance of livestock, fruits and perennial vegetation.
Terrain and habitat security	This is largely triggered by anthropogenic, climatic, geological and disregard to traditional norms and practices.
Livelihood and farming related: Thrust to fuel, fodder, water and food security	Lack of food, fuel, fodder and livelihood security leading to over exploitation resulting to resource degradation and environmental deterioration.
Institutional, academic, research and technology development	Responsive mechanism for curriculum modification, need based research and technology development on emerging issues in a problem solving approach. Mountain specificities entail no borrowed knowledge and technologies.
Socio economic aspects: Community skill and capacity	Skill and capabilities of community and development agencies sensitive enough to mountain specificities. It is essential to provide year round livelihood security to mountain rural people.
Dedicated hill cadre of farmers, technical and development personnel: Dedicated farmers centric institutions: Integrating indigenous knowledge and experience into action plan and practice.	Strong component of non-arable land; both individual and community owned. Conservation and habitat protection in mountains. While working for disaster management lets appreciate the fact that there is gross deficiency of relevant and dependable data base and processed information

The growing anthropogenic disturbances and disregard to ecological considerations have aggravated the magnitude of disaster which led to heavy loss of resources, infrastructure and lives. Stress has increased manifold for the Himalayan ecosystem while meeting the increasing needs of the community and conserving and aggrading the natural resources.

The mountain ecosystems demand high priority be given to natural resources management and community-based initiatives. Restoring ecological balance, undertaking appropriate scientific measures for treating the affected and potential hazardous areas should form basic strategy, while ensuring livelihood by promoting sustainable agriculture and allied activities, and alternate employment opportunities to retain population in mountains should also be taken up.

The following figure illustrates the state-wide social vulnerability assessed during the risk assessment.

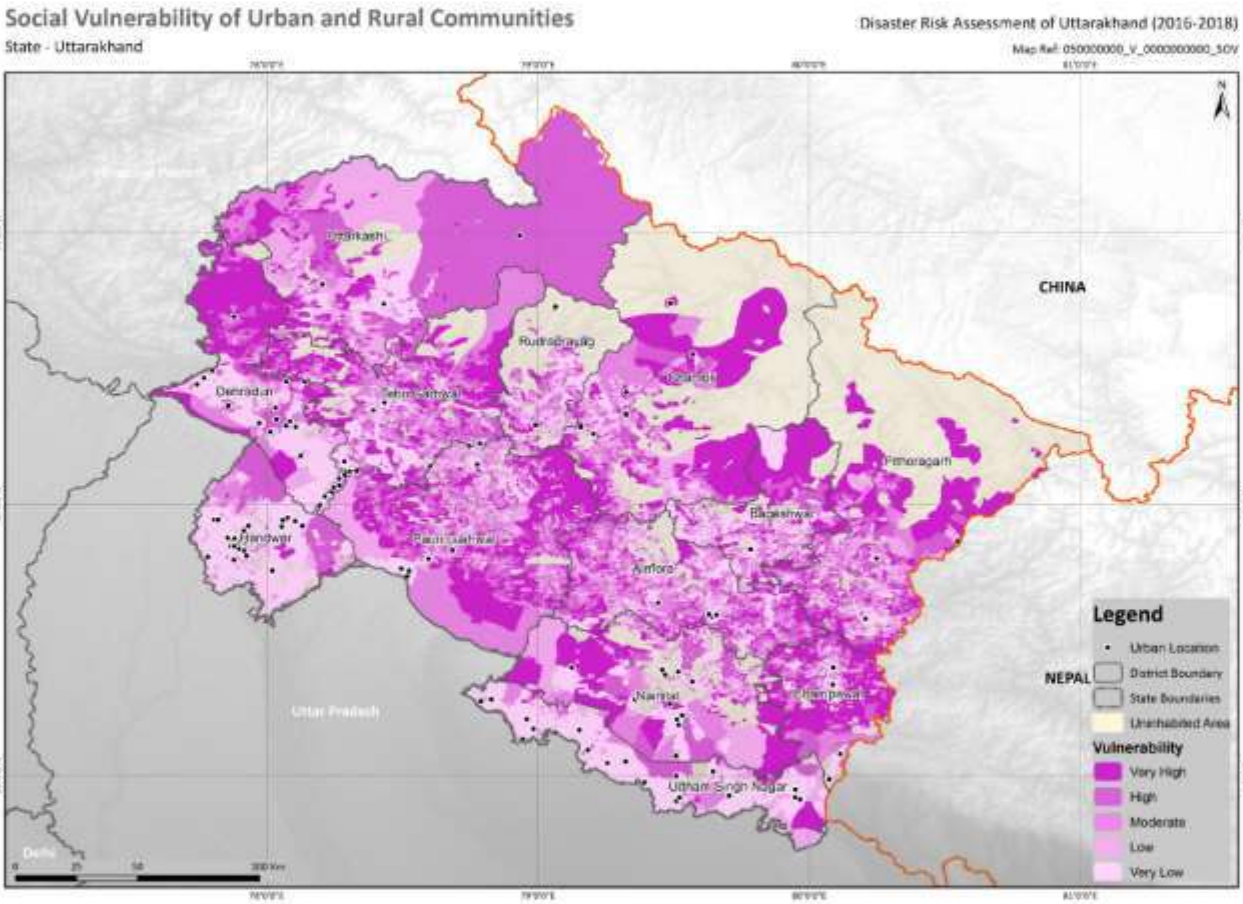


Figure 1.17: Social Vulnerability Index of Uttarakhand indicating the relative vulnerability of settlements across the state (Source: DRA JV)

1.5.5 Poverty and Unemployment

Poverty and lack of employment opportunities are other important concerns of the mountain communities. It reduces the socioeconomic resilience of communities against disasters and emergency situations. As per the report of DMMC (2015) the economic development of Uttarakhand has been concentrated mainly in four southern districts compare to rest nine districts. This disparity coupled with poverty and unemployment has been manifested in the large scale out migration from the villages.

1.6 COMMUNITY KNOWLEDGE

The community knowledge is accumulated over generations of living in a particular environment. It is a broad concept that covers all forms of knowledge, technologies, know-how, skills, practices and beliefs that enable the community to achieve stable livelihoods in their environment. It is a traditional cultural knowledge that includes intellectual, technological, ecological and socio-environmental knowledge. The disaster risk assessment will be most effective if that take into consideration local community knowledge, respect local cultures and socio-economic settings. That knowledge system has enabled the communities to live in harmony with their environments for generation and played important role in environmental conservation and disaster management.

Traditional Knowledge and Practices	
Koti Banal Architecture- the timber-reinforced Stone Masonry, aged old housing structure in the Rajgarhi area of Uttarkashi district, Koti Banal is the name of a village in the Yamuna Valley which represents the traditional knowledge and understanding of earthquake effects on buildings and their earthquake resistant design.	
Terrace cultivation - method of growing crops on sides of hills or mountains by planting on graduated terraces built into the slope. Though labour-intensive, the method has been employed effectively to maximize arable land area in variable terrains and to reduce soil erosion and water loss.	
Chal-Khal System- Large depressions in mountainous areas used for rainwater harvesting, of villagers dug small percolation pits on every bit of available land on the slopes that surrounded a drain line. The system prevented water and soil erosion and also increased percolation. This infiltrated the soil and recharged the groundwater, and ultimately the river.	

Banj- Oak Forests are one of the immensely important species for both rural livelihoods and for biodiversity, soil and water conservation, and now these are declining due to spreading extent of Pine Forests and climate change.	
Dhara & Naula – The ancient methods of water conservation efforts led to the construction of ookhars, dhara, mangras, nualas, and ghats/ gharats. These stand as examples of fine stone masonry work and stone architecture, owning to their sheer storage capacity, these helped people survive through periods of draughts.	
Gul- Kul- cultivation is done largely on terraced fields and since ancient times, the problem of irrigating the fields was resolved by diverting water from nearby streams or rivers through channels called guls-kuls. They are the best example of water resource management in the hills and are usually dug along the contours of the slope. Apart from irrigation, guls were used for drinking water and for running gharats or water mills	

Figure 1.18: Discussions with local village leaders near Rudraprayag, to learn from their understanding of geomorphological processes in their area and their perceptions of associated risks, (during the field survey undertaken in July 2016)

Traditional housing in Uttarakhand (e.g. Koti Banal) have proved to be resistant to earthquake in the recent centuries (see DMMC Dehradun, 2011). However most of the recent housing construction techniques did not consider ground shaking and other potential earthquake damaging effects. The Uttarakhand State started to reconsider earthquake resistance in housing construction in the aftermath of the Uttarkashi earthquake of October 20, 1991 in Aungi village. The earthquake and its consequences had made the villagers explore alternate sites on which they could be relocated. Several criteria were adopted to assess the suitability of each site for relocation after detailed discussions with members of various interest groups.

Most of the assessment was done by villagers themselves, especially the micro-climate and pest-proneness. Their long experience of site quality was combined with a detailed technical assessment and later presented to them for review, and they then selected the best option. The complete village was rehabilitated at a new site with proactive participation of villagers, promoting the local building materials with appropriate technology adoption for constructing earthquake resistance houses.

The local masons were trained for sustainable measures in order to mitigate the earthquake disaster in the hill areas. Such type of post disaster efforts could be further explored for its efficacies and up-scaling in the state."

CHAPTER 2
Summary of Risk and Exposure

2 SUMMARY OF STATE RISK AND EXPOSURE

The full suite of results is reported to block level in Volume 3, the State Atlas of Risk. However, this section provides a succinct summary of the outcome of the assessments of loss and exposure related to the different hazard classes. Results are also available online in the Disaster Risk Database administered by USDMA.

Probabilistic loss estimates have been determined for earthquakes and fluvial floods in the major river basins. Flash floods, landslides, and industrial hazards are assessed deterministically and described in terms of exposure of people and infrastructure to the various gradations of hazard susceptibility or severity. We do not replicate the Atlas in full in this section. Rather, we summarise some of the results and give an overview of risk and exposure at state level.

2.1 ATLAS OF RISK & ONLINE RISK DASHBOARD

The reader is referred to Volume 3 of the report, which comprises a detailed Atlas of exposure, vulnerability, and risk across the entire state of Uttarakhand. All results are reported to block level. Data on the risk is also available on the online Risk Database accessible via the USDMA website.

Risk results are also summarised online at http://www.udrdb.net/UDRDB/ (note: this URL will change once the system is transferred in full to USDMA)

The online dashboard of risk is available at http://www.udrdb.net/UDRDB/Dashboard and gives a summary of Average Annual Loss (AAL), Probable Maximum Loss (PML) and exposure for the state and individual district and blocks for each portfolio. This is an interactive and navigable dashboard. Graphs and tables are easily downloaded for reporting purposes.

2.2 MULTI-HAZARD RISK PROFILE (EARTHQUAKES AND FLUVIAL FLOODS)

The risk arising from earthquakes and fluvial floods has been quantified for the first time using probabilistic methods. The expected losses and Average Annual Loss arising from these events can be combined to present a "multi-hazard" measure of risk for these two classes of hazards.

The exposure from Flash Floods, Landslides, and Industrial Hazards is presented in Sections 2.4.6, 2.5, and 2.6, respectively.

The Combined AAL for Earthquakes and Floods is given below in Figure 2.1.

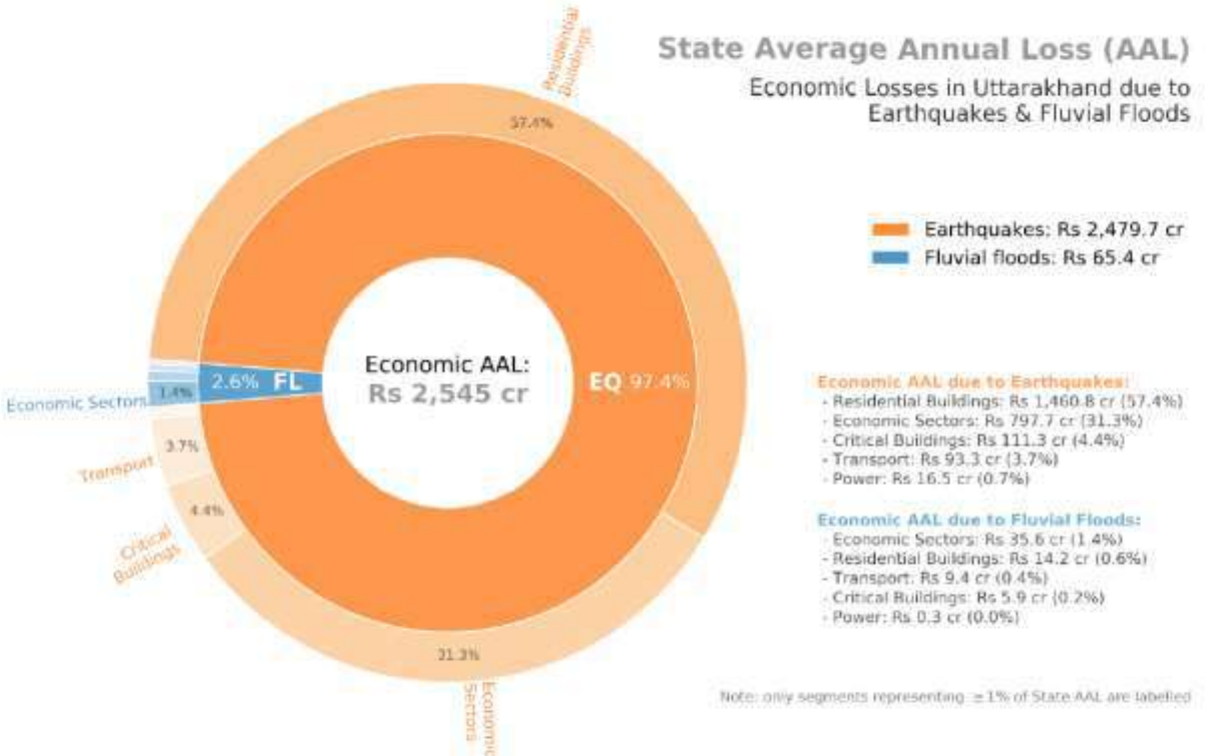


Figure 2.1: Combined AAL (Financial Losses) for Earthquakes and Fluvial Floods at State Level and Across All Portfolios

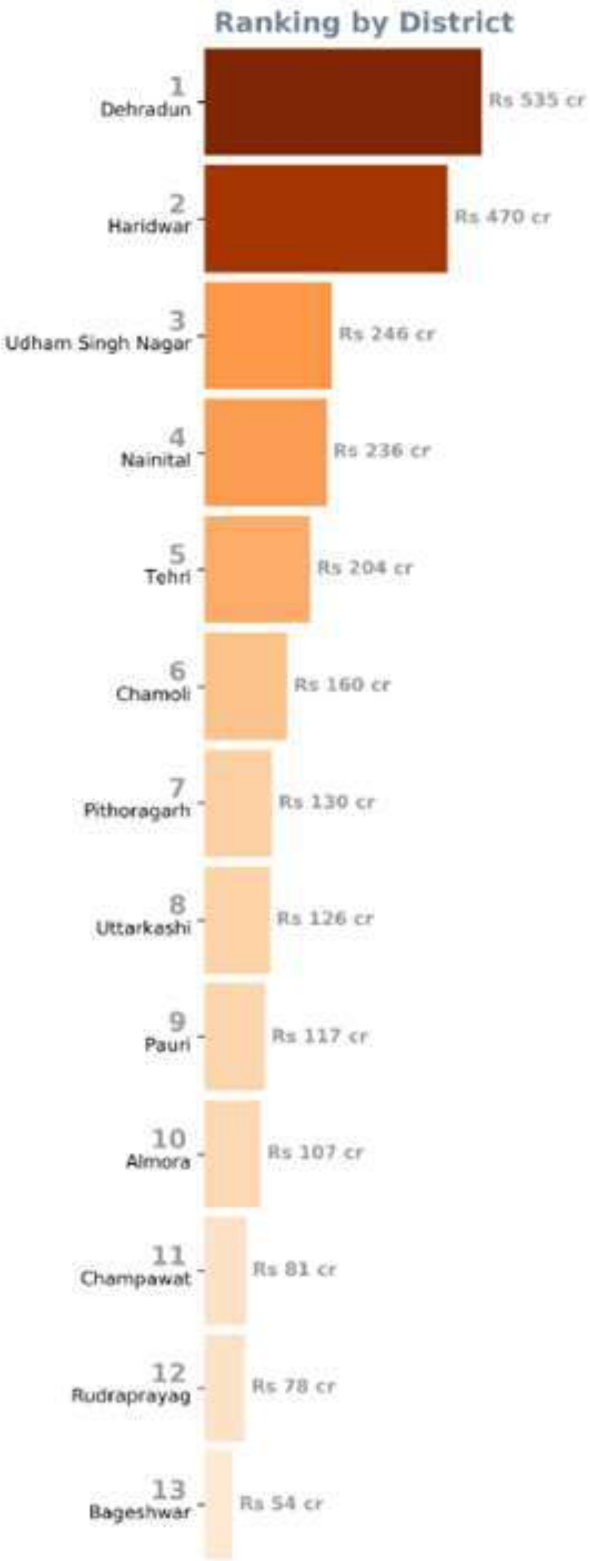


Figure 2.2: Ranking of Districts on Combined AAL (Financial Losses) for Earthquakes and Fluvial Floods Summed Across All Portfolios

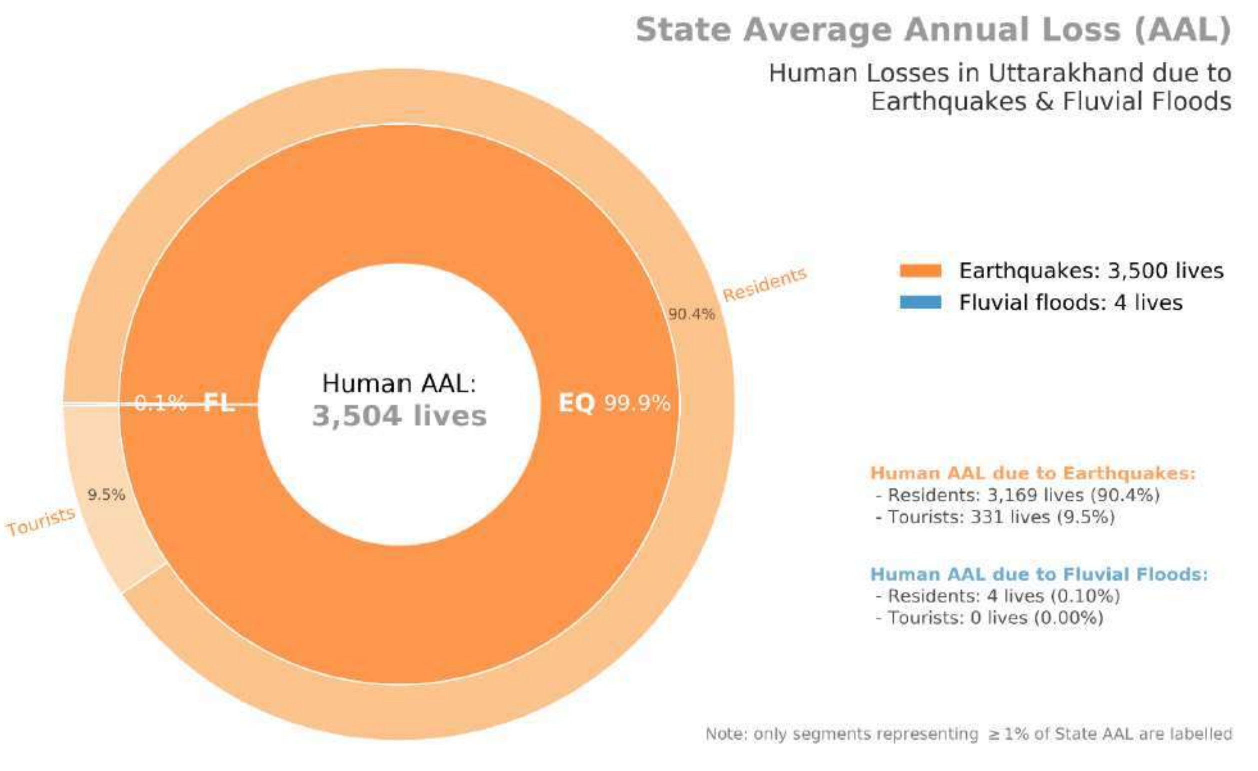


Figure 2.3: Combined AAL (Human Losses) for Earthquakes and Fluvial Floods at State Level and Across All Portfolios

Of the two hazards assessed probabilistically, the greatest losses that could occur for the state are a result of earthquakes. Earthquake risk dominates. Fluvial floods represent only a small proportion of the average annual loss for both infrastructure portfolios and people. This is to be expected, given the widespread devastation that earthquakes cause, and the fact that the flooding at low return periods is limited to areas where the exposure is reduced. Therefore, strategies and investments for risk reduction are best focused on earthquake mitigation, although the districts of Haridwar and Udham Singh Nagar must strengthen flood mitigation, as these represent the locations of highest expected losses.

Note that costs and losses incurred on an annual basis from landslides are, of course, understood to be very high. It is a chronic and expensive issue for the GovUk. It is estimated that at least 180 Crore rupees is required per annum to repair landslide damage (Source: DMMC staff member, pers comm), and the amount varies enormously. Although landslide exposure is calculated in this study, it is not a quantifiable probabilistic risk. This is because the hazard is not determined probabilistically and the vulnerability functions for structures are not fully defined.

2.3 EARTHQUAKE RISK

2.3.1 Summary of Earthquake Hazard Profile

According to the Probabilistic Seismic Hazard Assessment (PSHA) developed for Uttarakhand state, for a return period of 250 years are expected Peak Ground Accelerations (PGA) between 120 to 400 cm/s^2 across the state; this could be related with a Modified Mercalli Intensity Scale (MMI) between VII to IX.

On average the possible expected damage could be negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures and some chimneys broken (MMI-VII[3]).

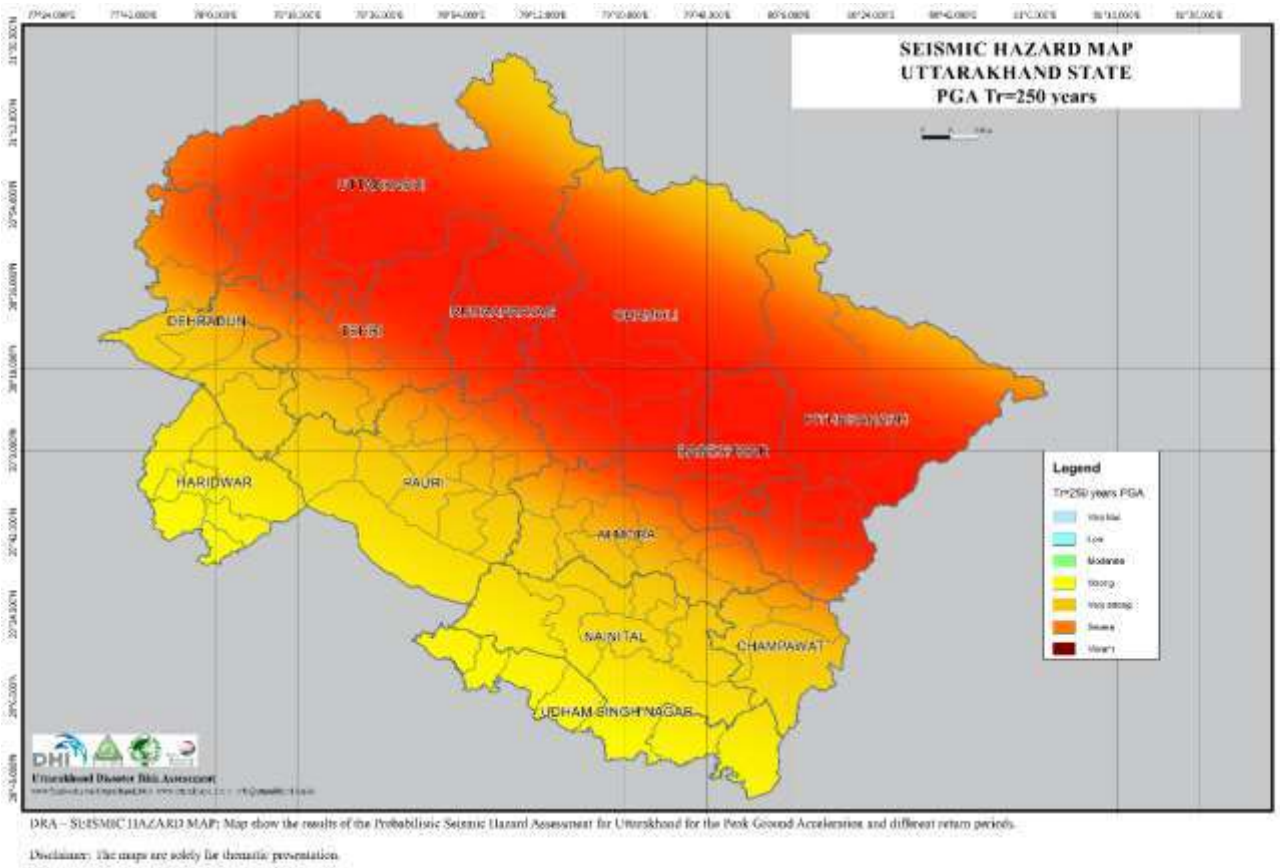


Figure 2.4: Hazard map for a return period of 250 years, PGA values classified in a qualitative scale

[3] https://earthquake.usgs.gov/learn/topics/mag_vs_int.php

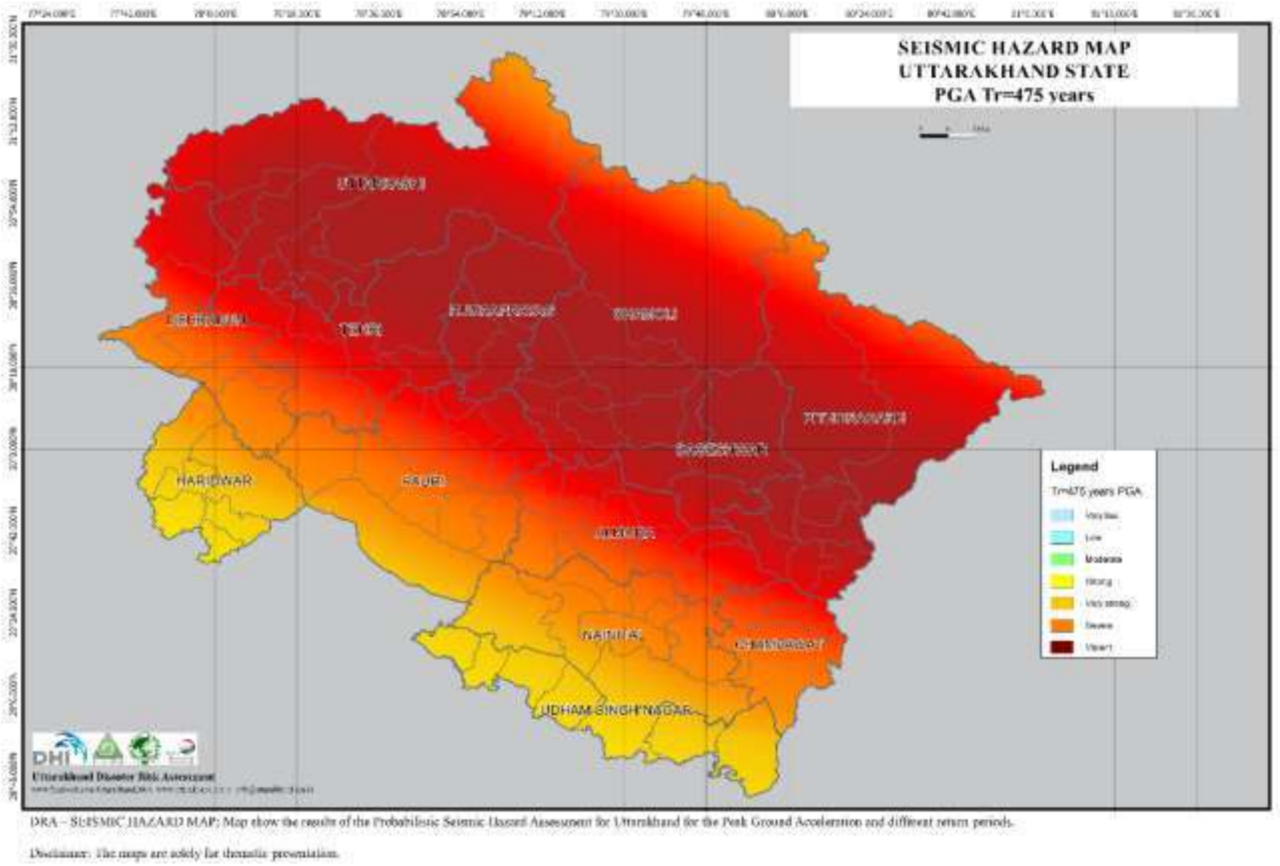


Figure 2.5: Hazard map for a return period of 475 years, PGA values classified in a qualitative scale

For a return period of 475 years are expected PGA values between 200 to 500 cm/s^2, those could be related with MMI between VIII to IX. In average the possible impacts could be slight damage in specially designed structures, considerable damage in ordinary substantial buildings with partial collapse, great damage in poorly built structures, fall of chimneys, factory stacks, columns, monuments, walls and heavy furniture overturned (MMI-VIII[4]).

[4] https://earthquake.usgs.gov/learn/topics/mag_vs_int.php

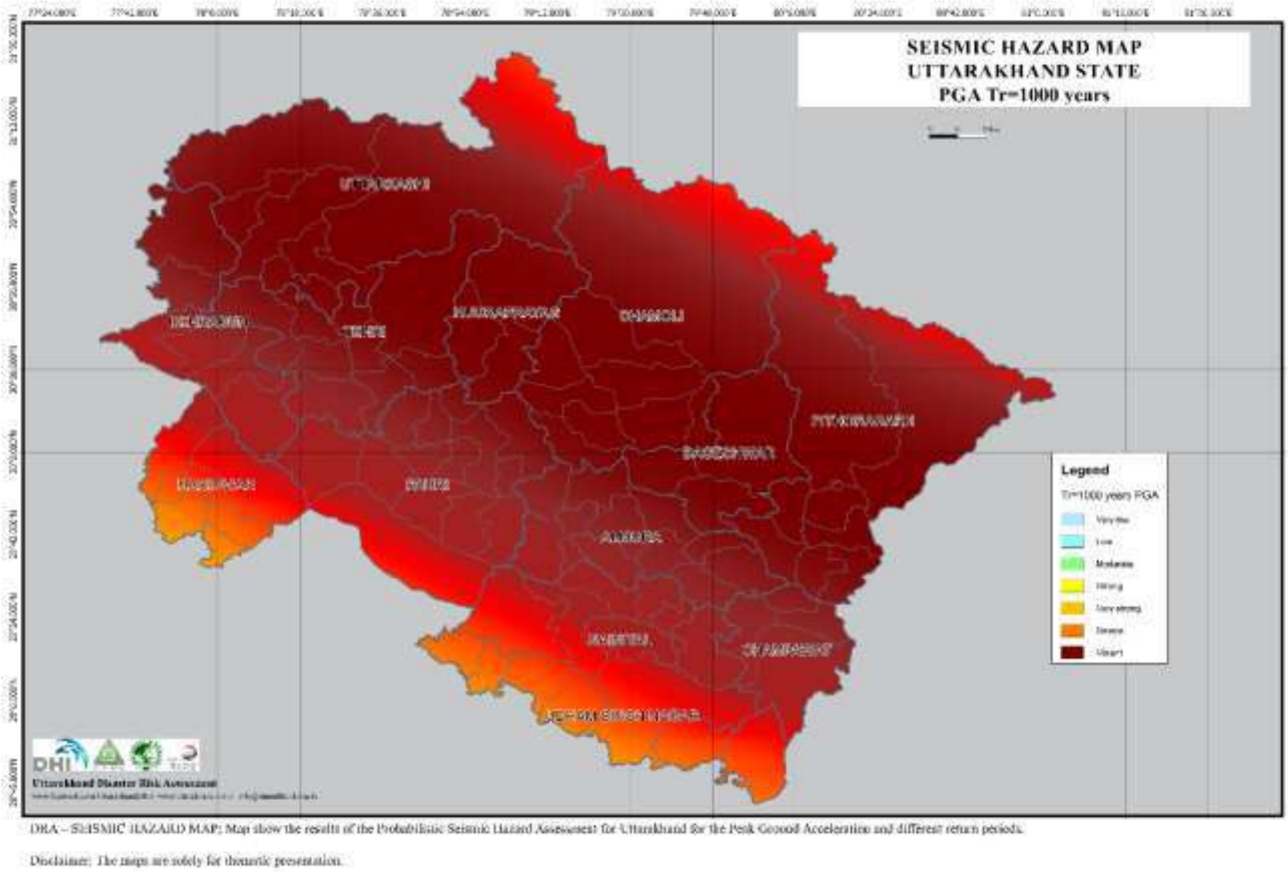


Figure 2.6: Hazard map for a return period of 1000 years, PGA values classified in a qualitative scale

For a return period of 1000 years according to the PSHA developed for Uttarakhand, PGA values between 450 to 700 cm/s^2 are expected across the state. Those could be related with MMI between IX to X. On average, the possible impacts could be considerable damage in specially designed structures, well-designed frame structures thrown out of plumb. Great damage in substantial buildings, with partial collapse, possible buildings shifted off foundations (MMI-IX[5]). In some areas with higher PGA intensity, well-built wooden structures could be destroyed; most masonry and frame structures could be destroyed with foundations, and rails may be possibly bent (MMI-IX).

2.3.2 Summary of Earthquake Risk

The exposure and Average Annual Loss across all future scenarios has been determined at State, District, and Block level.

The reader is referred again to the State Atlas of Risk, which contains further details and maps. However, here we present some summary statistics on exposure and the expected losses incurred due to simulated earthquake events.

[5] https://earthquake.usgs.gov/learn/topics/mag_vs_int.php

The exposure of portfolios of infrastructure and population to earthquakes of a given intensity is summarised in the figure below. Of the various portfolios, hydropower stations and health centres have the highest proportion exposed to very strong earthquakes. The least exposed, are the industrial estates, where almost 100% of the portfolio is exposed to only moderate or strong seismic events.

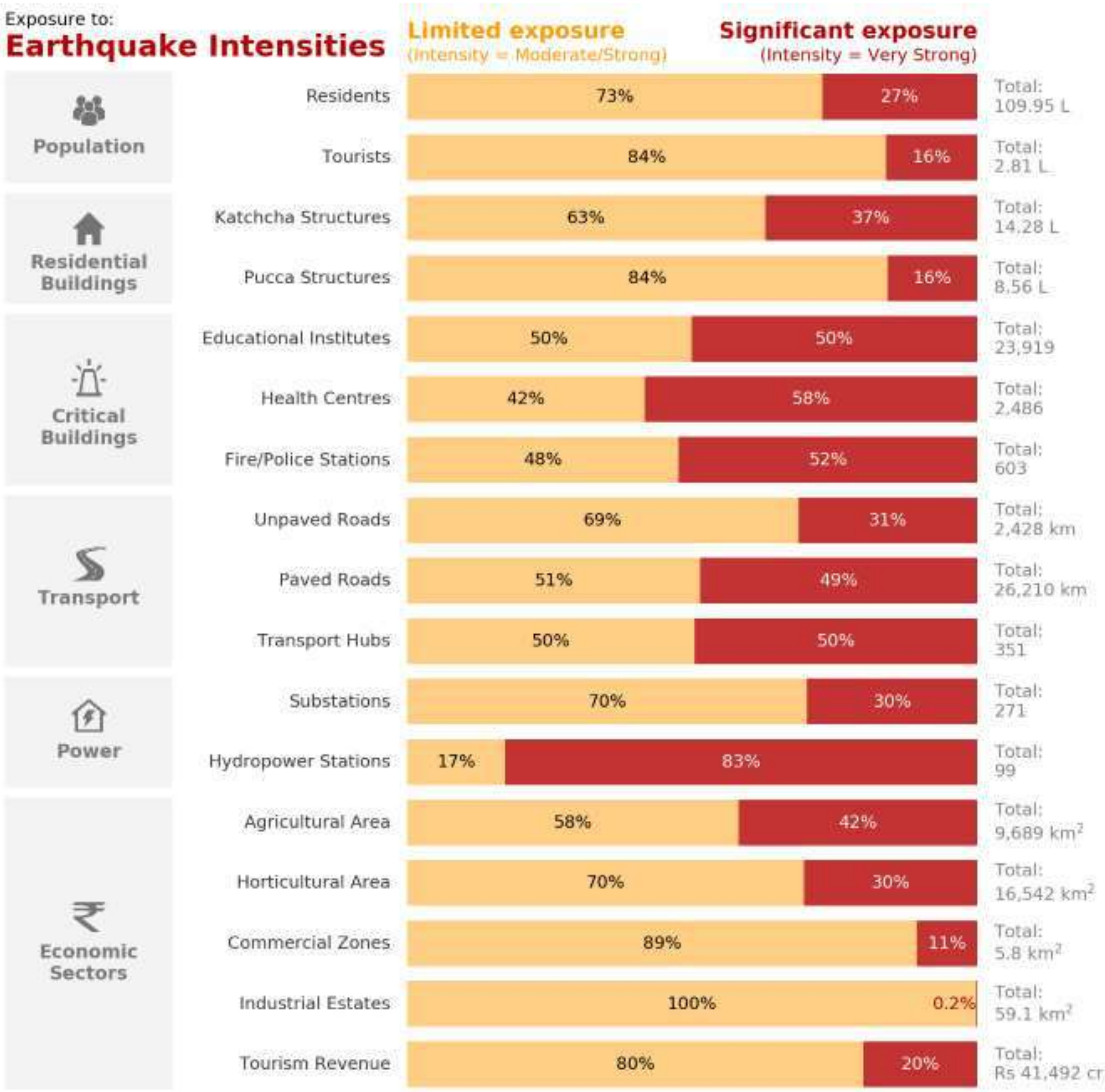


Figure 2.7: Exposure of Portfolios to Earthquake Intensity

The quantified economic and human risk arising from earthquakes is presented overleaf. Dehradun and Haridwar are the greatest contributors to the total across the state, with residential buildings and the economic sector of tourism being the highest contributing portfolios to the overall risk result.

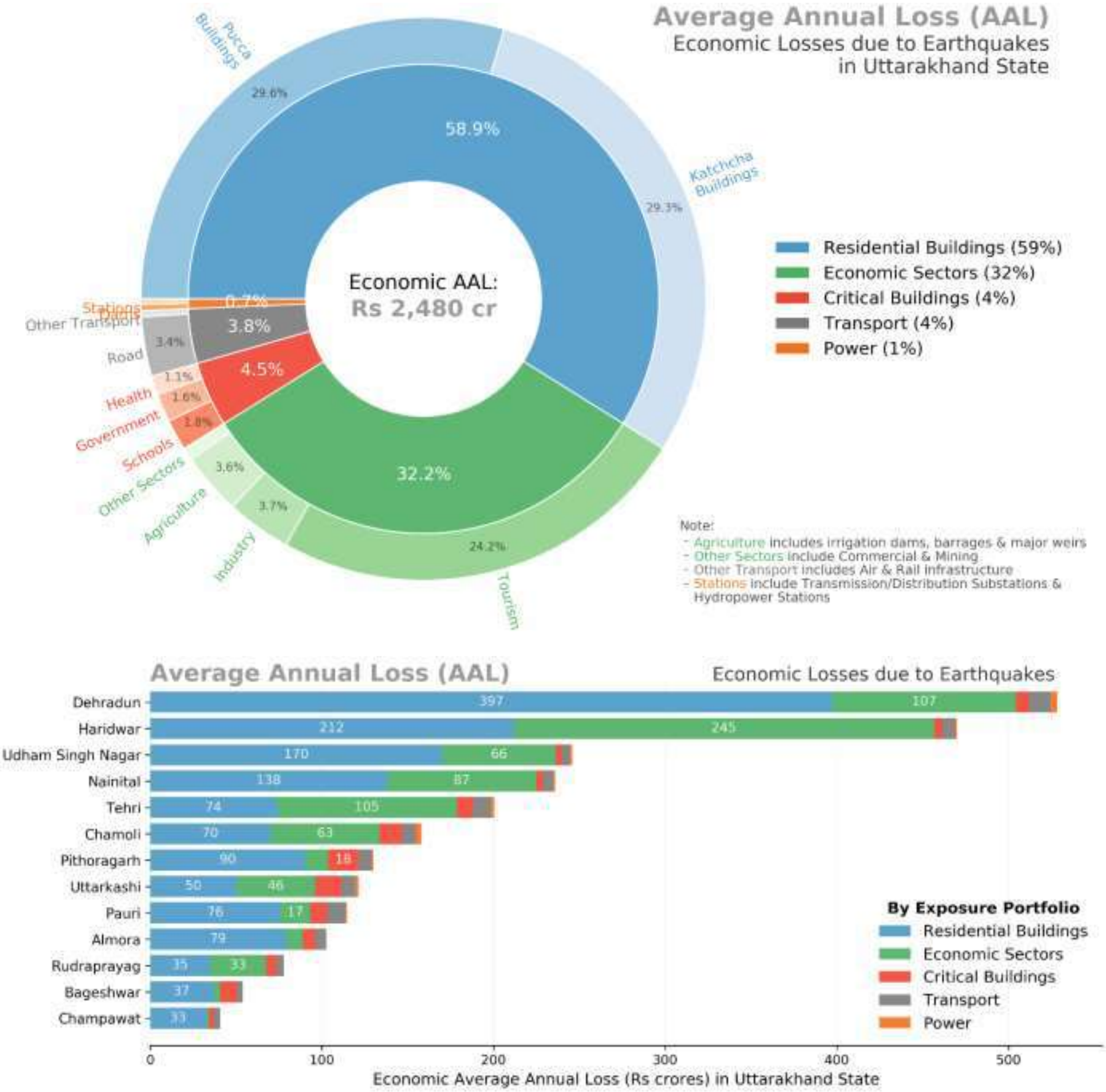
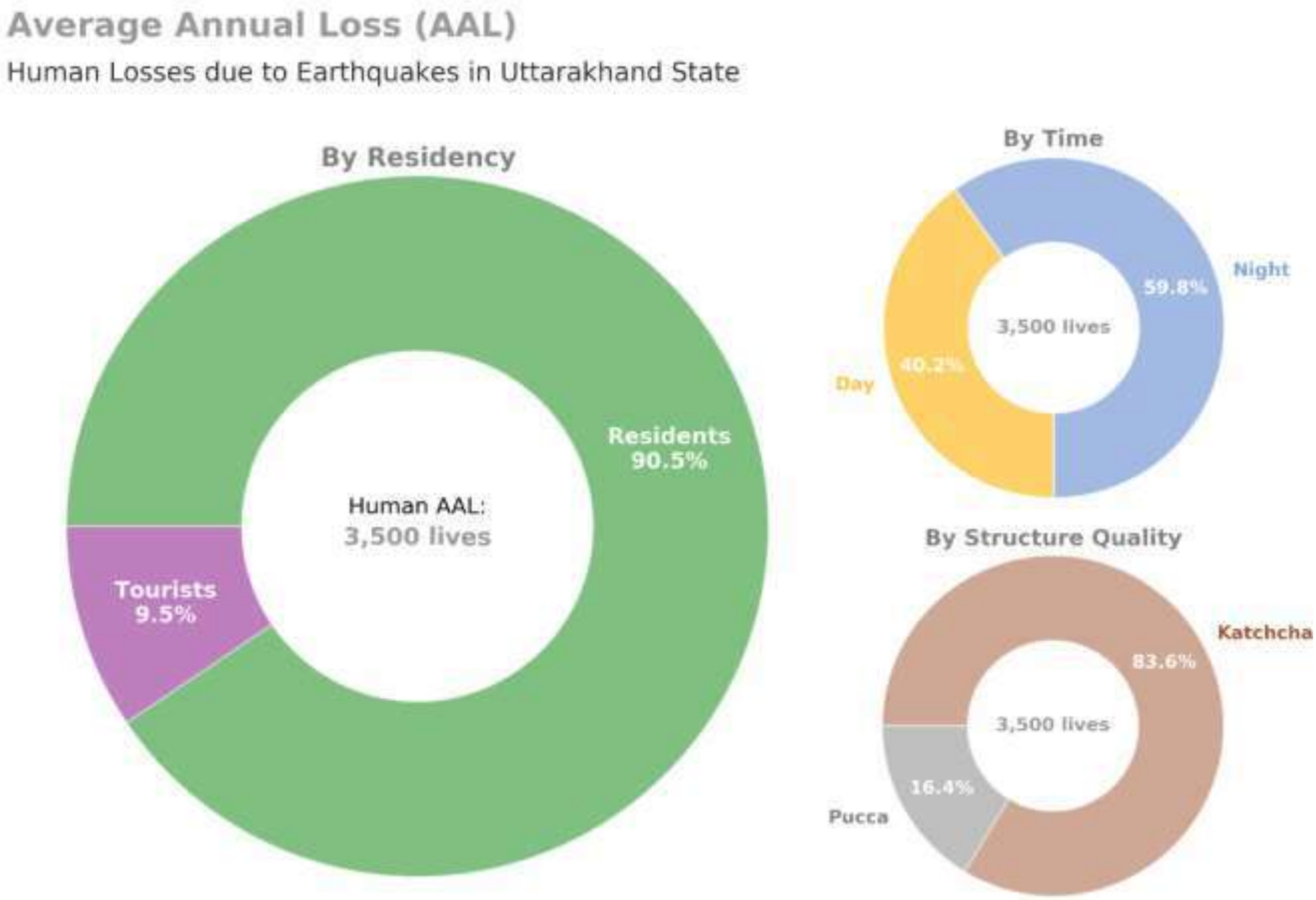


Figure 2.8: AAL (Financial Losses) for Earthquakes at State and District Levels and Across All Portfolios



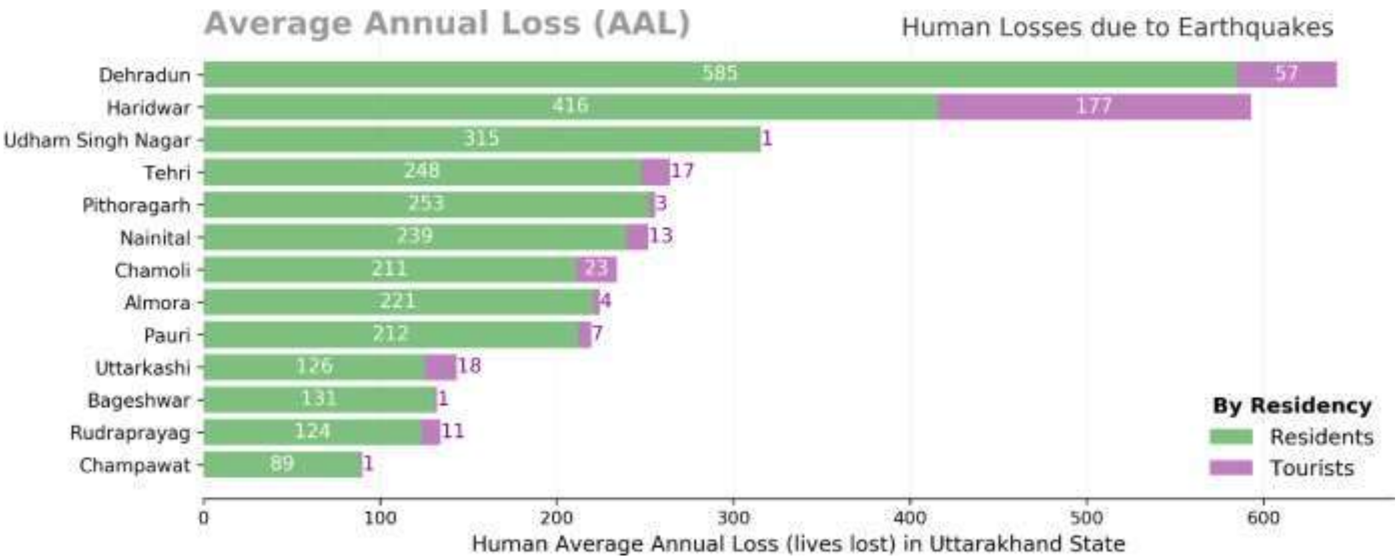


Figure 2.9: AAL (Human Losses) for Earthquakes at State and District Levels and Across All Portfolios

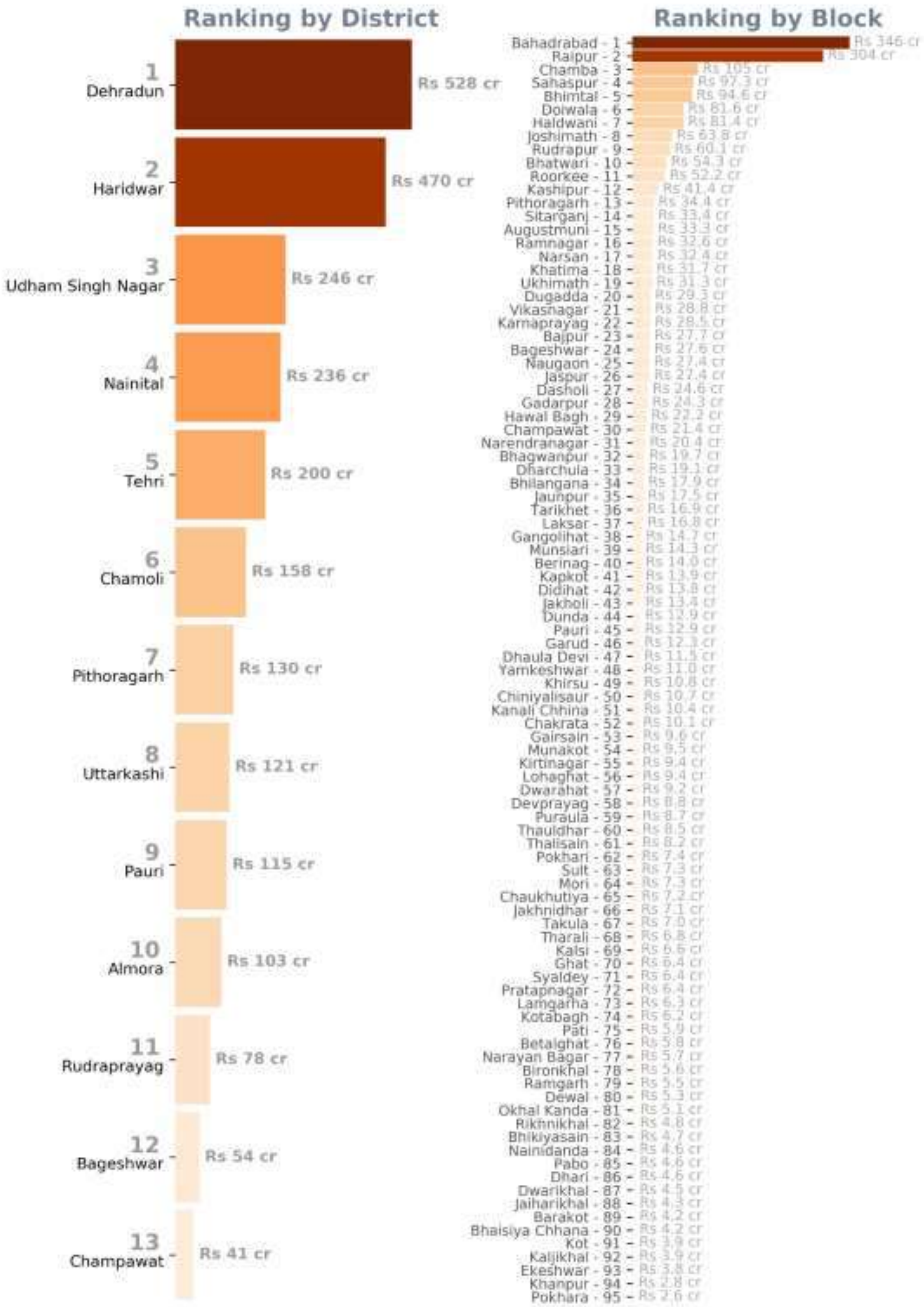


Figure 2.10: Ranking of Districts and Blocks by AAL (Financial Losses) for Earthquakes Across All Portfolios

Given the dominance of Dehradun and Haridwar Districts to the overall risk for the state, we highlight the statistics for these districts to in the following diagrams. For information about other districts, consult the district level atlases and also the online risk dashboard.

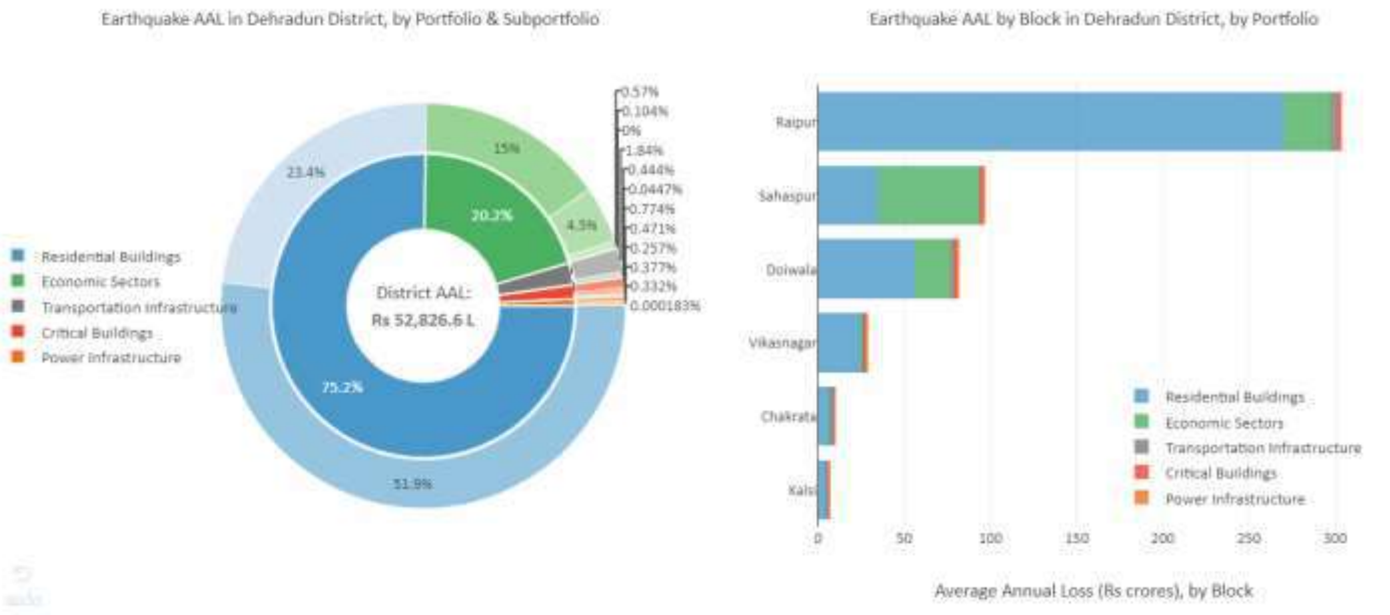


Figure 2.11: AAL (Financial Losses) for Dehradun District and Blocks for Earthquakes Across All Portfolios

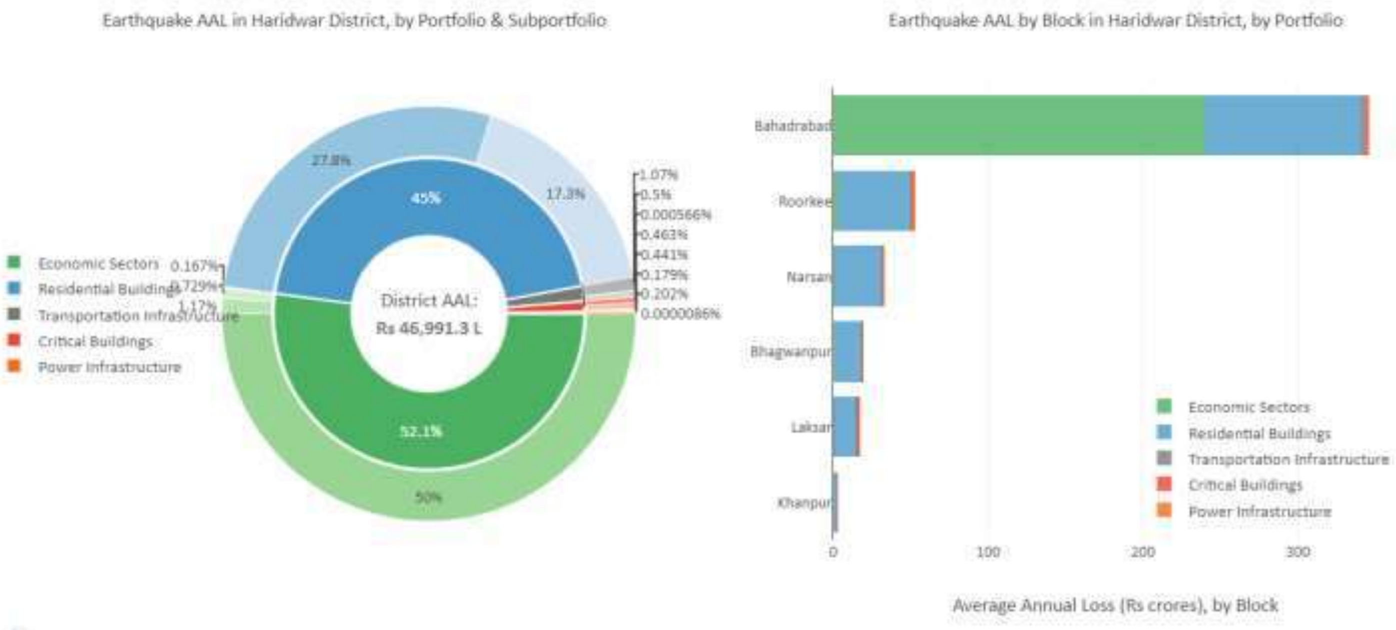
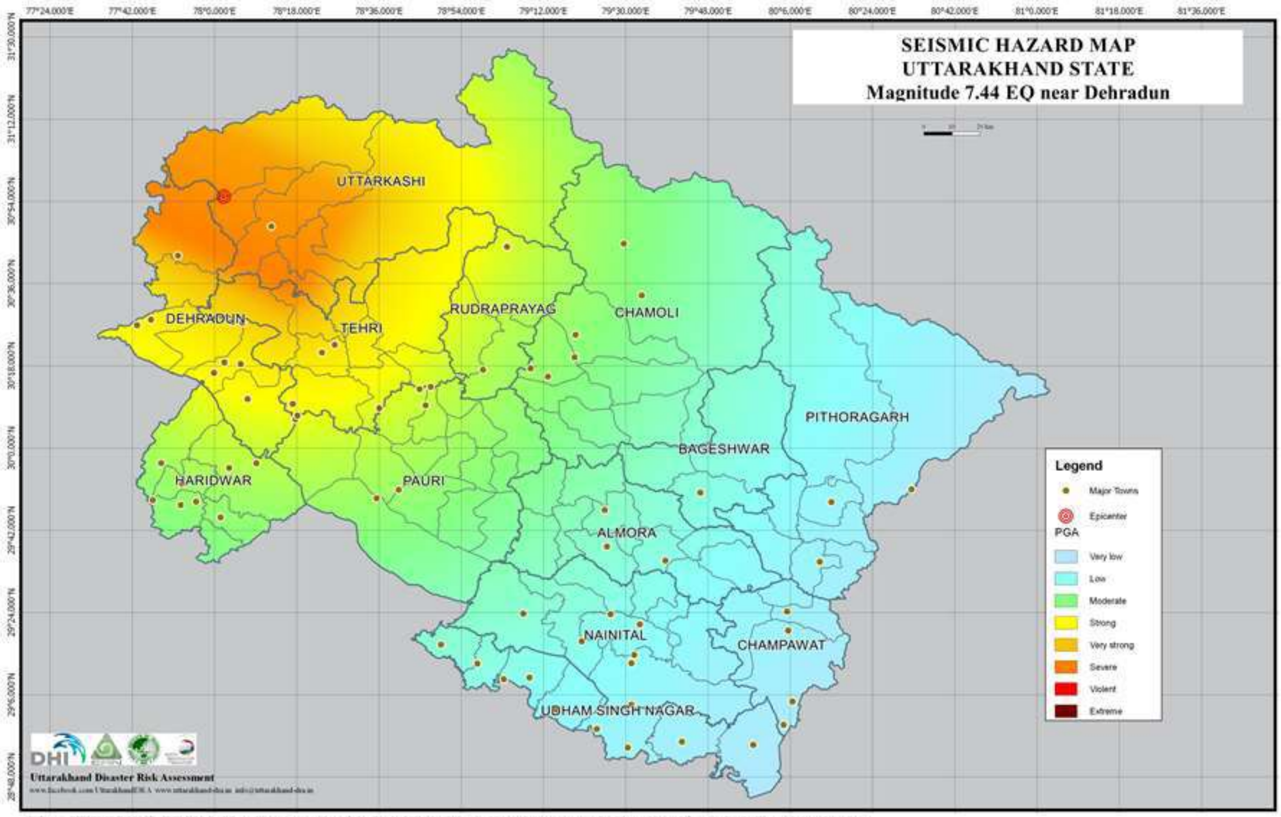


Figure 2.12: AAL (Financial Losses) for Haridwar District and Blocks for Earthquakes Across All Portfolios

2.3.3 Deterministic Scenarios to Demonstrate Model Resolution

The Probabilistic Seismic Hazard Assessment (PSHA) for Uttarakhand state was developed using a probabilistic model that considers the earthquake occurrence probabilities, attenuation characteristics and geographical distribution of earthquakes. The model computed approximately 80,000 probable earthquake events using historical information available in earthquake catalogs, for example, the following figure shows one of the probable earthquakes, a M7.4 near Dehradun. This figure shows the Peak Ground Acceleration (PGA) footprint from the epicenter (red dot) through all the state territory.

According with the PGA estimation for this EQ, in Dehradun the ground shaking will be felt Very Strong (137 cm/s^2), Severe (260 cm/s^2) in Uttarkashi, in Haridwar the PGA will be Strong (83 cm/s^2), Very Strong (108 cm/s^2) in Rishikesh, Strong (64 cm/s^2) in Chamoli, in Bageshwar, Almora and Nainital the ground shaking will be felt Moderate (36 cm/s^2) and Low to Moderate in Pithoragarh (27 cm/s^2). The difference in how the ground shaking could be felt in the different places is a function of the distance from the epicenter to the different locations; the closer a place is located to the epicenter, the PGA (and how it feels) is stronger.



DRA – SEISMIC HAZARD MAP; Map show the results of the Probabilistic Seismic Hazard Assessment for Uttarakhand for the Peak Ground Acceleration.

Disclaimer: The maps are solely for thematic presentation.

Figure 2.13: PGA footprint for a probabilistic EQ of M7.4 near Dehradun

If the location of the EQ epicenter is different, the PGA intensity in each location analyzed will also be different. For example, the following figure shows another probabilistic M7.4 earthquake, but with epicenter located at the opposite side of the state, in Pithoragarh District. According with the PGA estimation for this EQ, in Dharchula the probable intensity will be Severe (253 cm/s^2), Very Strong in Pithoragarh and Bageshwar (150 cm/s^2), in Almora and Chamoli the probable ground shaking will be Strong to Very Strong (110 cm/s^2), Strong (70 cm/s^2) in Nainital, Moderate (45 cm/s^2) in Rishikesh, Haridwar and Uttarkashi. Given the long distance from the epicenter to Dehradun, the estimated probable PGA will be Low to Moderate (36 cm/s2) in the state´s capital city.

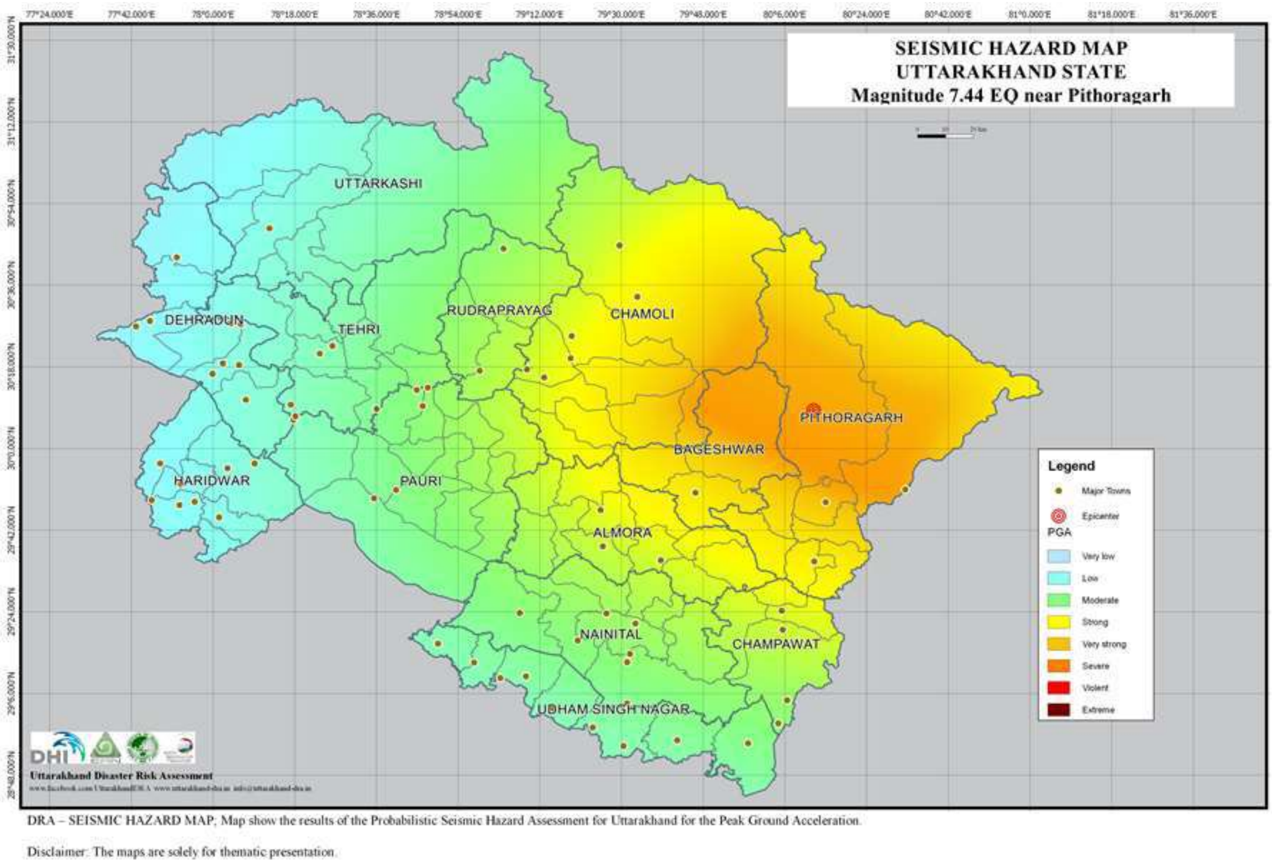


Figure 2.14: PGA footprint for a probabilistic EQ of M7.4 near Pithoragarh

Note: For the final report, we will include the risk estimates associated with these two scenarios.

2.4 FLUVIAL FLOOD RISK & FLASH FLOOD EXPOSURE

2.4.1 Overview of State River & Drainage System

Figure 2-15 illustrates the river basins of Uttarakhand.

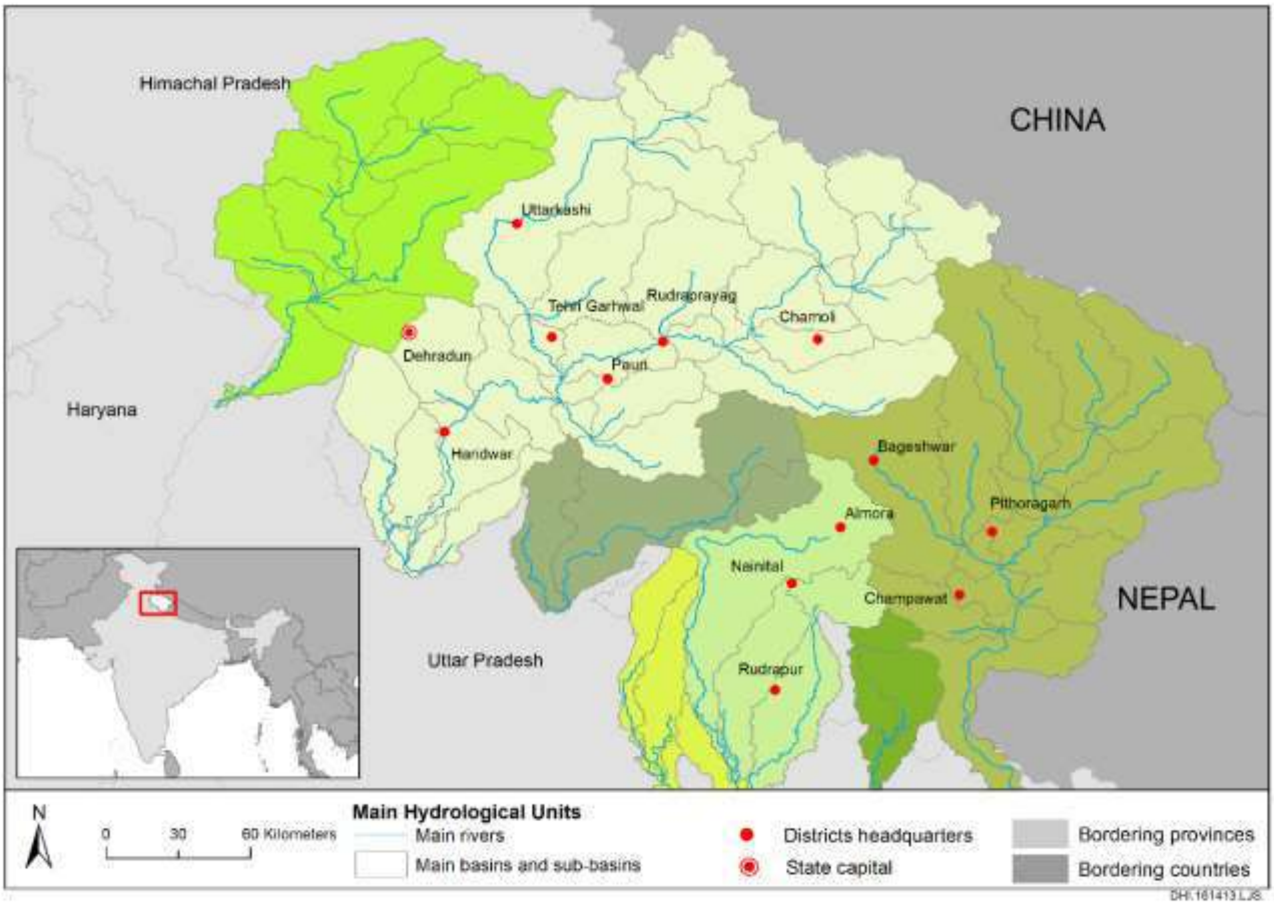


Figure 2-15: Main River Basins of Uttarakhand

The two major river basins of the state are the Ganga Basin and the Yamuna Basin. Within the Ganga basin in Uttarakhand, the area is subdivided into Alaknanda and Bhagirathi basins ending at Devprayag. The Alaknanda basin includes the major Rivers Alaknanda and Mandakini.

The Mandakini River joins Alaknanda at Rudraprayag and flows downward as River Alaknanda. This basin primarily lies in Chamoli, Rudraprayag, Tehri Garhwal and Pauri Garhwal districts. Small areas of Pithoragarh and Bageshwar district also fall in the Alaknanda basin.

Uttarkashi, Tehri Garhwal and Pauri Garhwal districts constitute the Bhagirathi basin. On the eastern part lies the Sarda basin. The rivers Dhauliganga and the Kali (which is the continuation of Dhauliganga) ending at Pancheswor are considered for this study.

The Alaknanda and Bhagirathi Rivers meet at Devprayag and move forward from this confluence with a new name "Ganga". The Dhauliganga and Kali rivers also lie in the Ganga basin, but they feed the River Ganga. The Dhauliganga river is fed by two head waters, namely Dharamganga and Lasser with a glacier close to the Darma Pass as their source.

The Dhauliganga joins Kali and serves as its important tributary. Kali flows through the India Nepal border which after reaching the plains is called Sharda. The river flows southeast across the plain to join Ghagra River, a tributary of Ganga.

2.4.2 Climatology of Uttarakhand Region

Uttarakhand lies on the southern slope of the Himalaya range and presents a climate that vary greatly with elevation, from glaciers at the highest elevations to subtropical forests at the lower elevations.

In general, Uttarakhand presents two different climatic regions in mainly the hills and the relatively smaller plains region. The climate in the northern part of Uttarakhand is typically Himalayan having cold winters with snowfall for quite a long time, good rainfall in the monsoon, and mild summers. This mountain range itself exerts an appreciable extent of influence on monsoon and rainfall patterns. Within the Himalayas, climate differs depending on altitude and position. The southern slope of the Himalayas receives high rainfall with longer sunshine duration and thus the area normally remains dry due to high rate of evapotranspiration. On the contrary, the northern slope though receives lesser rainfall remains moist due to short sunshine duration.

The type of climate that is mainly to be found in the south of Uttarakhand or the plains presents hot humid summers. The winters can be chilly with temperatures going below 5°C at times.

The State is bestowed with a relatively high average annual rainfall of around 1200mm. The rain normally starts in late April and continues up to September. However, the intensity of rainfall increases during the months of June to September.

Three main seasons affect the region in terms of temperature and rainfall amounts:

2.4.2.1 Summers

Summers in the plain region of Uttarakhand have similar climate as other surrounding plain regions of different states i.e., the maximum temperature can cross the 40°C mark and with a lot of humidity. Warm temperate conditions prevail in the Middle Himalayan valleys with temperature around 25°C. However, in the higher areas of middle Himalayas the temperature decreases at around 15 to 18°C. The season extends from April to June.

2.4.2.2 Winters

The Climate of Uttarakhand during winters in the plain region can be chilly with temperatures going below 5°C mark. The winters in the middle Himalayan valleys are very cold and in the higher areas the temperature can drop below the freezing point. The Himalayan peaks remain snow-capped throughout the year and many places receive regular snowfall. Throughout the state the temperature ranges from sub-zero to 15°C and the season lasts from November to February.

2.4.2.3 Monsoon

The monsoon is the most temperate season with temperatures between 15 to 25°C at most places which reigns from July to September. The state receives 90% of its annual rainfall in this season. The eastern parts of Himalayas are subjected to heavier rainfalls when westerns are relatively drier. Table1.2 below shows the climatic zones of Uttarakhand.

Table 2.1: Climatic Zones in Uttarakhand (Source: AHEC, IITR 2011)

<table>
<tr><th rowspan="2">Climatic Zone</th><th rowspan="2">Altitude (m)</th><th colspan="3">Average Temperature Range (^{0}c)</th></tr>
<tr><th>Annual</th><th>June</th><th>January</th></tr>
<tr><td>Tropical</td><td>300-900</td><td>18.9-21.1</td><td>27.2-29.4</td><td>11.1-13.3</td></tr>
<tr><td>Warm (Sub Tropical)</td><td>900-1800</td><td>13.9-18.9</td><td>21.1-27.2</td><td>6.1-11.1</td></tr>
<tr><td>Cool</td><td>1800-2400</td><td>10.3-13.9</td><td>17.2-21.1</td><td>2.8-6.1</td></tr>
<tr><td>Cold</td><td>2400-3000</td><td>4.5-10.3</td><td>12.3-17.2</td><td>1.7-2.8</td></tr>
<tr><td>Alpine</td><td>3000-4000</td><td>3.0-4.5</td><td>5.6-13.3</td><td>Below zero</td></tr>
<tr><td>Glacial</td><td rowspan="2">4000-4800
Above 4800</td><td rowspan="2" colspan="3">For 10 months, below zero and in July and August between 2.2-3.9</td></tr>
<tr><td>Perpetually Frozen zone (Cold Desert, No vegetation)</td></tr>
</table>

2.4.3 Overview of State Hazard Profile

Uttarakhand lies on the southern slope of the Himalaya range and presents varied terrain, landforms and climate. The Uttarakhand State can be divided into three zones: Himalayas, the Shivaliks and the Tarai regions. Elevation ranges from 200 m to 7,818 m (Mount Nanda Devi) with approximately 50% of the area characterized by steep slopes and above 2,000 m altitude.

Three major river basins cover the State: the Ganga Basin (24,000 km2), the Yamuna Basin (12,000 km2) shared with the Himachal Pradesh State and the Sarda Basin (15,000 km2) shared with Nepal. Their rivers and tributaries are fed from glaciers, snowmelt and monsoon rainfall, draining the largest, most elevated and steepest zones of the State. In the higher ranges, Glacier Lake Outburst Flows (GLOFs) - as experienced in 2013 in Kedarnath and the Mandakini River - can be direct threats to the downstream areas. Large scale weather systems orographically locked by the higher Himalayan ranges can lead to very localized and intense rainfall in the southern rims of the Himalayan valleys (1000-3000m elevation). These cloudbursts, combined with steep terrain and narrow valleys can produce highly destructive flash floods characterized by extreme flow velocities, high erosive power and large amount of debris. In these zones, sudden and devastating floods can originate either from extreme rainfall and/or from landslide dam-break. As experienced in 2013, the mechanisms leading to disastrous scenarios can be the consequence of a complex cascade of localized geological and hydrometeorological factors and conditions with potentially extreme damaging consequences over large river stretches.

The low-lying and flat terrains of the Terai region, at the outlet of the three main river basins, can be subject to fluvial flooding. There, inundations are the results of hydrological processes taking place at the full basin scale. Events are characterized by their slower onset, longer durations and larger extents. The districts of Haridwar and Udham Singh Nagar can be particularly exposed to fluvial flooding by the Ganga or Sarda Rivers or from one or several of the small to medium sized river systems (e.g. Kosi, Ramganga) finding their source in the Shivalikh mountain range. In those systems, flooding can develop over relative short periods of time (few hours). While the flooding processes are similar to those in the mountain ranges (e.g. short rainfall burst), flood water velocities and depths are lesser and flood extents and durations larger, possibly exacerbated by local ponding. In the most densely urbanised zones, flooding can originate from local ponding and lack of adequate drainage capacity, possibly exacerbated or combined by adjacent and larger rivers systems particularly in highly exposed areas like Haridwar and Rishikesh.

2.4.4 Flood Prone Areas (Exposure and Susceptibility)

People, assets and production exposed to flooding are unevenly distributed across the State. The largest proportion of state-wise economic production and population is distributed within the Terai and Shivaliks regions and possibly exposed to extensive, shallow and slow-moving flooding patterns. Due to the nature of flooding and the high exposure concentration in these zones, the districts of Haridwar, Udam Singh Nagar, Nainital, Dehradun and Pauri Gharwal are economically most exposed (agriculture, residential, commercial), with Haridwar presenting the highest exposure for the tourism sector.

For flash floods, larger variations across blocks and districts exists, depending on the assets of interests. Overall, the hilly regions present higher exposure to destructive or deadly flash floods (deep and high velocity flows) in very localized zones of concentration (assets and people). The agriculture sector is most exposed in Bagheswar, Tehri Garhwal, Pauri Garhwal and Uttarkashi with considerable variation within each district. Residential assets are exposed across all districts and especially in Dehradun and Pithoragarh. Transport infrastructure is most exposed to flash flood in the higher and steeper Himalayan region of Uttarkashi, Chamoli and Pithoragarh. Tourists and tourism revenues are predominantly exposed in the Upper Ganga River basin (Uttarkashi, Rudraprayag and Chamoli districts).

2.4.5 Fluvial Flood Risk Summary

Annual Average Losses associated with fluvial flood are expected to reach 66.4 Crore and to affect primarily the tourism sector (31.8%), followed by residential (21.4%), agriculture (20.9%), roads and transportation (14.1%) and critical buildings (8.8%). Tourism losses are dominated by indirect losses associated with interruption of business for several months after the flooding event. Those are expected to occur for 80% in the plains (Haridwar and Dehradun) then principally in the Uttarkashi and Tehri districts in the hills. Losses in the residential sector are again dominant in the districts of Haridwar and Dehradun most largely exposed to fluvial flooding. The districts of Pauri, Tehri, Champawat and Nanital in the hills are most likely to be affected.

Overall, losses in the residential sector (as well as commerce, industry, tourism and population) are considerably reduced thanks to structural protection programmes in place (e.g. Rishikesh, Haridwar) or being finalized (Srinagar) that help control the most frequent damages (below 100-year Return Period) in the most exposed areas. Agricultural losses predominantly occur in the Haridwar and Udam Singh Nagar districts. With difference to residential and tourism losses, agriculture annual average losses are driven by lower but more frequent damages to crop and crop production. The impact of fluvial flood on population is minimal (4-6 people killed yearly) and with nearly none losses expected for the high probability events and high losses in the low probability events.

The Tehri Dam, optimally managed for flood control throughout the monsoon season, could additionally allow to reduce peak flood probability by half (e.g. a 100-year flooding becomes a 200-year event) in the downstream area of Rishikesh and Haridwar where tourism, agriculture, residential and population exposure are highest in the State. The losses established and reported here only consider fluvial flood. Human and economic losses associated with flash flood and their secondary effects (scouring and erosion, debris flow) are not captured by this hazard type and can produce the highest and most frequent losses in the hills.

Exposure statistics across all portfolios are given in the following figure.

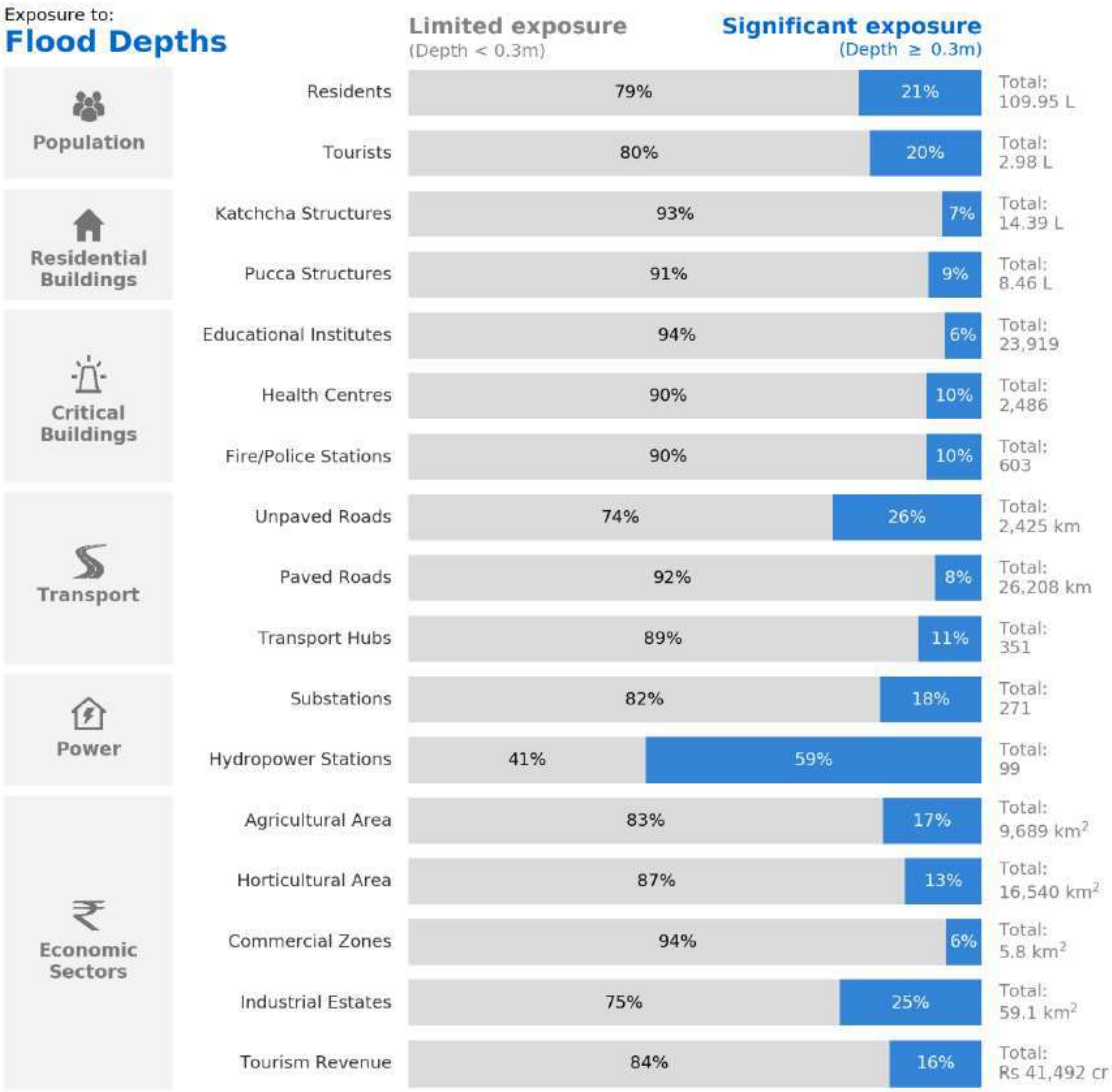
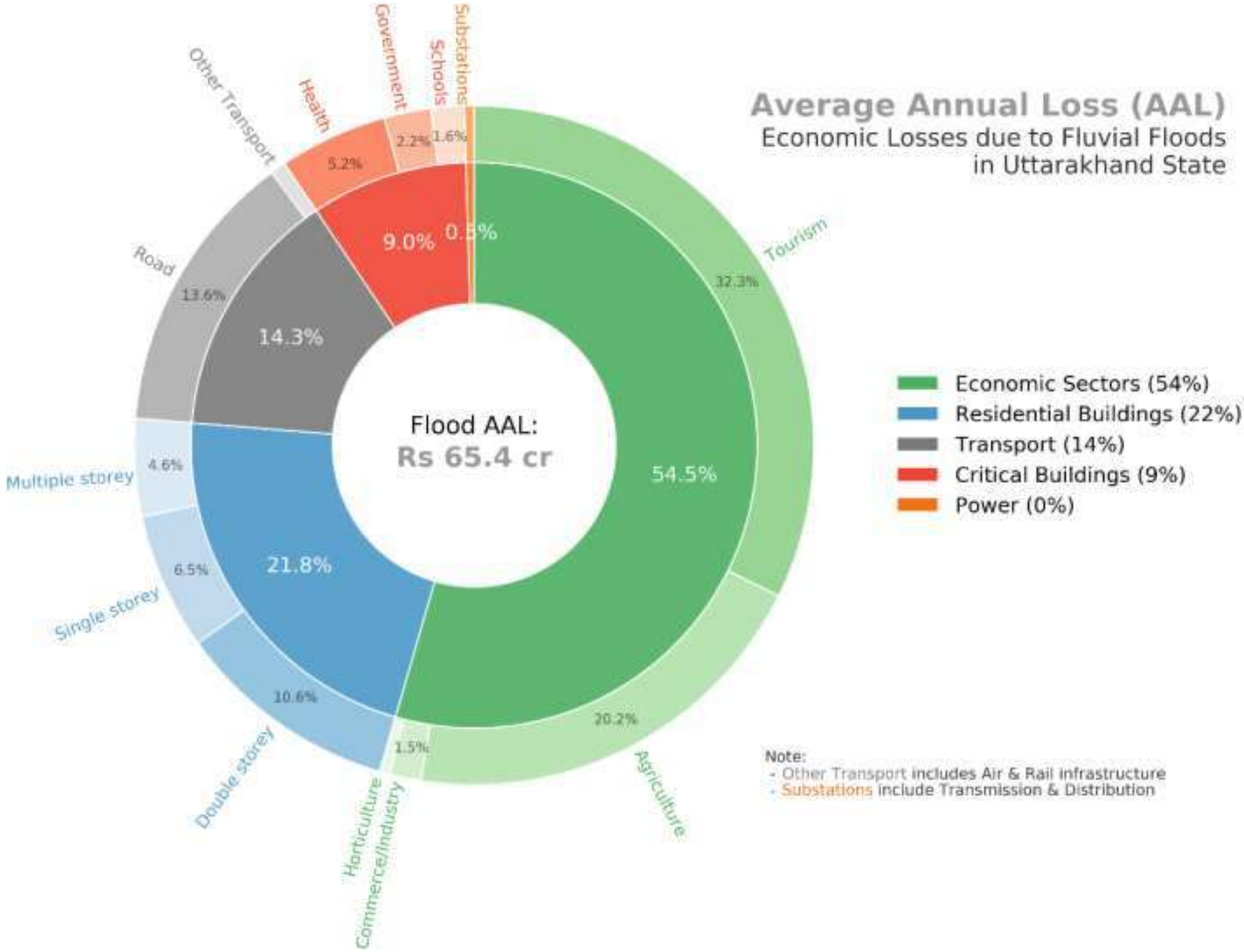


Figure 2.16: Exposure of Portfolios to Fluvial Flood Severity (Depth)

AAL for fluvial floods for both economic and human losses is shown in the following diagrams. This is summed across all portfolios. The reader is referred to the Atlas of Risk for further information.



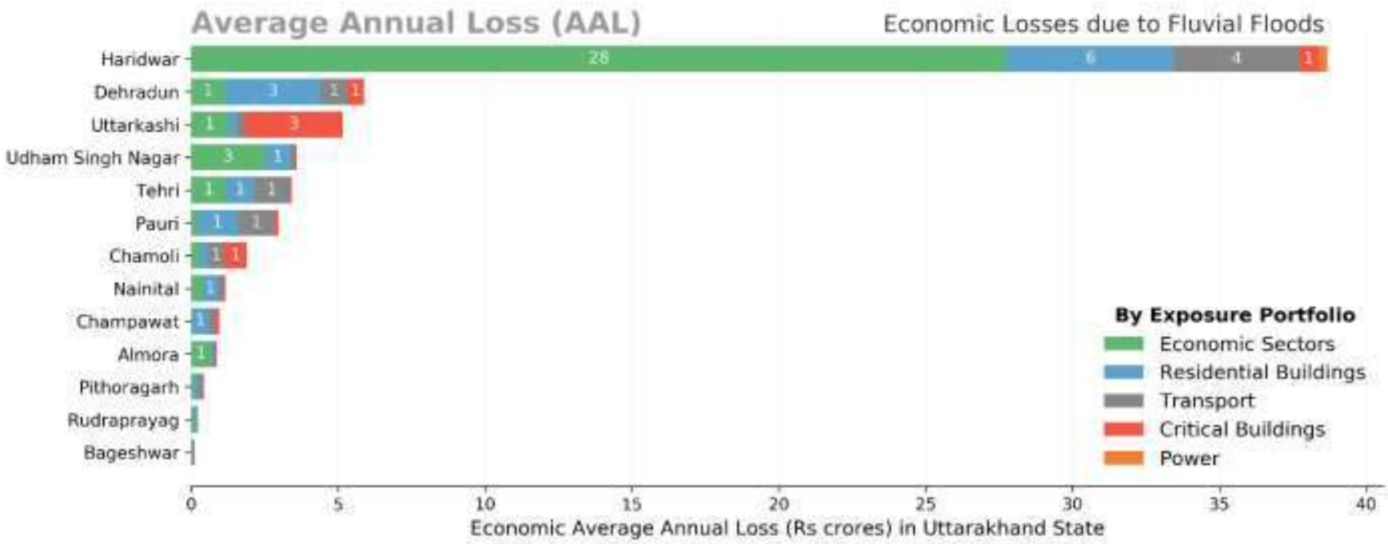


Figure 2.17: AAL (Financial Losses) for Fluvial Floods at State and District Levels and Across All Portfolios

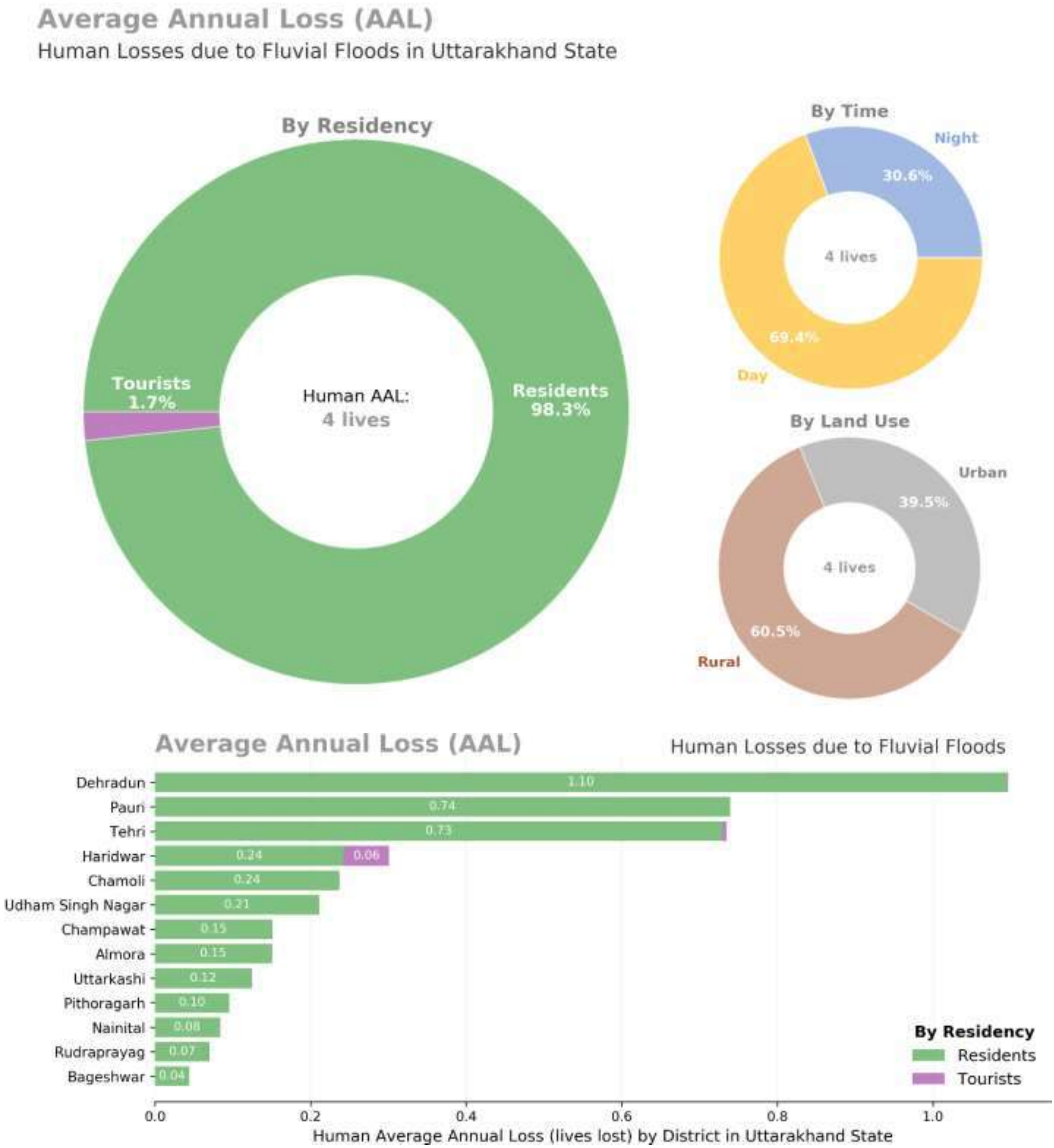


Figure 2.18: AAL (Human Losses) for Fluvial Floods at State and District Levels and Across All Portfolios

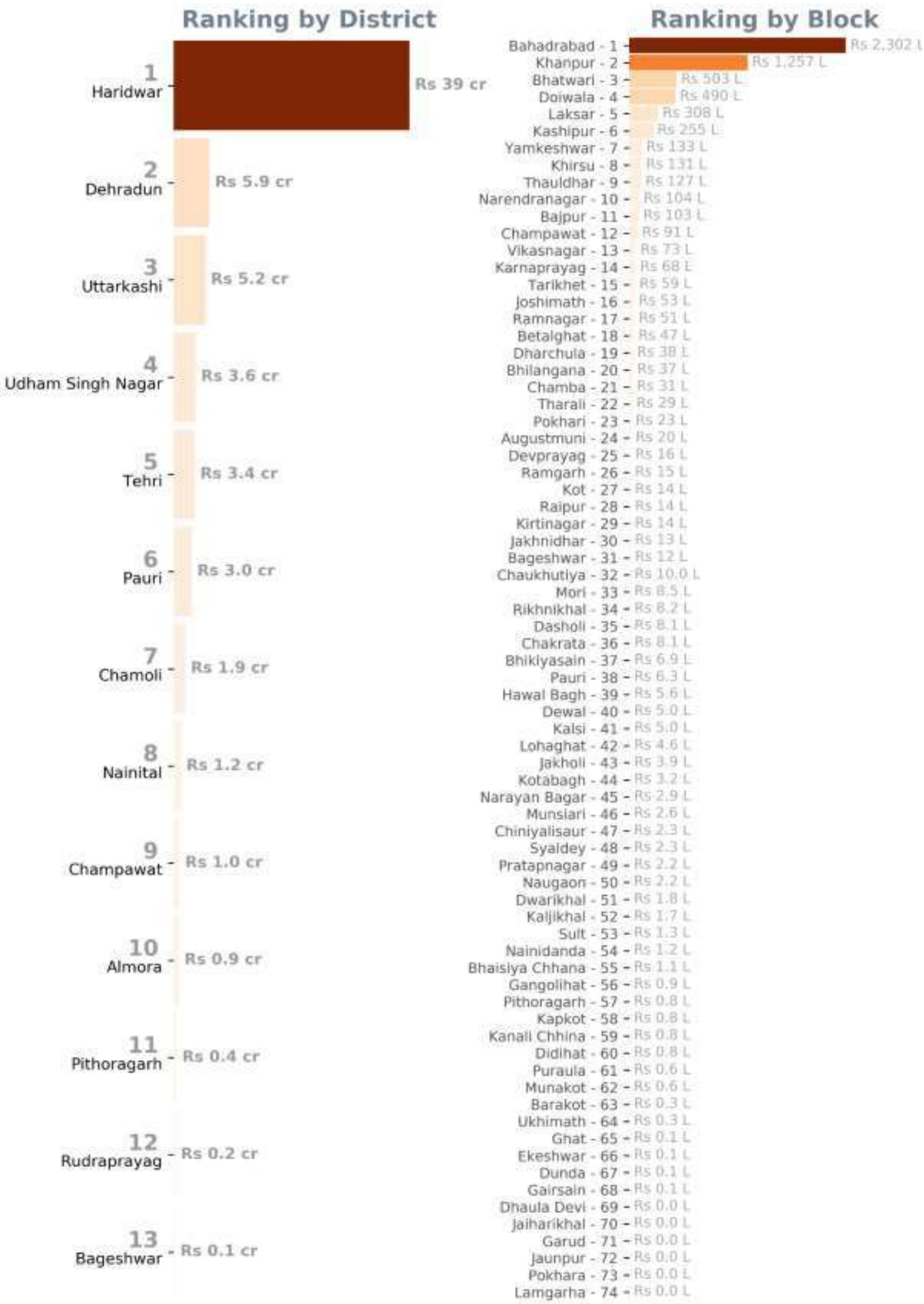


Figure 2.19: Ranking of Districts and Blocks by AAL (Financial Losses) for Fluvial Floods Across All Portfolios

Given the dominance of Haridwar District to the overall risk for the state, we highlight the statistics for this district in the following diagram. For information about other districts, consult the district level atlases and also the online risk dashboard.

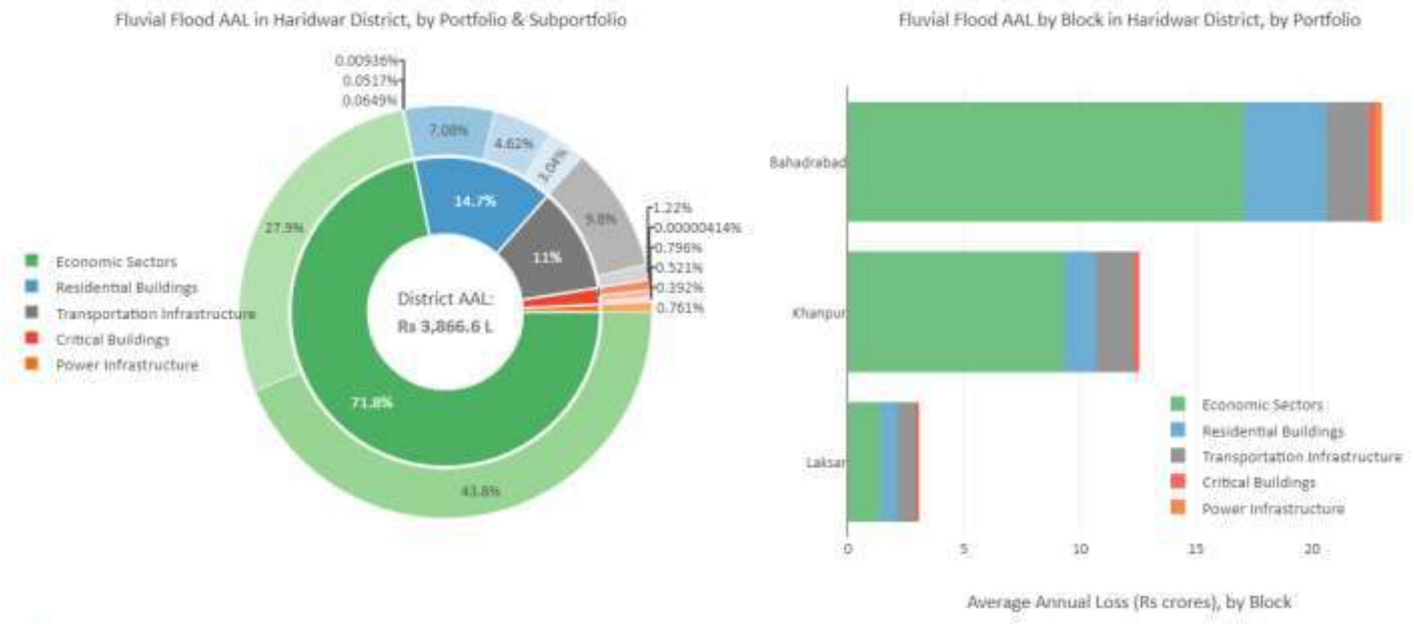


Figure 2.20: AAL (Financial Losses) for Haridwar District and Blocks for Fluvial Floods Across All Portfolios

2.4.6 Flash Flood Exposure Summary

The Atlas details the flash flood exposure for the whole state and each district and presents results for population exposure and each infrastructure portfolio. The figure below illustrates that a small proportion of most portfolios is exposed to 100 yr return period flash flood. Unsurprisingly perhaps, the proportion of hydropower facilities exposed to flash floods is relatively high at 40%.

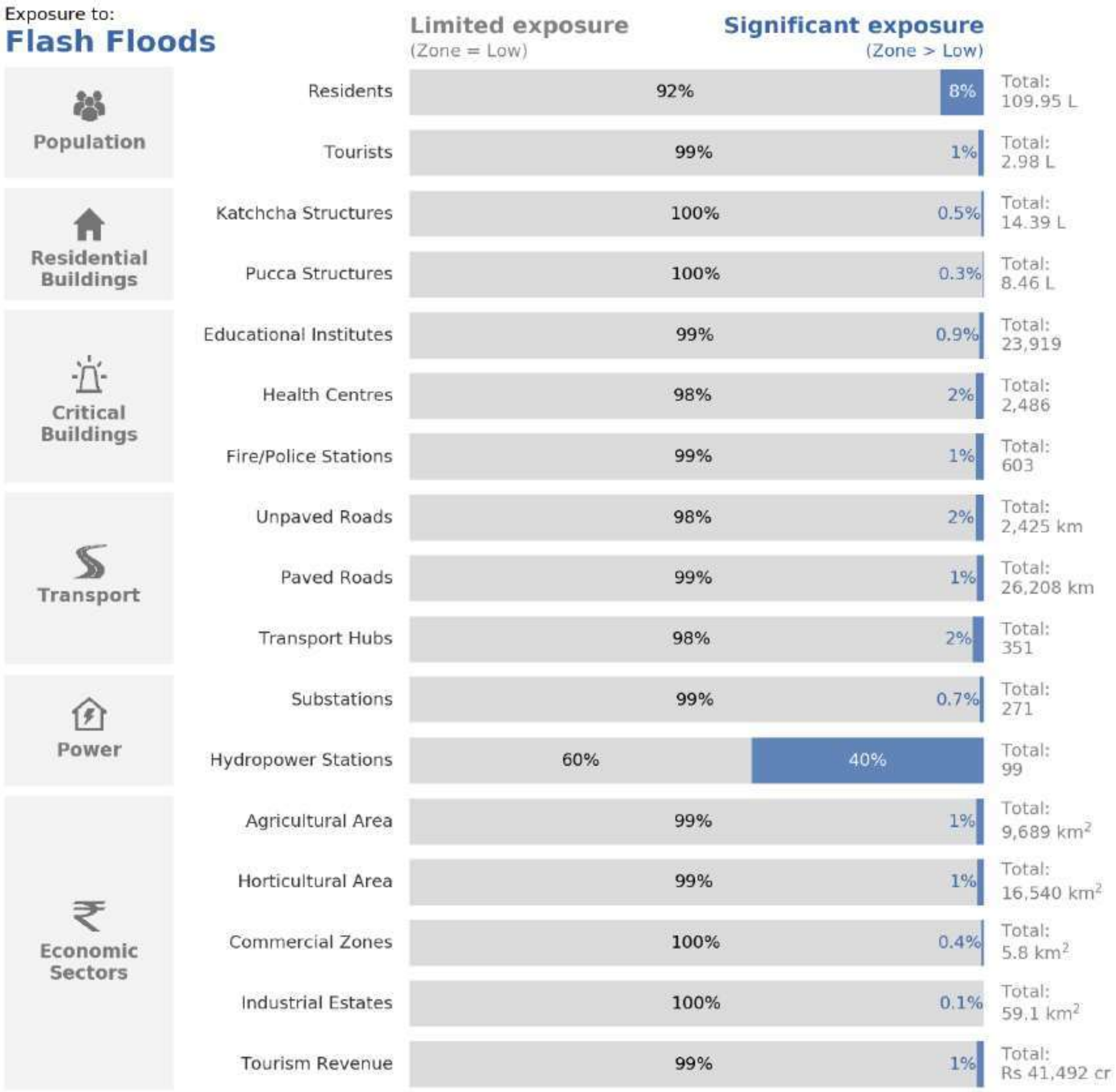


Figure 2-21: State-level Exposure of Portfolios to Flash Floods (100 Yr RP)

2.4.7 Climate Change Impacts

Impacts of climate change for 2050 have been established using hydrological modelling and statistical downscaling techniques from rainfall, temperature and evaporation. The data have been extracted from 14 different combinations of Global and Regional Climate models (RCM) including three Representative Concentration Pathways (RCP) - or possible climate future - corresponding to different scenarios of greenhouse gases emissions in the years to come. The conclusions of the analysis are as follows:

- Accumulated rainfall during the monsoon period (July-September) over the full Uttarakhand State could vary between -5% and +19% with an average of +5% (10 models predicting an increase). Within the State, the range of variation could range from -14% to +22%.
- Average annual maximum 24-hour rainfall over the full State could vary between -14% and +36% with an average of +12% (11 models predicting an increase). Locally, the range of variation could extend from -14% to +40%.
- 10-year and 50-year extreme discharge could increase on average by 30% and 50% respectively across the full State. Large variabilities exist between models with mean variations ranging from -15% to +100% (11 models predicting an increase). The 5 main catchments (Ganges, Yamuna, Sarda, Kosi and Ramganga) show little variation around the mean 30% increase for the 10-year discharge. For the 50-year discharge, the lowest mean increase occurs in the Yamuna catchment (+35%) and the maximum in the Sarda catchment (+60%).

In summary, the different climate change models and scenarios used tend to agree at 75% towards an increase in rainfall and discharge intensities with a tendency of largest increase for the Northern and Eastern parts of the State. Large variabilities remain on the magnitude of the changes across models, RCP scenarios, and at the local scale. Factoring climate change adaption into structural design protection levels should be made with care, possibly using a tipping point approach, and based on thorough considerations of most viable scenarios including costs, benefits and remaining uncertainties.

2.4.8 Making Use of the Maps and Generated Datasets

A wide range of datasets have been produced that can support decision making at the various stages of the disaster risk management cycle.

1. Flood hazard maps including flood depth and extents have been produced for different return periods for both flash flood/ponding and fluvial flooding. For fluvial flooding, the mean and standard deviation of flood water depth and extents are produced to account for the uncertainties in extreme discharge return period estimation and terrain roughness. By applying consistent methodologies at the scale of the State, the hazard maps provide a spatially coherent picture of flooding issues within Uttarakhand. By covering the full state, the resulting maps allow to identify priority areas objectively at the State level. However, large uncertainties remain and should be acknowledged in the decision making. The accuracy and resolution of the DEM did not allow to capture many of the drainage and floodplain features. It is as such recommended to use the provided flood maps for preliminary screening and planning but complement them with local detailed studies relying on high accuracy datasets (recommendations given in technical modelling reports).

2. Additional hazard layers have been provided to support scenario analysis, emergency planning and response. Those layers consist in:
   - the extreme rainfall intensities of approximately 120 sub-catchments covering the full state. Those rainfall intensities have been used to produce the flash flood hazard maps and can be used to identify relevant scenarios and predict possible impacts of events monitored from existing or new synoptic network.
   - The extreme discharge peak for 8 return periods (mean and standard deviation) at 200 locations along the major rivers, for the present climate and for the 14 climate change scenarios. These discharge intensities have been used to produce the fluvial flood hazard maps (mean and standard deviation corresponding to 16 discharge intensities at each location) required for probabilistic risk analysis. These discharge data can be used to identify relevant flood hazard scenarios (including climate change) and predict possible impacts of events monitored from existing or future gauging stations.
3. Flood exposure and risk maps are provided for the many different classes of assets, 3 key economic sectors (agriculture, tourism, and industry) and for the population. Risk maps aggregated by portfolios are also provided. Those maps allow to analyse the relative contribution of different bocks or districts to the human or economic losses of the overall or segments of the state economy or population distribution. Such results can help prioritize action by identifying hazard impacts and support cost benefit analysis of mitigation strategies at the state level. Besides, these results support the identification of critical buildings, infrastructure and zones under possible threat of specific hazard condition. They can help improve preparedness and assist in emergency and response situation after identification of corresponding hazard scenarios.

2.5 LANDSLIDE EXPOSURE SUMMARY

2.5.1 Summary of Landslide Susceptibility

Landslide susceptibility is the likelihood of a mass movement in an area on the basis of local terrain conditions. It predicts the locations “where” landslides are more likely to take place. Landslide susceptibility modelling has been executed in district-level by achieving considerable model accuracy.

The statewide landslide inventory was developed using the Google Earth resources, 6536 landslides were pinpoint on the recent satellites images. Spatial distribution of landslide inventory illustrate in the figure below.

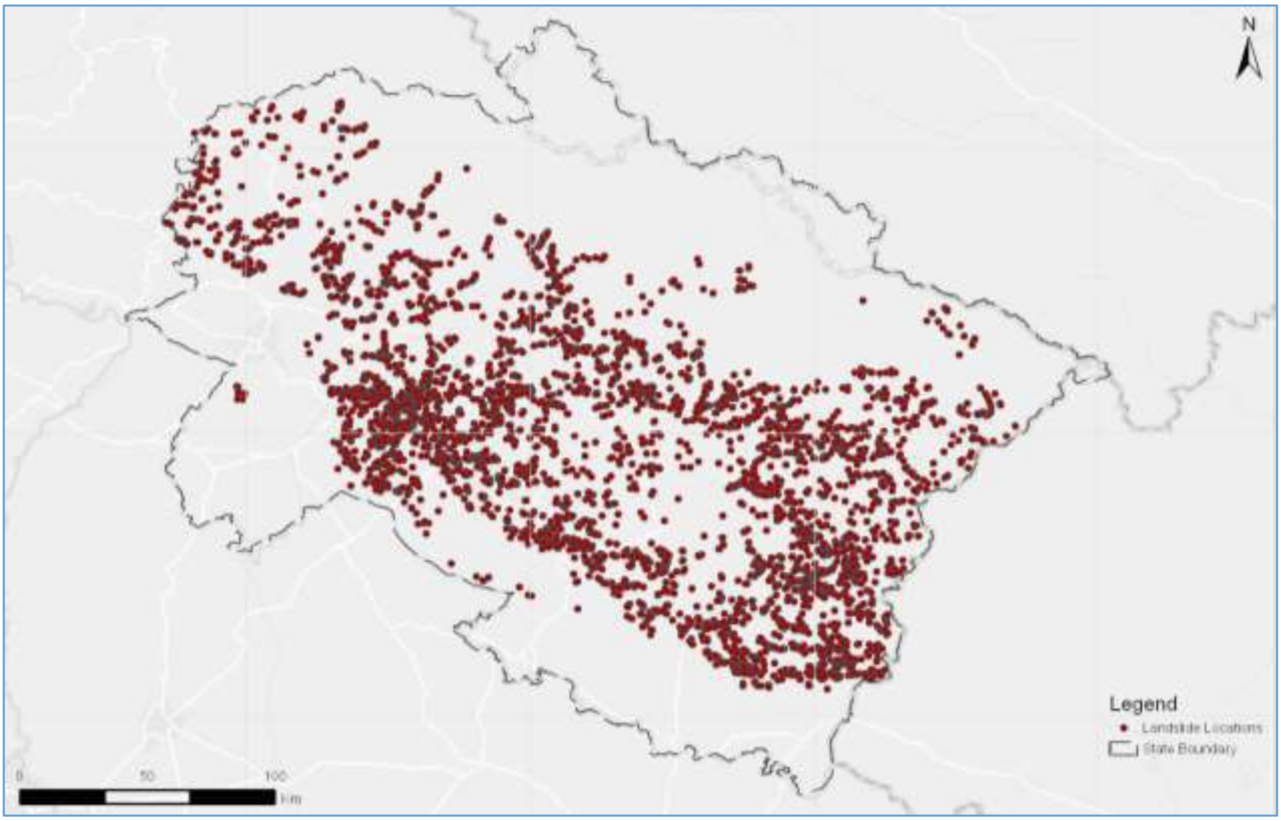


Figure 2.22: Historic Landslide Inventory

The landslide susceptibility analysis was conducted using Maxent modelling approach which have been used in various fields such as computer vision, spatial modelling, species modelling, natural language processing and many other fields. The following layers, slope, slope length, geology, soil, land-use, aspect, average monsoon rainfall, distance from thrust and faults, distance from road and distance from rivers were considered as landslide causal factors over the state.

For each district model, model performance is assessed, quantifying the benefit the model provides over a random prediction, with reference to a plot known as a Receiver Operating Characteristic (ROC) curve. This plot shows the Area Under Curve (AUC), for which a value of 0.5 is equivalent to a random prediction and a value of 1.0 would indicate a perfectly predictive model. For the district-level Maxent models run for Uttarakhand, an average AUC value of 0.9 was achieved, indicating a significantly superior performance over random prediction.

The following figure shows the Rudraprayag District model execution results; (a) initial probability outcome, (b) ROC curve and model performance statistics.

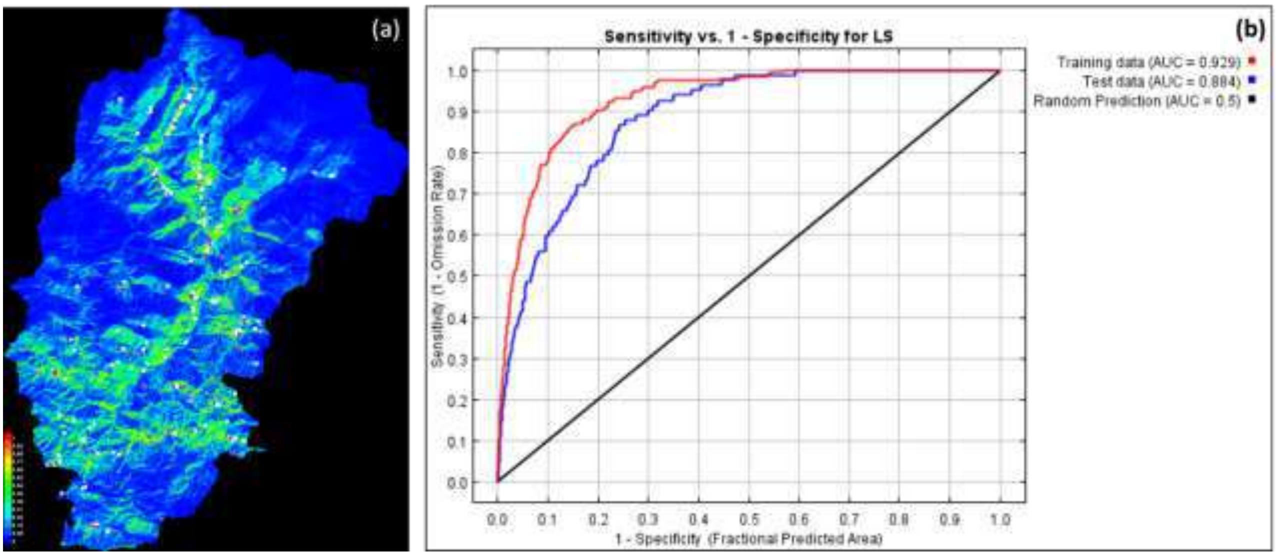


Figure 2.23: Model Output for Rudraprayag District

The results of these Maxent landslide models were reclassified into five categories, ranging from ‘None’ to ‘Very High’, in terms of landslide susceptibility (classification as follows)

- 0.0 – 0.2 : No Susceptibility
- 0.2 – 0.4 : Low Susceptibility
- 0.4 – 0.6 : Medium Susceptibility
- 0.6 – 0.8 : High Susceptibility
- 0.8 – 1.0 : Very High Susceptibility

The following map shows the landslide susceptibility results over the state. Also refer to the Atlas of Risk, where there is a larger format and more detailed map for the state and each district.

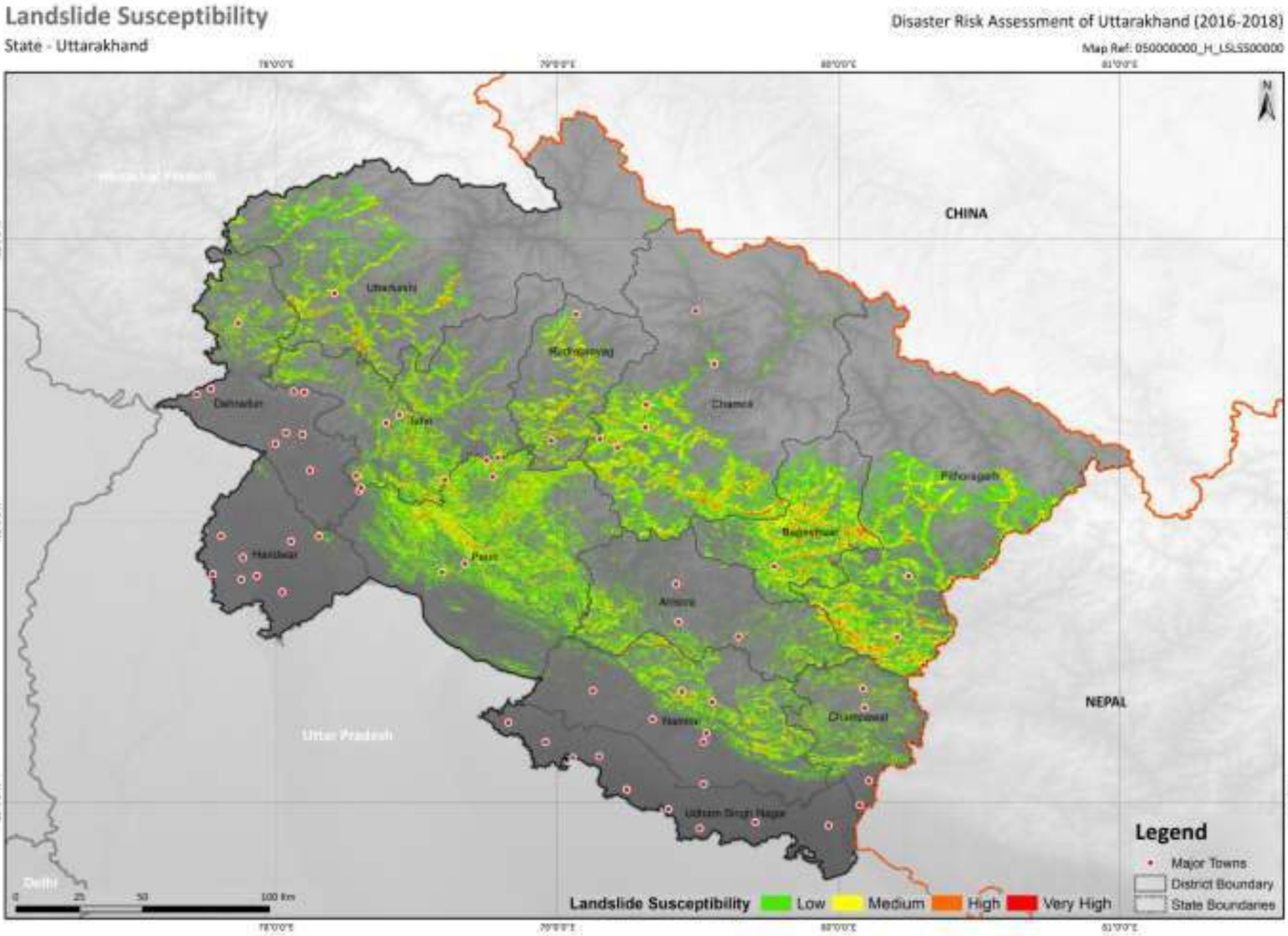


Figure 2.24: Landslide Susceptibility Map for Uttarakhand

Distance from road was determined to be the most significant contributor to the likely susceptibility to landslide of any given area; thus, reinforcing the observation that road construction can increase the occurrence of landslides.

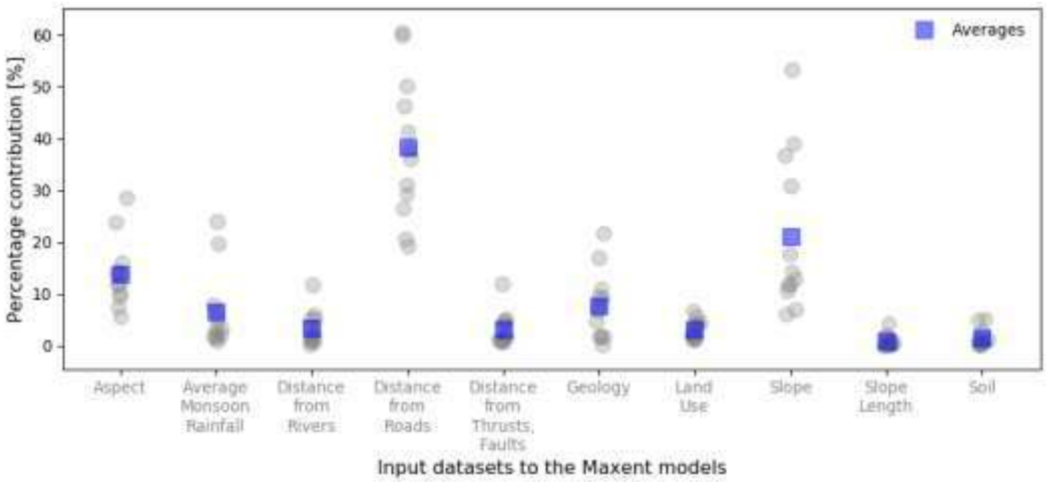


Figure 2.25: Contribution of Different Input Datasets to the Maxent Model of Landslide Susceptibility

Spatial averaging of landslide susceptibility results were carried out to obtain better susceptibility zonation. The zonation map is converted to vector GIS format for further analysis within the project and dissemination among the relevant state agencies.

The following figure illustrates the zoom in results in Rudraprayag district.

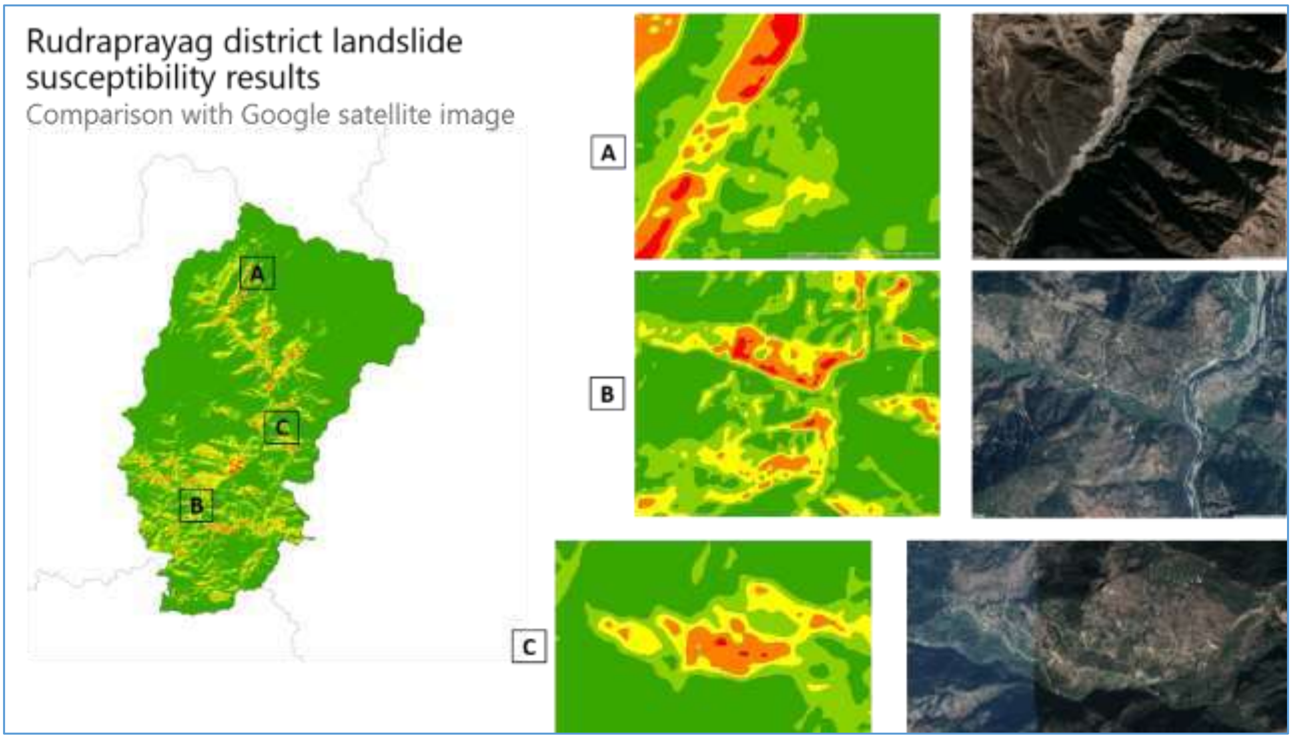


Figure 2.26: Demonstration of Spatial Averaging for Rudraprayag District

Moreover, the landslide zonation results further overlay with built-up area dataset, which was developed under the project.

The results facilitated exposure zonation over the state with respect to landslide susceptibility level, and the following figure shows a snapshot from one location in the state.

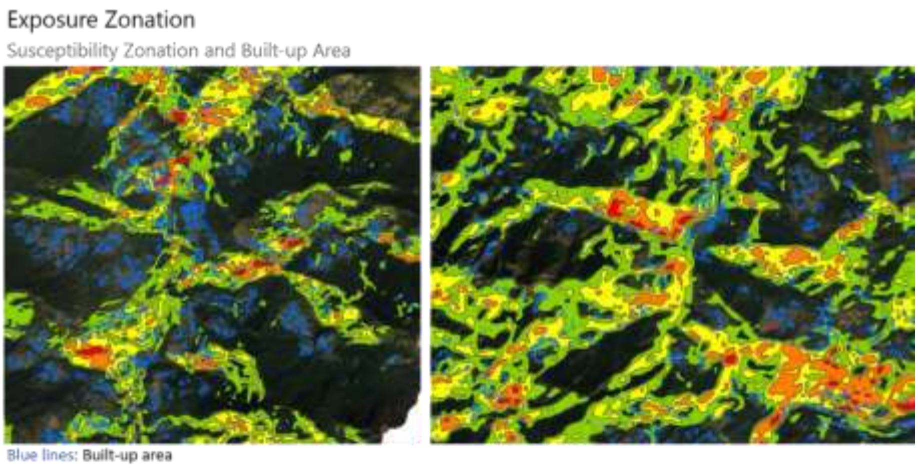


Figure 2.27: Snapshot of Landslide Susceptibility Zonation across Uttarakhand

2.5.2 Summary of Exposure to Landslides across Uttarakhand

The Atlas of Risk details the landslide exposure for all districts and blocks. The following figure simply summarises the exposure of all portfolios to landslides. Roads and hydropower facilities are most exposed.

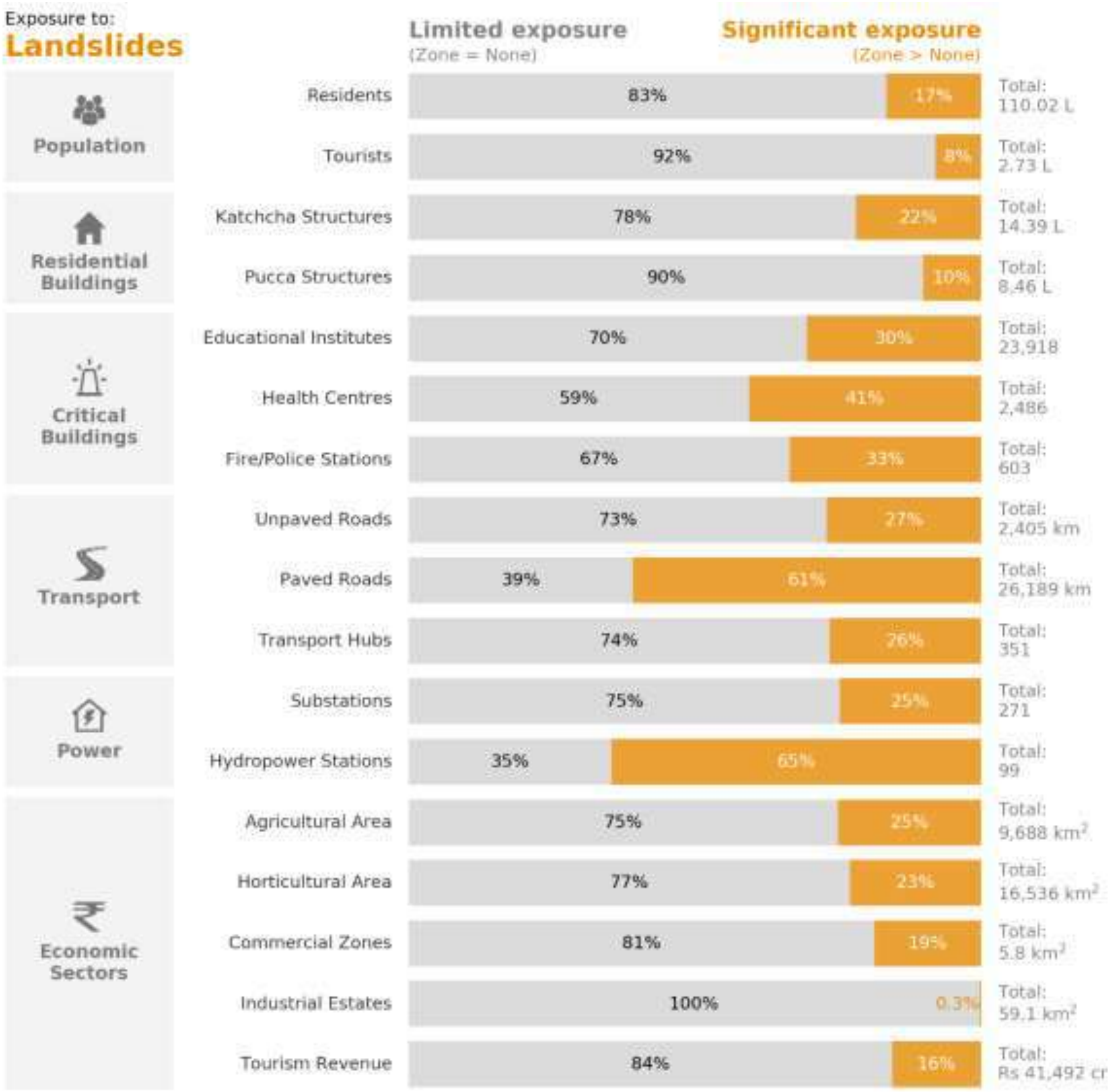


Figure 2-28: State-level Exposure of Portfolios to Landslides

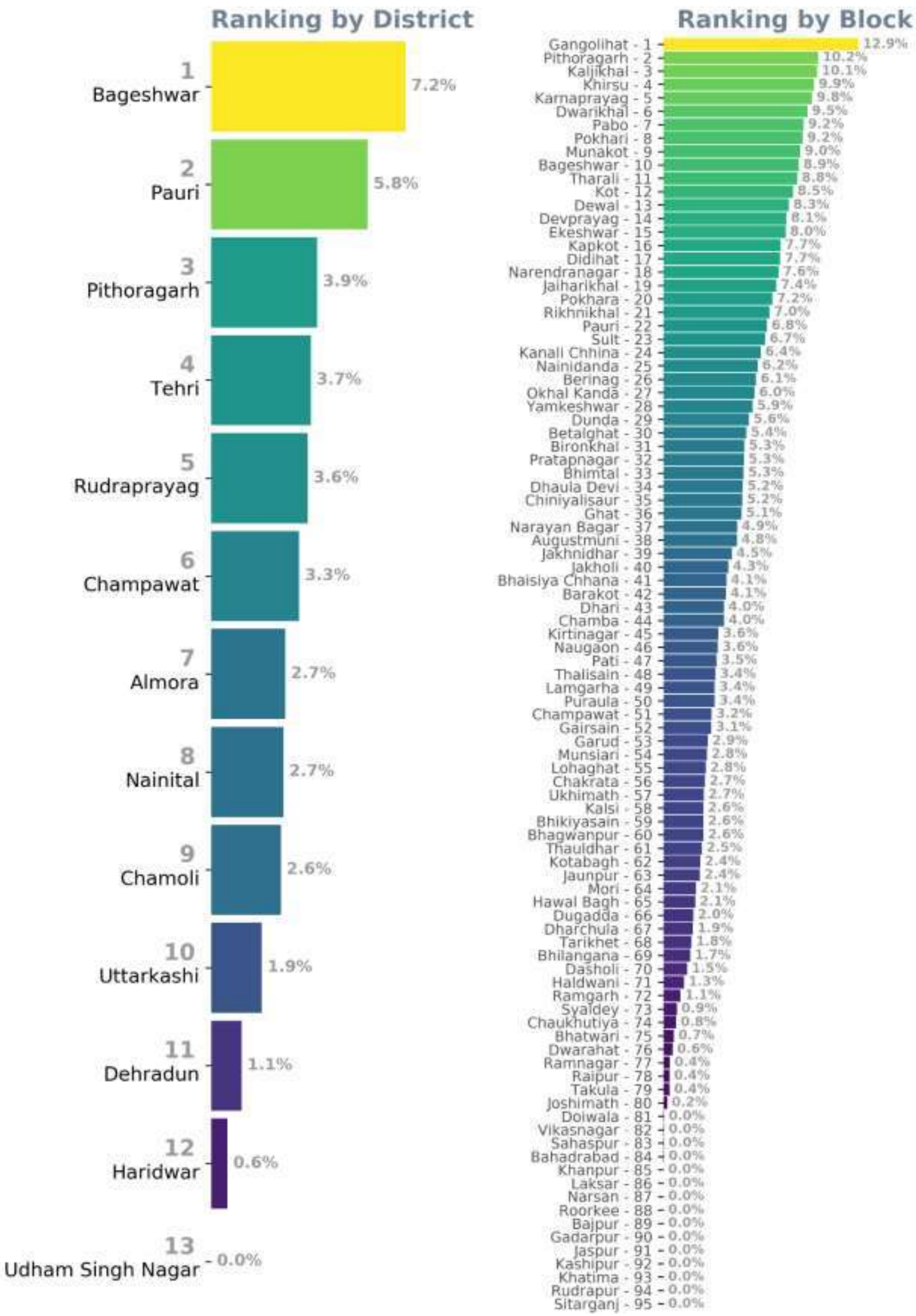


Figure 2.29: Ranking of districts (left) and blocks (right), based on a weighted average of the extent to which each is covered by different susceptibility classes (with higher susceptibility classes weighted more heavily)

2.6 INDUSTRIAL EXPOSURE SUMMARY

2.6.1 Facility Level Catastrophic Hazard Assessment

Potentially catastrophic industrial hazards have been assessed deterministically at facility level to determine the threat zone for each facility. The industrial hazards assessment has been performed only for confirmed Major Accident Hazard Industries (MAH) in Uttarakhand.

The full industrial hazard assessment is included in Appendix F and includes all model results and estimates for population and infrastructure exposed to industrial hazards. The assessment report in Appendix F and Section 3.5 of this report explain the process and criteria for shortlisting of Industries.

Focus is on assessment of potentially catastrophic risks to infrastructure and human life arising from pool fire, jet fire, explosion, fireball, boiling liquid expanding vapor explosion (BLEVE), and the extent of a potentially flammable toxic vapor cloud. The available data and limited time to undertake the study precluded the assessment of other hazard classes, but those listed represent the greatest threat to human life and property.

This section of the report simply summarises the outputs and presents examples of the facility level threat zones generated from the industrial assessment.

All data refined and improved throughout the course of this assessment has been returned to USDMA and must be used to guide improvement of the original data sources; many of which were erroneous.

The following hazardous substances are used by industries in Uttarakhand.

1. Liquefied Petroleum Gas (LPG)
2. Propane
3. High Speed Diesel (HSD)
4. Diesel
5. Chlorine
6. Cyclopentane
7. Volatile Organic Compounds (VOCs) in paints and thinners
8. Compressed Natural Gas (CNG)
9. Motor Spirit
10. Residual Fuel Oil (RFO)

11. Ethanol
12. Chrome Solution
13. Shocker Oil
14. Carbon Dioxide

The potential health impacts arising from the aforementioned hazardous materials are given in the table below.

Table 2.2: Health Effects due to Listed Hazardous Materials

Chemical	Health Effect
Propane	Exposure to higher concentration: Cardiac arrest, incapacitation, unconsciousness or seizure. Exposure to lower concentration: Damage to central nervous system, lung congestion, fluid fatigue, dizziness, vomiting, etc.
Chlorine	High level exposure: chest tightness, wheezing and non-cardiogenic pulmonary edema. Low level exposure: Eye/skin irritation, sore throat and cough.
HSD	Long-term exposure: Increase in cancer risk and inflammation in lungs. Short-term exposure: Irritation in eyes nose, throat and lungs.
Cyclopentane	High level exposure: Dizziness, coma, possible respiratory failure, etc.
Thinner	Inhaling thinner fumes can cause damage to brain and nerves, or even result in death.
Paint	Long-term exposure: Damage to central nervous system, liver and kidneys. Short-term exposure: Headache, eye irritation, nausea, dizziness and fatigue.
CNG	High level exposure: Loss of consciousness or even death. Low level exposure: Not harmful.
Ethanol	Inhalation can result in cough, headache, fatigue and drowsiness. Contact with skin can result in dry skin.
Diesel	Long-term exposure: Increase in cancer risk and inflammation in lungs. Short-term exposure: Irritation in eyes nose, throat and lungs.
RFO	Long-term exposure: Increase in cancer risk and inflammation in lungs. Short-term exposure: Irritation in eyes nose, throat and lungs.
Chrome Solution	Irrigation to respiration and damage to organs. Carcinogenic and highly toxic.

Shocker oil	Long-term exposure: Increase in cancer risk and inflammation in lungs. Short-term exposure: Irritation in eyes nose, throat and lungs.
Carbon dioxide	High concentration: Irritation of eyes, nose and throat. Low concentration: Not harmful.
LPG	Inhaling vapour can cause irritation to nose and throat, headache, nausea, vomiting, dizziness and loss of consciousness.
Motor spirit	Long-term exposure: Increase in cancer risk and inflammation in lungs. Short-term exposure: Irritation in eyes nose, throat and lungs.

2.6.2 Distribution and Status of Investigated MAH Industries

The concentration of major industries in Uttarakhand is in 6 out of 13 districts, namely Udham Singh Nagar, Nainital, Haridwar, Champawat, Almora, and Dehradun. The concentration of potentially hazardous industrial facilities is greater in the plain areas of the districts, and this trend is likely to remain in future since development policies in Uttarakhand and the prevailing threat of seismic hazards prevent expansion of hazardous industries in the hilly regions.

There are 15 integrated industrial estates promoted by the SIDCUL. The estates are listed below in Table 2.3.

Table 2.3: List of SIDCUL Industrial Estates in Uttarakhand

Sr. No.	District	Block	Name
01	Haridwar	Bahadarabad	Haridwar Integrated Industrial Estate
02	Haridwar	Bahadarabad	Bahadarabad Integrated Industrial Estate
03	Haridwar	Bahadarabad	BHEL Industrial Estate
04	Haridwar	Bhagawanpur	Shiv Ganga Industrial Estate
05	Haridwar	Laksar	Patanjali Food Park
06	Haridwar	Laksar	JK Typres Industrial Estate
07	Haridwar	Roorkee	Devbhumi Industrial Estate
08	Udham SN	Rudrapur	Pantnagar Industrial Estate
09	Udham SN	Sitarganj	Sitarganj Industrial Estate
10	Udham SN	Kashipur	Kashipur Phase 1
11	Dehradun	Raipur	IT Park
12	Dehradun	Sahaspur	Selaqui Industrial Estate
13	Nainital	Bhimtal	Batelghat Mini Industrial Estate
14	Paudi	Dugadda	Kotdwar Saggadi Industrial Estate
15	Tehri	Narendranagar	Dhalwala

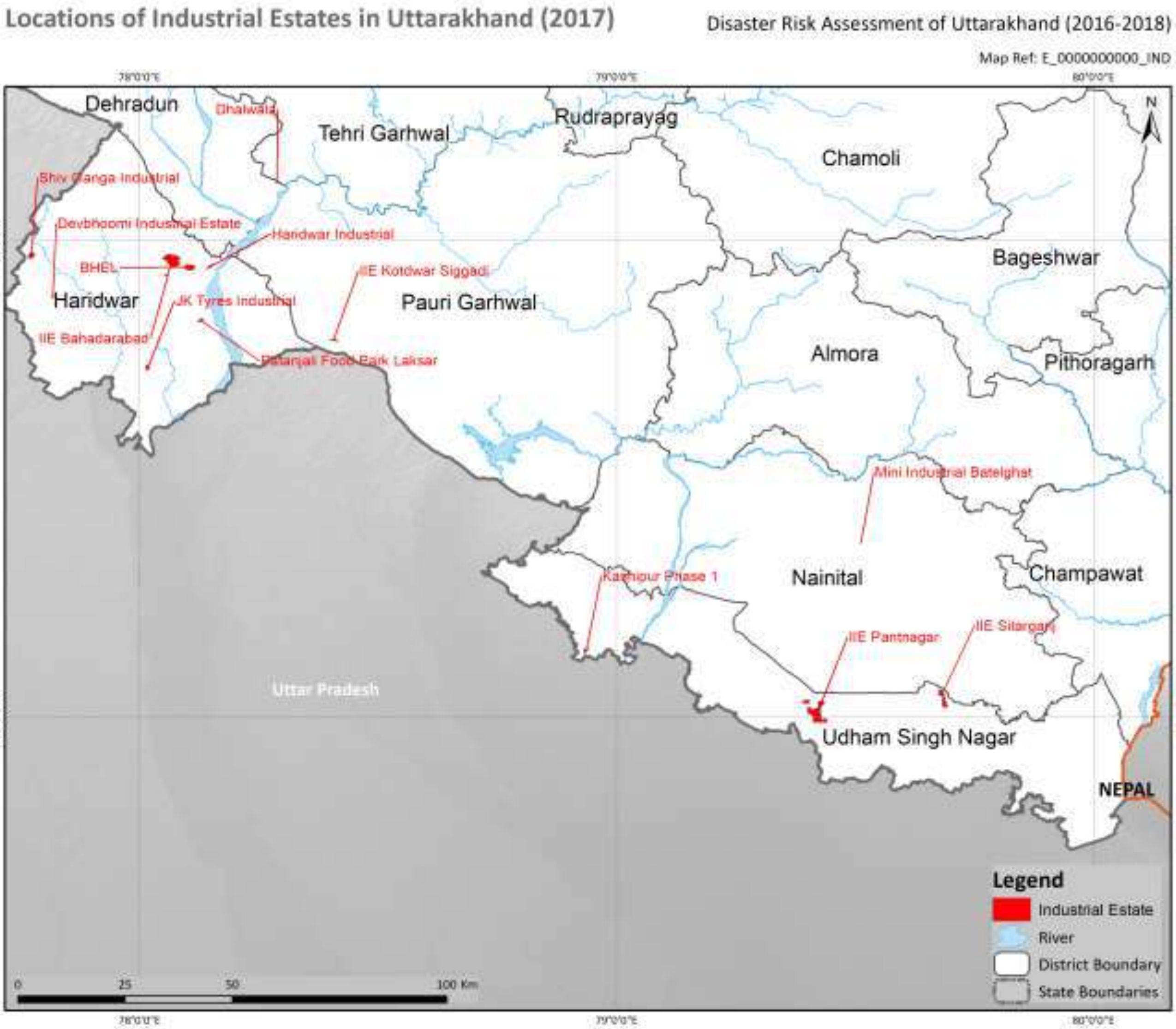


Figure 2.30: Location of Industrial Estates in Uttarakhand

The predominant hazardous materials used in the state include Liquified Petroleum Gas (LPG), Propane, High Speed Diesel, Diesel, Chlorine, Cyclopentane, volatile organic compounds (VOCs) in paints and thinners, compressed natural gas (CNG), motor spirit, residual fuel oil, Ethanol, Chrome solution, Shocker Oil, Carbon Dioxide etc. These were all considered when screening the facilities to determine the Major Accident Hazard (MAH) potential at the facility level.

The Directorate of Industries and Boilers originally provided a list of 41 number of Major Accidental and Hazardous Industries (MAH), and the inventory of Directorate of Industry and Boilers (DOIB) is incomplete and DDMOs in the districts and officials of SIDCUL industrial estates and clusters supplemented this list. In total, 74 facilities were shortlisted for the industrial hazard assessment and modelling for the hazard and exposure assessment. The status of these shortlisted industries is given in Table 2.4 below.

The status of industries is dynamic, and 25 industries originally listed by the DOIB were either confirmed as closed (17 of 25) or do not exist (8 of 25). These present no risk. Nainital District was found to have most of these erroneous or out of date records industrial installations. Out of the original 74 shortlisted facilities, 13 industrial installations were confirmed not to use or store hazardous material and, therefore, do not pose a significant threat. These installations are concentrated in Almora (6) and Champawat (5).

Of this original shortlist, only 23 are confirmed to pose a significant threat due to hazardous material present on site. Four (4) have underground tanks, precluding modelling of an explosion, but they too require monitoring to ensure there is no pollution from rupturing of the storage tank. Nine (9) declined to give data and must be carefully monitoring because they represent an unquantified risk. These 36 facilities all present a potential threat.

Table 2.4: District Distribution and Status of MAH Industries Shortlisted for the Industrial Assessment

District	Potential Threat			No Threat		Total
	Hazardous Profile	Underground Tank	Denied to Give Data	No Hazardous Material	Does not Exist or Closed*	
Udham Singh Nagar	16	1	2	1	3	23
Nainital	0	0	2	0	13	15
Haridwar	6	1	4	1	1	13
Almora	0	1	0	6	3	10
Champawat	0	1	1	5	3	10
Dehradun	1	0	0	0	2	3
Total	**23**	**4**	**9**	**13**	**25**	**74**

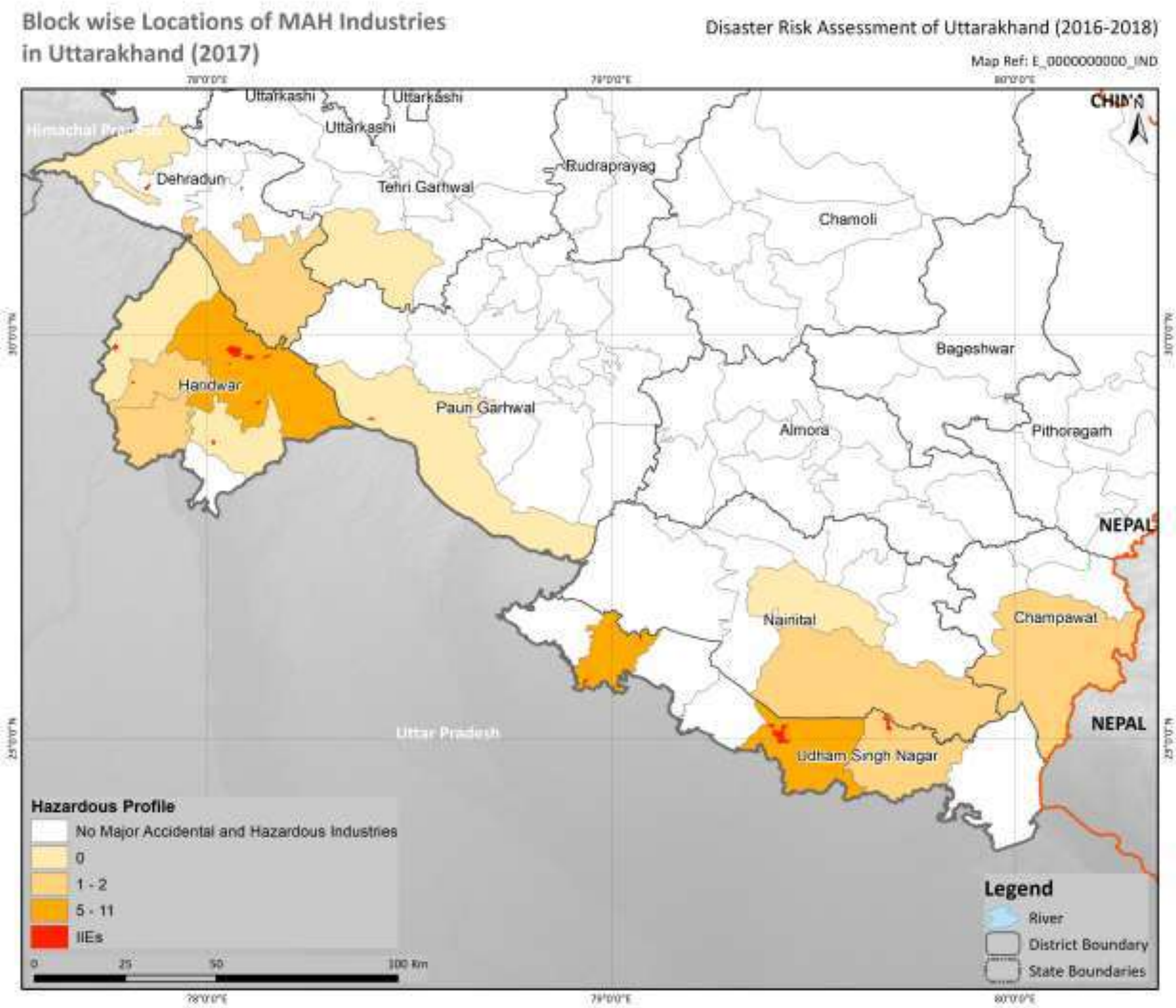


Figure 2.31: Distribution of the Shortlisted Potentially Hazardous Industrial Facilities

The 36 facilities that are confirmed operational and posing a potential threat are distributed across 11 blocks. Even the original list of 74 facilities was distributed across only 14 blocks out of 95 in total, indicating the limited distribution of potentially hazardous facilities within Uttarakhand. This block level distribution of industries is given in Table 2.5 below. Rudrapur block in Udham Singh Nagar has the highest number of facilities posing a potentially catastrophic chemical or fire hazard.

Table 2.5: Block Level Distribution of Industrial Facilities Posing a Significant Threat or Requiring Monitoring

District	Block	Hazardous Profile	Underground Tanks	No Response	Total
Champawat	Champawat	-	1	1	2
Almora	Tarikhet	-	1	-	1
Udham Singh Nagar	Jaspur	1	-	-	1
	Kashipur	3	-	1	4
	Rudrapur	10	1	2	13
	Sitarganj	2	-	-	2
Nainital	Haldwani	-	-	2	2
Haridwar	Roorkee	1	-	1	2
	Narsen	2	-	-	2
	Bharadabad	3	1	2	6
Dehradun	Doiwala	1	-	-	1
Total		**23**	**4**	**9**	**36**

Table 2.6: Industries with Confirmed Hazardous Material and Potential Threat

Ref. Code	Name of Industry	District	Block
DDN1	Hindustan National Glassware Industries Ltd. Glass Division	Dehradun	Doiwala
HRD2	Indian Bottling Plant	Haridwar	Bahadrabad
HRD4	Indian Oil Corporation LPG Bottling Plant	Haridwar	Narsan
HRD5	Hindustan Petroleum Corporation	Haridwar	Narsan
HRD6	Confidence Sylender and Petrachem Pvt. Ltd.	Haridwar	Roorkee
HRD12	MunjalSoa Ltd	Haridwar	Bahadrabad
HRD13	Neel Metals Products Ltd.	Haridwar	Bahadrabad
USN2	Surya Roshani Ltd Lightning Division	Udham SN	Kashipur
USN4	Naini Papers Mill Ltd.	Udham SN	Kashipur
USN5	Naini Tissues Ltd.	Udham SN	Kashipur
USN8	Voltas Ltd.	Udham SN	Rudrapur
USN9	Dukes Products (India) Ltd.	Udham SN	Rudrapur
USN10	Badve Engineering Ltd.	Udham SN	Rudrapur
USN11	Mahindra Ugine Steel Co. Ltd.	Udham SN	Rudrapur
USN13	Thai Summit – Neel Auto Pvt. Ltd.	Udham SN	Rudrapur
USN14	Bajaj Auto Ltd.	Udham SN	Rudrapur
USN15	Tata Motors Ltd.	Udham SN	Rudrapur
USN16	Siddharth Paper Mill Ltd.	Udham SN	Jaspur
USN17	La Opala RG Ltd.	Udham SN	Sitarganj
USN18	Parle Biscuits Pvt Ltd.	Udham SN	Sitarganj
USN19	Ashok Leyland	Udham SN	Rudrapur
USN20	Hindustan Zinc Ltd.	Udham SN	Rudrapur
USN21	Varroc Engineering Pvt. Ltd.	Udham SN	Rudrapur

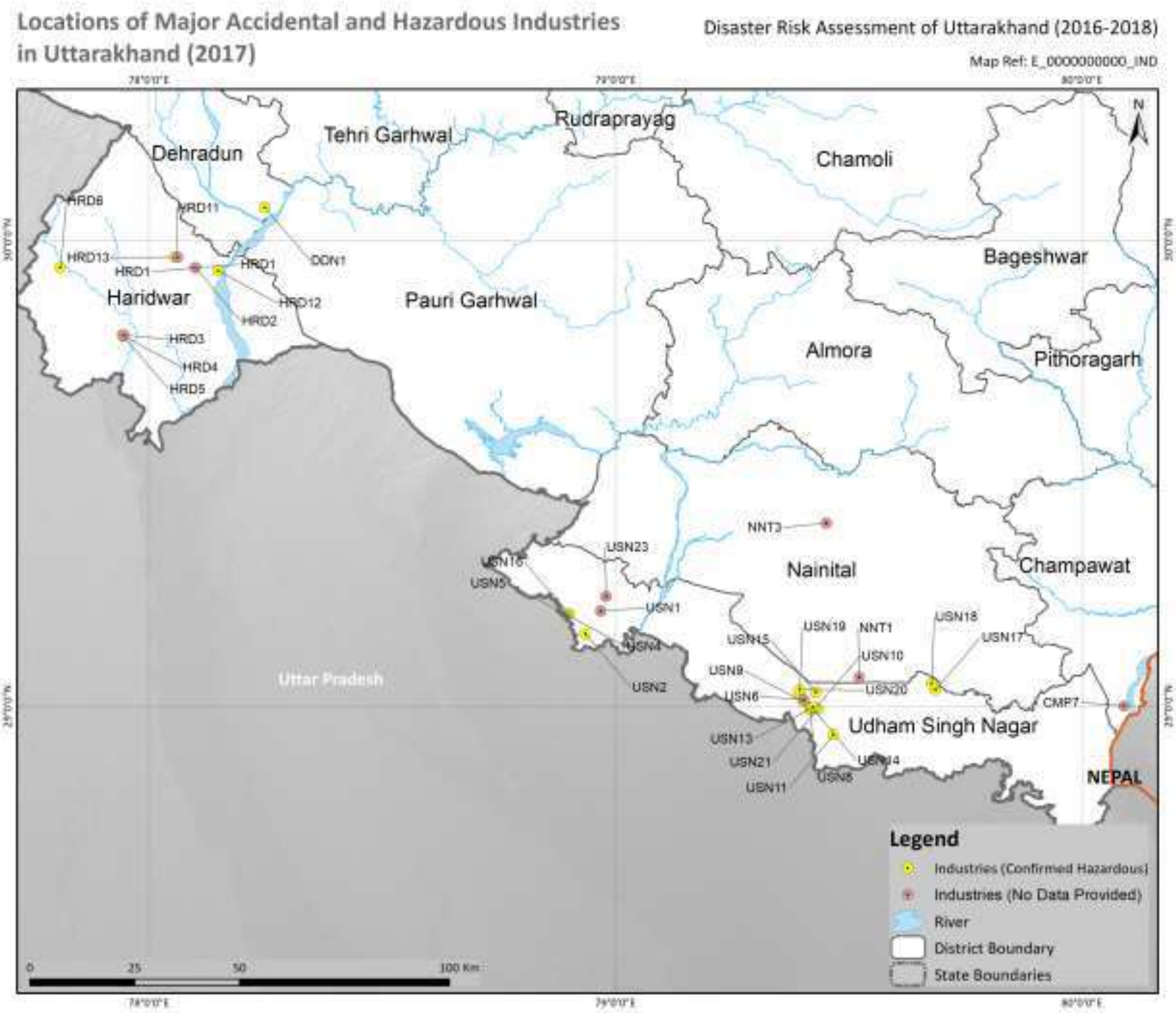


Figure 2.32: Location of Industrial Facilities with Confirmed Hazardous Profile & Those that Declined to Provide Information

Table 2.7: Industries with Underground Tanks and Posing a Potential Threat

Ref. Code	Name of Industry	District
ALM4	M/S Uttaranchal State Road Transport Nigam Depo Workshop	Almora
CMP5	M/s Uttaranchal State Road Transportation Nigam, Depo Workshop	Champawat
HRD8	A.G. Industries Pvt. Ltd.	Haridwar
USN7	Britannia Industries	Udham SN

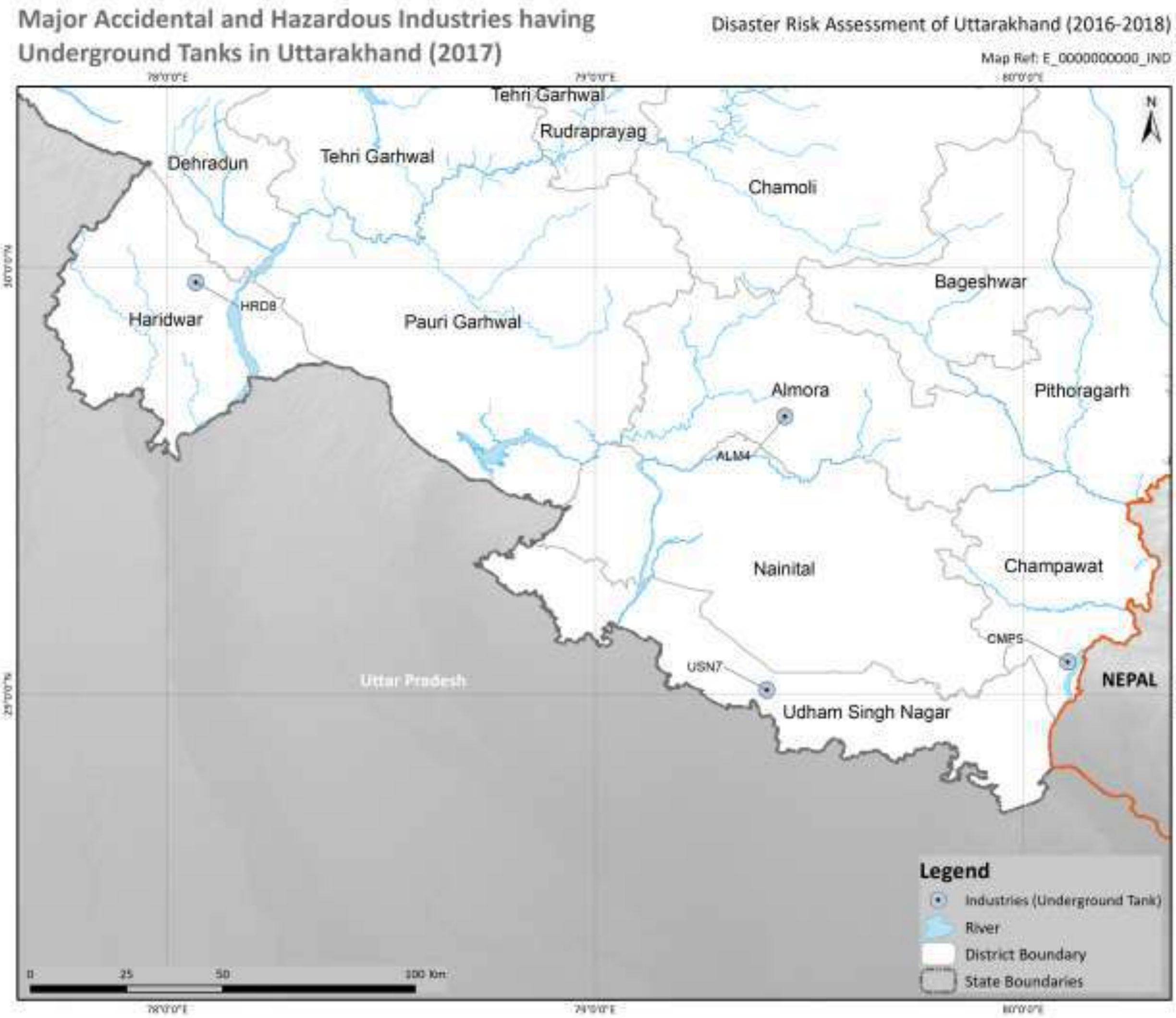


Figure 2.33: Location of Industrial Facilities with Confined Underground Storage Tanks

Table 2.8: Industries Declining to Provide Information and Posing a Potential Threat

Sr. No.	District	Block	Name of Industry
01	Haridwar	Bahadarabad	Hero Honda Motors Ltd
02		Bahadarabad	Century Foundry Forge Plant (BHEL)
03		Bahadarabad	Rockmen Industries India
04		Roorkee	Bharat Petroleum Corporation Ltd
05	Udham Singh Nagar	Kashipur	India Glycols Ltd
06		Rudrapur	Parle Biscuits Pvt. Ltd
07	Nainital	Haldwani	Century Pulp and Paper Mills Ltd
08		Haldwani	Indane Bottling Plant
09	Champawat	Champavat	Tanakpur Hydro Electric Project –NHPC

All of the industrial installations that declined to provide information are situated in or near dense industrial clusters and are expected to be using hazardous materials. The precautionary principle applies, and these facilities must be treated as hazardous and attempt made to quantify their potential threat in the future.

2.6.3 Exposure and Threat Zones

Threat zones giving the distinct hazard have been mapped and exposure to property and people has been assessed within these threat zones. Encroachment of development in to the threat zones of the MAH industries is a statewide concern. Enforcement of regulations preventing encroachment is poor. All maps of the threat zones are given in Appendix F, and an example for one facility (Dukes Products) is provided in Figure 2.34 of one threat zone plus a buffer zone.

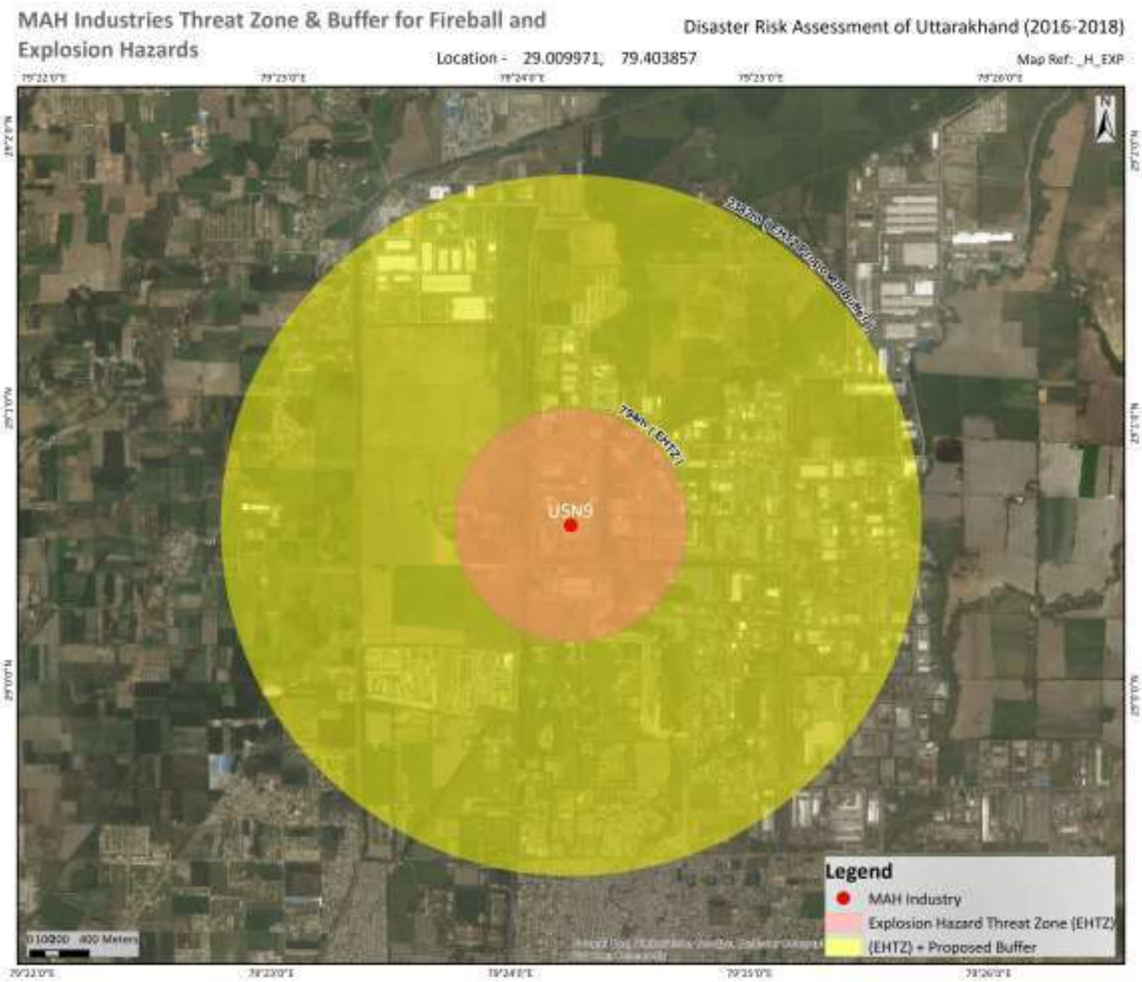


Figure 2.34: Example of Threat Zone Mapped for Facility USN9 (Dukes Products)

Table 2.9: Threat Area End Points Distance from Source Point in m Ø (diameter)

Code	District	Block	Industry name	Fire - Pool/Jet	Explosion - fireball - BLEVE	Flammable Area of Toxic vapor cloud
DDN1	Dehradun	Doiwala	Hindustan Glassware	63	490	261
HRD2	Haridwar	Bahadarabad	Indian Bottling Plant	64	966	264
HRD 12	Haridwar	Bahadarabad	Munjal Soya	63	0	261
HRD13	Haridwar	Bahadarabad	Neel Metals Pvt. Ltd	63	513	261
HRD4	Haridwar	Narsan	IOL-Bottling LPG Plant	177	0	0
HRD5	Haridwar	Narsan	Hindustan Petroleum	114	0	0
HRD6	Haridwar	Roorkee	Confidence Petrochem	64	945	263
USN2	Udham SN	Kashipur	Surya Roshani	65	567	261
USN4	Udham SN	Kashipur	Naini Paper	0	0	2800
USN5	Udham SN	Kashipur	Naini Tissue	0	0	2800
USN8	Udham SN	Rudrapur	Voltas Ltd	20	0	0
USN9	Udham SN	Rudrapur	Dukes Products	40	402	794
USN10	Udham SN	Rudrapur	Badve Engineering	12	0	0
USN11	Udham SN	Rudrapur	Mahindra Egine Steel	63	462	261
USN13	Udham SN	Rudrapur	Thai Summit - Neel Au	390	390	261
USN14	Udham SN	Rudrapur	Bajaj Auto	32	0	0
USN15	Udham SN	Rudrapur	Tata Motors	84	850	323
USN19	Udham SN	Rudrapur	Ashok Leyland	63	549	263
USN20	Udham SN	Rudrapur	Hindustan Zink Ltd	65	390	261
UNS21	Udham SN	Rudrapur	Varroc Engineering	63	390	261
USN16	Udham SN	Kashipur	Siddharth Paper Unit 2	63	383	260

Code	District	Block	Industry name	Fire - Pool/Jet	Explosion - fireball - BLEVE	Flammable Area of Toxic vapor cloud
USN17	Udham SN	Sitarganj	La Opala RG ltd	63	390	258
USN18	Udham SN	Sitarganj	Parle Biscuits	63	527	262

2.6.4 Exposure to Significant Industrial Hazards

The following table provides a block level summary of the built up area exposed within the threat maximum threat zone of significant industrial hazards.

Table 2.10: Block Ranking for Exposure within Maximum Threat Zones

Sr. No	Block	Built-up Area (m2)	Dispersion Area (m2)
1	Rudrapur	1,171,601	5,802,656
2	Bahadrabad	1,132,830	3,848,769
3	Kashipur	1,117,625	6,659,280
4	Roorkee	269,028	2,811,934
5	Sitarganj	262,779	1,350,385
6	Doiwala	191,433	756,025
7	Jaspur	83,189	460,219
8	Narsan	23,503	132,041
	Total	**4,251,988**	**21,821,309**

2.6.4.1 Threat: Thermal Radiation from Fire

Pool Fire: A pool fire occurs when a flammable liquid forms a puddle on the ground and catches on fire. ALOHA models and estimates the direct impact zone of pool fires on land. Thermal radiation is the primary hazard associated with pool fire.

Jet Fire: this type of fire occurs when a flammable chemical is rapidly released from an opening in a container and immediately catches on fire much like the flame from a blowtorch. ALOHA models jet fire from gas pipeline and tank sources. The primary hazard arising from this type of fire is thermal radiation.

ALOHA results are used to determine the likely end-point of the impact zone from the source point. The extent varies depending upon the flammable chemical under assessment, for instance Diesel, Petrol, Propane, Methane etc all result in different hazard characteristics. For each installation confirmed to have flammable and hazardous material in storage, the threat zones are visualized in three radii of intensity: (1) Red zone - potentially lethal within 60 seconds, (2) Orange - 2nd degree burns within 60 seconds, and (3) yellow - pain within 60 seconds.

Block wise assessment of these maximum threat end-points (circumference of the Yellow impact area) indicates that all of the 21 industries with a significant threat of fire have the threat area ranging from 12 m to 390m.

2.6.4.2 Threat: Thermal Radiation from Fireball and BLEV Explosion

If a flammable chemical is above its boiling point when the container fails, some or all of the liquid will flash boil and instantly become gas. This can result in an explosive fireball, and the extent of the fireball is determined by how much of the liquid chemical flash boils. This is termed a Boiling Liquid Expanding Vapor Explosion (BLEVE).

The ALOHA results indicate that the thermal radiation threat zones from BLEVE are significant for 15 installations with threat zone end-points ranging from 383 m to 966 m from the source point. Udham Singh Nagar has 11 of these installations, whereas 3 are in Haridwar, and the remaining 1 is in Dehradun. The highest threat zone distances are in Haridwar at facilities HRD 6 and HRD 2.

2.6.4.3 Threat: Flammable Area of Vapor Cloud

An outdoor vapor cloud explosion or toxic release is the result of the release of gas, vapor or mist in to the atmosphere, forming a cloud within the fuel's flammable limits causing subsequent ignition. The ALOHA model has been used to determine the end points of the flammable area of the vapor cloud generated from storage of Propane, Chlorine, or Heavy Gas.

Installations indicating the largest threat zone had estimated threat zone endpoints of 2800 m from the source, and these were for two paper industries in Kashipur. For other industrial facilities, endpoint distances ranged from 258m to 794m. Most of the industries have endpoint of 258 to 264. Five industries were assessed not to have this hazard.

2.6.4.4 Estimated Direct Damages to Buildings

Economical losses are due only to explosion and damage of buildings due to pool fire, jet fire and fire balls. There is no damage or loss to buildings due to vapour cloud. Losses were estimated for different intensities of hazard by taking a proportional of the construction cost per sq.m and relating to the intensity (red 80% loss, orange 60% and yellow 40%).

Table 2.11: Estimated Direct Damage to Buildings Arising from Simulated Events at Major Hazardous Industries

S.No.	Industrial Code	Tentative Economical Loss	
		Max.	Min.
1	USN2	1,593,219,432	26,423,736
2	USN4	0	0
3	USN5	0	0
4	USN8	2,268,384	2,268,384
5	USN9	1,156,276,968	5,647,056
6	USN10	653,088	633,504
7	USN11	527,253,072	288,384
8	USN13	1,188,665,976	12,398,616
9	USN14	12,195,168	2,296,272
10	USN15	2,076,615,456	3,181,488
11	USN16	482,796,384	21,586,176
12	USN17	672,873,480	15,218,232
13	USN18	1,121,559,024	22,115,928
14	USN19	1,451,128,944	29,801,736
15	USN20	341,171,232	20,406,600
16	USN21	1,072,532,568	4,238,280
17	DDN1	1,289,375,256	9,097,368
18	HRD2	5,014,715,304	21,966,720
19	HRD4	94,042,776	66,926,736
20	HRD5	58,415,736	56,465,592
21	HRD6	1,526,192,232	51,304,056
22	HRD12	23,298,816	288
23	HRD13	1,973,923,872	16,819,752
Total:		**21,679,173,168**	**389,084,904**

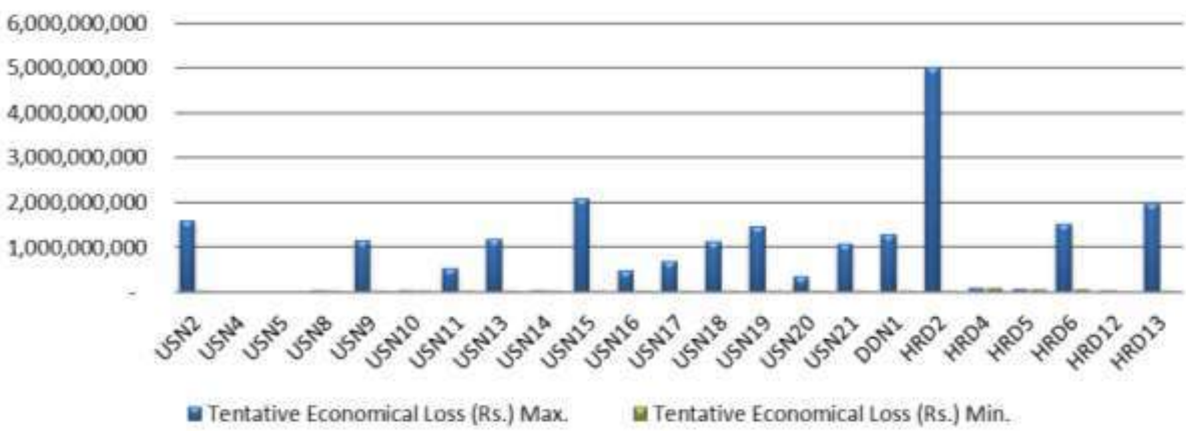


Figure 2.35: Chart showing Tentative Economical Loss of Hazardous Industries

It has been observed that the district of Udham Singh Nagar has the most hazardous industries and that the district of Haridwar is also under high risk because the industries present in this district are situated in the densely populated/constructed areas.

According to Figure 50, the industry code HRD 2 (Indane Bottling Plant situated in Badrabadh Industrial Estate) is located in a very densely populated region.

2.6.4.5 *Estimated Human Losses*

To estimate the human loss, we have considered the area under different intensities of hazard within the impact zone and considered the estimated population density of the impacted area. The level of human loss is as follows for each impact intensity: red 100% mortality, orange 70% mortality and yellow 50% mortality. The level of causalities and affected people will also depend upon the time of the event - day and night results. It may be varied based on different scenarios, but we have considered an average population density of respective district.

Table 2.12: Human Loss Comparison of Listed Hazardous Industries

S.No.	Industrial Code	Tentative Human Loss		
		Pool Fire, Jet Fire & Fireball	Vapour Cloud	Total Human Loss
1	USN2	422	48	470
2	USN4	0	1399	1399
3	USN5	0	1399	1399
4	USN8	0	0	0
5	USN9	200	47	247
6	USN10	0	0	0
7	USN11	280	47	328
8	USN13	200	47	247
9	USN14	1	0	1
10	USN15	200	74	274
11	USN16	192	47	239
12	USN17	200	46	246
13	USN18	365	48	413
14	USN19	396	48	444
15	USN20	200	47	247
16	USN21	200	47	247
17	DDN1	283	40	324
18	HRD2	1516	57	1574
19	HRD4	46	0	46
20	HRD5	19	0	19
21	HRD6	1364	57	1421
22	HRD12	6	56	62
23	HRD13	399	56	455

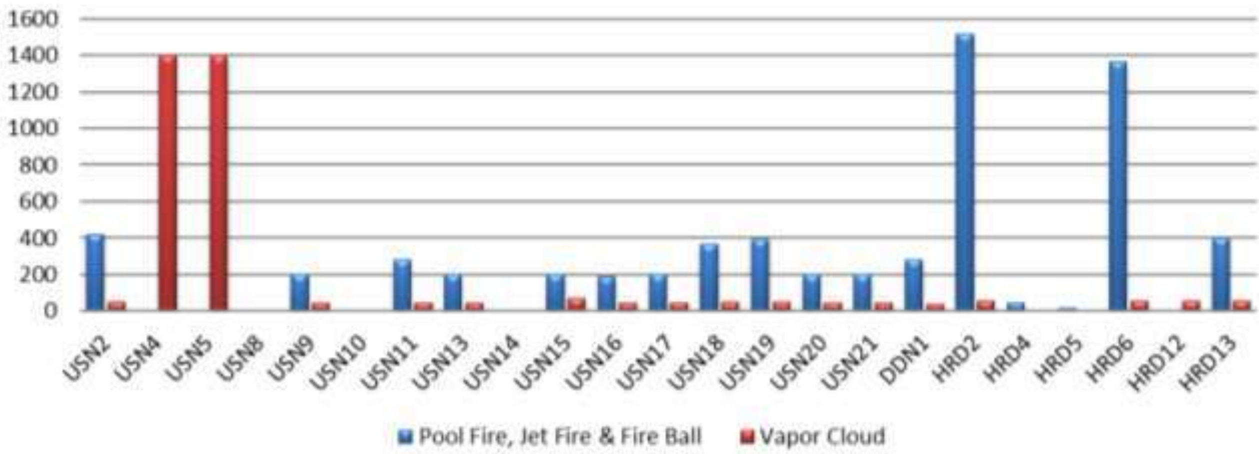


Figure 2.36: Chart showing tentative loss in various Hazardous Industries

The highest social loss due to pool fire, jet fire and fireball is found to arise from industrial codes USN4 and USN5.

The highest social loss due to vapour cloud is found to arise from HRD2 and HRD6.

2.6.5 Buffer Zones

Similar to provisions made for buffer zone for pollution control measures, there is no guideline for buffer zoning ahead of endpoint distance of modelled radius of hazard threat zone. Now the time has come to give importance for planning of disaster preparedness, mitigation. The present practices allows some precaution and preventive measures. It is therefore suggested that the buffer zone - radius of two times of the yellow end point distance for evolving planning and reinforcing regulatory measures to check the encroachments, growing population in hazard sensitive area.

Accordingly, the team has generated maps showing outer radius (beyond yellow endpoint of threat zone from source point) as buffer zone. The reader is referred to Appendix F for the maps.

2.6.6 Exposure to Hazardous and Bio-medical Waste Sites

Most bio-medical waste in the state is generated from 4 major cities (as per data available) - Dehradun, Roorkee, Haldwani and Kashipur. The data suggests that among all the cities of Uttarakhand, Dehradun is generating the most bio-medical waste, around 4,188.2 kg/day, which is collected and transported by MPCC/Pehal and treated by deep burial in landfill sites.

Field surveys noted that all the cities in the state do not have adequate treatment facilities, most if not all waste, is collected from the institutions and is dumped openly by the collection agency in a separate or common landfill. It is observed that all the waste generated from the different institutions such as hospitals is collected separately by the different collection agencies in different cities and then transported to the dump yards or landfills allocated by the Nagar Nigam.

It is observed that the general composition of bio-medical waste is non-hazardous/non-toxic and, with time, it will naturally break down. Most landfills are located on the outskirts of the cities where the population density is very low so that the chance of direct contact and infection to the public is reduced. No major river or water body is directly connected to the landfill area and so contamination to the surface water is unlikely.

However, the landfills are underlain by natural ground and there is no provision in place such as an impermeable base to stop leachate seeping into the groundwater increasing the risk of ground water contamination in nearby areas. It was also observed that bio-medical waste and general waste are commonly found together in some of the landfills. Available data of total bio- medical waste generated in Uttarakhand from the 4 major cities (Dehradun, Roorkee, Haldwani and Kashipur) along with projected total bio-medical waste generation is shown in following table. The reader is also referred to the table confirming the status of Pathology Labs, Private Hospitals, Veterinary Hospitals, Govt. Hospitals 2013 in the Industrial Facility Hazard and Exposure Assessment in Appendix F.

Table 2.13: Bio-medical Waste Projection and Annual Requirement

Data	Year	Total No. of Hospital	Total No. of Waste Generated (kg/day)	Total No. of Waste Treated (kg/day)	Untreated Waste (kg/day)	Annual Projection of Untreated Waste (kg/year)
Data Available	2013	338	1355	1084	271	98915
	2014	358	1426	1141	285	104025
	2015	351	1408	1126	282	102930
Projected	2016	372	1487	1190	297	108549
	2017	364	1458	1166	292	106433
	2018	386	1544	1235	309	112723
	2019	379	1514	1211	303	110525
	2020	401	1604	1283	321	117057
	2021	393	1572	1258	314	114774
	2022	416	1665	1332	333	121557
	2023	408	1633	1306	327	119187

It is recommended that all landfills for bio-medical waste should be separately identified by Government of Uttarakhand authorities on the basis of various factors such as population density, water body, transportation facilities, capacity, etc. Waste treatment infrastructure is strongly needed to be reinforced by the Government of Uttarakhand as the quantity of untreated waste is projected to increase year by year. It has been highlighted in field studies that the most widely used method of treating waste is deep burial, which is not standard procedure of treating bio-medical waste, consequently increasing the risk of contamination to the ground water. The Government of Uttarakhand is advised to make strict guidelines for the treatment of bio-medical waste and implement them in all cities.

Discussions with the public while undertaking the field surveys found that no standard procedure for collecting bio-degradable waste from residential areas exists and even quantities of waste are also not clear. There is an immense need of strict guidelines at every Nagar Nigam level.

2.6.7 Debris Dumping Sites, Effluent and Spillage Release Sites

During field investigations, debris dumping sites, effluent and spillage releasing sites were observed at the following industrial installations.

Table 2.14: Confirmed Debris Dumping and Effluent Release Sites

Sr. No.	District	Block	No of industrial installation with affluent spillages	Affluent / spillage Injected in to Ground	Released in to surface water drain points	Debris dumping sites -
01	Champawat	Champawat	No traces	---		---
02	Almora	Tarikhet	No traces	---		---
03	Almora	Hawalbag	No traces	---		---
04	Nainital	Haldwani	1 - Century Paper and Pulp Co.	Traced	Gaula River	Traced dumping improper
05	Udham SN	Jaspur	1 Sidhharth Paper Mills	Traced		Traced
06	Udham SN	Kashipur	4 India Glycols, Surya Roshni, Naini Paper, Naini Tissue	Traces need further investigation		
07	Udham SN	Rudrapur	10 Installations	Traces need further investigations		
08	Udham SN	Sitarganj	2 La Opala RG and Parle Biscuits	Traces, need further investigation		
09	Haridwar	Roorkee	1 Confidence Petro	Traces		
10	Haridwar	Narsen	2 Indian Oil and HPC	Traces		
11	Haridwar	Bahadarabad	6 BHEL, Indian Bottling, Hero Honda,	Traces		

Sr. No.	District	Block	No of industrial installation with affluent spillages	Affluent / spillage Injected in to Ground	Released in to surface water drain points	Debris dumping sites -
			Rockmen, Munjal Soya, Neel Metals			
12	Haridwar	Laksar		No traces	----	----
13	Dehradun	Vikasnagar	No traces	No traces	----	----
14	Dehradun	Doiwala	1 Hindustan Glass	Traces	Local seasonal flowing nalla	Unorganized Dumping

During conformation of the hazard profile and site visits, the field team could trace that:

1. All the 27 industries are indulged in either affluent / spillage release in to surface run-off of water of local seasonal or perrenial river flows or in to ground water. The more serious issues in this regard are in Haldwani, Bahadarabad, Roorkee, Narsen, Rudrapur, Kashipur, Jaspur, and Doiwala blocks in Nainital, Haridwar, Udhamsingh nagar and Dehradun.
2. Injecting effluent and spillage in to the ground is prevailing in those blocks where there are no surface water drain points where these can be released.
3. Industrial Waste is being dumped in an unorganized and unscientific way. During site visits, the deteriorated ground conditions - release of chemical and other unwanted pollutants in the ground and ground / surface water as well as in the air.
4. There is a need to strengthen enforcement of the water, air regulations, and compliance of industrial effluent disposal as well as waste disposal following every legal and policy framework by the competent authority.
5. Information, education and communication will be helpful to bring awareness and collective action of all industries.
6. SIDCUL and the competent authorities within the state may promote best practices of managing effluent, pollution checks, water quality monitoring of all ground water and surface water sources used for the drinking purpose.

2.6.8 Transportation Risk of Hazardous / Volatile Material

Oil tankers transiting hazardous and volatile material to the respective industries represents a very dangerous hazard for the area and people in the vicinity of the main transport corridors. Under the study, a hazard scenario was assessed for an exploding oil tanker with a standard capacity of 12,000 liters moving through a densely populated area. ALOHA modelling was used to generate thermal radiation hazard from a jet fire.

The model results indicated a potentially lethal threat within 52m from source point over the initial 60 seconds. Up to 162 m from source point, the impact will be 2nd degree burns within 60 seconds. Up to 324 m from the source, there will be experience of pains within 60 seconds.

It was observed that some of the industries have a good number of tanker movements with hazardous chemicals. A separate and comprehensive assessment of the transport routes is required, with a detailed study of routes followed by the truckers / tankers.

Figure 2.37: Scenario Modelled for a Tanker Explosion During Transport

2.6.9 Conclusions from Industrial Assessment

The following conclusions can be drawn from the industrial hazard assessment:

- The state of Uttarakhand has 13 districts, out of which there are 3 districts that are assessed to pose a significant threat from potential industrial hazards; namely Udham Singh Nagar, Hardiwar and Dehradun.
- 74 industries and 4 oil depots were short-listed from Department of Industries and Boilers data for the hazard assessment.
- 23 industries are identified as hazardous in which 16 are in Udham Singh Nagar District, 1 in Dehradun District and the remaining 6 in Haridwar District.
- Most of these hazardous industries are located in the district of Udham Singh Nagar. There were 9 industries (~12%) who denied giving the data required for this study and it is unknown whether or not they use and/or store hazardous chemicals.

- Under the category of underground tanks, 4 industries are listed (~5%) and have a hazardous profile, although ALOHA modelling cannot be undertaken for underground tanks and it is concluded that these facilities present a lower hazard to neighbouring communities given the underground containment.
- The highest social loss due to vapour cloud is attributed to facilities HRD2 and HRD6.
- The facility HRD2, which is in the district of Haridwar, has the highest capacity of risk if a catastrophic event occurred with an estimated economical loss of Rs. 5,014,715,304.
- This study shows that the district of Udham Singh Nagar has the highest number of hazardous industries. It has been noted that Haridwar District is also under high risk because the industries present in these districts are situated in densely populated and constructed areas.
- The facility HRD 2 - Indane Bottling Plant, is located in Badrabadh Industrial Estate, which is situated in a very densely populated region thus some steps should be taken for the socio-economic safety.
- Human loss is based on risk factor and the population density of its respective districts. The highest human loss is found in the Udham Singh Nagar and Hardiwar districts, where industries are located in densely populated area.
- From the ALOHA modelling of the transportation system it has been recommended that 2 trucks or tankers with volatile materials should maintain a distance of 500 metres from each other to minimize the risk.

CHAPTER 3
Methods for Hazard Assessments

3 METHODS FOR HAZARD ASSESSMENTS

This section of the report summarises the approach and methodology for hazard modelling and for the assessment of risk (earthquakes and fluvial floods) and exposure (flash floods, landslides, and industrial hazards). This is a critical component of Component 3 of the terms of reference (TOR). As required under the TOR, emphasis is placed on describing the hazard modelling approaches in detail, and their scope and limitations.

3.1 SEISMIC HAZARD MODELLING

3.1.1 Introduction

This chapter presents the probabilistic seismic hazard analysis (PSHA) performed for the state of Uttarakhand. A brief description of seismotectonics and seismicity aspects of the region is presented, (as the basis for the selection of the regional seismic source model), followed by a discussion of the instrumental and historical earthquake catalogues used in our analysis. Based on seismotectonics and the earthquake catalogues, the region was divided into source zones. For each of these zones, the seismic parameters were estimated and the selection of an appropriate ground motion prediction equation (GMPE) was assessed.

Extensive literature exists on PSHA of the region and the parameters used to perform the analysis. Not surprisingly, there is often considerable disparity in the estimated parameters and, hence, the results. In our analysis, the estimation of the parameters was based on the simplest seismic source model that was consistent with the available data.

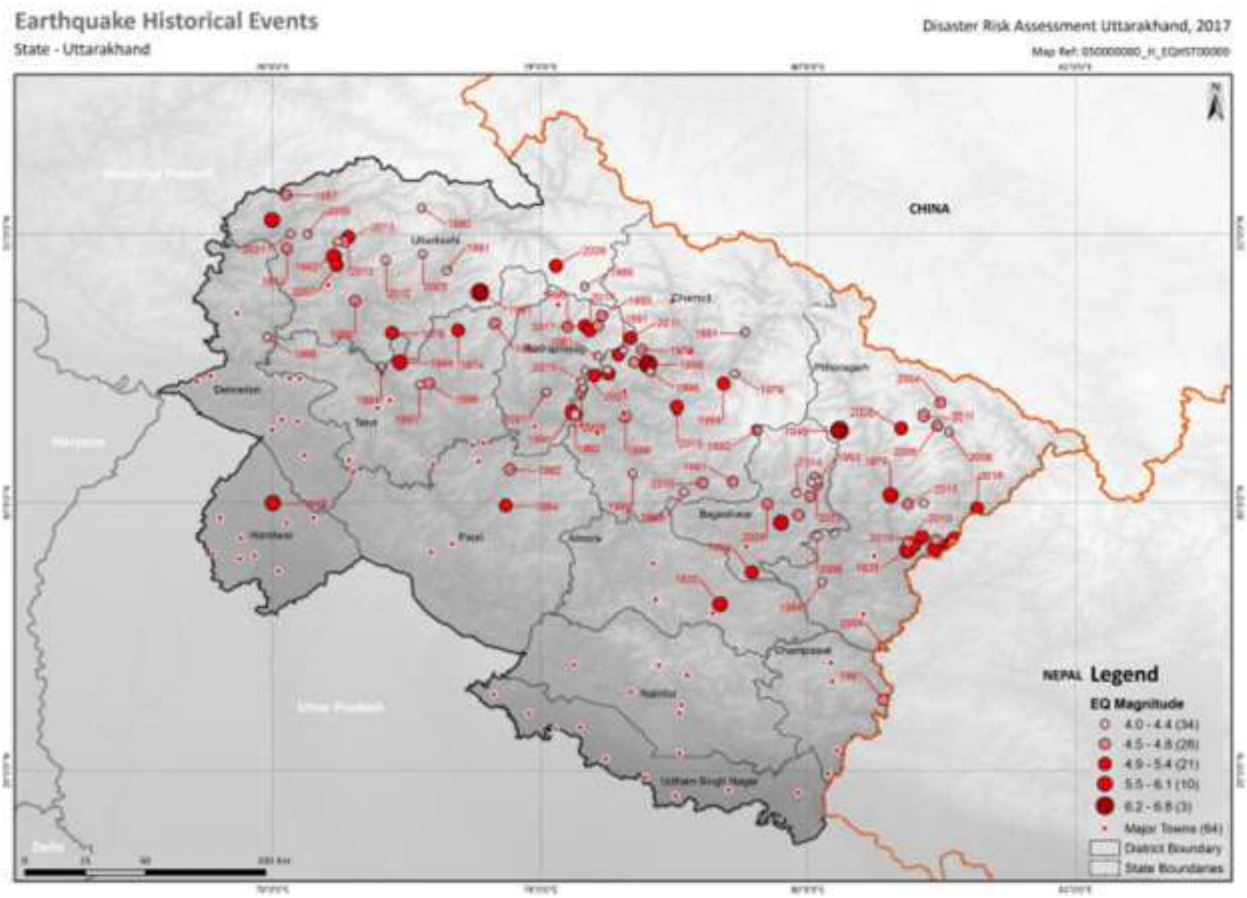


Figure 3.1: Historic Seismic Events in Uttarakhand (Magnitude >4.0)

3.1.2 Seismotectonics of the Himalayan Arc

Seismicity along the Himalayan arc is a consequence of the continent-to-continent collision of the Indian and Eurasian plates. A simplified geological map of the Himalayan arc and a NS section across central Nepal are shown in Figure 3.2 (Avouac, 2009). GPS data along the arc indicate that the Himalayas accommodate about half of the 40 mm/yr convergence rate between Indian and Eurasian plates (e.g. Bilham, Larson, & Freymueller, 1997; Jouanne et al., 2004; Larson & Freymueller, 1999; Stevens & Avouac, 2015). The convergence is perpendicular to the arc, increasing eastward from 13.3 ± 1.7 mm/yr to 21.2 ± 2.0 mm/yr (Figure 3.4, from Stevens & Avouac, 2015).

The Main Himalayan Thrust (MFT) is fully locked in its updip part, over a width of ~100 ± 20 km. The 3.5-km elevation along the arc roughly coincides with the downdip edge of the locked zone. The GPS data does not suggest any barrier which may control the lateral extent of a rupture. The width of the partially coupled part of the MHT (the transition zone over which the coupling decreases from one to zero) appears variable along the arc. It has been suggested that the inter-event time and magnitude of updip earthquakes are related to the width of the transition zone (R. Bilham, personal communication, 2017).

Assuming that the measured surface strain is elastic, Stevens & Avouac (2015) estimate the seismic moment build up rate to be 15.1±1.1×1019 N m/yr along the arc, (from 730E to 960E, roughly 2000 km in length).

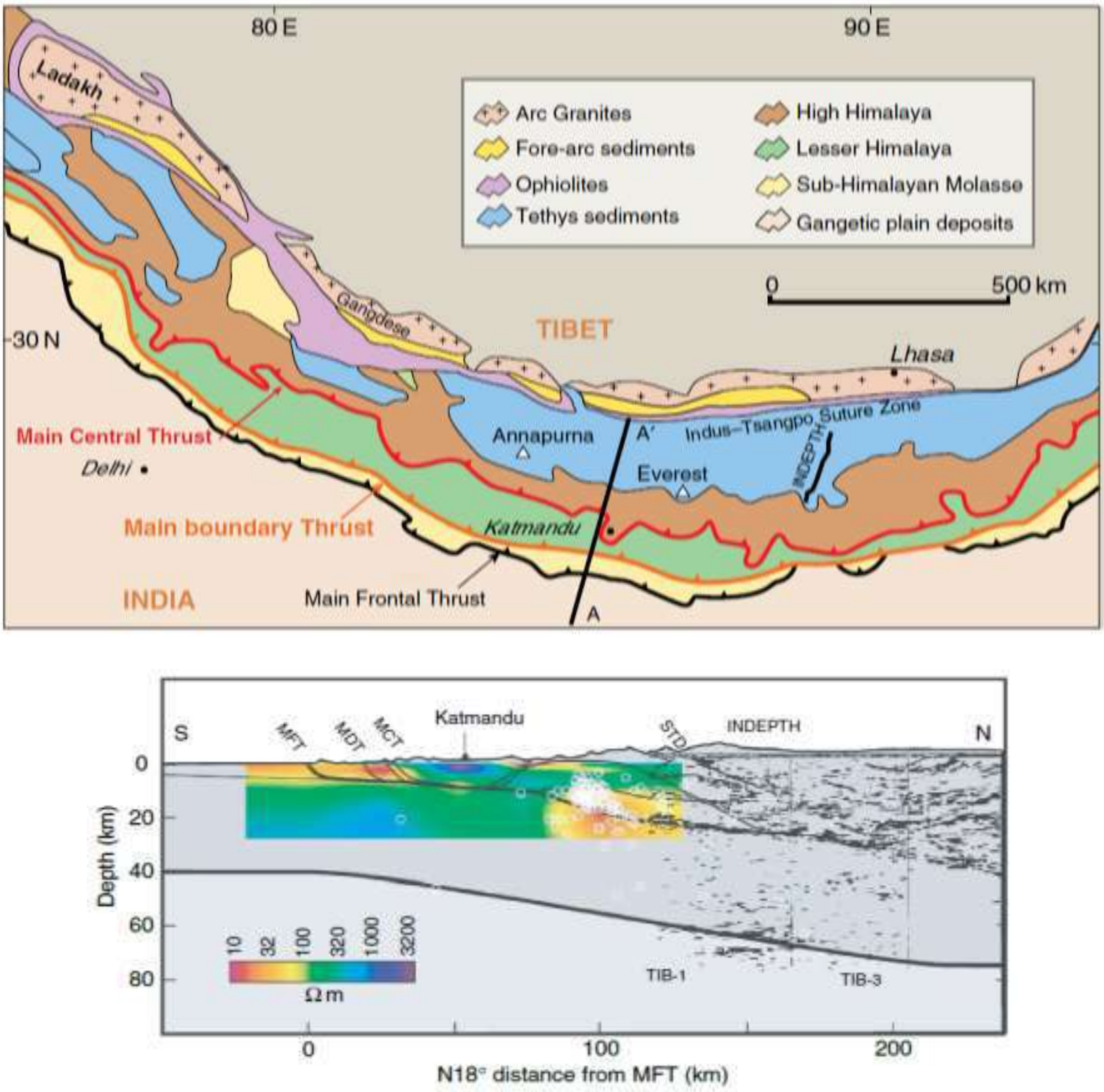


Figure 3.2: A simplified geologic map of the Himalayan arc (top), with a section (bottom) along AA' (from Avouac, 2009). White circles are hypocentres of microearthquakes

In Figure 3.3, the pattern of coupling is shown in red, overlain by the approximate locations of earthquakes Mw7.5–8 for the past 200 years and ≥8 for the past 500 years. Light blue bars indicate the rate of seismic moment release, and the approximate extent of surface ruptures of two potential major earthquakes, (dated to ~1400 A.D. and ~1100 A.D. from paleoseismic studies), is also shown.

The probability distribution function (pdf) in the inset shows the seismic moment build-up calculated from the coupling model, and the yellow bars show its distribution along the strike of the arc.

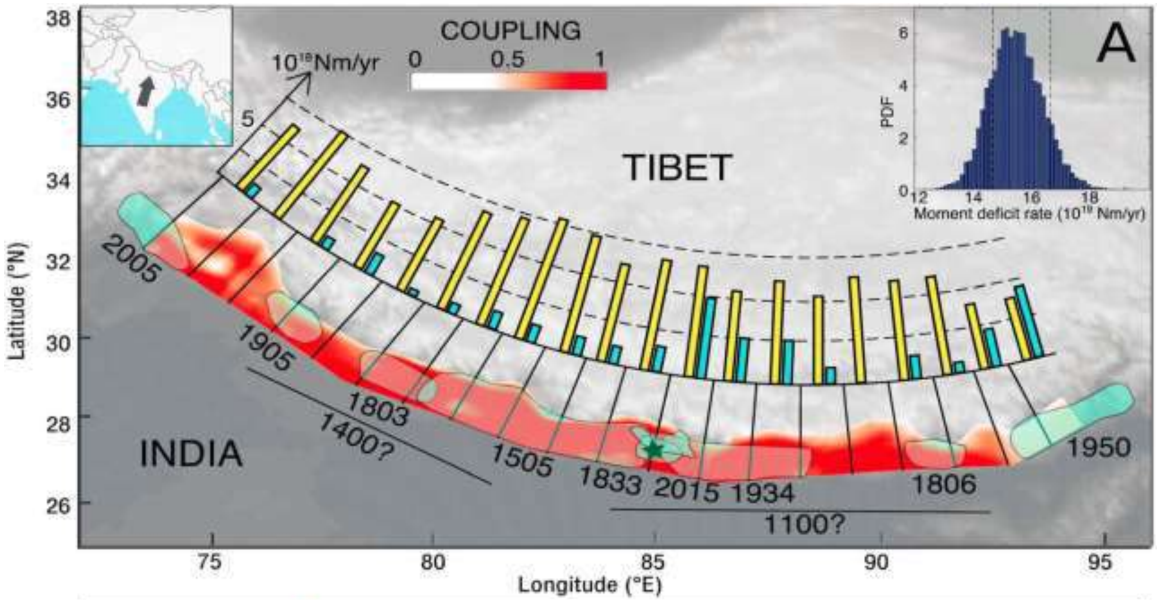


Figure 3.3: Interseismic coupling on the Main Himalayan Thrust (from Stevens & Avouac, 2015)

Figure 3.4 illustrates the same coupling pattern, now with the surface trace of the Main Frontal Thrust in dark blue and the 3500m elevation contour line in light blue. The 3,500m contour seems to mark the downdip extent of the locked fault zone.

The MHT appears locked from the surface, where it emerges along the front of the sub-Himalaya, following the trace of the Main Frontal Thrust to beneath the front of the high Himalaya. Red arrows show convergence across the range in mm/yr, while the black dots indicate seismicity from the National Seismic Centre, Nepal (NSC) and NEIC catalogues. The grey bars show the distribution of the number of earthquakes above 4.9 of the de-clustered NEIC catalogue.

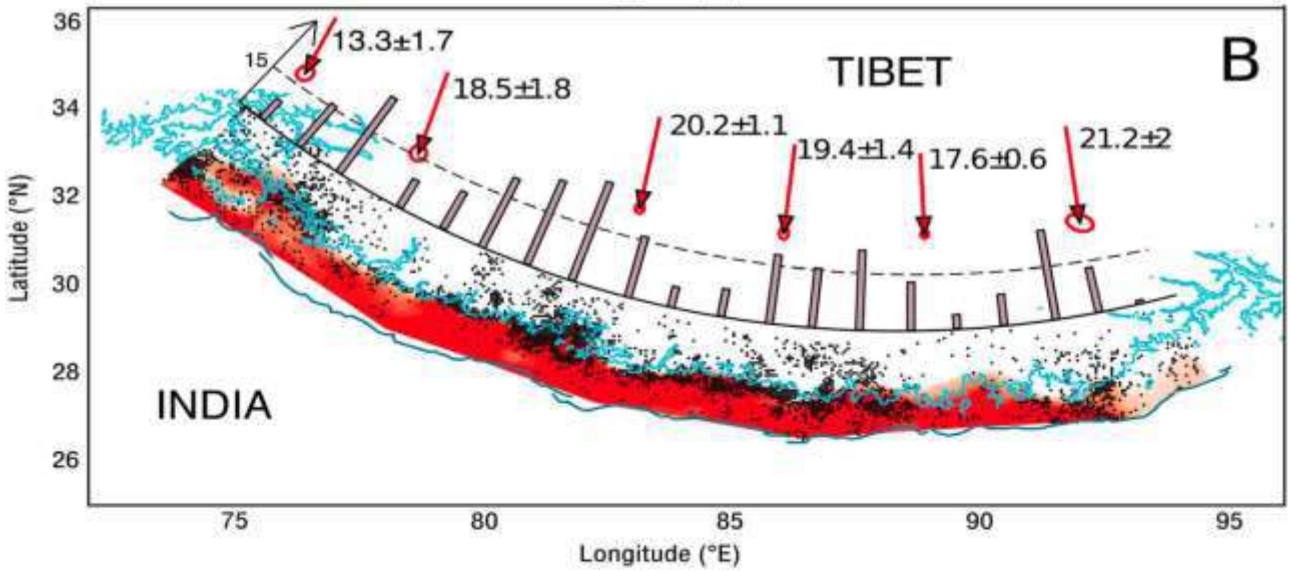


Figure 3.4: Moment buildup on the Main Himalayan Thrust (from Stevens & Avouac, 2015)

3.1.3 Observations regarding seismicity along the Himalayan Arc

Microseismic studies reveal that seismicity across the arc occupies a diffuse volume roughly centred below the 3,500m contour line, where the dip of the MHT changes. Figure 3.2 and Figure 3.5 provide examples from Nepal and Kumaon-Garhwal, respectively. Most of the seismicity occurs above the MHT, while larger earthquakes (Mw≥7), presumably, occur on the MHT. In the Kumaon-Garhwal region of Himalaya, seismicity is concentrated along a narrow line (Figure 3.5).

Except for an updip cluster, there is a lack of seismicity between this line and the Main Frontal Thrust (MFT). A lack of seismicity in the updip portion of MHT can also be seen in Nepal (Figure 3.2, bottom). The diffused nature of the seismicity does not allow us to associate events with faults such as MFT and Main Boundary Thrust (MBT) which connect with the shallow dipping MHT.

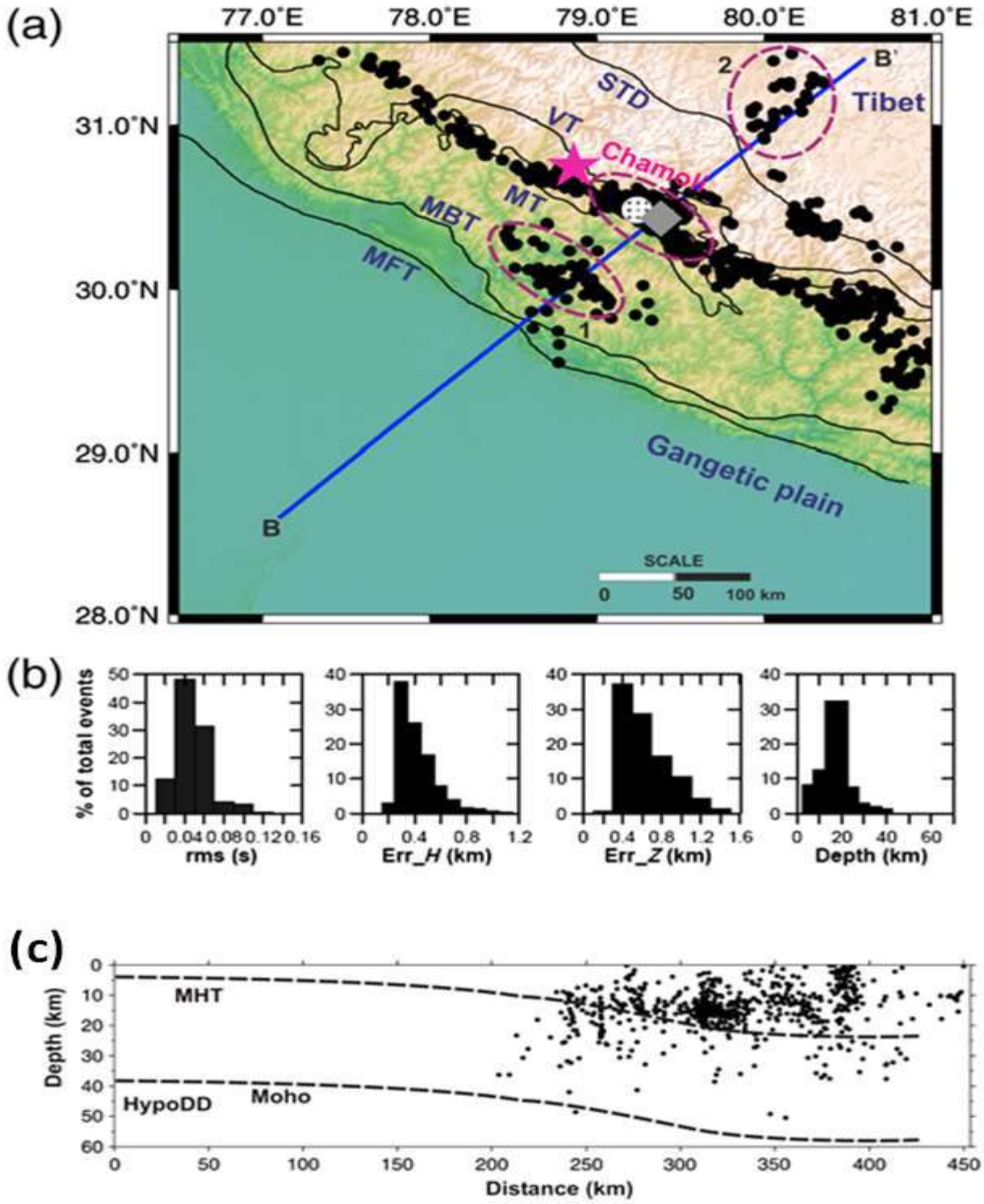


Figure 3.5: Epi-central distribution (from Mahesh et al., 2013)[6]

The rupture during the well-studied 2015 Gorkha earthquake (Mw7.9) occurred on the downdip part of the MHT, in the distance range of 45 to 95 km from the MFT, leaving the updip segment, 45 km wide, intact (

[6] (a) Epicentral distribution of the 950 earthquakes (filled dots) relocated using double-difference method (hypoDD) in the Kumaon-Garhwal region of Himalaya during April 2005 and June 2008. Note that much of the seismicity is concentrated along a narrow line. Except for an up dip cluster, there is a lack of seismicity between the line and the MFT (MT: Munsiari Thrust; VT: Vaikrita Thrust; STD: Southern Tibetan Detachment).

(b) Histograms showing error statistics for hypocentre (km), time residual (s), and depth distribution of earthquakes.

(c) Depth distribution of all earthquakes, located using double-difference (hypoDD) along an arc-normal cross-section BB´.

Figure 3.6). Thus the earthquake incompletely ruptured the MHT (from R. Bilham - personal communication, 2016).

This may also have been the case during the 1905 (Mw7.7) Kangra earthquake. It is likely that large earthquakes (7≤ Mw≤8) occur only on the downdip portion of the MHT (45 to 100 km from the MFT) and the great earthquakes (Mw > 8) rupture the MHT up to the MFT (Figure 3.7).

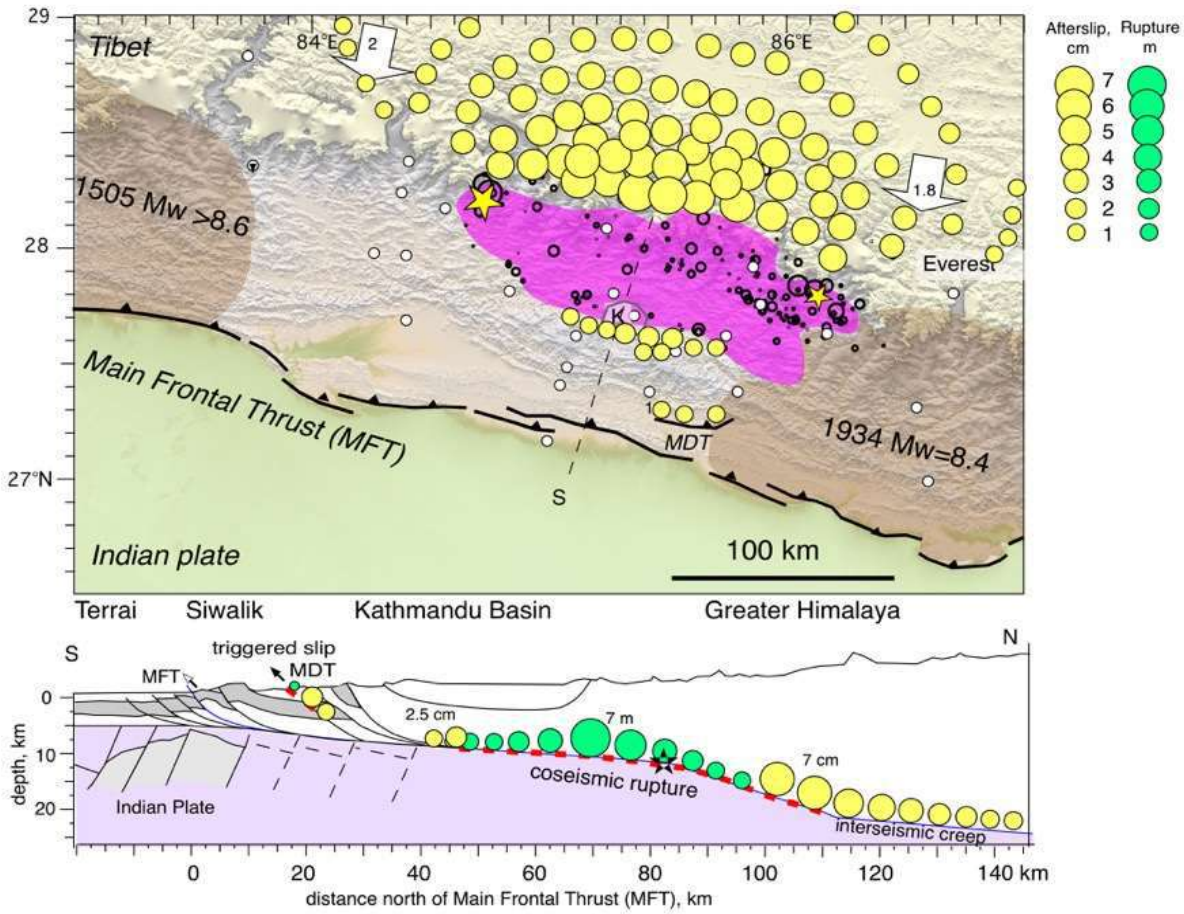


Figure 3.6: The 2015, Mw7.9, Gorkha rupture (violet) showing inferred afterslip (yellow circles scaled in cm) on the MHT six months after the mainshock, a time when 90% of the post seismic displacements were complete – from R. Bilham (personal communication, 2016).[7]

[7] In the lower panel a section across the Himalaya is shown with coseismic slip and triggered slip on the (MDT) Main Dun Thrust (red dashed line) depicted by green circles proportional to slip in meters. Afterslip (with amplitudes ≈ 1% of coseismic slip and equivalent to a Mw=7.1 earthquake) is shown as yellow circles in cm. Geodetic convergence rates are arrowed in cm/yr. Black circles aftershocks, white circles are GPS points. The mainshock epicentre is indicated by a star.

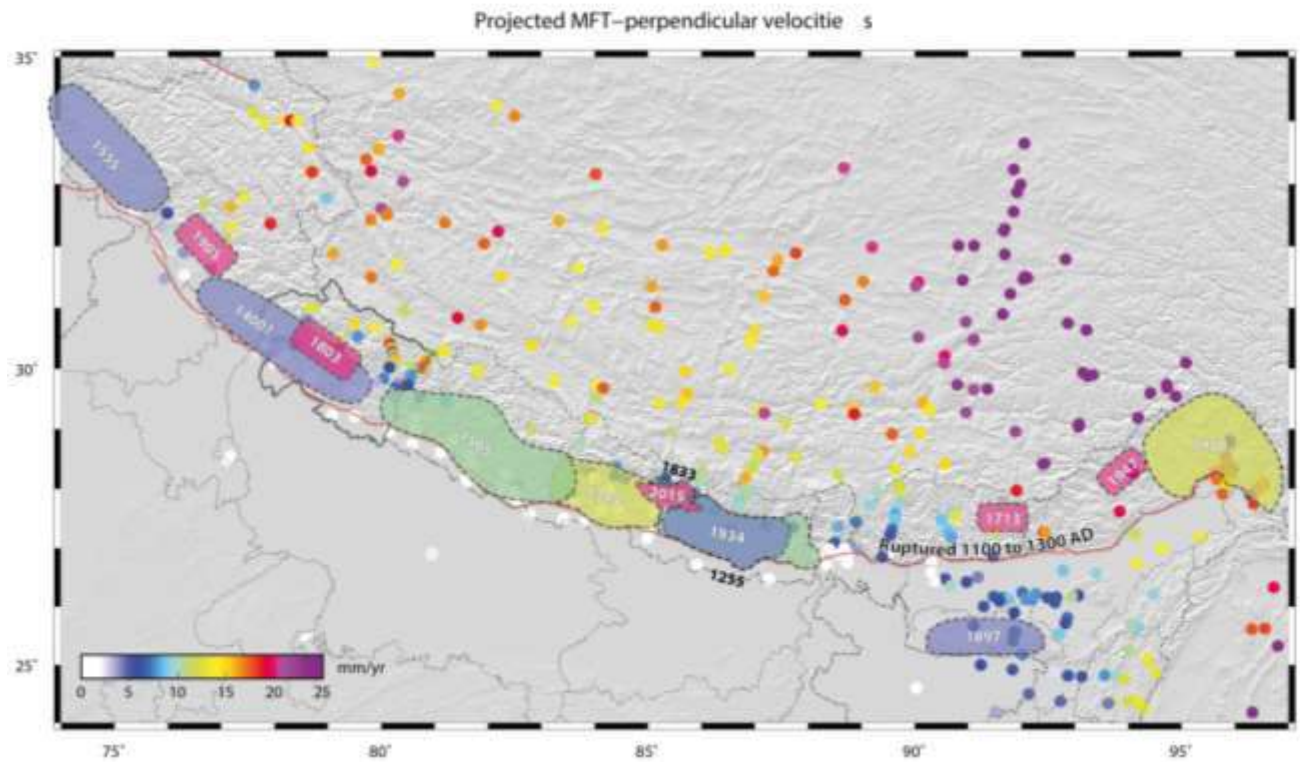


Figure 3.7: Rupture areas of large/great earthquakes along the Himalayan arc compiled by Earth Observatory of Singapore (Wang, 2016).[8]

A limited number of focal mechanisms are available along the arc. Many of these earthquakes probably occurred not on the MHT itself but on faults which connect with the MHT. It follows that from available focal mechanisms the dip of the MHT can't be reliably estimated. In our analysis, we will approximate the dip of MHT as 7° and its depth at the MFT as 7 km. These values are consistent with sections shown in Figure 3.2, Figure 3.5 and

Figure 3.6.

3.1.4 Regional Seismic Source Model

Uttarakhand is not only exposed to earthquakes that occur in the Himalayan thrust zone but also to those that occur from the Indian Stable Continental Region, at the south, to the Tibetan Plateau at the north. A preliminary report on a seismic source model for Uttarakhand, prepared by the Earth Observatory of Singapore (EOS), recommends the area of interest being extended by 500 km from Uttarakhand's NW and SE borders and 300 km from its north and south borders, and to divide this area into three major zones (Wang, 2016).

These three major zones are:

[8] Magnitudes of these earthquakes, compiled by Stevens & Avouac (2016), are: 1555 Mw7.6; 1905 Mw7.7; 1400 Mw>8.5; 1803 Mw7.5; 1505 Mw8.2; 1344 Mw>8.0;1833 Mw7.5; 2015 Mw7.9; 1934 Mw8.4; 1255 Mw8-8.5; 1100 Mw>8.5; 1950 Mw8.7.

1. Himalayan Thrust Zone
2. Indian Stable Continental Region (SCR) – named by EOS as IN regions
3. Tibetan Plateau and Karakoram Fault Zone

Each of these three zones is further divided into subzones. Figure 3.8 illustrates the zones and subzones proposed by EOS, with the colour codes differentiating the major zones. The figure also shows active faults in the region.

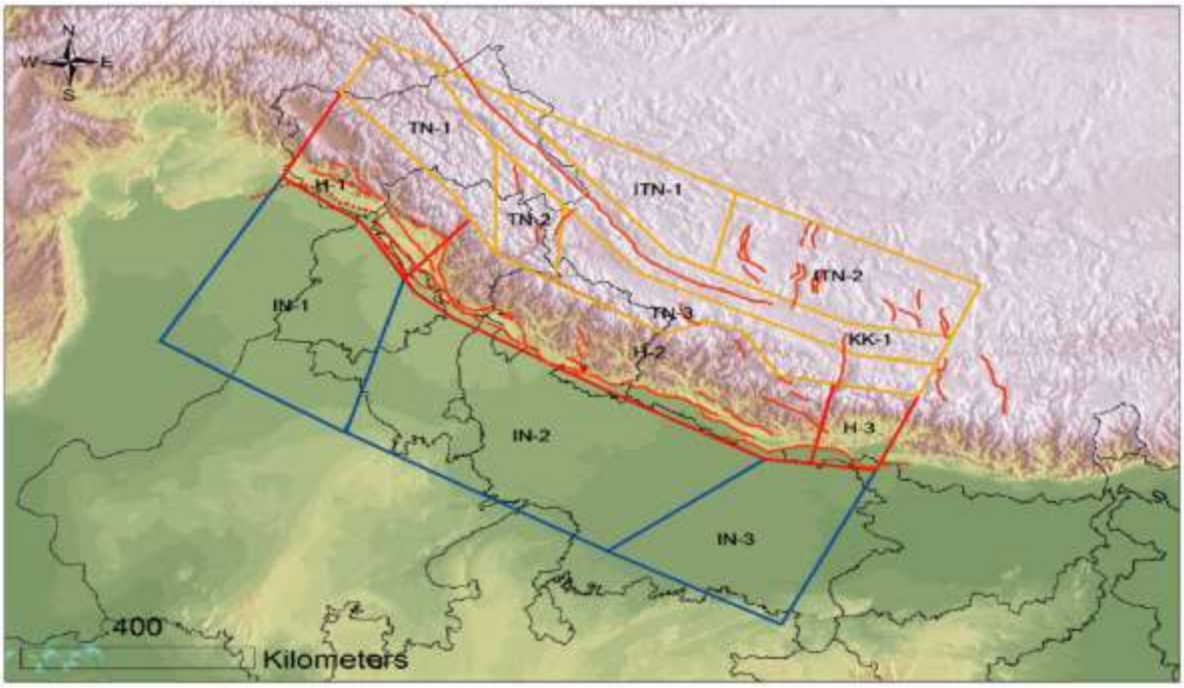


Figure 3.8: Regional source zonation proposed by Earth Observatory of Singapore (Wang, 2016)[9]

The division of the Himalayan Thrust zone into three subzones, as suggested by EOS, seems unwarranted. As mentioned earlier, the GPS data suggests that the MHT is uniformly locked from the surface over a width of 100 ± 20 km along the arc, with little variation in the geometry of the downdip edge of the locked zone, and with no resolvable barrier which may arrest the rupture propagation along the arc (Stevens & Avouac, 2015). The rupture areas of large and great earthquakes during the past millennium, although very poorly known for older events, seem to suggest that they can occur anywhere along the arc (Figure 3.7).

Instead, a six-section Himalayan Arc segmentation proposed by Bungum, Lindholm, & Mahajan (2017) was adopted, which does not lead to relatively large uncertainty in the estimation of

[9] Red polygons: Himalayan Thrust Zone (divided in 3 subzones: H-1, H-2 and H-3)

Blue polygons: Stable Continental Region (SCR) of India (divided in 3 subzones: IN-1, IN-2 and IN-3)

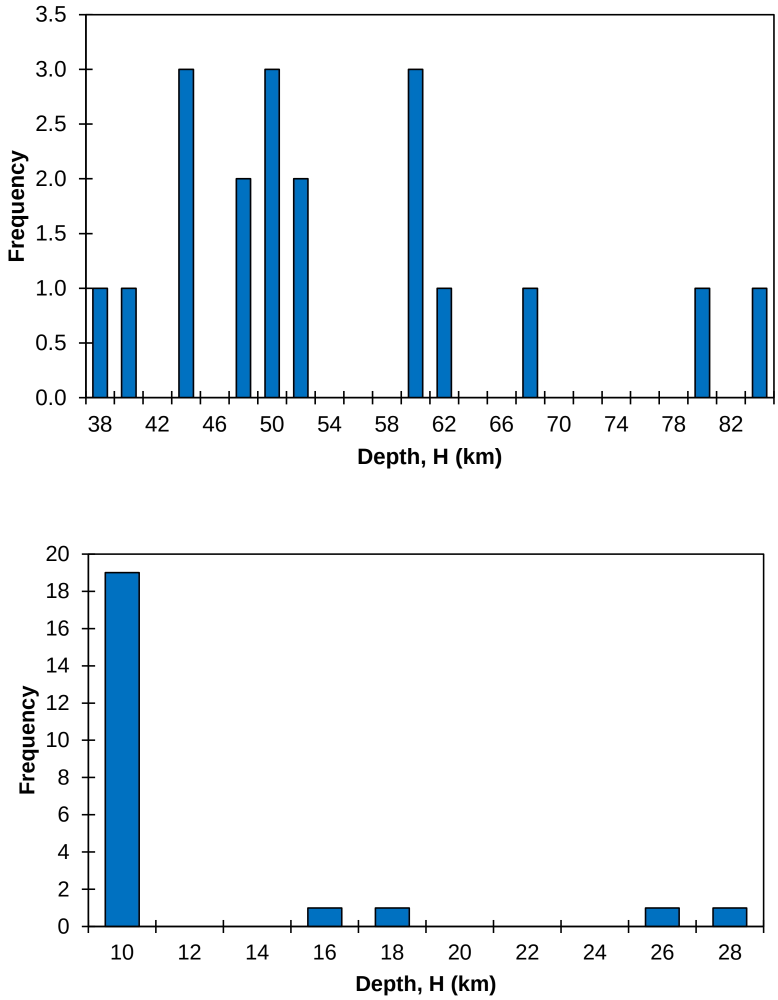
Yellow polygons: Tibetan Plateau (divided in 5 subzones: TN-1, TN-2, TN-3, ITN-1 and ITN-2) and Karakoram Fault Zone (KK-1)

Orange lines: Locations of active faults (mapped from the Digital Elevation Model and from published data) parameters of the Gutenberg-Richter relationship. On the other hand, normal to the arc, the MHT was divided into two segments: H-1 and H-2. H-1 extends from the MFT to 110 km downdip along the MHT, while H-2 extends from 50 to 150 km. Thus, the two segments overlap in the distance range of 50-110 km. They were assigned 7.0 ≤ Mw ≤8.0 earthquakes on the interface H-2 and the diffused seismicity of lower magnitude to the volume above H-2. Great earthquakes (Mw>8.0), which may reach the MFT, are assigned to H-1. A slightly smoothed MFT is taken as the southern limit of H-1; this smoothness permits accommodation of rupture areas of even megathrust earthquakes (Mw ≤ 9.0) anywhere along the arc. The proposed subzones, H-1 and H-2, of the Himalayan Thrust zone, superimposed on the seismicity map from NEIC-USGS catalogue and focal mechanisms from Global CMT catalogue are shown in Figure 3.11 and Figure 3.12. Most, though not all, events in the Himalayan Thrust Zone have a thrust focal mechanism.

A modification to these three subzones of the Indian Stable Continental Region (SCR), proposed by EOS, was made. The seismicity in the SCR is low and diffused. However, most of the events can be accommodated by the two smaller subzones, SCR-1 and SCR-2, shown in Figure 3.11 and Figure 3.12. The earthquakes in SCR-1 are somewhat deeper (30 km<H<70 km) than those in SCR-2 (H<20 km). In Figure 3.9 are presented the depth histograms for SCR-1 and SCR-2, excluding those events with depth equal to 33 km (default value assigned to unknown depth). In SCR-1, 8 events (out of a total of 28) are reported with a 33 km depth, while in SCR-2 there are 9 events (out of 35).

Focal mechanisms of 3 small earthquakes in and near Delhi indicate strike-slip faulting with some normal-faulting component (Bansal et al., 2009; Singh et al., 2010). We note that these mechanisms are distinct from that of the Moradabad earthquake of 15 August 1966 (mb5.6). The T axis of the 1966 earthquake was perpendicular to the Himalayan arc. Molnar, Fitch, & Wu (1973) and Molnar et al. (1977) interpreted the 1966 earthquake to be a consequence of stretching of the upper part of the lithosphere as it thrusts under the Himalayas. It is possible that the three small Delhi events may have resulted from local stress concentration so that they may not reflect the general stress regime of the region. In this study, normal-faulting focal mechanisms will be assumed for all events in SCR-2. There is only one event in SCR-1 subzone (1 April 1996, Mw 5.2, H=92 km), whose solution, listed in the Global CMT catalogue, is thrust. Thrust mechanism will be assumed for all events in SCR-1.

(a)



(b)

Figure 3.9: Depth histograms: (a) SCR-1, (b) SCR-2

The original seismic regions proposed for the Tibetan Plateau zone and its subdivision (T-1, T-2, T-3, IT-1 and IT-2), along with the Karakorum fault as a separate subzone (KK), were not modified. The entire region is characterised by relatively shallow seismicity (0≤H≤35 km, see Figure 3.10) and strike-slip and normal-faulting earthquakes (Figure 3.12).

Note that it all seismicity was assigned to the areal sources mentioned above. The number of well-located earthquakes is probably not sufficient to assign to individual faults which have been mapped in the region of interest.

Based on all aspects here exposed, 26 seismic regions were defined which are presented in Figure 3.13.

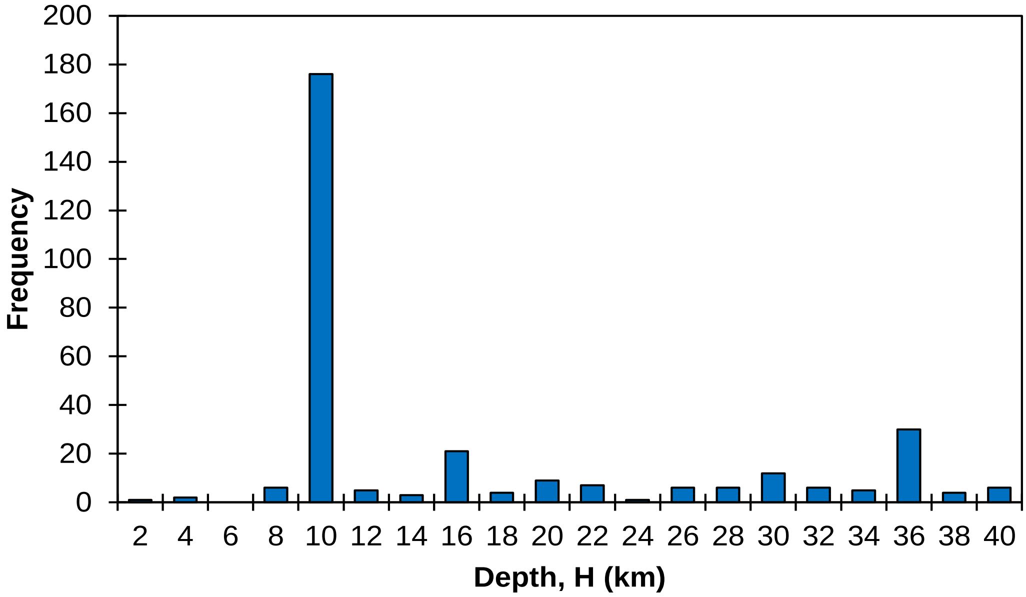


Figure 3.10: Depth histogram for the Tibetan Plateau and Karakorum fault zones, (noting that there are 156 events, out of a total of 538, reported with unknown depth (H=33 km))

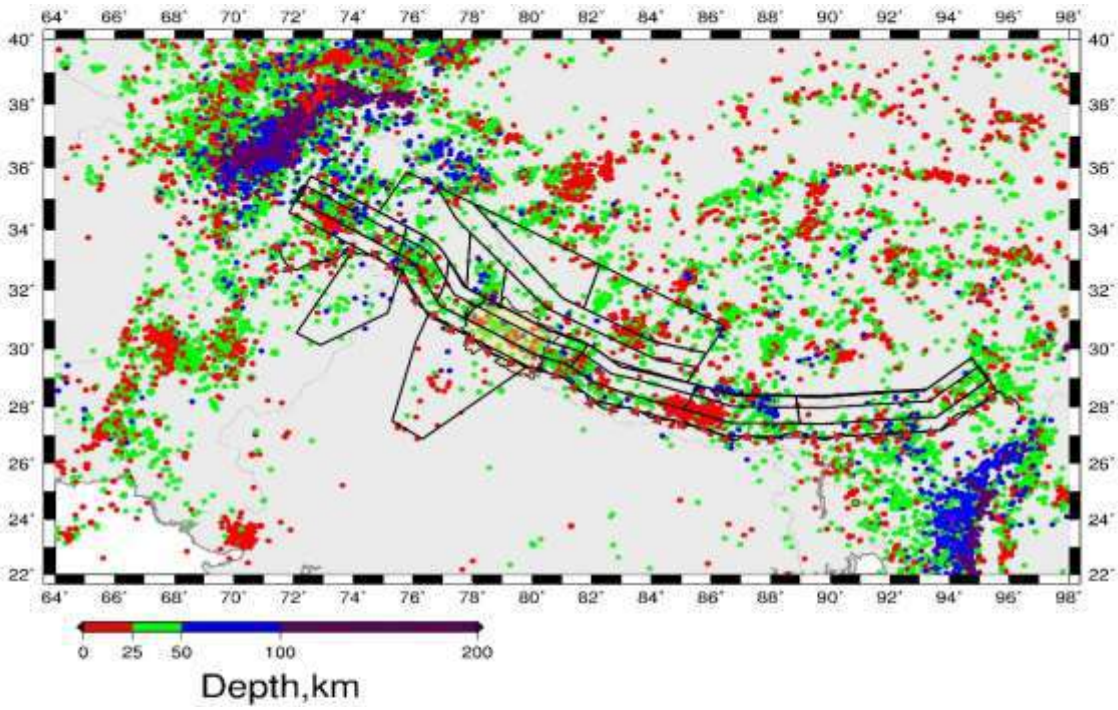


Figure 3.11: Seismicity from NEIC, U.S. Geological Survey catalogue. The definition of the MFT and source zonation which have been proposed and used in this study are shown.

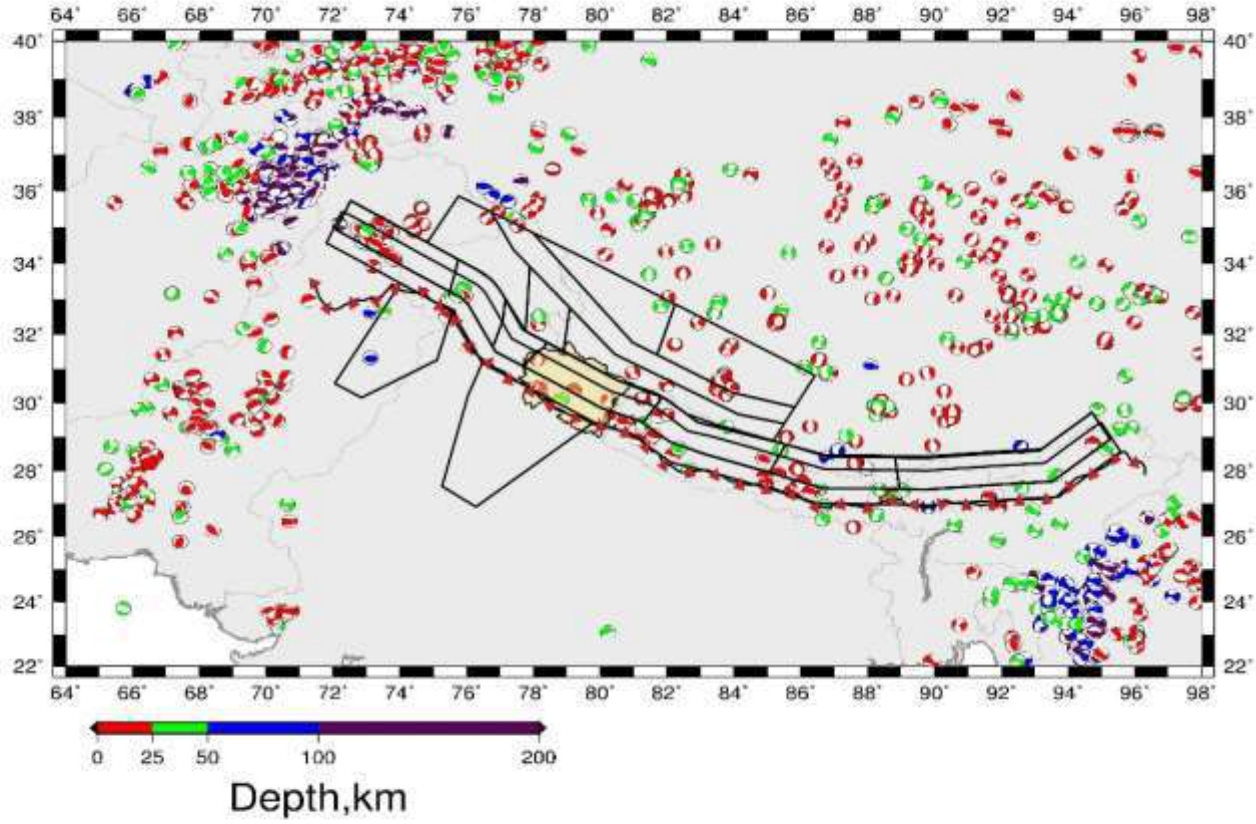


Figure 3.12: Focal mechanisms from Global CMT catalogue and the source zonation proposed and used in this study

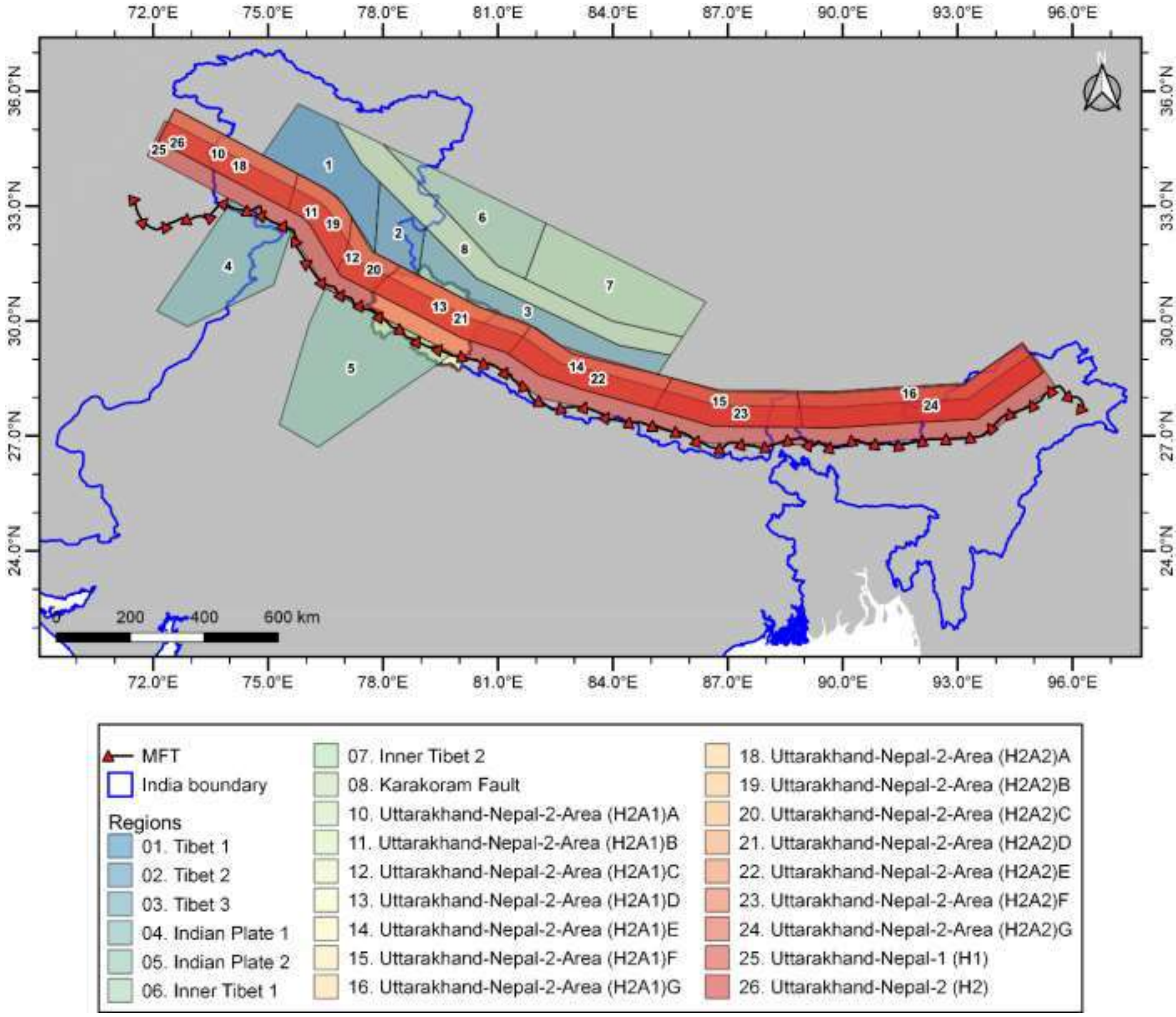


Figure 3.13: Seismic sources defined to this study

3.1.5 Earthquake catalogue

3.1.5.1 IMD catalogue

Seismicity reported in local earthquake catalogues often have an uneven seismograph distribution in the network and is affected by an increase in the number and quality of seismic stations with time. There is also the problem of type of reported magnitude in the catalogue, the formula used in its computation, and undocumented changes in the practice with time. In these regards, the earthquake catalogue of the India Meteorological Department (IMD) / National Centre for Seismology (NCS) is not the exception. The magnitude of most earthquakes reported in the

IMD/NCS catalogue is ML and, for smaller events, Mc. It is not clear whether an attenuation function appropriate for India or Richter´s original attenuation function, developed for California, has been used in the calculation of ML. Many papers deal with the conversion of magnitudes ML, mb, and Ms of Indian earthquakes to Mw (Baruah et al., 2012; Bora, 2016; Das, Wason, & Sharma, 2012a, 2012b, 2013, 2014; Di Giacomo et al., 2015; Wason, Das, & Sharma, 2012).

We used the Mw-ML and Mw-Mc relationships given by Bora (2016), and Mw-mb and Mw-Ms relationships developed by Di Giacomo et al. (2015) to generate proxy Mw magnitudes for the IMD catalogue. These equations are presented below.

$$M_W = 1.38 m_b - 1.79 \qquad M_W = \exp(-0.222 + 0.233 M_S) + 2.863$$
$$M_W = (0.98 \pm 0.04) M_L + (0.19 \pm 0.15) \qquad M_W = (0.93 \pm 0.04) M_C + (0.35 \pm 0.14) \tag{1}$$

Epicentres and magnitudes from the IMD catalogue are shown in Figure 3.14.

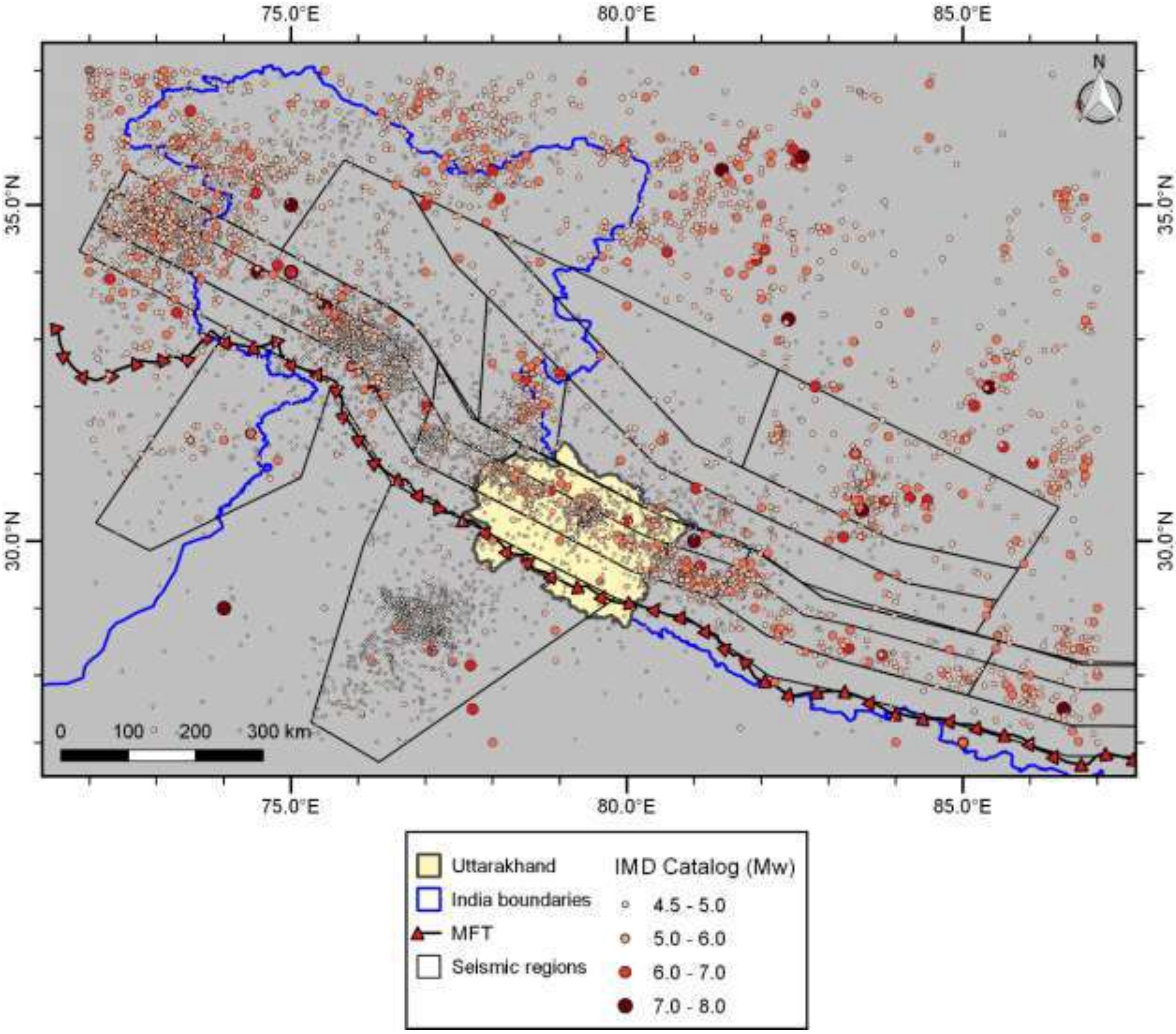


Figure 3.14: Epicentre and magnitude distribution of the IMD catalogue

From Figure 3.15 and Figure 3.16, it can be observed that the IMD catalogue is complete from 1970 to 2014 for magnitude Mw ≥ 4.5

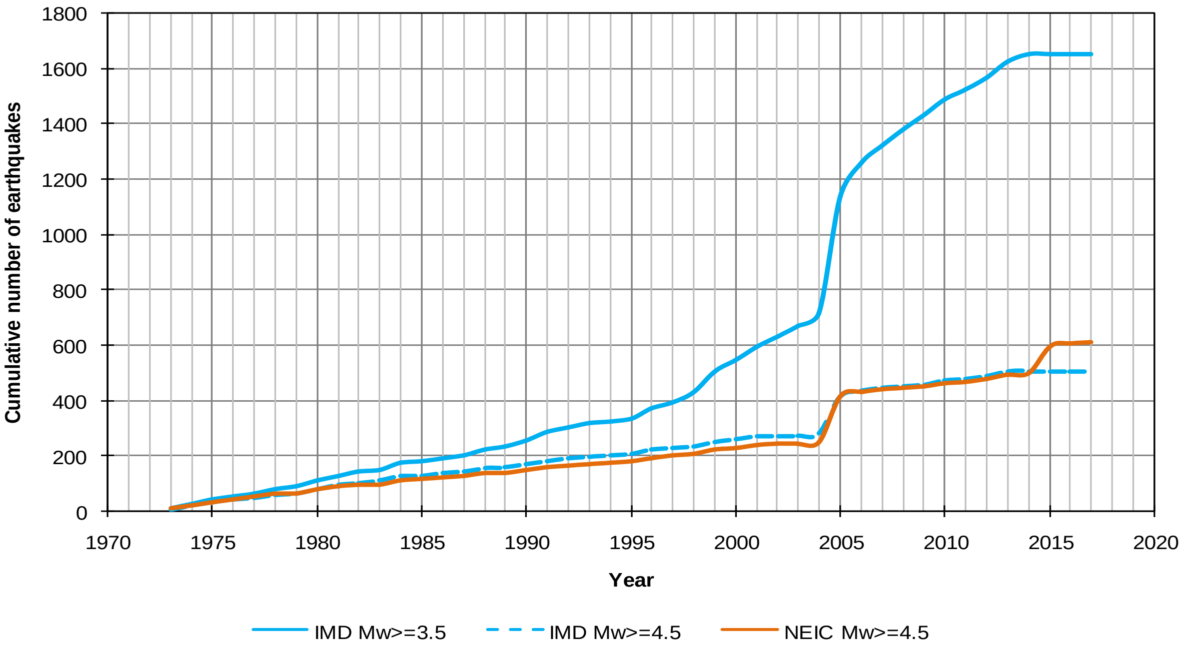


Figure 3.15: Cumulative number of events in the seismic regions of H-1, H-2, SCR-1 and SCR-2, (starting from 1973)

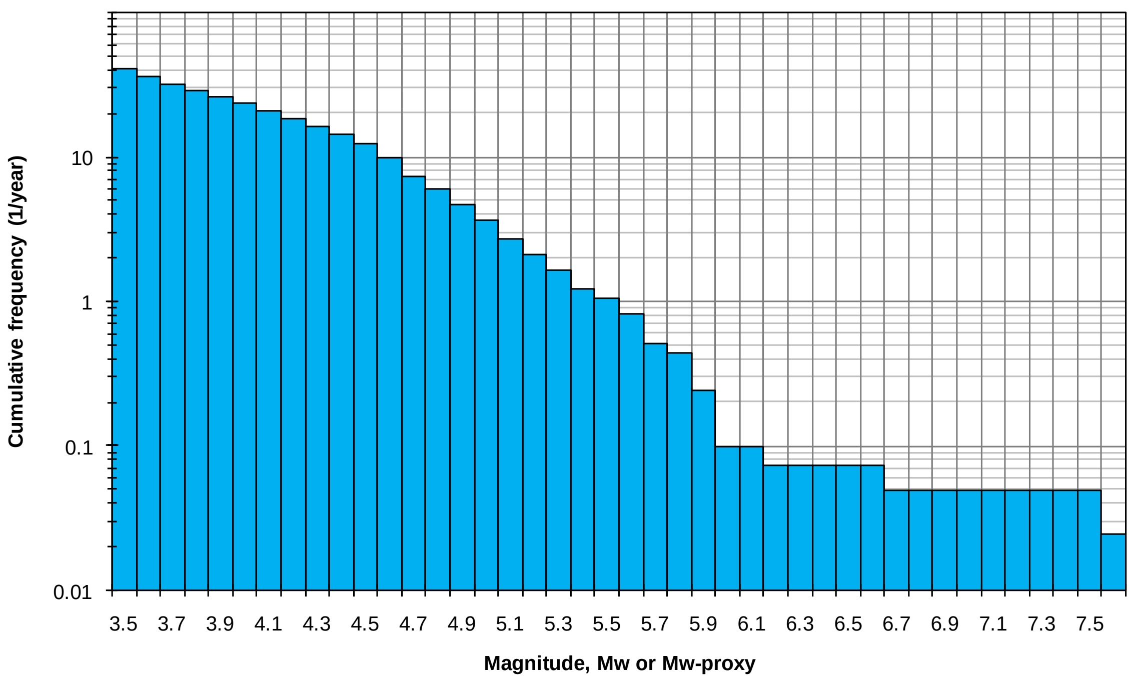


Figure 3.16: Cumulative frequency of events in the IMD catalogue in the seismic regions of H-1, H-2, SCR-1 and SCR-2, (from 1973 on). The catalogue appears to be complete for Mw ≥ 4.5.

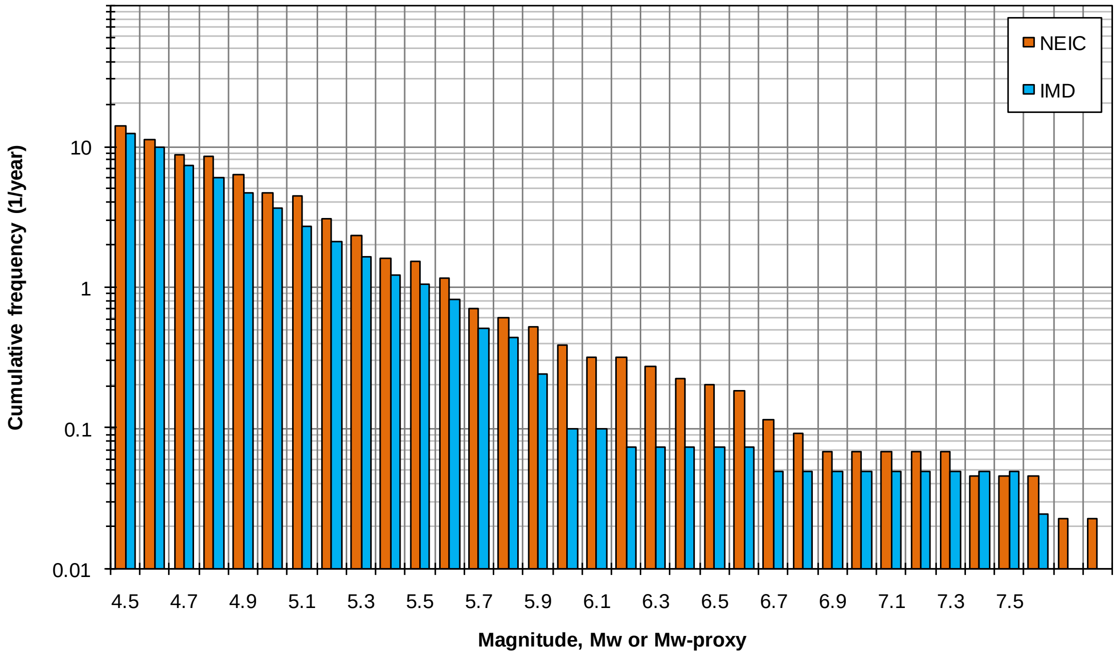


Figure 3.17: Cumulative frequency of events in the IMD and NEIC catalogues in the seismic regions of H-1, H-2, SCR-1 and SCR-2, (from 1973 on). Both catalogues appear to be complete for Mw ≥ 4.5.

3.1.5.2 NEIC-USGS and ISC-GEM catalogues

To verify homogeneity in location and magnitude, the ISC-GEM and NEIC-USGS catalogues were merged to create a working catalogue for the region of interest, which covers a rectangular area delimited from 70°E to 97°E, and from 25°N to 37°N. From the time-magnitude distribution of earthquakes in the ISC-GEM version 4.0 catalogue (Figure 3.18), three periods of completeness are identified (Storchak et al., 2013):

- 1900-2014 for Mw≥7.5
- 1918-2014 for Mw≥6.25
- 1926-2014 for Mw≥5.5

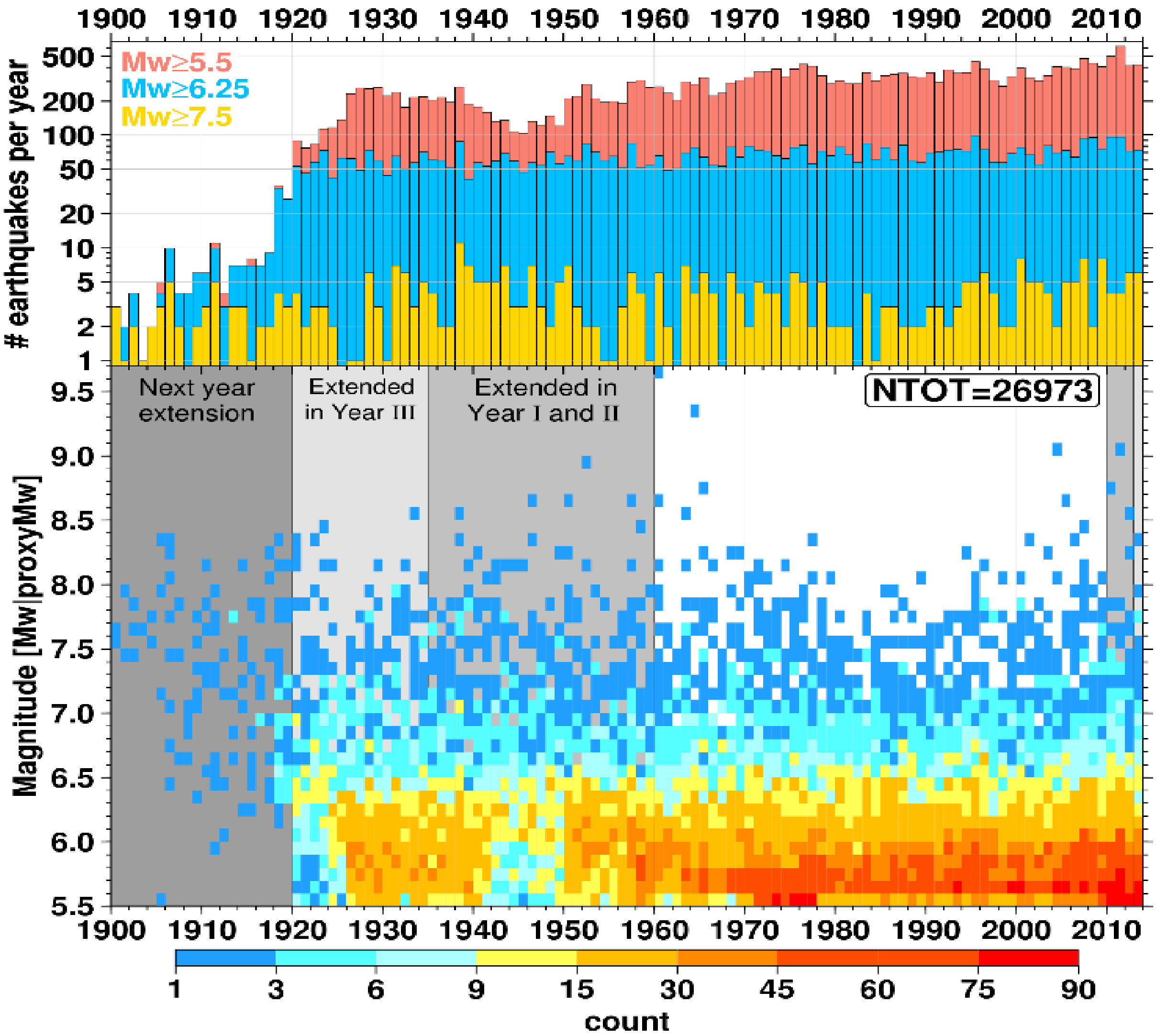


Figure 3.18: Time-magnitude distribution of ISC-GEM catalogue (taken from International Seismological Centre, 2017)

Additionally, all events listed in the NEIC-USGS catalogue for the region of interest, (during the period from 1973 to 2017), were extracted. The catalogue lists Mw for some events. For many (generally smaller) earthquakes, it lists magnitudes in mb and/or Ms, converting these magnitudes to Mw. For the sake of uniformity, the same conversion equation was used as that used to produce the ISC-GEM catalogue, namely (Di Giacomo et al., 2015):

$$M_W = 1.38 m_b - 1.79 \qquad M_W = \exp(-0.222 + 0.233 M_S) + 2.863 \qquad (2)$$

Based on Figure 3.19 and Figure 3.20, it appears that the NEIC-USGS catalogue is complete for Mw ≥ 4.5 from 1973 to 2017.

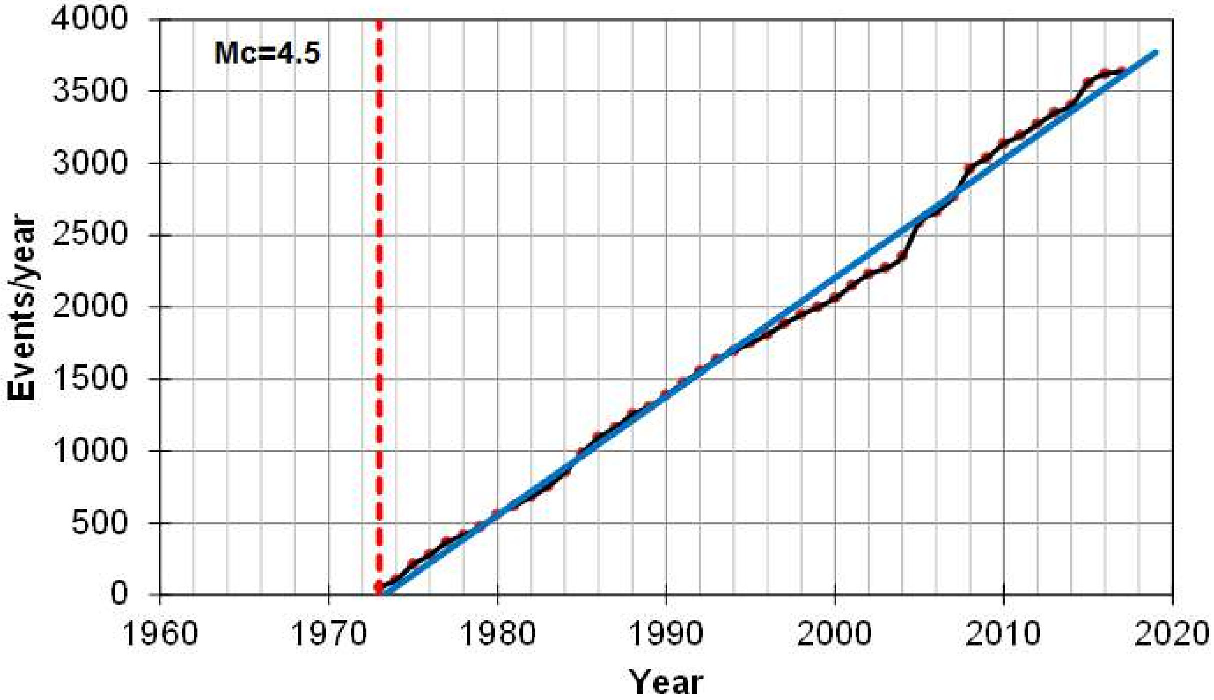


Figure 3.19: Completeness threshold for NEIC-USGS catalogue

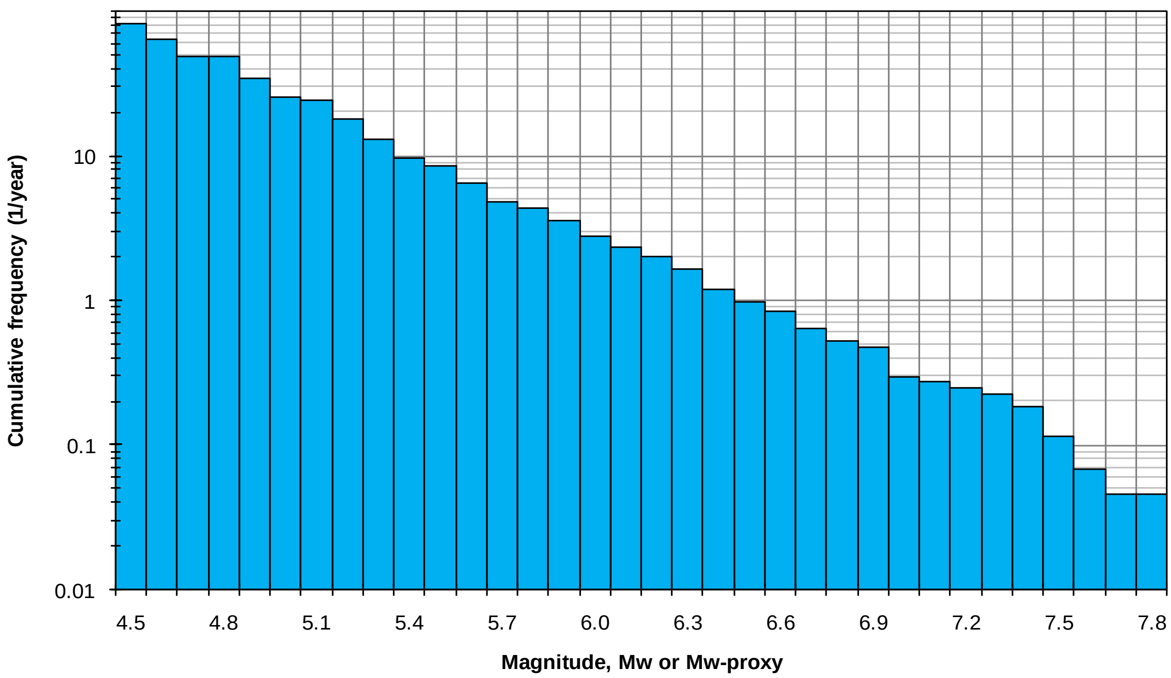


Figure 3.20: NEIC, U.S. Geological Survey catalogue cumulative frequency

Figure 3.21 graphically illustrates the manner in which ISC-GEM and NEIC catalogues were merged. The figure also shows the different completeness thresholds with their respective magnitudes.

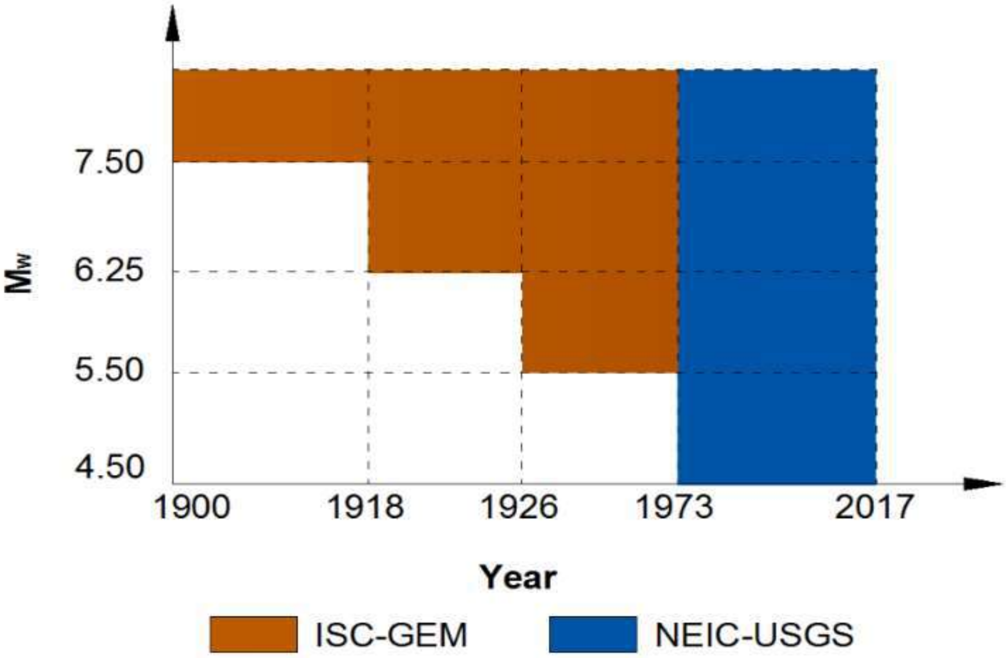


Figure 3.21: Periods of completeness and earthquake catalogues

Figure 3.22 illustrates the seismicity of the region of interest from both catalogues (ISC-GEM, 1905-1972; NEIC-USGS, 1973-2017), along with the source areas.

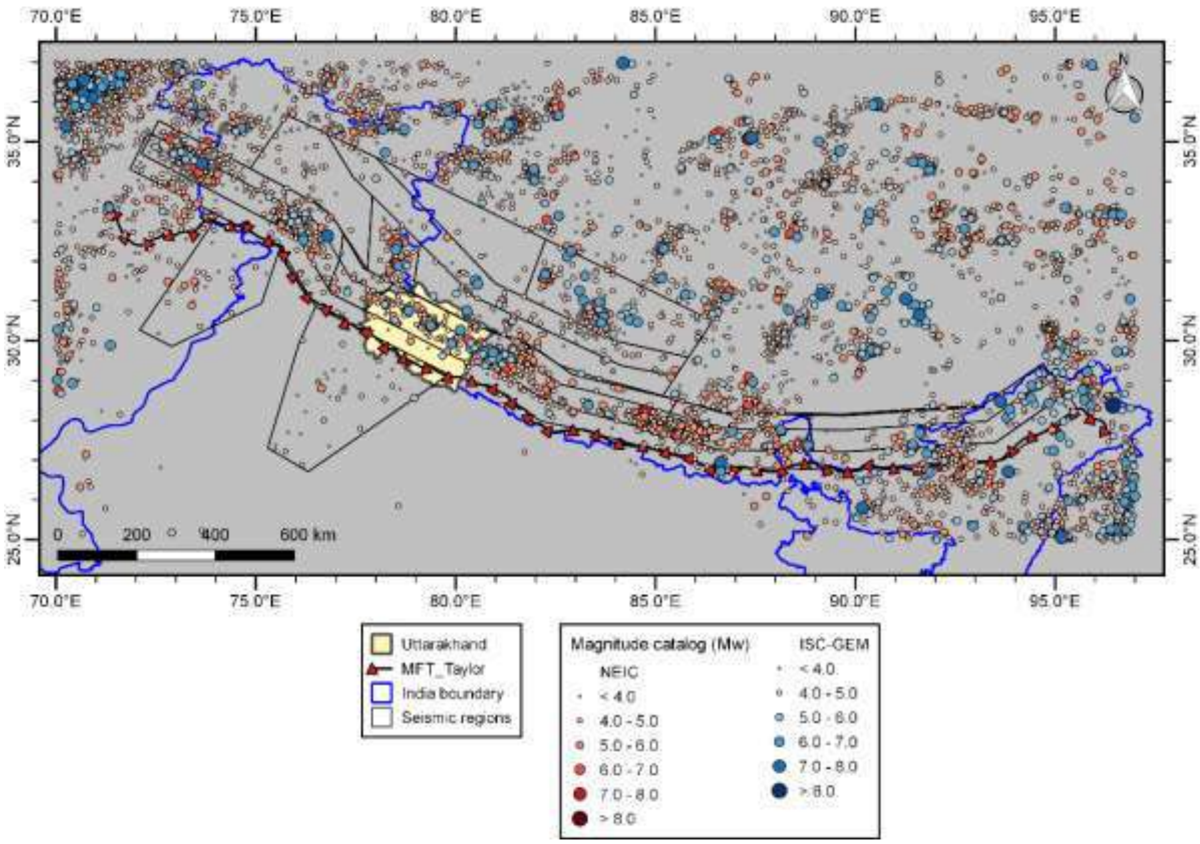


Figure 3.22: ISC-GEM and NEIC-USGS catalogues and seismic regions

3.1.5.3 Working catalogue

In order to take optimal advantage of the three earthquake catalogues available, all three were joined into one working earthquake catalogue. Two of them (ISC-GEM and NEIC-USGS) have a lack of information in SCR-1 and SCR-2 regions, therefore, the data of these regions is covered solely by the IMD catalogue, and the others by ISC-GEM and NEIC-USGS catalogues. In Figure 3.23 and Figure 3.24, the cumulative frequency in regions SCR-1 and SCR-2 (respectively) is presented. It can be observed that the IMD catalogue is more complete for these regions.

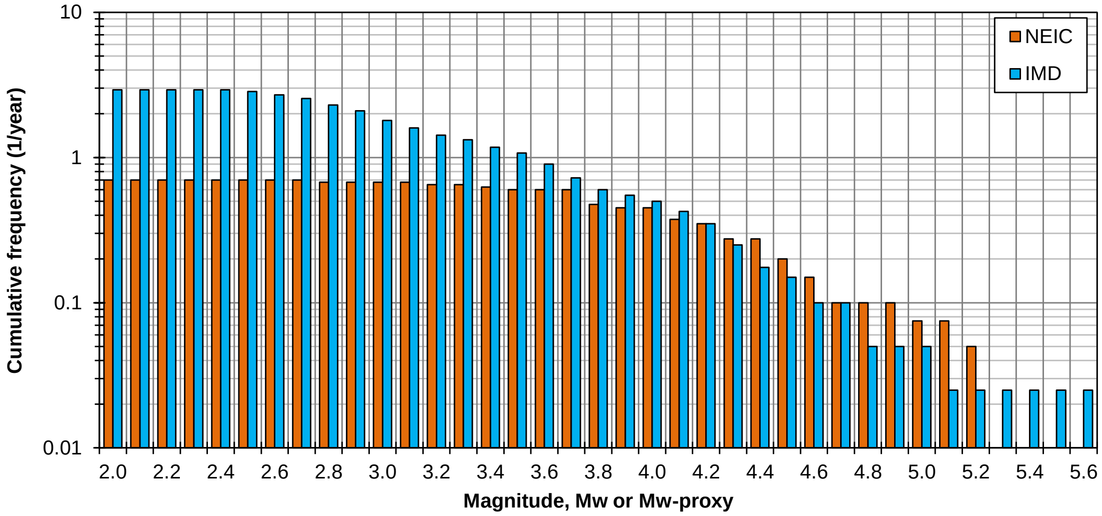


Figure 3.23: NEIC vs IMD catalogues (from 1973 on) in the SCR-1 region

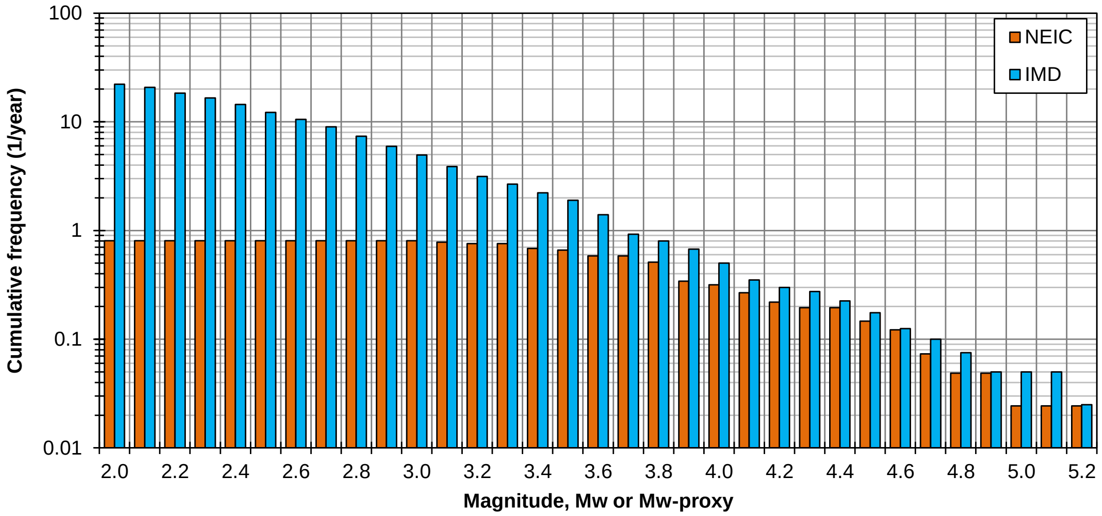


Figure 3.24: NEIC vs IMD catalogues (from 1973 on) in the SCR-2 region

The final catalogue contains 3,957 records, between 1905 and 2016, and covers magnitudes from 4.5 to 8.6. The final catalogue defines four periods of completeness:

- 1900-2016 for Mw≥7.5
- 1918-2016 for Mw≥6.25
- 1926-2016 for Mw≥5.5
- 1973-2016 for Mw≥4.5

In Figure 3.25, the epicentral and magnitude distribution of this working catalogue are shown. It should be pointed out that all events out of seismic sources will not be considered for the seismic parameters calculation; they were included into the map to show a general overview of seismicity present in the region.

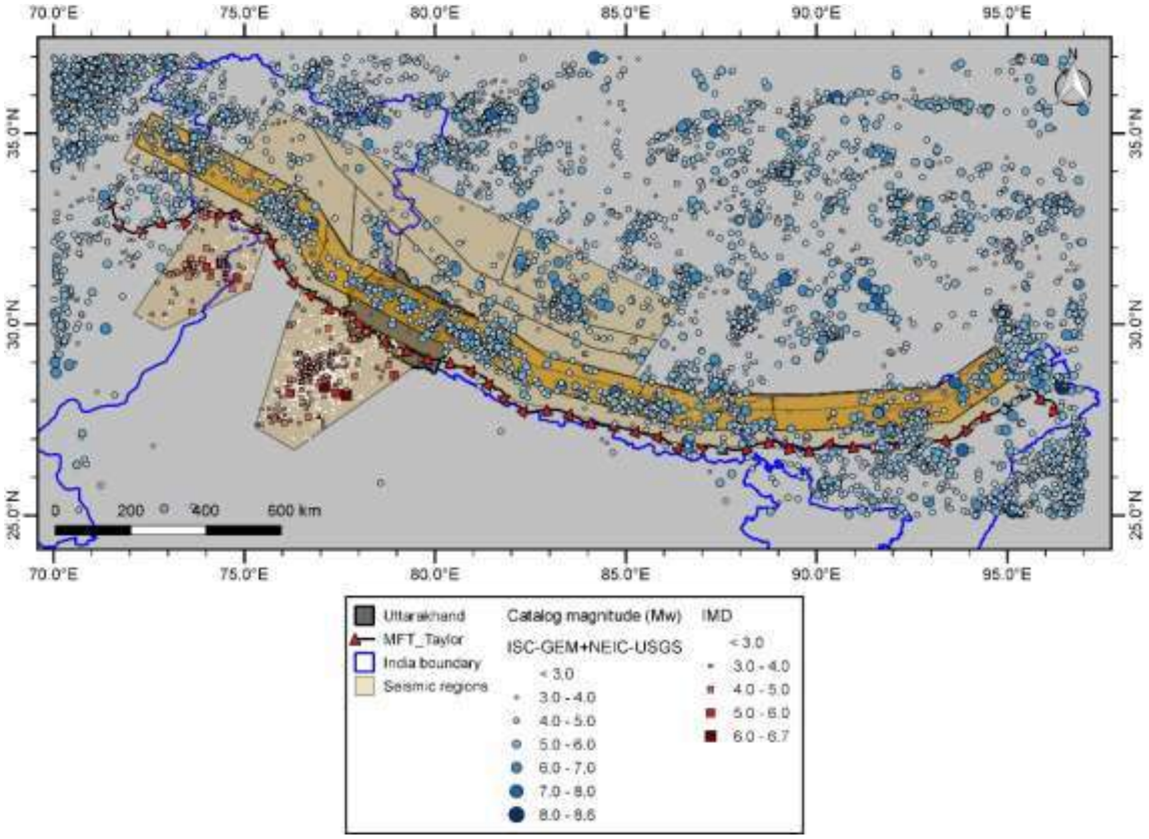


Figure 3.25: Working catalogue (ISC-GEM + NEIC-USGS + IMD)

3.1.5.4 *Declustering process*

Declustering process was assessed for T-2 and H-2 regions. Other regions were not declustered because their seismic parameters did not present any changes with this process. Two declustering process were used, Gardner & Knopoff (1974) and Reasenberg (1985), in the T-2 and H-2 regions, (respectively).

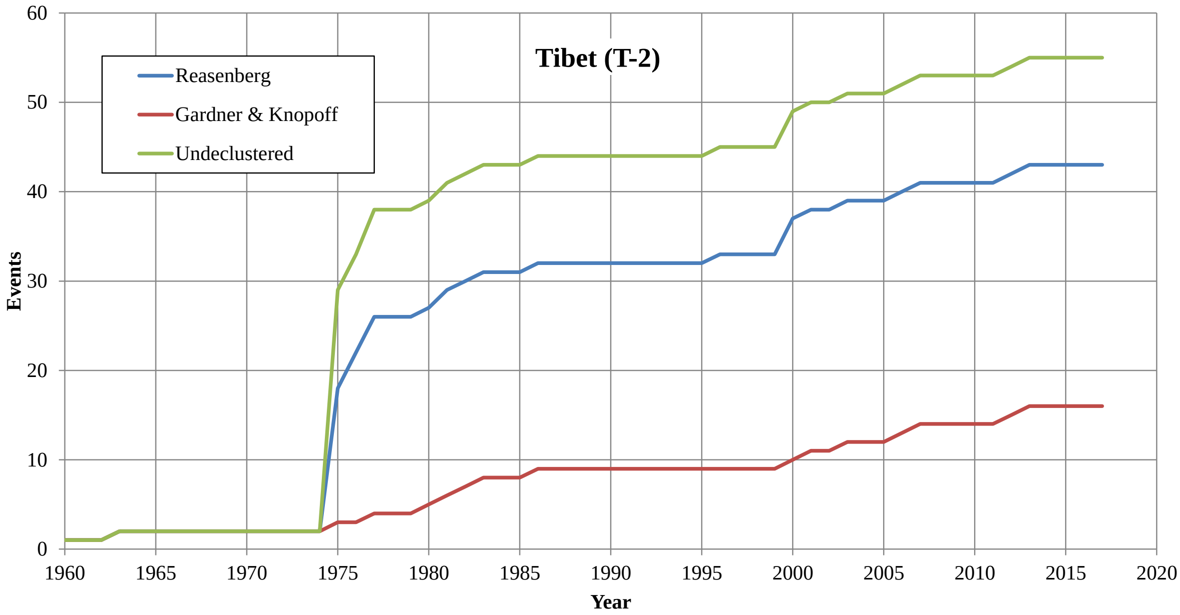


Figure 3.26: T-2 region declustering process

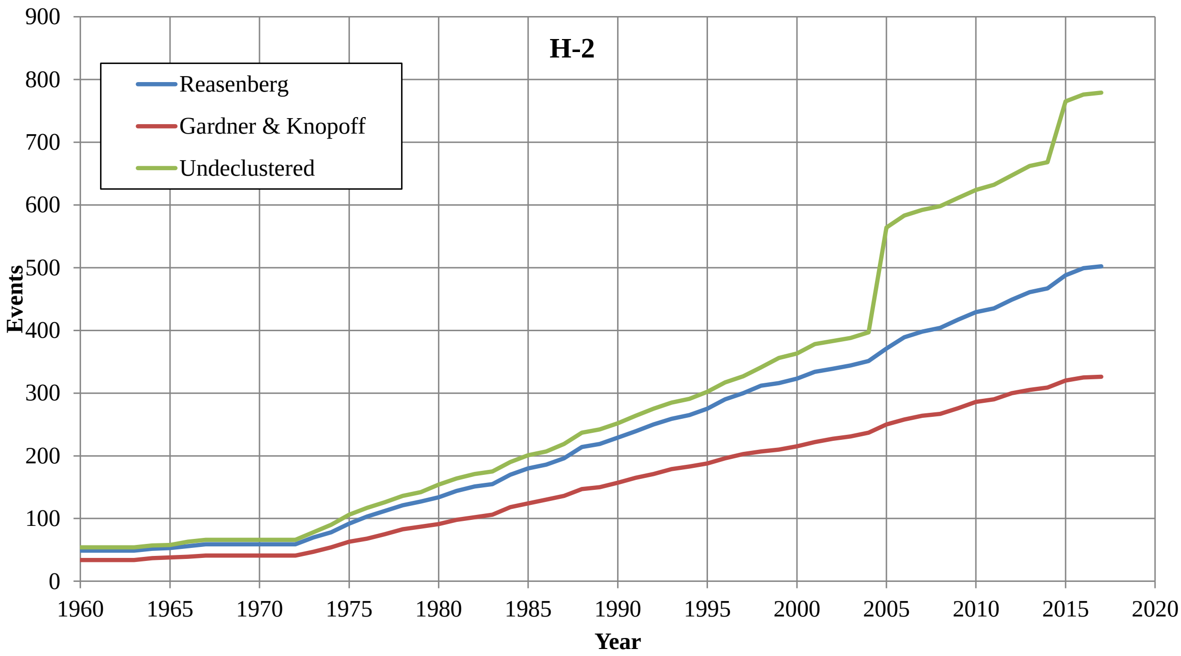


Figure 3.27: H-2 region declustering process

3.1.6 Seismic parameters

Stevens & Avouac (2016) have compiled a catalogue of Mw≥7.5 earthquakes in the Himalayan Thrust Zone for the past 1,000 years from various sources (Table 3.1). Their proposed rate for large/great earthquakes of different magnitude ranges is given in Table 3.2.

This information is included in estimating parameters of the Characteristic Earthquake (CE) and Gutenberg-Richter (G-R) relationship for subzones H-1 and H-2. For the other regions, the

Gutenberg-Richter (G-R) relationship was assigned and its parameters (β and λ) were assessed based on the working catalogue defined previously. The seismicity parameters for each region are shown in

Table 3.3.

Table 3.1: Earthquakes above magnitude 7.5 for the past 1,000 years in the Himalayan Thrust Zone from paleoseismic, historical and instrumental catalogues, from Stevens & Avouac (2016)

Date	Magnitude	Location
1100	>8.5	Eastern Himalaya
1255	8-8.5	Nepal
1344	>8.0	Nepal
1400	>8.5	Western Himalaya
1505	8.2	Western Nepal
1555	7.6	Kashmir
1720	7.5	N. Uttar-Pradesh
1803	7.5	Garwhal
1806	7.7	Samye
1833	7.7	Nepal
1905	7.7	Kangra
1934	8.4	Bihar-Nepal
1950	8.7	Assam
2005	7.6	Kashmir
2015	7.8	Gorkha-Nepal

Table 3.2: Proposed rates of large earthquakes in the Himalayan Thrust Zone estimated based on the data provided in Table 3.1. Note that ranges given are at the 1-sigma confidence level, and that for magnitude 7.5, the past 200 years of data have been scaled up to 1,000 years, (based on Stevens & Avouac (2016))

Magnitude	Number per 1000 years
≥ 9.0	0-2
≥ 8.5	3-4
≥ 8.0	6-9
≥ 7.5	33-50

Table 3.3: Seismicity parameters for Gutenberg-Richter and Characteristic Earthquake Models

Gutenberg-Richter Model					
Region	**M_0**	**λ**	**β**	**$CV\beta$**	**M_U**
Tibet 1	4.5	0.166	5.785	0.378	7.3
Tibet 2	4.5	0.323	2.005	0.25	7.3
Tibet 3	4.5	0.385	2.007	0.2425	7.3
Indian Plate 1	4.5	0.006	1.463	0.3015	7.0
Indian Plate 2	4.5	0.007	1.228	0.2887	7.0
Inner Tibet 1	4.5	0.051	2.881	0.7071	7.0
Inner Tibet 2	4.5	1.484	1.944	0.1147	7.0
Karakoram Fault	4.5	0.432	2.294	0.2182	7.9
Uttarakhand-Nepal-2-Area (H2A1)A	4.5	0.961	2.469	0.114	6.55
Uttarakhand-Nepal-2-Area (H2A1)B	4.5	0.87	2.3	0.1195	6.55
Uttarakhand-Nepal-2-Area (H2A1)C	4.5	0.13	2.975	0.3162	6.55
Uttarakhand-Nepal-2-Area (H2A1)D	4.5	1.251	2.22	0.0985	6.55
Uttarakhand-Nepal-2-Area (H2A1)E	4.5	0.727	2.095	0.1291	6.55
Uttarakhand-Nepal-2-Area (H2A1)F	4.5	1.005	2.199	0.1098	6.55
Uttarakhand-Nepal-2-Area (H2A1)G	4.5	1.089	1.081	0.062	6.55
Uttarakhand-Nepal-2-Area (H2A2)A	4.5	0.641	2.469	0.114	6.55
Uttarakhand-Nepal-2-Area (H2A2)B	4.5	0.58	2.3	0.1195	6.55
Uttarakhand-Nepal-2-Area (H2A2)C	4.5	0.087	2.975	0.3162	6.55
Uttarakhand-Nepal-2-Area (H2A2)D	4.5	0.834	2.22	0.0985	6.55
Uttarakhand-Nepal-2-Area (H2A2)E	4.5	0.485	2.095	0.1291	6.55
Uttarakhand-Nepal-2-Area (H2A2)F	4.5	0.67	2.199	0.1098	6.55
Uttarakhand-Nepal-2-Area (H2A2)G	4.5	0.726	1.802	0.1026	6.55
Uttarakhand-Nepal-2 (H2)	6.5	0.1484	2.257	0.036	8.05

Characteristic Earthquake (CE) Model				
Region	**Tr**	**σ_M**	**M_0**	**M_U**
Himalayan Arc 1 (H-1)	80	1.0	8.0	9.0

3.1.7 Ground Motion Prediction Equations (GMPEs)

Five different GMPEs were used in the model, some of them with focal mechanisms variations. In addition, two hybrid models were built based on those attenuation models.

- Zhao et al. (2006)
- Atkinson (2008) – reverse and normal mechanisms
- Chiou & Youngs (2014) – normal and strike-slip mechanisms
- Sharma, Douglas, Bungum, & Kotadia (2009)
- Arroyo & Singh (2017) – attenuation model developed in this project based only on data from the Himalayan Arc
- Hybrid model 1: (Arroyo & Singh, 2017; Sharma et al., 2009; Zhao et al., 2006)
- Hybrid model 2: (Arroyo & Singh, 2017; Zhao et al., 2006)

In Figure 3.28 and Figure 3.29, attenuation curves and response spectra obtained with such GMPEs are presented, respectively.

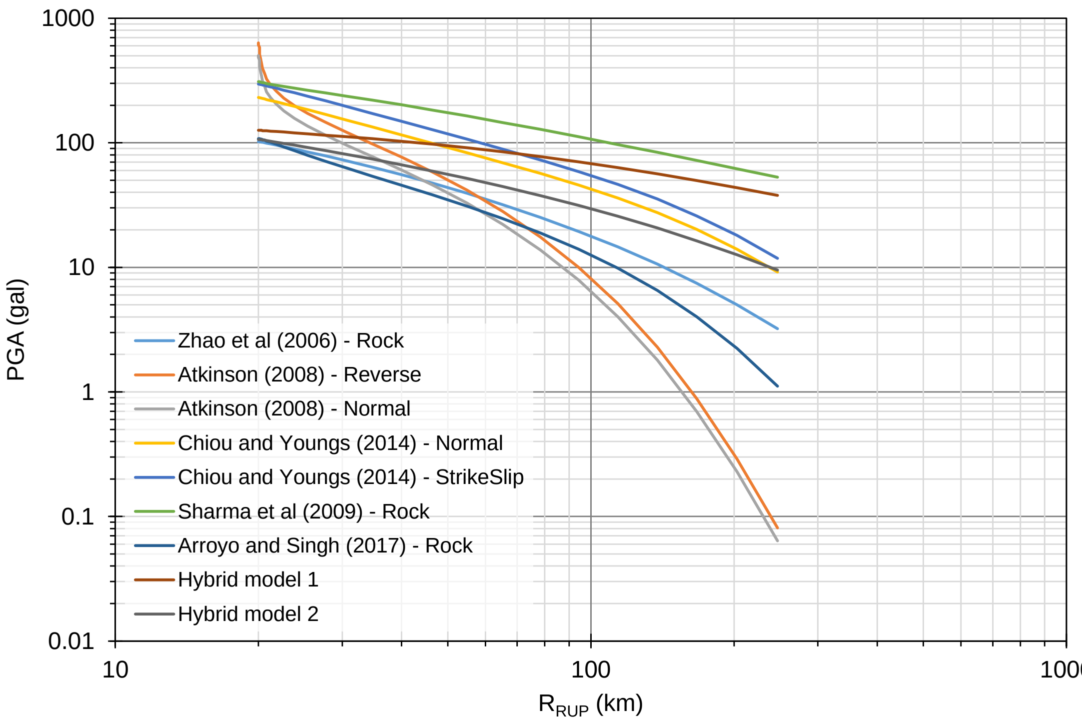


Figure 3.28: Attenuation curve of median peak ground acceleration (PGA) for a 7 magnitude event with 20 km hipocentral depth

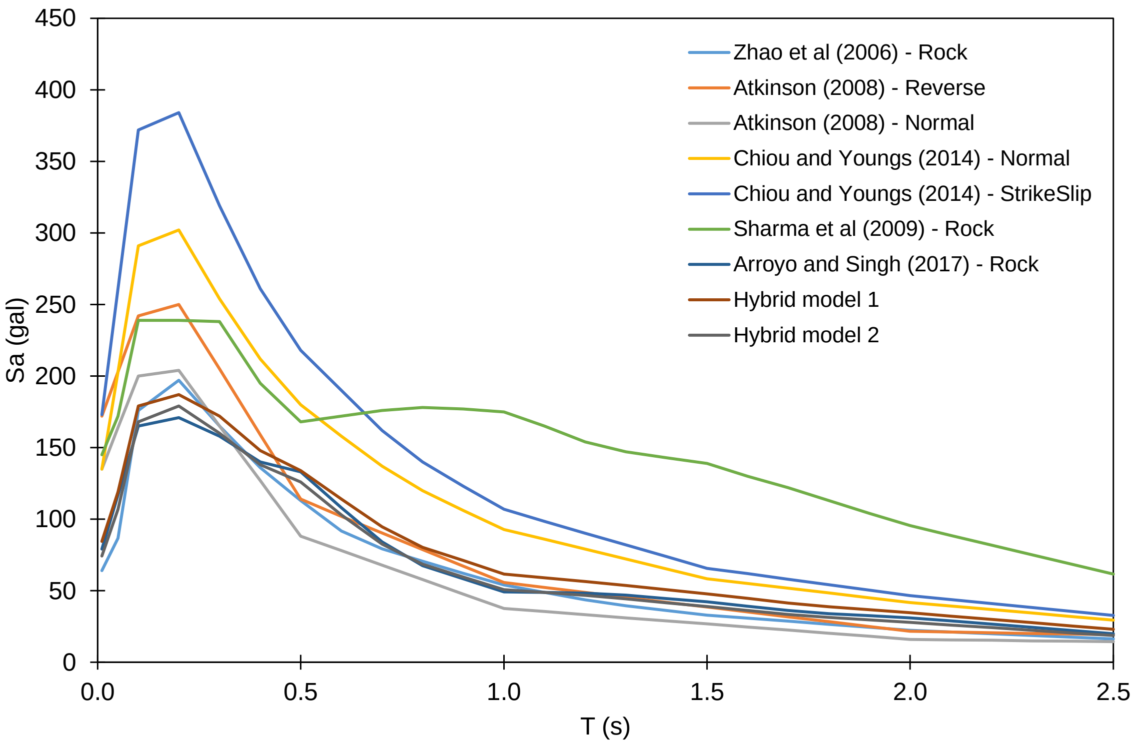


Figure 3.29: Response spectra for a 7 magnitude event with 20 km hipocentral depth and 40 km epicentral distance

3.1.7.1 Ground motion prediction equation for the Indo-Gangetic Plains

As mentioned earlier, the importance of reliable prediction of ground motions from future Himalayan earthquakes in the Indo-Gangetic Plains (IGP) can hardly be overemphasised. However, up until now, this has not been possible due to the lack of earthquake records. The data of the 2015 Gorkha earthquake sequence recorded by the CIGN and IIT-R network provide an opportunity to partially remedy this deficiency.

Our analysis is based on 13 earthquakes records listed in Table 3.4 (4.3 ≤ Mw ≤7.9). It includes records from the 2015 Gorkha, Nepal earthquake (Mw7.9), four of its aftershocks, and 8 earthquakes in the India-Nepal region (4.3 ≤ Mw ≤7.6). The focal mechanisms are available for the larger events (Mw≥5.2). They are consistent with rupture on shallow-dipping thrust faults. We have compiled all available data in the Indo-Gangetic Plains region to construct our GMPE. Stations in the IGP are classified as soft-soil sites, while those in the arc are grouped as hard sites.

Table 3.4: Earthquakes used in this study

Event	Date	Lat (^{0}N)	Long (^{0}E)	Depth, km	M_w
Nepal Mainshock	2015/04/25	27.91	85.33	12	7.9
Nepal Aftershock 1	2015/04/25	27.86	84.93	21	6.7
Nepal Aftershock 2	2015/04/26	27.56	85.95	20	6.7
Nepal Aftershock 3	2015/05/12	27.56	86.10	12	7.2
Nepal Aftershock 5	2015/05/16	27.37	86.26	12	5.3

Event	Date	Lat (^{0}N)	Long (^{0}E)	Depth, km	M_w
Chamoli	1999/03/28	30.75	78.86	21	6.5
Kangra	1986/04/26	31.59	76.06	15	5.5
Khursali	2007/07/22	30.91	78.30	26	4.7
Pakistan	2005/10/08	34.37	73.47	12	7.6
Pithoragarh	2008/06/15	29.42	81.06	26	4.3
Uttarkashi	1991/10/20	32.15	78.86	12	6.8
Uttarkashi	2012/02/09	30.94	78.31	10	4.6
Rudraprayag	2017/02/06	30.55	76.06	19	5.1

Figure 3.30 presents a plot of magnitude (Mw) versus distance (R), summarizing the data used in our analysis. Here *R* is the closest distance to the rupture surface. Number of usable recordings were: (1) for PGA 354 (252 from the 2015 Gorkha, Nepal earthquake sequence and 102 from the other 8 earthquakes) with 133 from soft-soil site and 221 from hard sites; (2) for SA 282 (202 from the 2015 Gorkha, Nepal earthquake sequence and 80 from other 8 earthquakes) with 88 from soft-soil site and 194 from hard sites; and (3) for PGV 334 (248 from the 2015 Gorkha, Nepal earthquake sequence and 86 from the other 8 earthquakes), with 129 from soft-soil site and 205 from hard sites. This dataset is roughly four times larger than the datasets which we used in the construction of a previous GMPE for the region (Singh et al., 2017).

The thickness of the sediments in the IGP increases from south to north, reaching a depth of ~4 km near the foothills of Himalayas. This sedimentary column has been modelled by two layers overlying a basement (Srinagesh et al., 2011; Srinivas, Srinagesh, Chadha, & Ravi Kumar, 2013). Shear-wave velocity in the soft alluvial upper layer is between 0.2 and 1.3 km/s. The average shear-wave speed in the upper 30 m is known only at Lucknow, which can be assigned class D of NEHRP. The IGP sites have a variable shear-speed structure in the upper 30 m and most likely belong to class C, D or E.

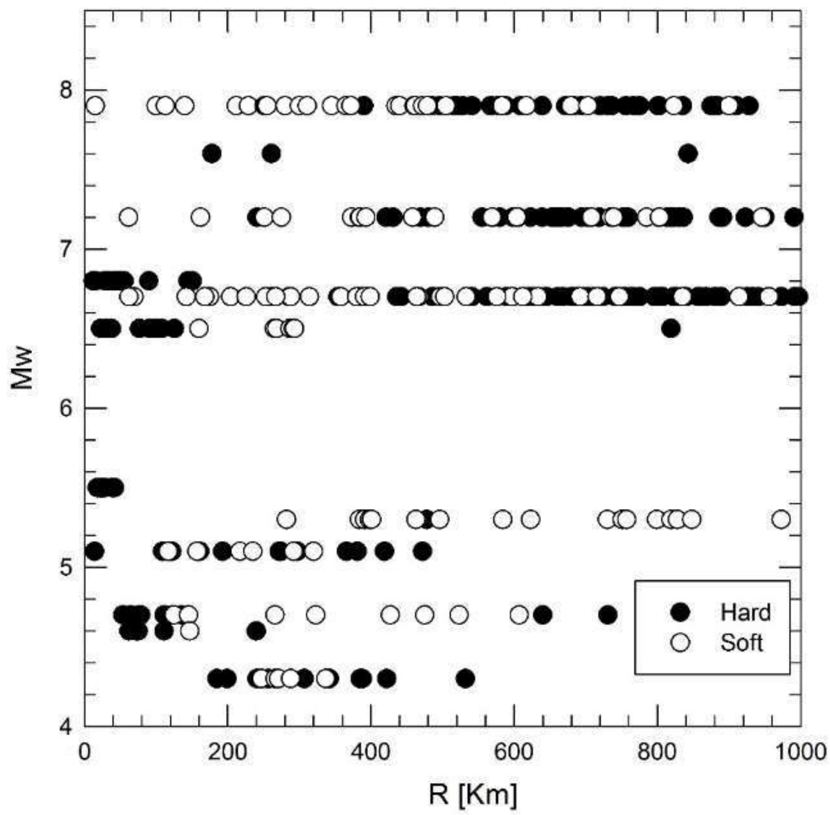


Figure 3.30 Magnitude (Mw) versus distance (Rrup) plot summarising the data used in the derivation of GMPE for the IGP. Mw6.2 aftershock data was not used because of contamination of signal from Mw7.2 aftershock which occurred about half an hour earlier

3.1.7.2 Regression analysis

To derive the GMPE we considered a functional form which is based on an approximate solution of a circular finite-source model (Arroyo, García, Ordaz, Mora, & Singh, 2010; Singh et al., 1989):

$$y = \alpha_1 + \alpha_2 M_w + \alpha_3 \ln\left[\frac{E_1(\alpha_4 R_{rup}) - E_1\left(\alpha_4 \sqrt{R_{rup}^2 + r_0^2}\right)}{r_0^2}\right] + \alpha_5 S \qquad (3)$$

$$r_0^2 = 1.4447 \times 10^{-5}\, e^{2.3026 M_w}$$

where y is the natural logarithm of the geometric mean of the two horizontal seismic intensities, S is a dummy variable equal to 1 for soft sites and equal to zero otherwise and $E_1(x)$ is the well-known exponential-integral function which is defined as

$$E_1(x) = \int_x^{\infty} \frac{e^{-t}}{t}\, dt \qquad (4)$$

A characteristic of this functional form is that its third term simultaneously accounts for (a) near-source saturation effect, (b) geometric spreading, (c) inelastic attenuation, and (d) dependence of attenuation on magnitude (Arroyo et al., 2010). As *R* approaches to infinity this term approaches to $\frac{e^{-\alpha_4(T)R}}{2R^2}$, thus the geometrical spreading and anelastic attenuation of *SA* are given by $\left[-\left(\alpha_3(T)\alpha_4(T)R + 2\alpha_3(T)ln(R)\right)\right]$.

When *R* becomes comparable to r_0 the near-source effect is controlled by the coefficient α_4. As α_4 increases, saturation of *SA* increases; on the other hand, as α_4 becomes zero, saturation vanishes. We note that the proposed function allows for oversaturation (i.e., the value of *SA* starts to decrease when M_W exceeds a certain threshold). It might be viewed as an empirical modification of $\alpha = 2\pi/\beta Q_0$ (Eq. 5) to take into account the variation of the quality factor Q_0 with frequency.

$$a_{rms} = \frac{2\sqrt{2}CM_0 f_c^3}{\sqrt{\pi\kappa f_c}} \times \left[\frac{E_1(\alpha R) - E_1\left(\alpha\sqrt{R^2 + r_0^2}\right)}{r_0^2}\right]^{1/2} \quad (5)$$

Although the existence of this effect is questionable, we proceeded with this functional form, since saturation level will be finally determined in the regression by the available data.

The intensities considered were *PGA* in cm/s^2 and *PGV* in cm/s. We performed the regression analysis through a Bayesian scheme developed by Ordaz, Singh, & Arciniega (1994) and (Arroyo & Ordaz, 2010a, 2010b). The prior information required by the Bayesian scheme was set following a previous study (Arroyo et al., 2010).

Generally, intra-event variability is found to be larger than inter-event variability. However, in our case the inter-event variability is larger because of the peculiar intensities observed during the M_w7.9 mainshock.

Plots of residuals, in log units, as a function of magnitude and distance are shown in Figure 3.31 and Figure 3.32 respectively. A moderate bias is observed in the case of M_w, produced by the unusual intensities during the M_w7.9 event. After several tests and in view of the limitations of our dataset, we decided to keep the model as simple as possible, abstaining from correcting such bias by including additional terms to the functional form. On the other hand, no significant trend is observed in the residuals with respect to R (Figure 3.33).

In view of the limitations of our dataset, we recommend caution in extrapolation of the GMPE outside the interval of *Mw* and *R* shown in Figure 3.30. Also, it is noted that the GMPE is not expected to work well for sites outside of the IGP, and when significant non-linear soil behaviour is expected.

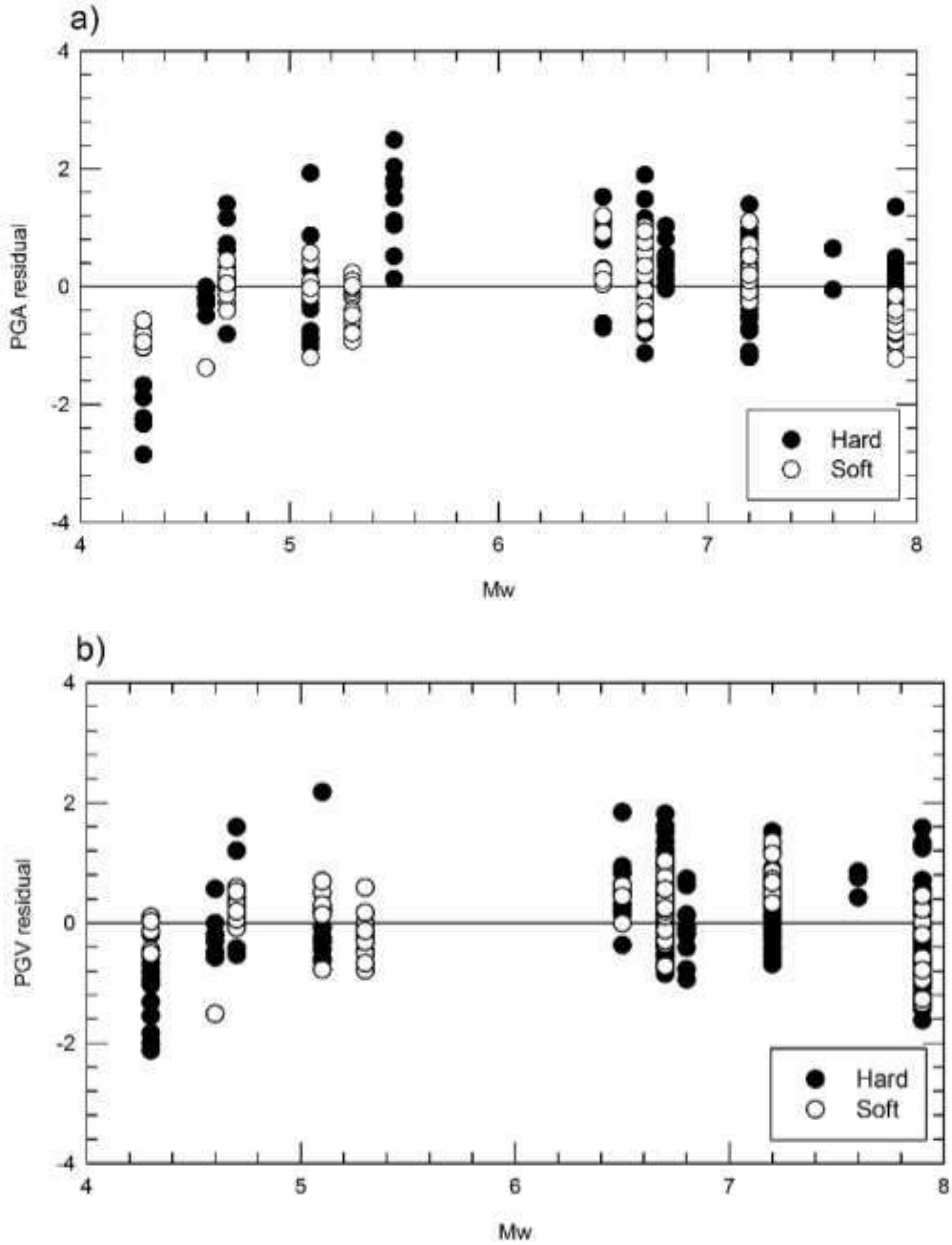
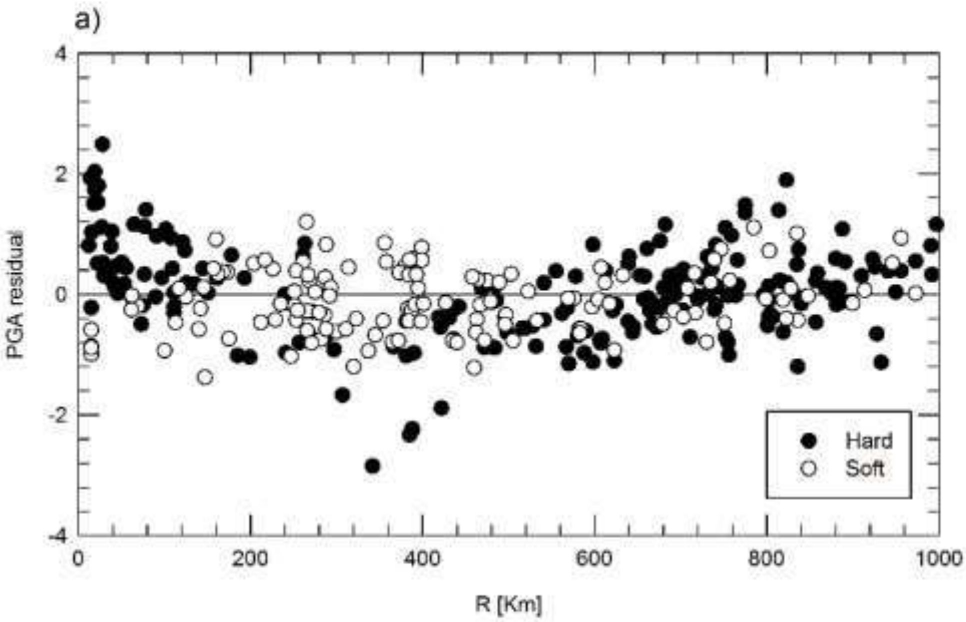


Figure 3.31: Residuals (in natural logarithmic units) for the model as a function of *Mw*. (a) *PGA*, (b) *PGV*



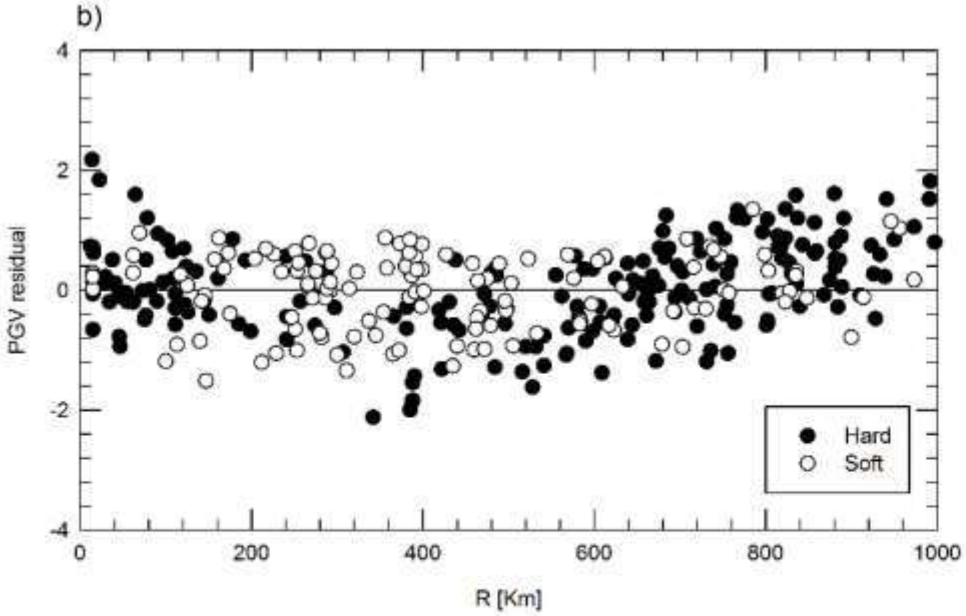


Figure 3.32: Residuals (in natural logarithmic units) for the model as a function of R_{rup}. (a) *PGA*, (b) *PGV*

Figure 3.33 compares observed PGA values in our dataset with median PGA values computed from the proposed GMPE. On average, our model fits well to data except for the Kangra Mw=5.5 earthquake and Pithoragarh Mw=4.3 earthquake. Anomalously high PGAs were observed during the Kangra earthquake that are not well reproduced by our model. On the other hand, our model yields much higher PGAs than the observed during the Pithoragarh Mw=4.3 earthquake.

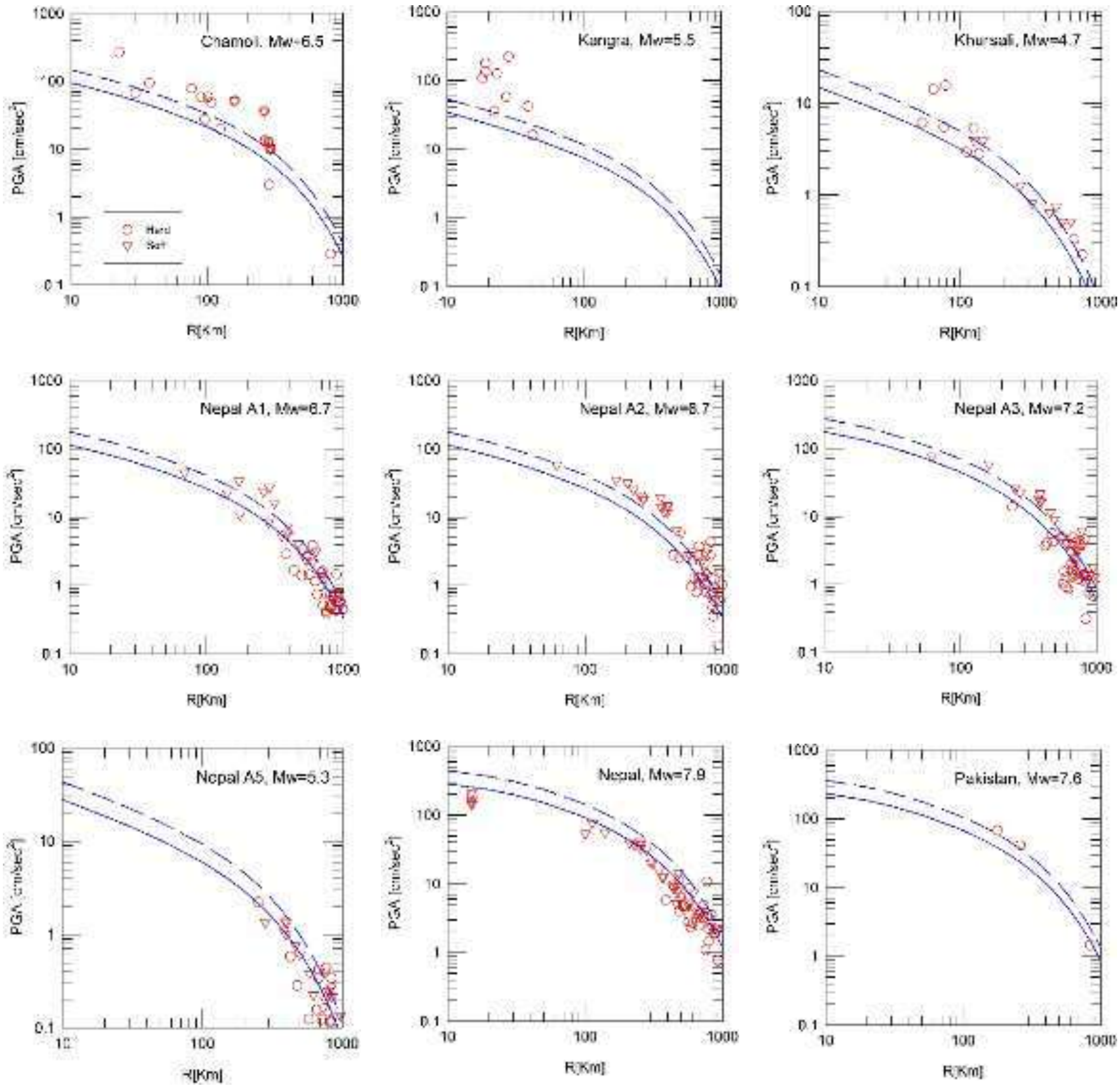


Figure 3.33: Comparison of observed PGA values and median values from the proposed GMPE (continuous line GMPE for hard sites and dashed line GMPE for sedimentary sites)

3.1.8 Tools and Software Used

The hazard model was created using R-CRISIS ver. 18.2 (Core library 15.6.1.0) developed by Ordaz et al. (2015) which gives a user-friendly environment to calculate seismic hazard. The program computes seismic hazard using a probabilistic model that considers the earthquake occurrence probabilities, attenuation characteristics and geographical distribution of earthquakes. R-CRISIS operates with a dynamic integration procedure, which allows fast computation of hazard in extended areas.

Hazard results are mainly given, for each computation site, in terms of probabilities of exceeding a given intensity value in different time-frames. It is also possible to obtain hazard results in terms of non-exceedance probability and equivalent exceedance rate.

3.1.9 Datasets Used for the Event Catalogue

Once a hazard model is constructed, hazard maps can be computed. However, risk calculations are not done using these maps but using an event set constructed from the hazard model and fully consistent with these maps. In our case, we created a set of stochastic events starting at magnitude 4.0 and ending at the maximum magnitude of the corresponding seismic region. We generated events with an average spacing of 15 km, and sampling six magnitudes at each location. In our experience, this density of events is enough to achieve accurate loss results. Figure 3.34 and Figure 3.35 show the location of the epicenters of the most relevant events in Uttarakhand and its vicinity, for M≥6.0 and M≥7.0, respectively. The epicenters are depicted on top of the hazard map of PGA for 475 years return period.

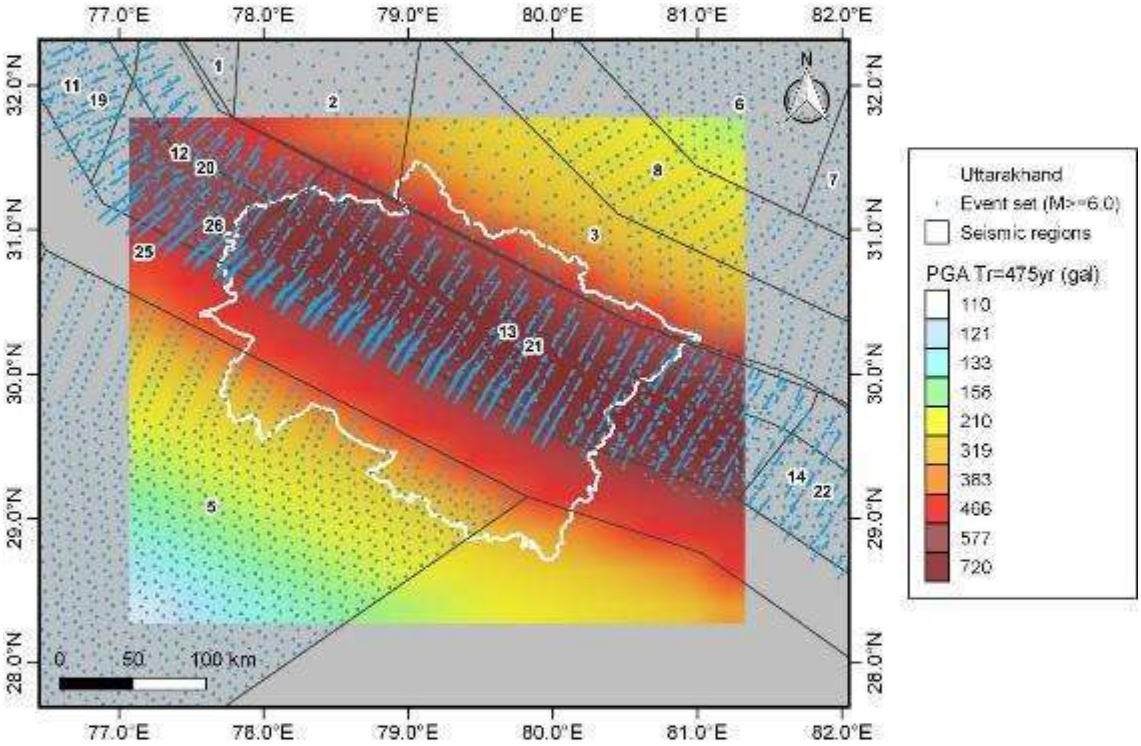


Figure 3.34: Earthquake epicenters for a stochastic event set with M≥6.0. Colored region depicts PGA accelerations for 475 years return period

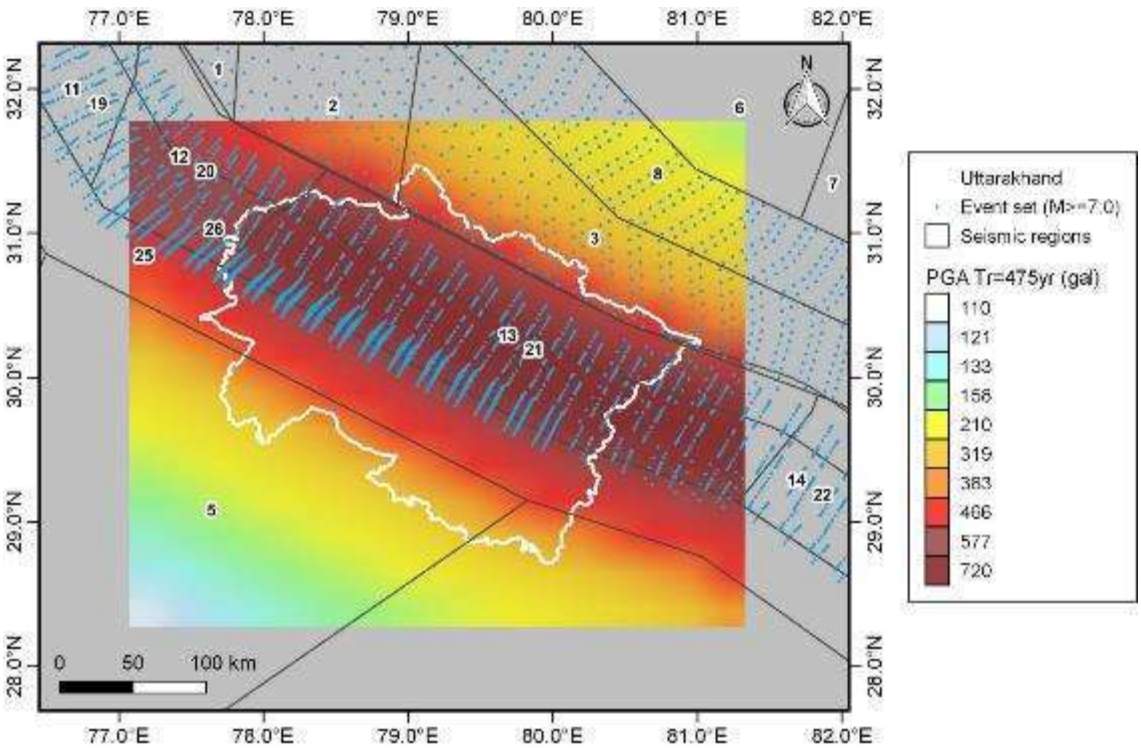


Figure 3.35: Earthquake epicenters for a stochastic event set with M≥7.0. Colored region depicts PGA accelerations for 475 years return period

3.1.10 Limitations, Gaps, and Critical Assumptions

Although Uttarakhand is an active seismic region, few GMPEs have been developed due to the paucity of earthquake records (e.g. Sharma et al., 2009). The data of the 2015 Gorkha earthquake sequence recorded by CIGN and IIT-R network provided an opportunity to partially remedy this deficiency and a new GMPE was built.

Initially, Himalayan Arc zone was considered as a single region approximately 2,500 km long. However, Bungum, Lindholm, and Mahajan (2017) propose a geotectonic transverse segmentation of the Himalayan Arc. Finally, we decided to divide the Himalayan Arc into seven sub-regions named from A to G, as was discussed in Chapter 3.1.4.

3.2 FLUVIAL FLOOD HAZARD MODELLING

The overall workflow for probabilistic modelling fluvial flood hazards is illustrated in Figure 3.36. Continuous and distributed rainfall will be generated using a calibrated rainfall-runoff model using historical observations. The rainfall time-series relies on the combination of different data sources including the IMD Grid dataset and satellite observations (GPM, TRMM) calibrated and quality controlled using 30 years of peak discharge at several locations, temperature and evaporation time-series have been extracted from numerical weather model. Historical records have been further subdivided a catalogue of 5 days windows events used for hydrodynamic simulations and analysis of extreme water levels along the main rivers.

For the hazard modelling purpose of this study and considering the topography and slope of the terrain, the flow can be approximated as unidirectional. A one dimensional hydrodynamic model (MIKE1D) solving the full shallow water equations will be set up to simulate water level and flow velocity variations. The model reaches simulate flow in reaches draining catchment areas above 600 km^2, corresponding to the spatial resolution of the IMD rainfall data. The 600 km^2 drainage area also corresponds approximately to the drainage size required for a catchment lag-time close to the temporal resolution (24h) of the IMD Rainfall (with variation depending on the average catchment slope). The NAM rainfall-runoff model will be used to simulate discharge along the reaches.

The NAM model will be calibrated with discharge observations wherever available and model parameters transferred based on land-use analysis and expert judgement in un-gauged catchments. The model will be built using existing available models and geomorphological data. Wherever data are not available, an approximation of the in-bank conveyance capacity will be proposed based on regression derived from available surveyed data, out of bank conveyance volumes will be extracted from the CARTOSAT DEM at 10m resolution where the data quality allows.

The model will be run continuously for each event (5 days window). Afterwards, flood maps will be generated using linear interpolation of simulated water levels over the DEM at the frequencies required for analysis at 10m and 30m resolution and where the quality of the DEM allows (see Section 3.2.6.1).

The 30m resolution maps will be used for subsequent risk analysis and considering the 25Y, 50Y, 100Y, 250Y, 500Y Return Periods. A series of 10 m maps are produced in hot spots areas and where the DEM quality allows for the 100Y and 500Y Return Periods.

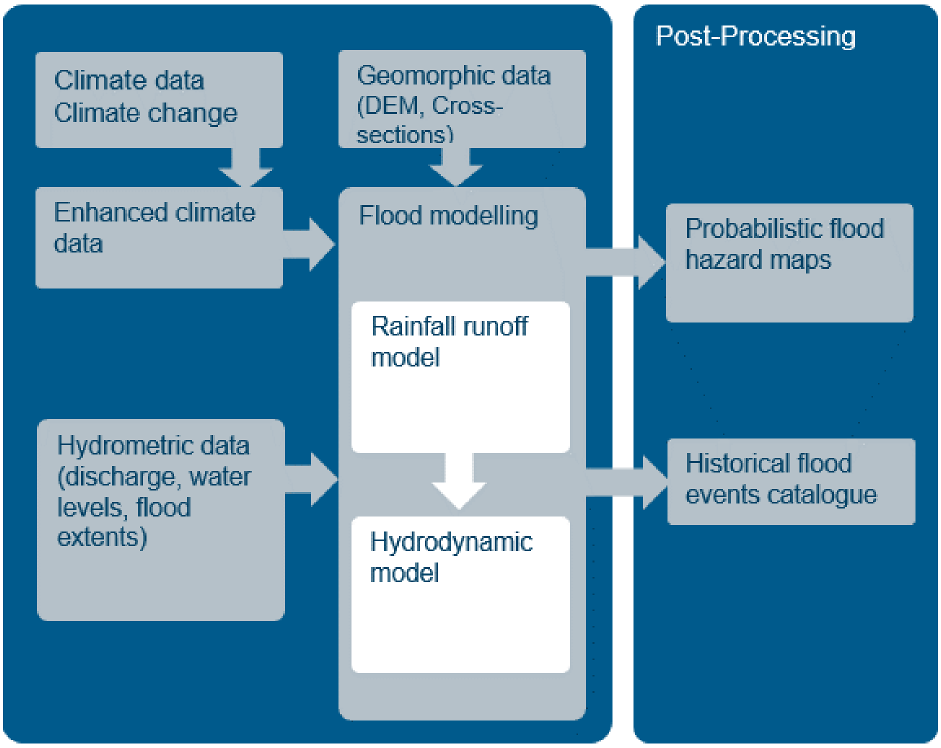


Figure 3.36: Fluvial flood probabilistic hazard modelling workflow

3.2.1 Hydrological Modelling

The fluvial flood model is developed to cover the catchments and reaches shown in Figure 3.37. The sub-catchment units represent the different conceptualized and lumped hydrological sub-models. In view of the temporal resolution of the hydrometric data available (discharge and rainfall at daily scale), the fluvial flood hazard mapping will be carried out only for the largest sections of the river (drainage area >600km2) and where the DEM is assessed of sufficient quality. The remaining river sections will be covered under the flash flood modelling component.

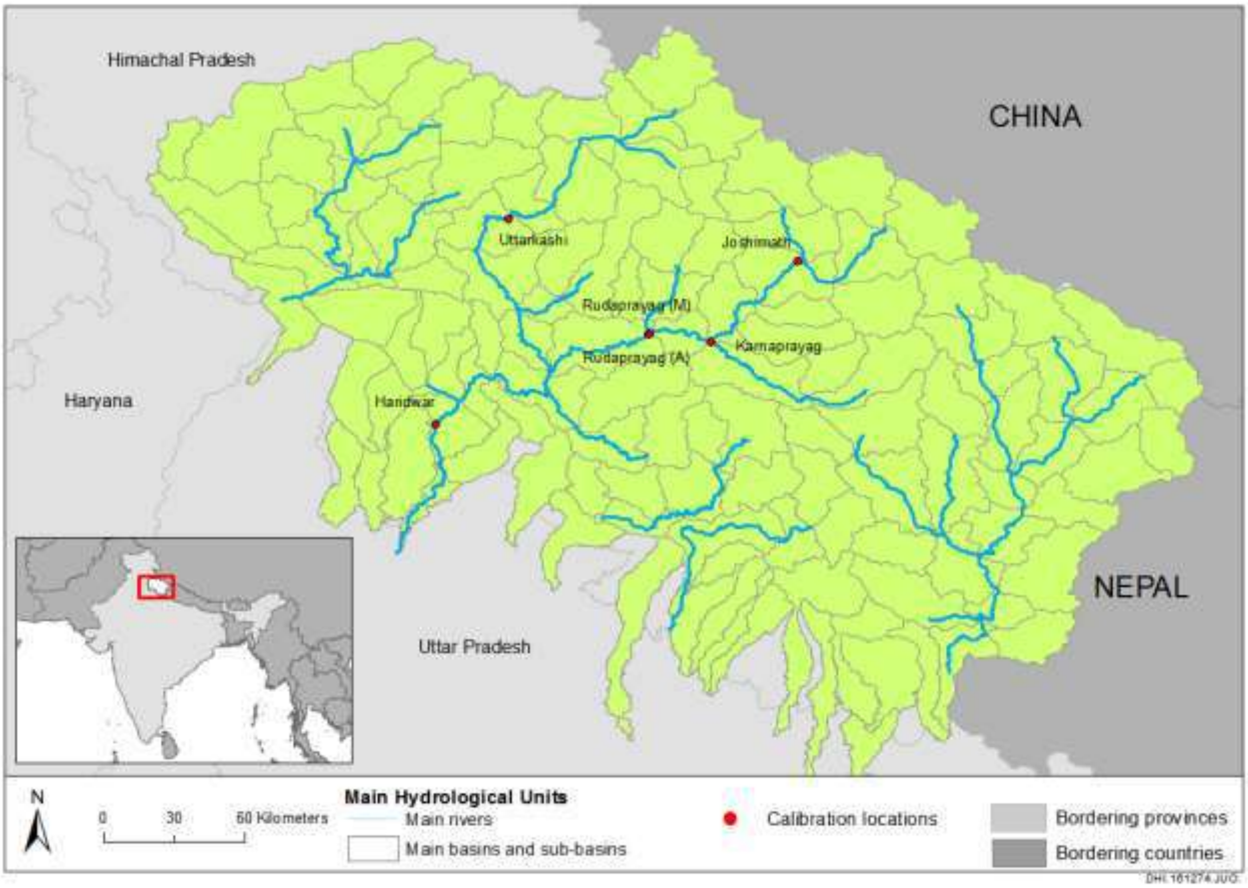


Figure 3.37: Catchment, sub-catchments and main rivers defined for fluvial flood hazard modelling

Hydrological modelling is carried out using the NAM rainfall-runoff model developed by DHI. The NAM model is a lumped, conceptual rainfall-runoff model simulating overland flow, interflow and base flow as a function of precipitation, evaporation and the water storage in each of four mutually interrelated storages representing the total storage capacity of the catchment (including snow and snowmelt) (see Figure 3.38). In view of the limited number of available calibration locations, a regional approach has been applied.

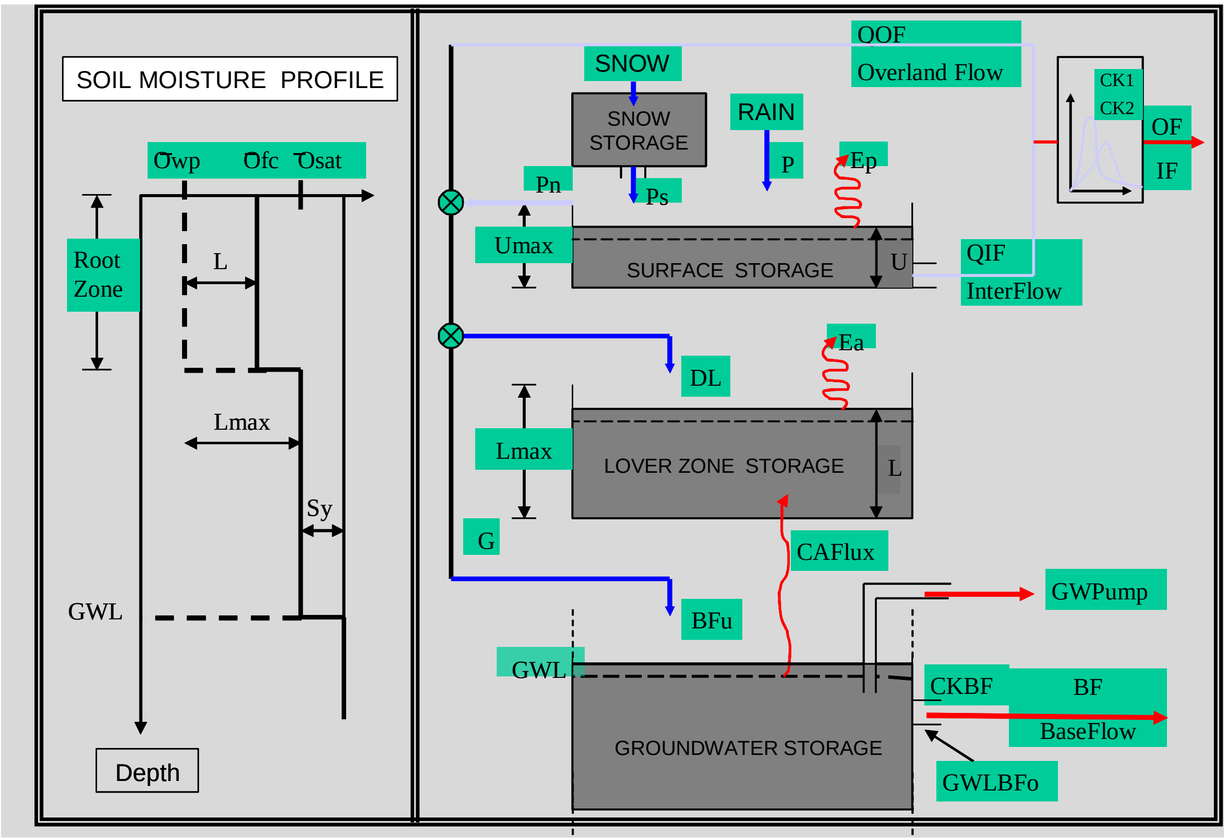


Figure 3.38: NAM model structure and parameters (DHI, 2017)

For gauged catchments where rainfall and runoff data are available for a sufficiently long period (5-10 years) the NAM model can be calibrated. In the specific application, only 10 days average discharge and annual maximum discharge are available. In this context the NAM model will be calibrated for mass balance conservation (using the 10 days average) and yearly peak (using the AMS).

For estimation of NAM model parameters a methodology has been developed that relates calibrated NAM parameters with physiographic catchment characteristics. The parameters of the NAM model are estimated using the land-use, DEM and soil characteristics for the full basin. The parameters are first established based on those data sources and expert judgement rules: e.g. typical approach for modifying of the different NAM parameters is illustrated in Table 3.5.

Table 3.5: NAM parameter description and adjustments.

Parameter	Representation	Difference in catchment characteristics	Impact on parameter value
U_{max}, L_{max}	Maximum water content in surface storage and lower zone/root storage	More agricultural land or soil types with higher water retaining capacity	Increase
CQOF	Overland flow coefficient	Lower permeability, higher slope	Increase

Parameter	Representation	Difference in catchment characteristics	Impact on parameter value
CKIF	Interflow drainage constant	More agricultural land	Decrease
$CK_{1,2}$	Time constant for overland flow and interflow	Larger catchment, lower slope	Increase
TOF, TIF, TG	Overland flow, Interflow and groundwater recharge threshold values	Less homogeneous soil types	Decrease
CKBF	Time constant for base flow	Larger catchment, lower slope	Increase

As an example, for flood modelling the dominant parameters are CQOF and $CK_{1,2}$ representing overland flow and catchment routing. These two parameters are considered analogous to, respectively, the runoff curve number and the catchment lag time available in the Unit Hydrograph Method (UHM), which can be estimated using catchment characteristics. The runoff curve number and lag time are estimated using the method described by Costache (2014). The lag time is computed according to the Soil Conservation Service (SCS) formula:

$$T_{lag} = \frac{(\,3{,}28\ 10^3 L)^{0.8}\ (\frac{1000}{CN} - 9)^{0.7}}{1900\ Y^{0.5}}$$

where *L* is the hydraulic length [km], *Y* the average slope [%], and *CN* the average Curve Number [-]. The Curve Number, developed in 1954 by SCS, is an indicator of the surface runoff potential, depending on land use, soil type and slope. An example of CN values developed using different globally available datasets are presented in Table 3.6 with land use classes extracted from the ESA (European Space Agency) dataset as developed in 2012 as part of its Climate Change Initiative (CCI) and soil types published by the Harmonized World Soil Database (USDA-NRCS) reclassified in 4 Hydrologic Soil Groups HSG according to Rawls & Brakensiek (1983).

Instead of calibrating a set of parameter for a single location, the calibration process aims at modifying the rules used to derive the model parameters. Based on the first parameters established, the calibration process aims at modifying the parameter dependency rules developed (based on geomorphological characteristics and land-use using an area weighted average) uniformly across all sub-basins.

Table 3.6: Curve number according to land cover, soil group and slope (based on Rawls & Brakensiek, 1983)

LC (Land Cover)	ID	SO (Soil)											
		1 (HSG-A)			2 (HSG-B)			3 (HSG-C)			4 (HSG-D)		
		SL (Slope)			SL (Slope)			SL (Slope)			SL (Slope)		
		1 (0-2%)	2 (2-6%)	3 (> 6%)	1	2	3	1	2	3	1	2	3
Cropland	1	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
Grassland/Herbaceous	2	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
Mixed Forest	3	0.09	0.14	0.21	0.13	0.20	0.26	0.17	0.24	0.30	0.21	0.28	0.40
Cropland, Irrigated	4	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Forest	5	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.30
Shrubland	6	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
Bare/Open Areas	7	0.05	0.10	0.14	0.08	0.13	0.19	0.12	0.17	0.24	0.15	0.21	0.28
Wetlands	8	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Urban Areas	9	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
Water Bodies	10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

3.2.2 Rainfall Data Correction

Different rainfall data sources have been used for hydrological simulation. The detailed list is given in Section 3.2.10.

A variety of rainfall data products have been acquired and merged to produce the final historical rainfall data set. The objective of the rainfall enhancement exercise is to maximize rainfall temporal and spatial coverage to ensure that rainfall volumes, extremes and orographic variations are best captured. Figure 3.39 shows a comparison in terms of temporal and spatial coverage of the IMD rainfall products and TRMM 3B42 calibrated products. The analysis performed on the different datasets lead to the following conclusion and processing approach to enhanced rainfall data:

- IMD Grid is used as base rainfall data as it provides the longest set of observations (100 years). However, the interpolation procedure applied in the dataset and the effective number of observations in the state can lead to large errors in the rainfall estimation for continuous simulations. To avoid large inconsistencies in the rainfall data, a quality check of the rainfall data has been applied during the discharge calibration process and using the 36 years of available maximum discharge series (1980 – 2015).
- Considering the limitations of ground stations to reproduce the orographic variation of rainfall, GPM data is used to identify sub-basin weightage corrections of non-extreme rainfall in the hydrological model in mountainous areas poorly covered by the synoptic network.
- A mass balance analysis is performed against annual rainfall 10 days average discharge at few locations to identify a volume correction to the GPM corrected IMD GRID product. A uniform

weight of 1.2 across the State is found to produce the best balance overall between the different gauging stations.

The ECMWF data (https://www.ecmwf.int/) is used to define evaporation and temperature for each sub-basin and an elevation correction across the different elevation zones present at the sub-basin level. The CHIRPS data has been used in the few catchments located in Nepal in order to produce the inflows from the tributaries located outside the Indian country borders.

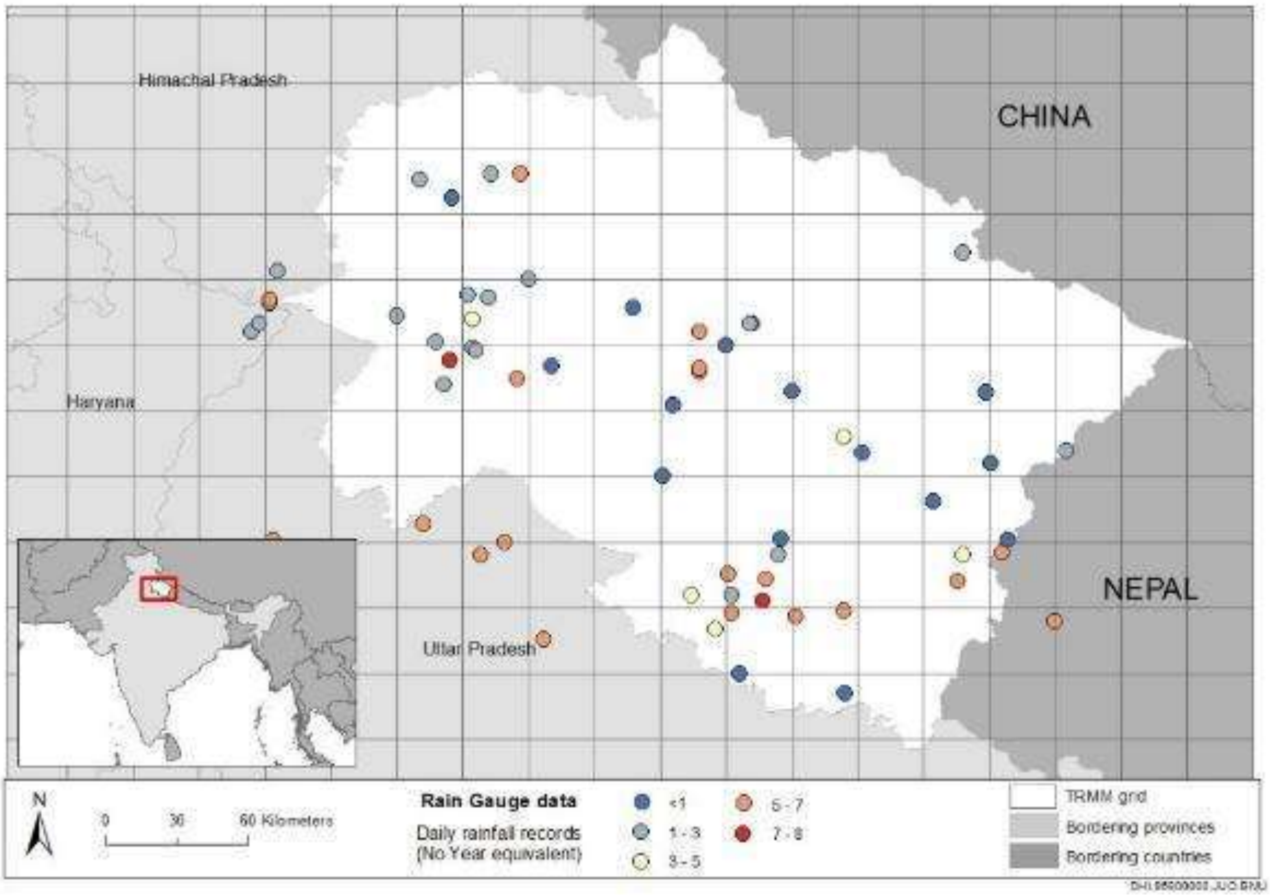


Figure 3.39: Comparison of spatial and temporal distribution of IMD Rain Gauges (most recent stations) and TRMM (16 equivalent year of measurement across the full state)

3.2.3 Snow Modelling and Orographic Rainfall Data Correction

Too much snow is generated if the Mean Average Rainfall (MAR) is not corrected and redistributed in the elevation zones. When the snow storage is full in an elevation zone of the NAM snow model any new snow that is generated is transferred to lower zones that have not reached the limit. Hence too much snow is generated at higher elevations if the precipitation is distributed evenly. To avoid excessive accumulation of snow the precipitation has been redistributed following precipitation-elevation relationships estimated from analysis of 2 years of GPM data.

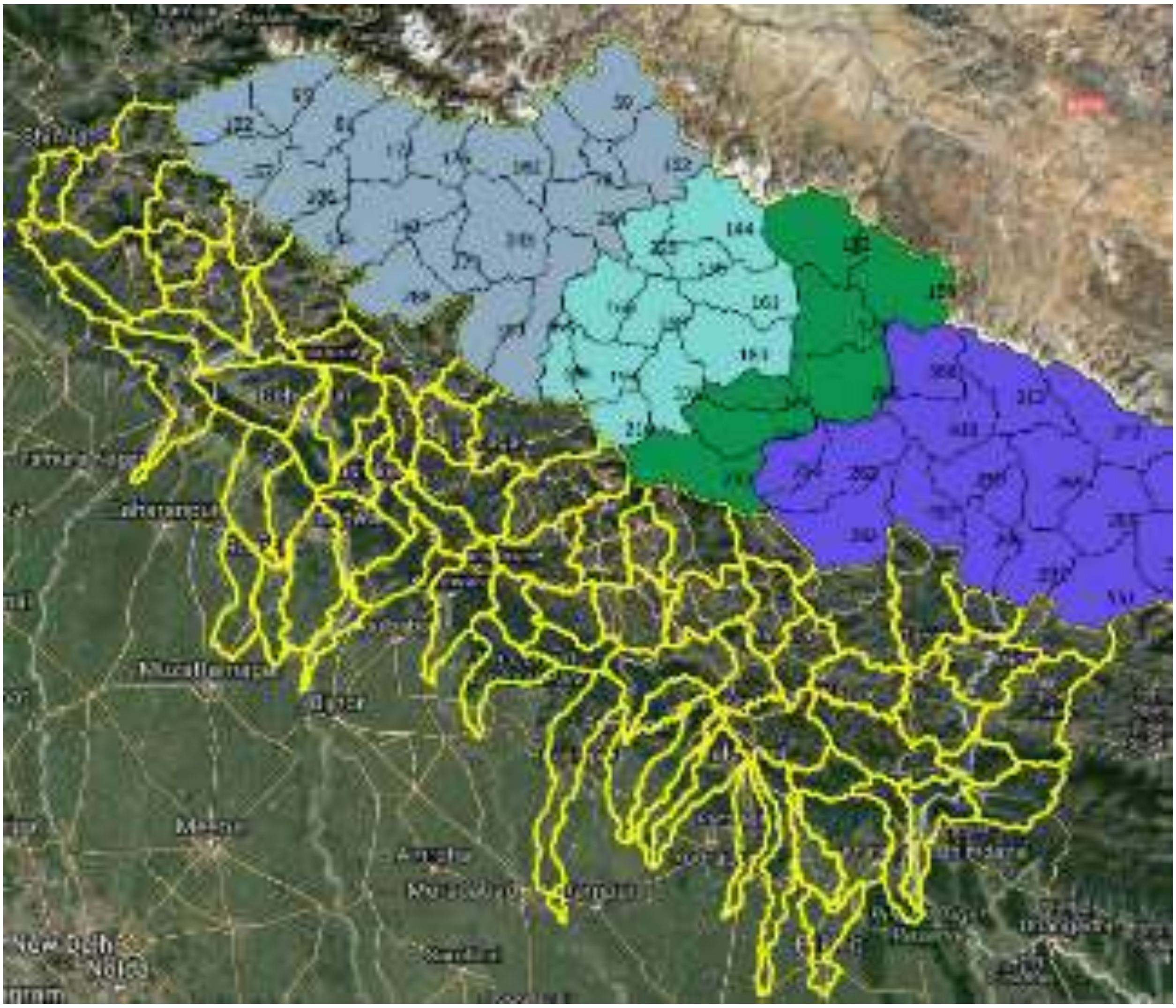


Figure 3.40: Catchment groups with snow zone corrections

It is difficult to find a good overall relation between annual precipitation and elevation for the area as a whole as illustrated on Figure 3.40 where the relation between precipitation amount and elevation is not very clear. A better result is obtained by dividing the area and extract individual linear relationships for the different catchment groups shown on Figure 3.40. Figure 3.41 reveals that significantly different relations between east and west and between the west and eastern catchments in the central part. The catchment rainfall in the groups also shown in Figure 3.40, are redistributed with their corresponding relationship.

In Figure 3.41 the precipitation is plotted with the minimum and maximum value of a 300m up-sampled SRTM map to illustrate the uncertainty on what elevation is actually represented by the grid cell. The average (black) is used.

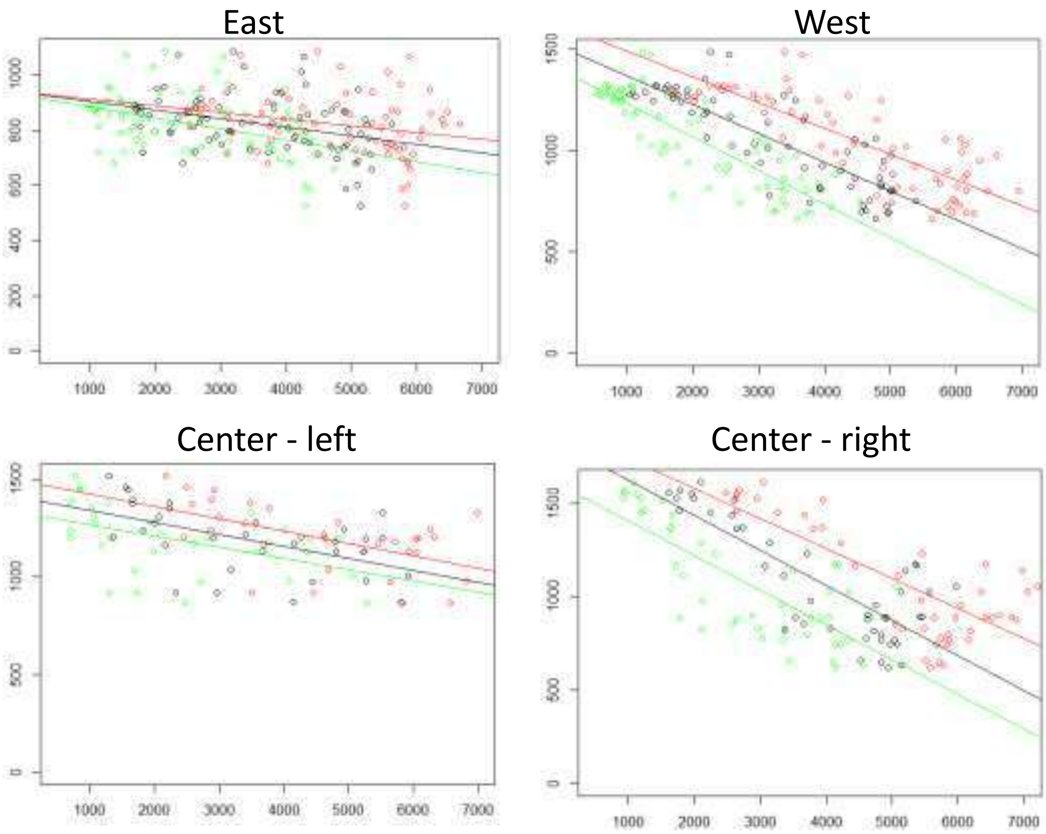


Figure 3.41: Elevation – precipitation relationships extracted for groups in Figure 3.40. Note East is limited to 1000mm. elevation in individual GPM grid cells against mean annual precipitation in same grid cell extracted from GPM. Green is minimum elevation, red maximum elevation and black average of 30 x 30m SRTM data inside grid cell.

The simulated snowmelt was found to be too low early in the season compared to the observed 10-day average discharges. To increase the snowmelt a constant degree/day factor of 4.5 is used instead of the seasonal variation that was previously used. 4.5 corresponds to values in the summer months.

3.2.4 NAM Model Parameters

3.2.4.1 Upper part of the basin – calibrated catchments

Catchments with more than half of the catchment area above 3500m is defined as mountain catchments and given the same parameter set as was found to give reasonable results for the catchments upstreams Joshimath, Uttarkashi and Karnaprayag.

Peaks where overall too high and has been reduced by lowering CQOF to 0.35 and increase the CK1,2 derived from direct landform analysis with a factor 3. When routing a significant part of the water through the ground water reservoirs the catchment runoff response is dampened and reflects very high roughness. Excessively high CK1,2 values are thereby avoided and a faster response from the overland flow reservoirs can be maintained.

A reduction of the peak values of around 1/3 due to routing has been assumed and the CK1,2 parameter is therefore lowered slightly to achieve higher peaks than the observed annual maximum. The simulated annual maximum peak often does not correspond in time with the observed and the accuracy seems to vary between different years. Estimation of approximate levels of the peak values by adjusting the CK1,2 has therefore been visually from the calibration plots and observed annual maximums (see Section 3.2.5).

3.2.4.2 Lower part – non calibrated catchments

In the lower part of the basin (catchments with limited or no snow melt) it has not been possible to calibrate the NAM model. The IMD Gridded data benefits from more spatial and temporal coverage and a similar uniform weightage of 1.2 is applied similarly to the weight applied to the upstream catchments for water balance correction. An overview of the location of the catchments is found in Figure 3.42. A validation of the approach is given using the Annual Maximum Series of discharge at Bhimgoda Dam, Haridwar.

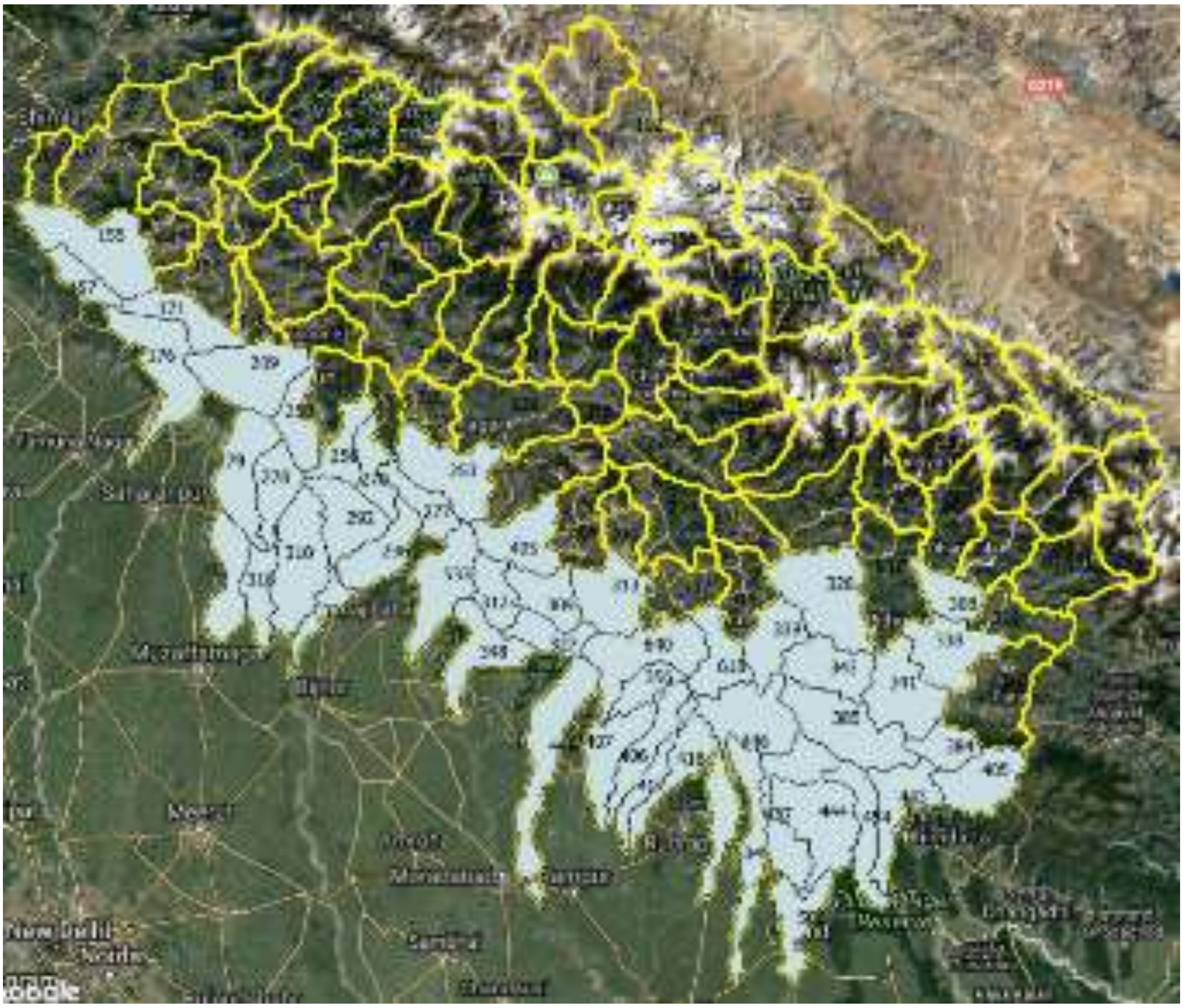


Figure 3.42: Overview of lower catchment with no snow melt

In the lower part of the basin it is assumed that the catchments has a higher runoff coefficient assumed equal to the runoff coefficient estimated from the curve number method (CQOF equal to 0.6-0.7).

3.2.5 Calibration and Validation

3.2.5.1 Water balance

The water balance calibration is performed using 10 days average data over the 2010-2014 period. No other continuous discharge data have been made available to the Consultant. The calibration exercise ensure that rising and receding base flow are adequately captured by the model and that water balance errors are minimized over the accumulation period. The water balance errors are generally lesser than 15% for all stations. The 2013 period has been removed for Mandakini as the instruments have been affected by the June 2013 flood, producing unrealistic accumulated discharge volumes.

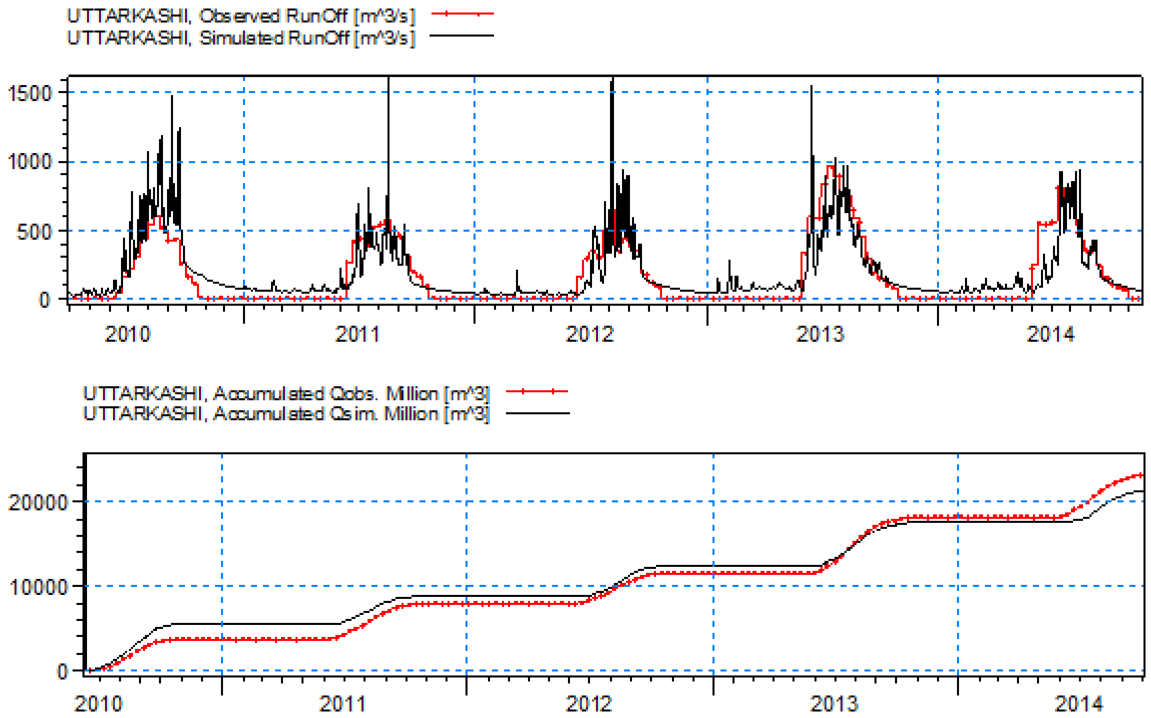


Figure 3.43: Water balance calibration for Uttarkashi station. Top: black = 1 hour simulated discharge, red =10 day averaged observation; Bottom: accumulated discharge volume black simulated, red = observed.

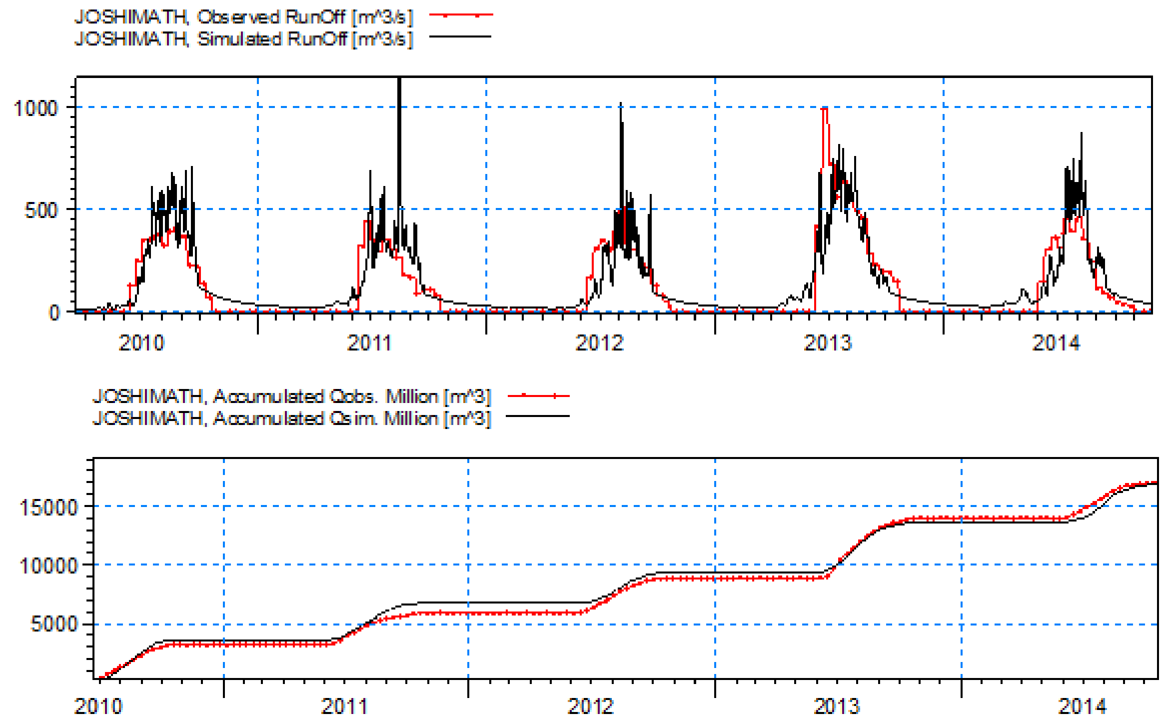


Figure 3.44: Water balance calibration for Joshimath station. Top: black = 1 hour simulated discharge, red =10 day averaged observation; Bottom: accumulated discharge volume black simulated, red = observed.

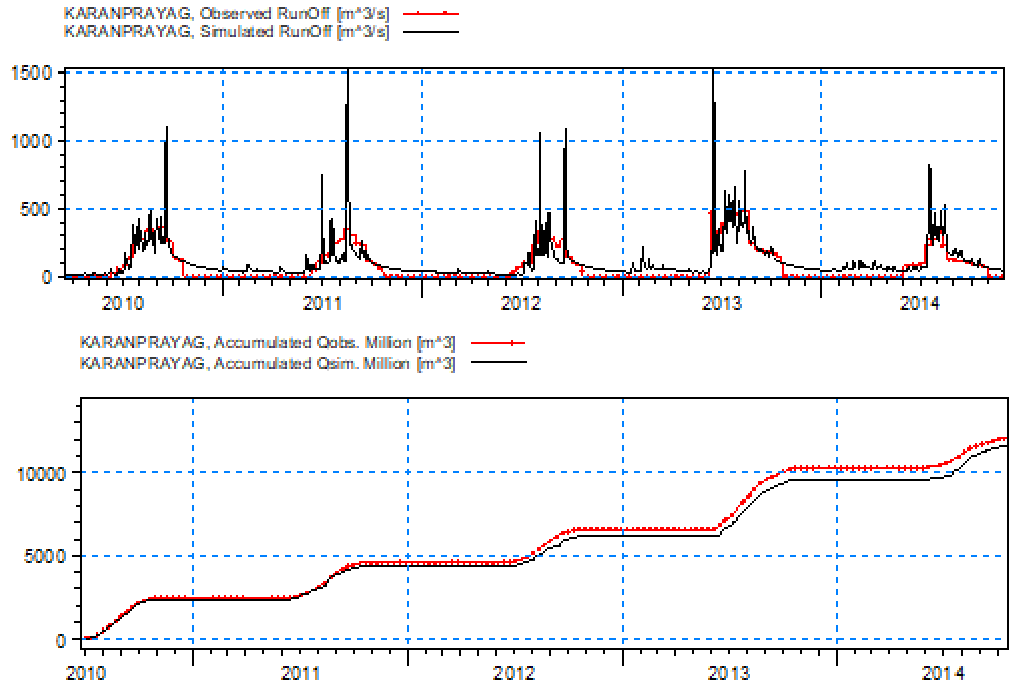


Figure 3.45: Water balance calibration for Karnaprayag station. Top: black = 1 hour simulated discharge, red =10 day averaged observation; Bottom: accumulated discharge volume black simulated, red = observed.

3.2.5.2 Peak discharges

The Annual Maximum Series provided are used for the calibration of the discharge peaks over and identify major quality gaps between the rainfall and discharge datasets. As mentioned earlier, the IMD rainfall dataset is poorly representative of the mountainous region as the spatial and temporal coverage is too sparse. Similarly, the discharge dataset is not full reliable as some records appear to be missing and the overall quality could not be assessed without access to continuous daily or hourly records and rating curves used.

The full 1980-2015 period is used to assess the model and data performance as the same data will be used for continuous simulation and events analysis for the flood hazard mapping. Following this process, the year 1997 and 1998 are judged not representative in terms of rainfall, the volumes produced at Haridwar are much below other yearly records and peaks are not reproduced downstream. Similarly the year 2011 across the different stations with the IMD data providing large uniform rainfall records for the full Ganges basin which did not correspond to any experienced discharge event (either in the discharge data or literature). Similarly a large peak is produced in 1985 in Uttarkashi for which no record was found. Those years 1985, 1997, 1998 and 2011 have been removed from the event set due to quality issues. Despite discrepancies with the discharge data, the year 1995 and 2012 have been kept as the discharge data seem to not be representative (e.g. a large peak was experienced in Uttarkashi in September 1995 and the water level rose above the danger level in Haridwar in 2012).

For the 2013 event, extreme peaks have been recorded at Rudaprayag (Alaknanda and Mandakini). Those peaks can originate from different processes including: instrumentation or back-calculation errors due to large morphological changes or blockage associated with landslides and GLOF, increased snowmelt at the beginning of the monsoon season associated with large rainfall and/or limitation of the daily rainfall records. The latest has been investigated and the 24h daily rainfall over the 16-17-18 June have been redistributed to maximize the 24h max rainfall over the 17 June to re-centre the maximum 24hr intensity around this date (note that the 24 hour max rainfall is distributed over the 16 and 17 of June). A sub-daily rainfall dataset would allow to capture better this type of processes. The changes in rainfall redistribution affects the peak discharges at Uttarkashi and Joshimath which are believed to be underestimated by the measurement stations or not measured at all (the annual peak for 2013 in Uttarkashi is marked on 24th July and on 27th June for Joshimath). Finally the peaks at Haridwar are reproduced adequately, validating the model for the downstream and non-calibrated catchments. The 2013 peak at Haridwar is reproduced without the Tehri Dam peak attenuation leading to peak discharge of 22,000 m3/s well above the 15,000 m3/s recorded. Removing the inflows from the Bagirathi River to reproduce the Tehri Dam impact would lead to a reduction of the peak discharge down to 16,500 m3/s. The 2013 peak simulated are kept for the final event set simulation and used for worst case scenario mapping.

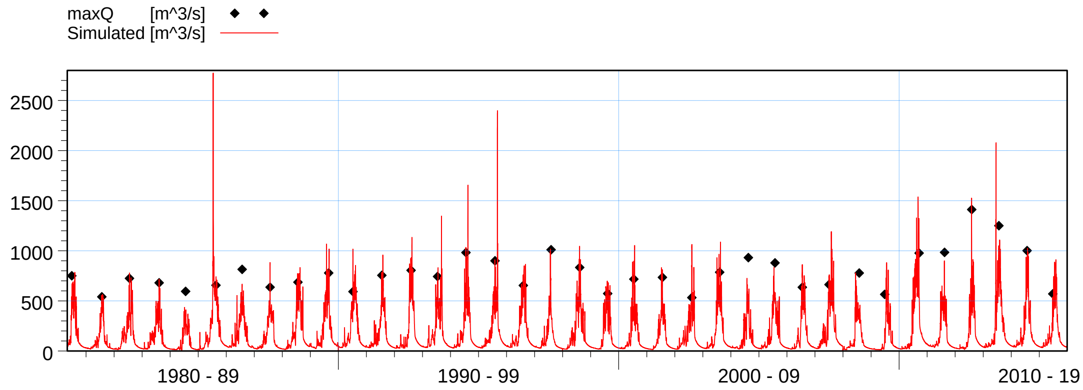


Figure 3.46: Simulated discharge (red) and annual maximum observation (black dot) at Uttarkashi.

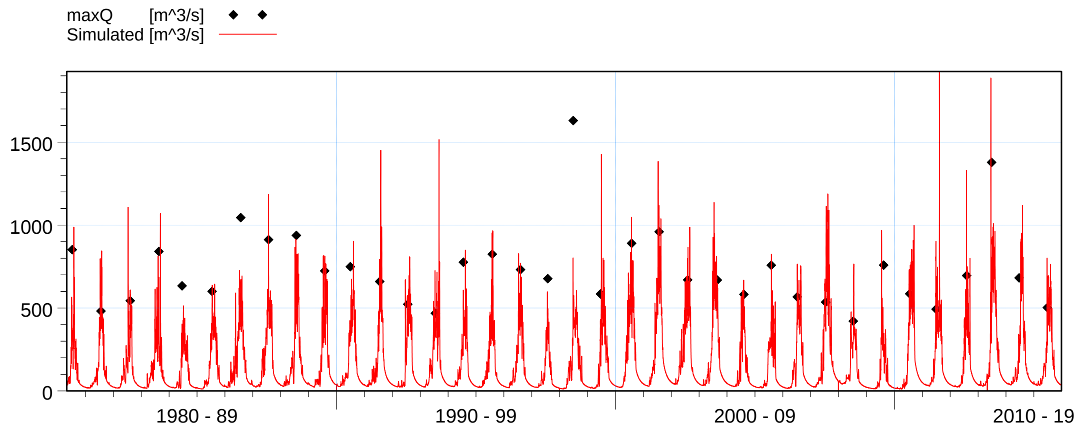


Figure 3.47: Simulated discharge (red) and annual maximum observation (black dot) at Joshimath

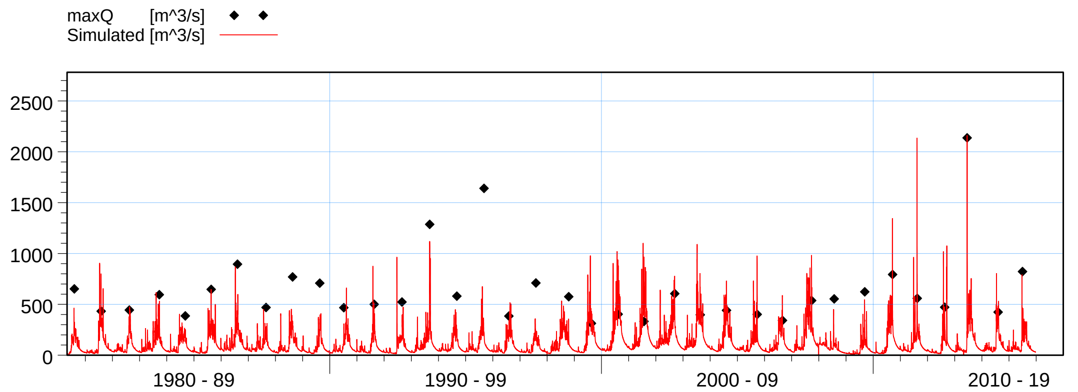


Figure 3.48: Simulated discharge (red) and annual maximum observation (black dot) at Karanprayag

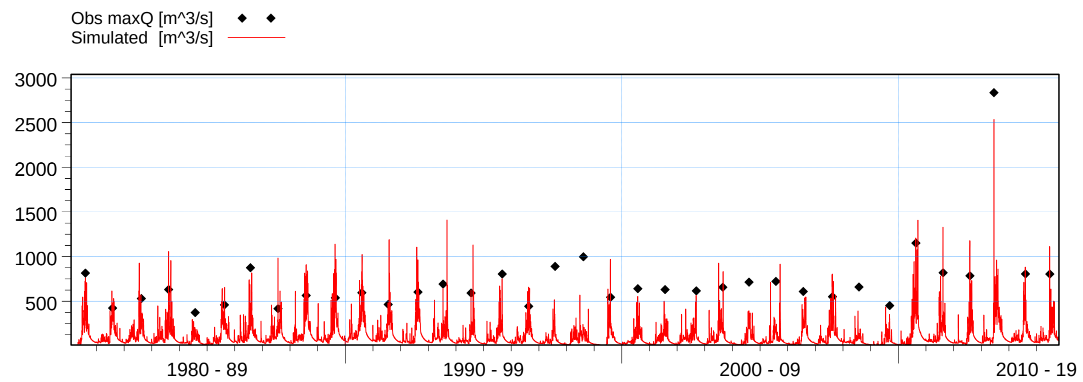


Figure 3.49: Simulated discharge (red) and annual maximum observation (black dot) at Rudaprayag – Mandakini

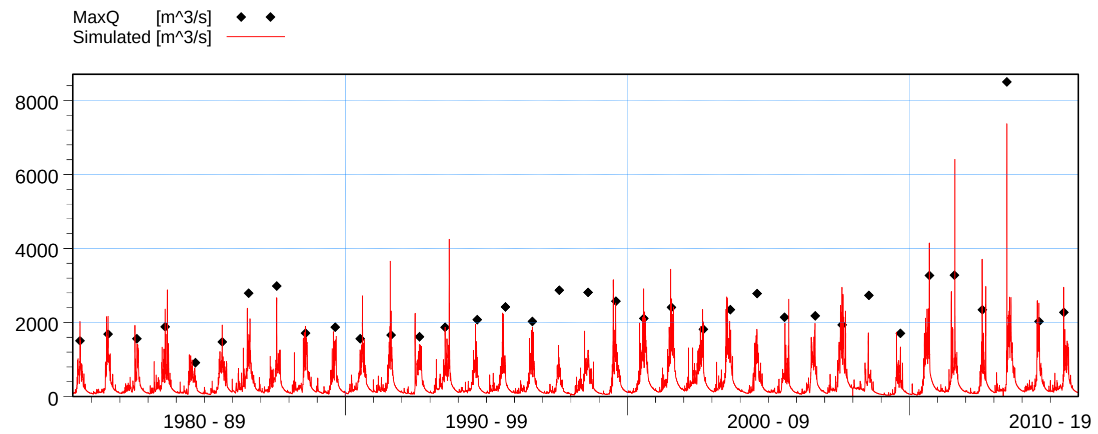


Figure 3.50: Simulated discharge (red) and annual maximum observation (black dot) at Rudaprayag – Alaknanda

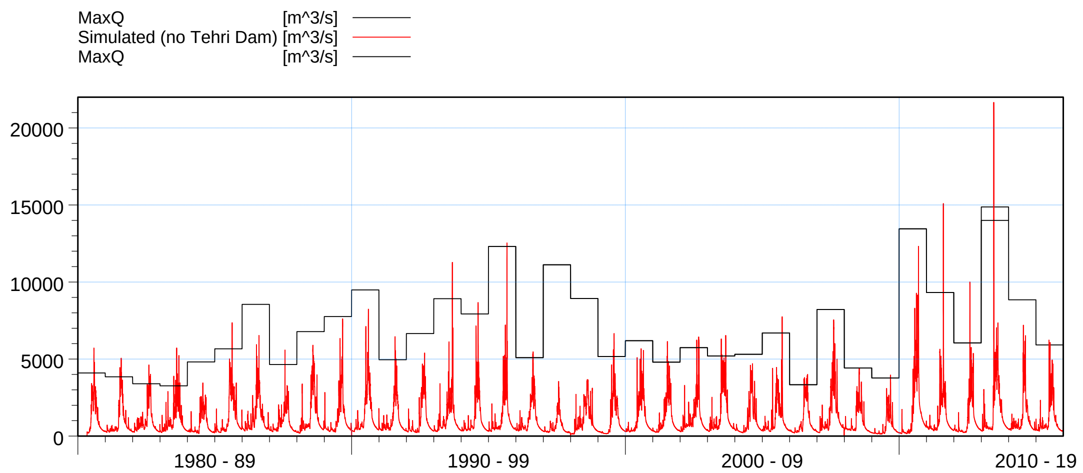


Figure 3.51: Validation of the overall model at Bhimgoda Dam, Haridwar. Simulated discharge (red) against Annual maximum discharge (black). Years 1997, 1998 and 2011 are removed of the final event set due to rainfall data quality issues.[10]

[10] The 2013 discharge do not consider the retention of the Tehri Dam and is in line with the back-estimation of discharge by THDC (21,519 m3/s. Agrawal (2017). Simulation of the June 2013 Flood at Tehri Dam. 3Rd National Dam

3.2.6 Hydrodynamic Modelling

The hydrodynamic modelling is performed with MIKE11. The flood wave propagation in the river channels use an unsteady one dimensional hydrodynamic model based on the full St Venant equations. The equations are transformed in a set of implicit difference equations over a computational grid consisting of a network of branches schematized using alternate Q- and h-points. For those points, the discharge and the water levels are computed at each time-step using a 6-point Abbott-scheme (Abbott and Ionescu, 1967). Advanced computational modules are included for description of flow over hydraulic structures, including possibilities to describe structure operation. Water level computation (and h-point locations) are done where cross-sections (section of river perpendicular to the flow) are defined by the user and identified along the river branch at defined chainages.

3.2.6.1 Digital Elevation Model

THE DEM is critical to assess flood risk as it allows to relate the elevation of the exposed elements to the water level elevation originating from flooding. A series of recommendation were provided by the Consultant regarding DSM and DTM products (freely available and commercial products). The 30m SRTM (elevation accuracy: 10m LE90) and the 10m Cartosat DSM from NRSC (elevation accuracy: 10m LE90) have been acquired. With stated 10m resolution and slightly better accuracy than SRTM, the Cartosat 10m product has been used for flood modelling.

The quality of the DEM in terms of absolute and relative elevation errors, particularly in the mountainous regions poses a significant on the quality of the flood hazard modelling (see examples in Figure 3.53 to Figure 3.56). The main limitations and corrections of the DEM product are listed below:

- The DEM can capture drainage system only in the range of 5-6 times the resolution of the DEM. In this case, assuming a very good and accurate dataset, it can be expected that the DEM could resolve only non-submerged rivers in the 50-60m width range. Reality showed that in many cases the DEM was not able to resolve rivers with width > 150m.
- Due to the nature of the mountainous terrain and steep terrain, large errors can be found in the river alignment and narrow valleys. A hydrologic enforcement has been applied (DEM carving, see Soille et al., 2003) has been used to re-establish the river bed elevation and ensure a downstream flowing profile of the rivers. This process allows to correct errors in the DEM in mountainous regions and remove man-made flow obstructions such as bridges and dams. A median elevation error has been found in the range of 5m across the full State, providing indication of the uncertainty range of river bed elevation. All zones with errors in river profile

Safety Conference, IIT Roorkee. Available online at https://damsafety.in/ecm-includes/PDFs/Conference/3NDSC/Presentation/TS2/TS2_4.pdf estimation above 5m have been classified as unsuitable (see Figure 3.52) for flood hazard mapping as the simulated water levels would most likely be below the elevation captured by the DEM. Wherever the DEM quality alternates too frequently and over too short spans, the section has been classified as completely unsuitable if no settlements are located in proximity of the river. The remaining sections ensure that the river profile error is limited but do not necessarily ensure the quality of the DEM for flood mapping.

- Artifact originating from the acquisition procedure are clearly visible and can affect the results quality even in areas where the river alignment elevation is judged acceptable (5m or less error).
- In the larger and flatter floodplains along braided rivers, the DEM has been hydrologically corrected by applying a classic depression filling algorithm.
- Being a DSM, the in-bank river cross-sections cannot be resolved. An estimation of the in-bank conveyance has been done using surveyed cross-section data available (see section below).
- In the flatter and mostly densely built areas, buildings have been removed using a block minimum smoothing filtering procedure using the building blocks manually digitized and used for the exposure modelling.
- The DSM product do not present a uniform and consistent elevation across the state and relatively to established benchmark. The large relative errors (8m in areas with slope <20%, 5m median for river bed elevation estimation in mountains) make impossible to relate with enough accuracy existing surveyed cross-section or water level benchmarks with the existing DSM dataset.

Considering the large terrain variations and narrow gorges where towns can be located, a 1-2m resolution DEM is required across the State with enough accuracy relative and absolute accuracy to be able to integrate the DEM product with detailed surveys that have been carried out in the State.

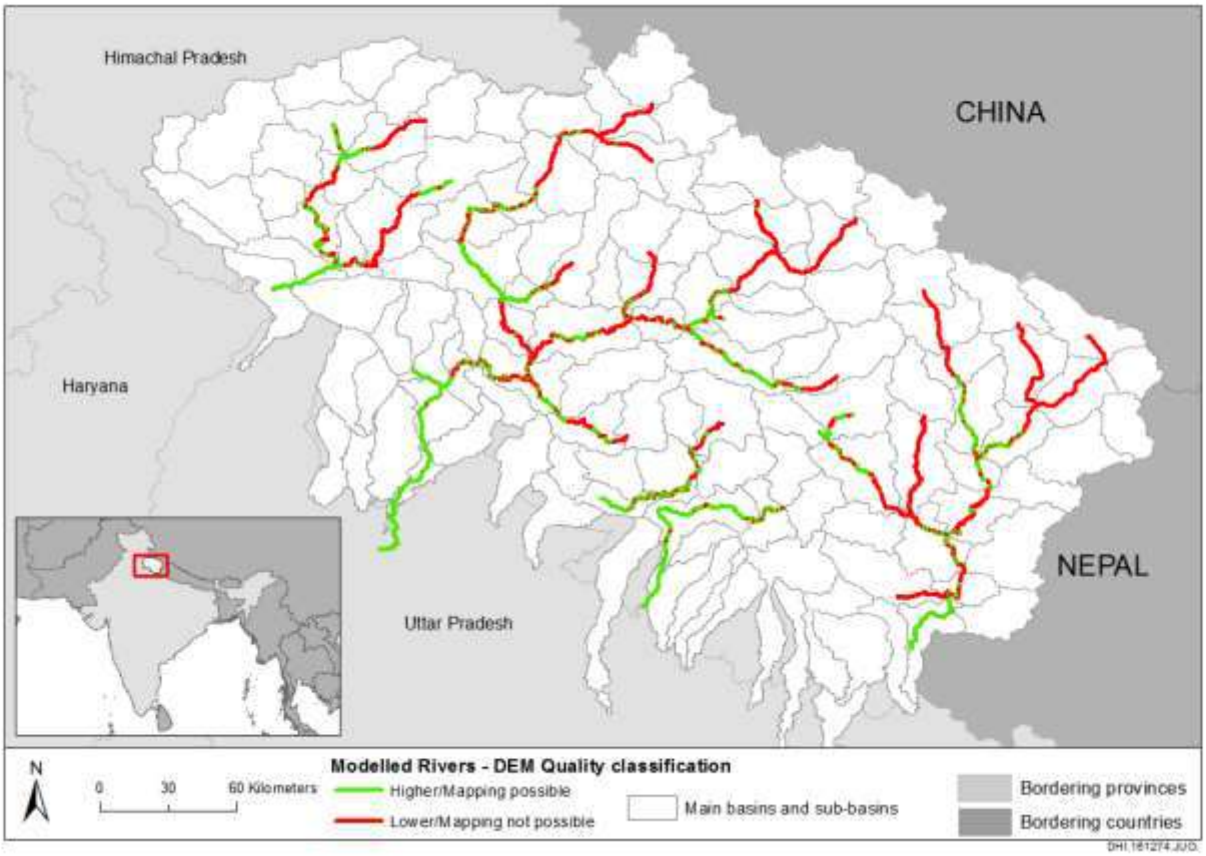


Figure 3.52: River sections: mapping suitability classification following hydrologic enforcement analysis

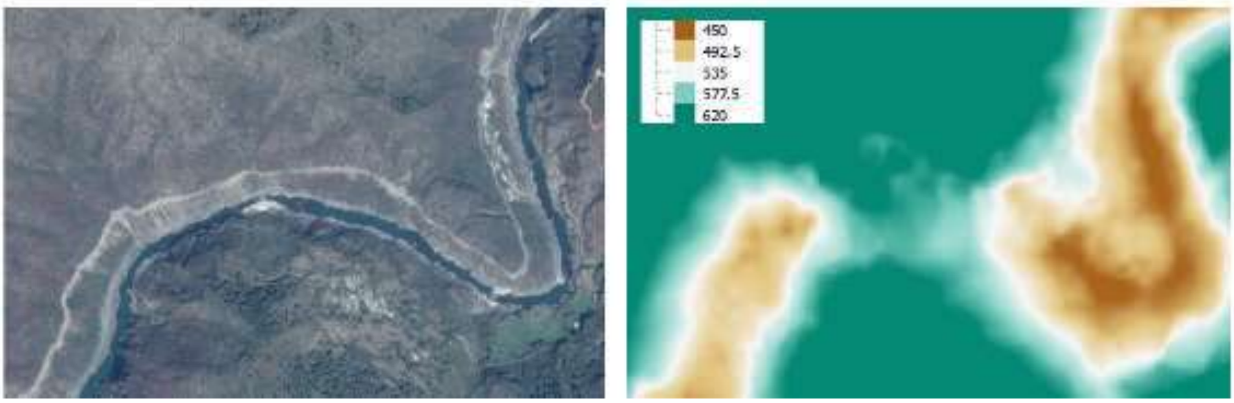


Figure 3.53: Example of inconsistencies and errors frequently encountered in the DEM: Incoherent river elevation profile – river width >80m (steep terrain) not resolved by the 10m DEM product

Figure 3.54: Example of inconsistencies and errors frequently encountered in the DEM: Incoherent river elevation profile – river width >200m – flatter terrain

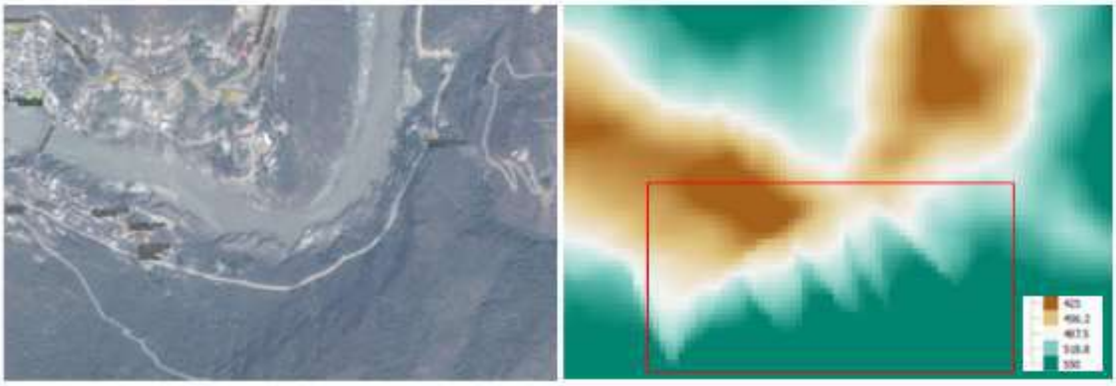


Figure 3.55: Example of inconsistencies and errors frequently encountered in the DEM: Slope and terrain presenting geometrical artefacts

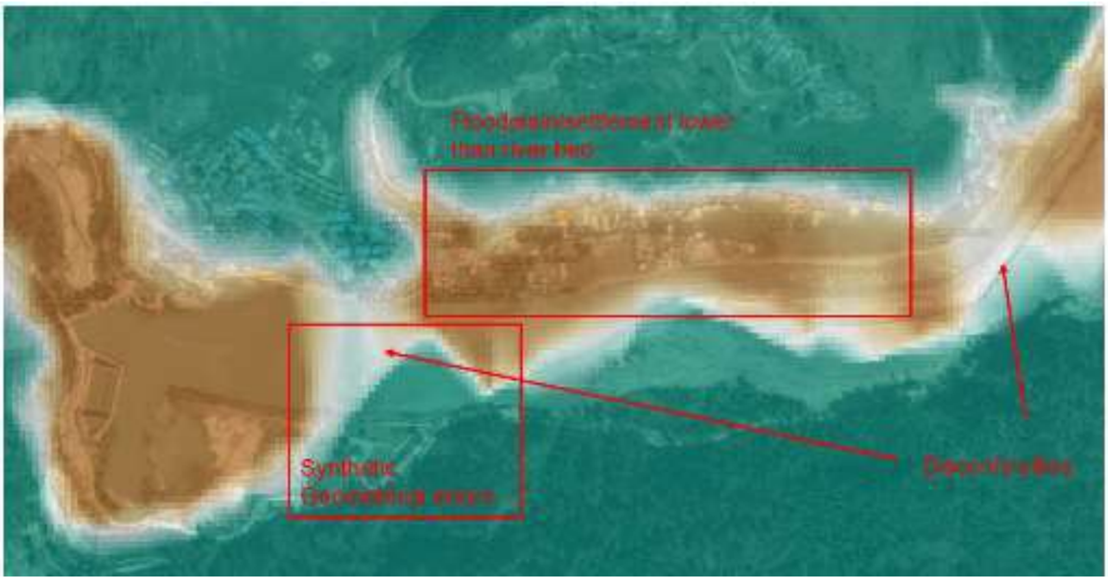


Figure 3.56: Example of inconsistencies and errors frequently encountered in the DEM: Floodplain lower than river bed (river width > 200m)

3.2.6.2 River network and cross-sections

The river network is extracted from the Cartosat 10m DEM (see Figure 3.37). Based on a shapefile of the river network and the digital terrain, elevation and catchment area profiles are created along each branch of the river network. The information generated is then processed to automatically create in-bank cross-sections between surveyed cross-sections data and used to describe the hydraulic routing within MIKE11. The cross-section processing follows the steps as below:

- Cross-sections chainages are identified at defined intervals (e.g. 100 m to 3 km) based on: the DEM representativeness of the river bed elevation (by identifying locations with minimal difference between the carved and original DEM), the building exposure and expected changes in slope, the availability of surveyed cross-sections data (app. 130 locations).
- The Cartosat DTM derived cross-sections, the low flow conveyance is assumed not captured. Although not critical for largest flood (the low flow conveyance is usually very small compared with floodplain conveyance), an estimation of the low flow conveyance for non-surveyed cross-sections is proposed using the following formula (see Modrick et al., 2014; Gardner and Waite, 2013):

$$A_i = \alpha \, e^{\beta d_i}$$

with A_i [m^2] is the low flow cross-section area at a location i, d_i [km^2] is the drainage area at *I*, and $\alpha = 0.008$ and $\beta = 1.056$ parameters fitted (R^2 = 0.52) using the 10th to 90th cross-sectional area percentiles of the surveyed cross-sections data (see Figure 3.57).

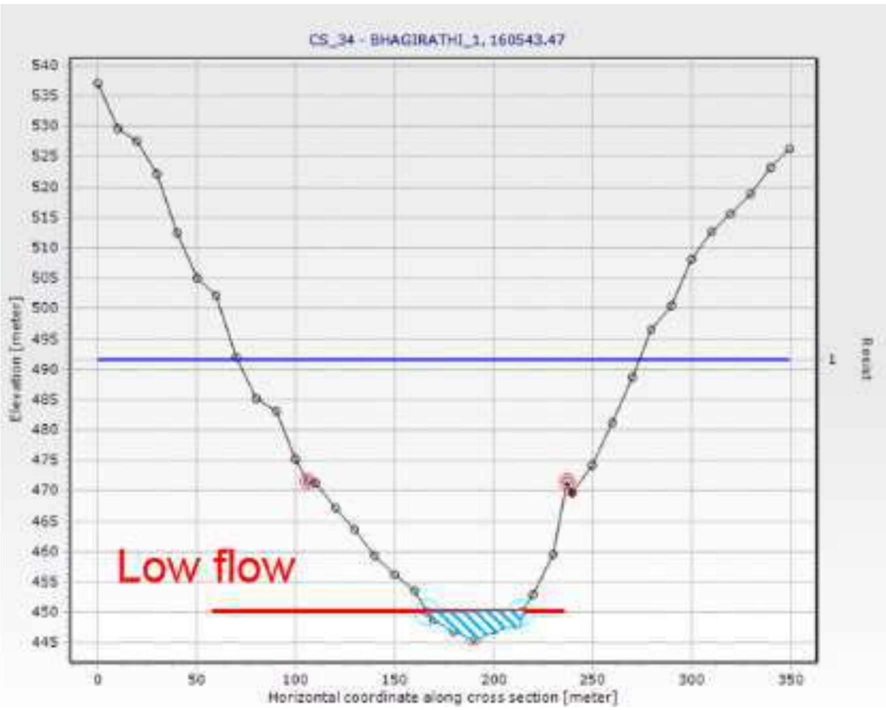


Figure 3.57: Example of cross-sectional area as available from surveyed data

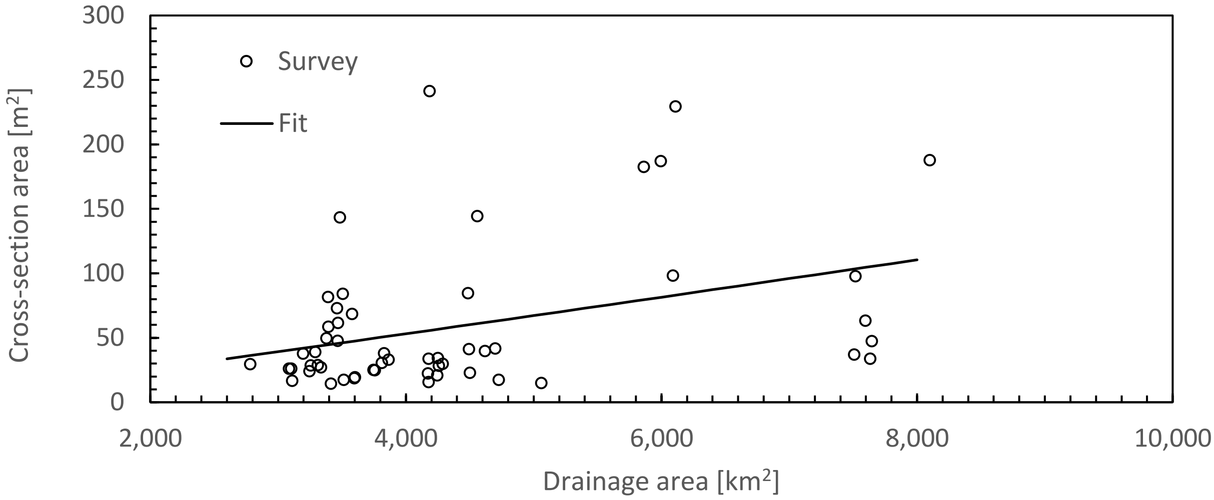


Figure 3.58: Fit of low flow cross-section areas to upstream drainage areas. Large variations exist due the high morphological changes that can be expected in the mountains.

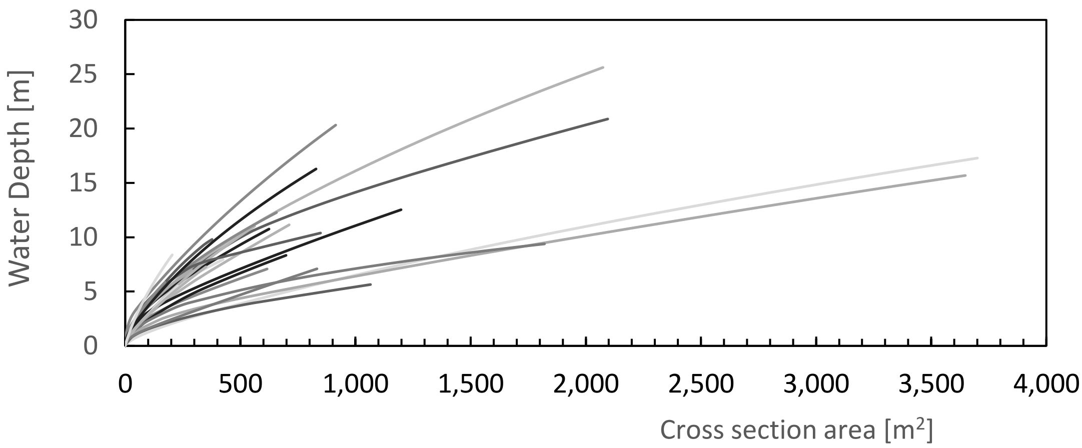


Figure 3.59: Example of cross-sectional area variation with water depth. The low flow contribute generally to capture adequately the water depth within the first 1 to 4m. The water depth for larger events is dominated by a proper characterisation of the conveyance that should be extracted from a digital terrain model

3.2.6.3 Roughness parametrization

Following discharge calibration and assuming constant cross-section conveyance, roughness is the main calibration parameter to generate water levels. Only 10 days average water level have been made available at the discharge calibration locations. Those water level measurements are largely influenced by the changes in cross-section conveyance and river bed elevation that occur frequently (during each large event) in Uttarakhand. Under consideration of such uncertainties, river bed roughness is treated probabilistically to account for manning's n uncertainty and indirectly for cross-section conveyance variation. Note that capturing directly the uncertainty associated with river morphological changes would require a much larger set of geomorphological data and more complex and computationally intensive hydrodynamic and geomorphological models.

Considering the scale of the modelling and the limited data for calibration, a pragmatic approach was adopted considering the riverbed roughness (Manning's n) as an uncertain variable following a truncated log-normal distribution as recommended by NCHRP[11] with parameters listed in Table 3.7 based on categorization from land-use/elevation and slope and following the guidelines of Chow[12] (

Table 3.8) and Woldemichael et al. (2010)[13] and the calibration exercise conducted using 10 days averaged water levels (Figure 3.60). The manning distribution has been used to perform a sensitivity analysis of the water levels across the model domain resulting in water levels varying between 0.2 m (in the largest floodplains) up to 1 m.

Table 3.7: Manning n parameters for the truncated lognormal distribution according to land-use and slope/elevation

River section	mean	COV	min	max
>2000 m asl or average slope > 5%	0.07	0.025	0.065	0.08
500-2000 m / average slope < 5%	0.06	0.025	0.055	0.07
<500 m asl	0.05	0.025	0.045	0.06
< 500 m asl or braided river with mix crops/bushes	0.04	0.025	0.035	0.05

Table 3.8: Typical manning n values for different types of channels and floodplains

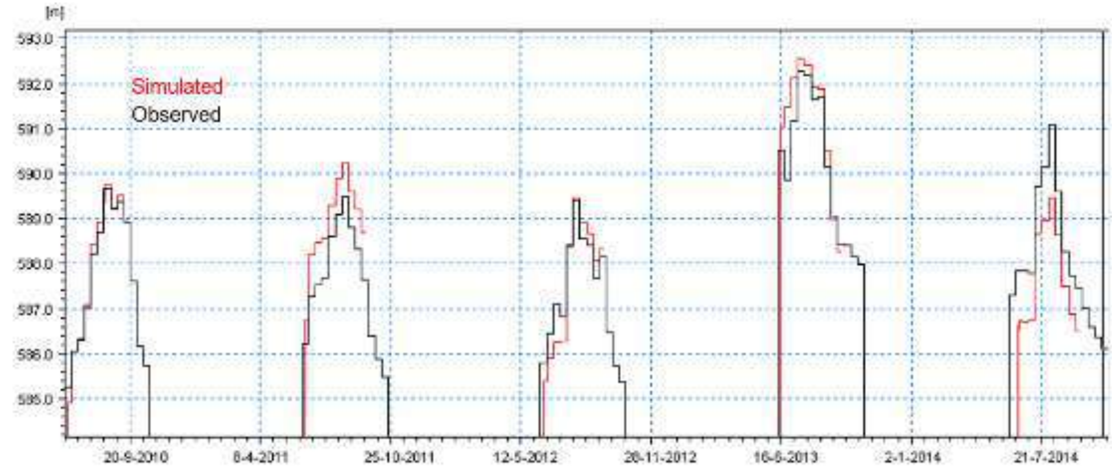
Features	Min	Mean	Max
Mountain stream a. Bottom: gravels, cobbles, few boulders [1]	0.03	0.04	0.05
Mountain stream b. Bottom: cobbles with large boulders [1]	0.04	0.05	0.07
Floodplain cultivated areas. No crop [1]	0.02	0.03	0.04
Floodplain cultivated areas. Mature row crops [1]	0.025	0.035	0.045
Floodplain cultivated areas. Mature field crops [1]	0.03	0.04	0.05
Braided river [2]	-	0.025/0.04	-

1. Chow (1959); 2. Woldemichael et al. (2010)

[11] National Cooperative Highway Research Program (2013). Risk-based approach for bridge scour prediction – Final Report. Available on-line at http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP24-34_FR.pdf, last accessed 13 Dec 2017

[12] Chow, V. (1959). Open channel hydraulics.

[13] Woldemichael, A. T., Degu, A. M., Siddique-E-Akbor, A. H. M., & Hossain, F. (2010). Role of Land–Water Classification and Manning's Roughness Parameter in Space-Borne Estimation of Discharge for Braided Rivers: A Case Study of the Brahmaputra River in Bangladesh. IEEE Journal of selected topics in Applied Earth observations and remote sensing, 3(3), 395-403.



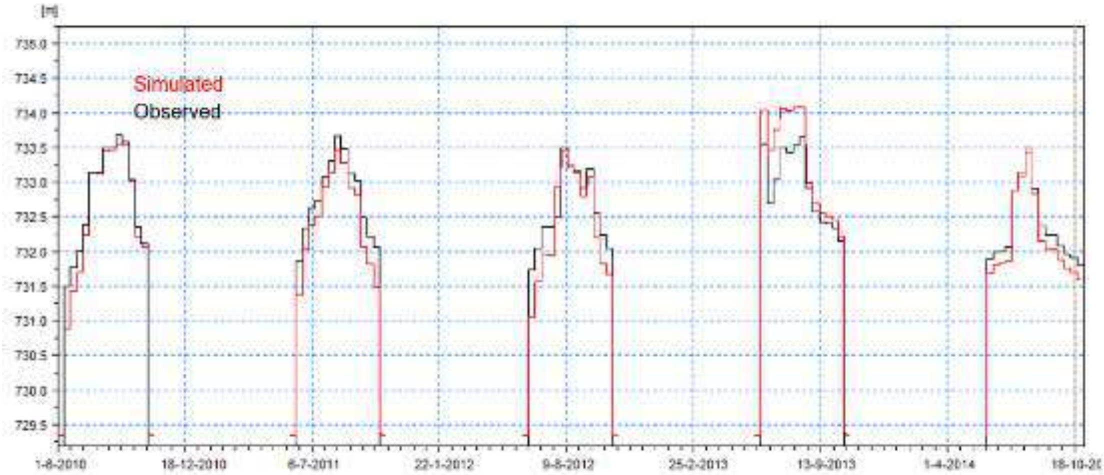


Figure 3.60: Water level calibration at Rudarayag Alaknanda (top) and Karnaprayag (bottom) based on 10 days-average discharge and water level (adjusted to Cartosat DEM level). Morphological cross-section changes are not included in the model. Manning n values estimated at 0.065

Finally, a validation is performed using flood extent extracted from satellite imagery for the 2013 flood event in Ganges basin, downstream of Haridwar (Figure 3.61).

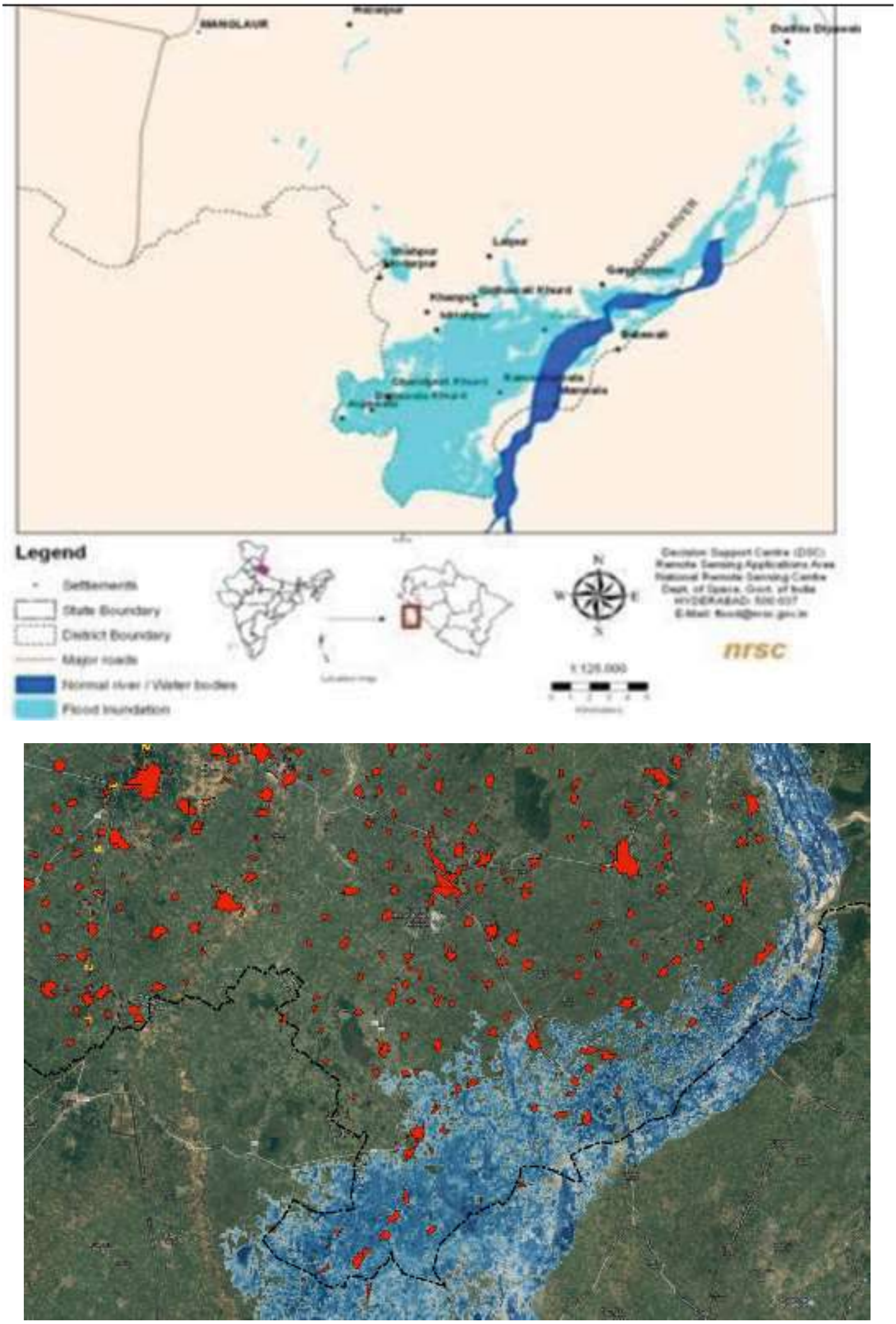


Figure 3.61: Flood inundated areas in part of Uttarakhand State. Top: Based on the analysis of RISAT-1, 18th June 2013. Source NRSC. Bottom: Based on MIKE11 Hydrodynamic simulation (Discharge app 15,000 m3/s).

3.2.6.4 Dams, embankments and structures

Only the major dams have been considered in the hydraulic model (Tehri, Srinagar, Koteshwar, Maneri I and II). The dams are conservatively assumed at full reservoir level, which is estimated based on the DSM, satellite imagery and from official sources. By design the spillways and gates are able to accommodate peak floods above the 1,000Y Return Period and have been inserted in the model to ensure proper conveyance within the flood design capacity of the structures. It should be noted that the Tehri dam can have a significant flood retention effect (as experienced in 2013) and the flood hazard results are then conservatively estimated downstream the Bhagirathi River.

The embankments location and flood design levels have been acquired for the most vulnerable flood location downstream Haridwar. The structures are design to accommodate a 100Y flood (app. 18,000 m3/s) but not elevation details have been provided. Similarly, the structures are not captured in the DSM. The model has been set-up without the flood defenses and the resulting flood hazard and risk can be altered in post-treatment to account for the 100Y protection level.

3.2.6.5 Boundaries

The hydrodynamic model boundaries have been extended beyond the State administrative boundaries to minimize the boundary influence on the results. The boundary is specified as a QH relationship using the Manning formula and the local average slope and roughness at the boundary location.

3.2.7 Event Set and Flood Mapping

3.2.7.1 Event set

From the 33 years of historical simulation, extreme value analysis (EVA) is performed using the Annual Maximum Series and a GEV-LMOM fitting at regular intervals (8-10km) and after each confluence in the model, corresponding to approximately 300 locations in Uttarakhand. The discharge for the return periods (5, 10, 25, 50, 100, 250, 500 and 1000) are extracted with the standard deviation associated with the fitting and using a bootstrapping resampling. The discharge location and values will be provided in the form of a GIS layer.

Each return period and standard deviation is used as boundary to run the hydraulic model for synthetic event directly downstream the extracted point discharge. At confluences, the discharge of same return periods are used for both branches. Simulated time series of water levels for the entire simulation period are stored for each cross-section in the model. The flood maps are then produce for each return period using the mean and standard deviation of the discharge EVA.

3.2.7.2 *Flood mapping*

The estimated water level extremes are then interpolated using a TIN based linear interpolation method to create a smooth water level raster for each return period. The smoothed water level raster is used with the DEM to produce the water depth raster.

3.2.8 Climate Change

The climate model data used in this study is an ensemble of 14 Regional Climate Models (RCM) from the Coordinated Regional Climate Downscaling Experiment-South Asia (CORDEX-SA) project (Giorgi et al., 2009). The 14 simulations are based on 3 RCMs driven by 6 different General Circulation Models (GCM) of the Coupled Model Inter-comparison Project Phase 5 CMIP5 (Table 2.9). The spatial resolution of the RCMs is 0.44˚ or approximately 50 km. For all the RCMs, the periods 1986-2005 and 2046-2065 are considered for the study as control and future periods. Daily precipitation and temperature have been extracted from the 14 RCMs for the two periods and for each catchment available in the hydrological model using nearest neighbor interpolation to the catchment centroid.

The downscaling method needs to ensure a proper representation of extreme precipitation, as this is expected to be driving flooding events at the scale of the Upper Ganga Basin (see Wijngaard et al., 2017). Statistical downscaling of daily precipitation and temperature is performed using the change factor quantile mapping method (CFQM). The method has been tested and applied in numerous climate change studies (e.g. Sunyer et al, 2015), and it establishes correction factors for different probability intervals in the empirical Cumulative Density Function (CDF) of wet days estimated for each month for the observations, and the control and future periods of the climate model data.

The perturbation of the observations is carried out as follows: (1) in the observation data, the probability of the variable intensity of each wet day is established from the CDF of the observed data for the corresponding month, (2) the relative change is calculated from the CDF of the control and future data for this month and probability, (3) the observed values are multiplied (for precipitation) or added (for temperature) by the quantile change factor estimated to produce the future time-series.

In this application, days are defined as wet for precipitation above 1 mm and dry days in the observations are not modified. Monthly change factors are established for each probability of the empirical CDF following the Cunnane plotting position. If different probabilities are obtained for the control and future period, linear interpolation between intensities is applied to obtain the precipitation intensity for all the probabilities. The tail of the control and observations are fitted with a gamma distribution for extrapolation of the monthly change factors.

Changes in potential evapotranspiration are estimated using the downscaled temperature data with the formulation of Kay & Davies (2008):

$$\Delta\, PE_T = \frac{R_e}{\lambda\, \rho_w 100}\, \Delta\, T$$

where Δ T is the change in temperature, λ is the latent heat flux [J/kg], ρ_w is the density of water [kg/m3] and Re [J/m2/s] is the extraterrestrial radiation estimated from the latitude of each of the catchment centroid, the solar constant, the solar declination and for each day of the year (see for example Allen et al., 1998). Resulting changes are reported in terms of:

- Discharge Return Periods (mean)) for all climate change scenarios across the Uttarakhand State
- Flood maps for the mean water level at each location and across all climate change scenarios for 8 return periods.

Table 3.9: Matrix of RCM–GCM-RCP combinations used in this study and source of the RCMs.

RCM\GCM	CCCMa CanESM 2	CNRM-CM5	CSIRO-Mk-3-6-0	IPSL-CM5A-LR	EC-EARTH	MPI-ESM-LR	RCP	Institute
RegCM4-4							2.6	Indian Institute of Tropical Meteorology (IITM)
	X	X	X	X			4.5	
	X	X	X	X			8.5	
RCA4					X		2.6	Swedish Meteorological and Hydrological Institute (SMHI)
					X		4.5	
					X		8.5	
REMO2009						X	2.6	Climate Service Centre (CSC) Germany
						X	4.5	
						X	8.5	

3.2.9 Tools and Software Used

The pre-processing, model simulation and post-processing use the following software:

- MIKE11 for hydrological and hydrodynamic simulations
- ARCGIS/QGIS for pre processing and post processing
- R statistical software/MIKE Info for data processing and event generation

3.2.10 Datasets Used

The main flood hazard-related data sets collected and processed are summarised in Table 3.10. As well as the official data sets collected, a selection of secondary data sets have been acquired, all freely available and often based on remotely-sensed data. A combination of those different data source is used to produce enhanced model data quality. More details are available in the Sections above.

Table 3.10: Collected data sets of relevance to the flood hazard modelling

Use	Data	Format	Instrumentation	Scale	Source
Meteorological data	Historical measured precipitation	Spreadsheets, shape files	Rain gaugess	National	Indian Meteorological Department/DMMC
	TRMM Rainfall	Raster/Grid, Time series	TRMM	Global	TRMM, NASA
	CHIRPS Rainfall	Raster/Grid, Time series	Remote Sensing-Mixed	Global	
	GPM Rainfall	Raster/Grid, Time series	Remote Sensing	Global	NASA, JAXA
	IsoPluvial maps	maps; Equations	Rain gauges - interpolation	State	IMD
	Daily rainfall	Raster/Grid, Time series	Rain gauges - interpolation	India	IMD
	Daily precipitation, surface air temperature, surface specific humidity	Gridded model data: Historical and future projections	Dynamical downscaled model projections (RCP 4.5 and RCP 8.5 projections)	Regional	CORDEX
	Temperature Evaporation	GRID	NWP simulation	Global	ECMWF
Hydrological data	Drainage network	MIKE 11	Processing of remotely-sensed topography data	Major rivers and tributaries	DHI Internal
	Catchment and drainage areas	Shape files	Derived from topography data	Sub-basin 300-800 sq.km	DHI Internal

Use	Data	Format	Instrumentation	Scale	Source
	Drain and river cross sections / river bathymetry	CAD drawings, spreadsheet tables	Survey	Major rivers	River Morphology Study
	Drain and river cross sections	MIKE 11	Processing of remotely-sensed topography data	Several major rivers	DHI Internal
	River control structures (dams, weirs, pumps)	Reports, CAD drawings, shape files	Mixed	Several major rivers	Online information, pending further details from different organisations
	River flow data, (water levels and discharge/debit)	Spreadsheet tables	10 days average monsoon discharge Annual maximum series discharge	Several major rivers	Central Water Commission
Topographical data	CartoSat	Raster Grid 10m	Stereographic	State	USAC
	DEM	Raster/Grid 30m	Radar	Global	SRTM
	Land cover / use	Grid/Raster	Remote sensing	Global	ESA Land Cover
	Hydrological soil groups	Gird/Raster	Remote sensing	Global	USDA-NRCS

3.2.11 Limitations, Gaps, and Critical Assumptions

The flood hazard modelling suffered from major data limitations and gaps. The resulting hazard maps are not recommended for community level planning purpose but are seen as useful for State wise risk estimation. The main gaps and limitations are identified as follows.

- Data:
    - Geomorphic data: The quality of the DEM is a major issue for the Uttarakhand State and lead the range of uncertainties in the hazard modelling by a large margin (see Table 3.11). The Cartosat 10m product perform very poorly in capturing elevation variation

in the very hilly and high slope terrain. The existing surveyed cross-section database is too limited to capture all slope variations. Large inconsistencies exist also in floodplains (e.g. water bodies higher than surrounding terrain) rendering the flood mapping exercise highly uncertain. The spatial resolution of the DEM do not allow to capture minor drainage features (<50-60m) and in many cases even larger ones in mountain ranges. For a proper flood mapping and zoning, a 1m to 2m spatial resolution DSM product with <1m vertical accuracy (relative and absolute) is required along the main rivers and in urban centres. 2m to 5m DSM with similar vertical accuracy is recommended for the larger floodplains.

- Hydrometric: There is a need to improve the temporal and spatial resolution of the climatic variables recorded. Climate data is extremely complex to capture accurately particularly in Uttarakhand Himalayan Region. Despite the effort dedicated at improving the quality of existing dataset, it is recommended to improve the monitoring of climate variables across the full state and different elevation zones. Daily rainfall cannot capture adequately the rainfall variability. Hourly rainfall monitoring is recommended. The planned acquisition and operation of weather monitoring radar across the State by IMD should support these recommendation. It is critical also to get access to high quality discharge and water level measurements (hourly time scale) to understand hydrological and hydraulic processes. The lack of access to such dataset present great limitations on the model calibration and overall quality.

Table 3.11: Summary of the main types of uncertainties identified and estimated in the flood hazard modelling

Type of uncertainties	App. error expected [m]	Comment
Cartosat DEM overall	8	RMSE for slope<20% - Effective spatial resolution >10m
Cartosat DEM – River alignment	5.5	Median depth of hydrologic enforcement required in the DEM
hydrometric measurement/simulation	0.2 – 1.6	Dependent on location (e.g. narrow gorge or)
Cross-section optimal distance	0.2 – 0.5	See Castellarin, 2009[14]
Synthetic cross-section conveyance	0.2 – 0.8	See Section 3.2.6.2

[14] Castellarin, A., Di Baldassarre, G., Bates, P. D., & Brath, A. (2009). Optimal cross-sectional spacing in Preissmann scheme 1D hydrodynamic models. *Journal of Hydraulic Engineering*, *135*(2), 96-105.

- Modelling:
    - The flood hazard modelling only simulates water level variations. It does not take into account the cumulative risks of erosions and deposition that take place during a flood. Those processes can be the main economic and human risk drivers in most mountainous zones.
    - The probabilistic approach requires a very fast and efficient model to perform thousands of simulations. A trade-off is then required between efficiency and accuracy. A one dimensional model is used to overcome computational constraints at the expense of a more accurate two dimensional modelling.
    - For the Ganga Basin, the hazard modelling assumed the Tehri Dam being full at the time of the flood event. The flood hazard and risk downstream the Dam can be considered overestimated.

3.3 FLASH FLOOD HAZARD MODELLING

3.3.1 Extreme rainfall event derivation

For each catchment, an area-weighted average of the 24 hour extreme rainfall amount, (based on IMD's iso-pluvial maps for 25, 50 and 100 year events), is calculated. This provides the amount of rainfall (in mm) associated with the 24 hour duration storm, for each of the considered return periods, (**a** in the flow-chart presented in Figure 3.62).

Based on analysis of past storms in this region, CWC's "Flood Estimation Report for Western Himalayas – Zone 7" manual states that the 6 hour duration rainfall amount (**b**) may be assumed to be 0.725 times the 24 hour amount, (irrespective of return period). This is reduced further (**c**) based on the Areal Reduction Factor (ARF) corresponding to the catchment's area, and then temporally distributed into an hourly time-series following the ratios provided in the same CWC report (**d**).

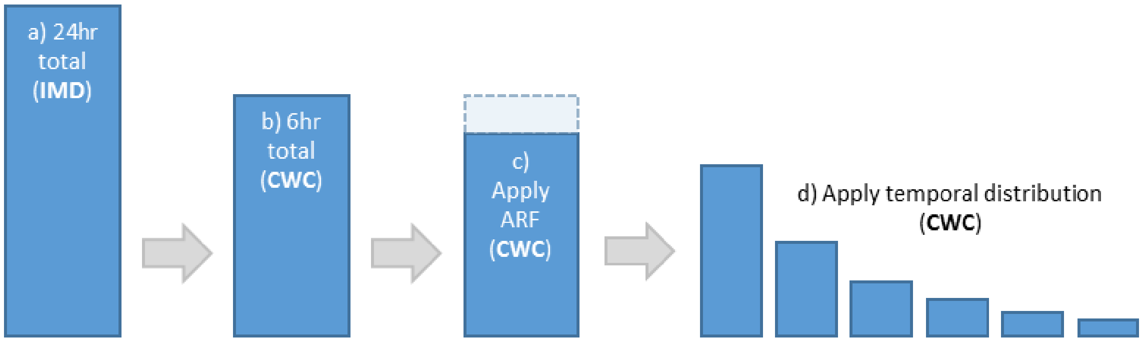


Figure 3.62: Workflow for the development of 6 hour extreme rainfall time-series

3.3.2 Flash Flood Modelling

Flash flood hazards are modelled using a different methodology, (compared to fluvial flood hazards), given that they differ significantly in terms of their spatial and temporal scales, (localised and short-term events, typically six hours or less), as well as the hydrodynamic processes by which they cause damage, (with high flow velocities and associated forces playing an important role, rather than inundation depths alone).

As prescribed in the project's Terms of Reference, flash floods are modelled using a deterministic approach, whereby a limited number of scenarios are run, relating to extreme rainfall events of known return periods. These are computed for each of the hydrological catchments discussed in Section 3.2.1, based on the iso-pluvial maps published by IMD, and then converted to event time-series following the method defined by CWC in their "Flood Estimation Report for Western Himalayas – Zone 7".

As illustrated in Figure 3.63, individual flood models are set up for each of the catchments considered, (more than 100 catchments of roughly 500 km^2 each, covering the entire state), with additional model inputs including maps of topography, (DEM), and surface roughness, (based on land use land cover maps). The results of each model simulation are then post-processed to obtain maps of various flash flood intensity measures, which are used for loss calculations in the CAPRA simulations.

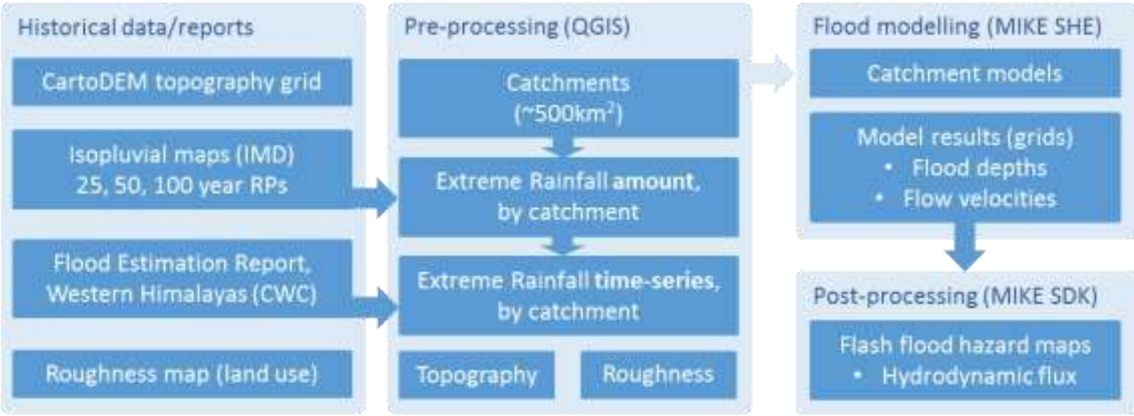


Figure 3.63: Flash flood deterministic hazard modelling workflow

The flood model used, (MIKE SHE, which will be described in more detail in Section 3.3.6), is run separately for each of the state's catchments, with a simulation time of nine hours, (to fully simulate the runoff resulting from a six hour rainfall time-series, derived as outlined in Section 3.3.1). An important modelling decision was the simulation time-step, which needed to be large enough for the total numerical computation time to fit within the project schedule, while still small enough to provide sufficiently detailed results, as well as being appropriate to the time-scales of flash flood phenomena.

In contrast to earthquakes (where peak forces are typically of short duration, i.e. a few seconds) and fluvial floods (where inundation-caused damage acts over hours or even days), the peak flow forces associated with flash floods are generally sustained for a period of a few minutes. For this reason, a simulation time-step of three minutes was selected as the optimal solution to these three objectives.

3.3.3 Pre-processing of topography data

The DEM (raster/grid of topography values) is one of the most important inputs to a flash flood model, given the impact it has on simulated depths and velocities as rainfall-runoff flows across the surface. However, before it can be input to the model, three important pre-processing steps are required, (de-noising, hydrological filling and river carving), which are described in more detail below.

Importantly, it is noted that all of these steps are *irreversible*, in the sense that it is not possible to reconstitute the original DEM using the derivative obtained from either process.

3.3.3.1 Denoising

Most DEM products contain some random noise, as a result of the sensing technologies and/or processing used to derive them. While this is not a significant problem for many other geospatial applications, it can have adverse impacts on flood model results, affecting the distribution of flood depths and even the flow-paths taken. For this reason, the input DEM was denoised as a first pre-processing step, in an attempt to filter out some of this random noise while still maintaining the important topographical features.

In recent years, significant efforts have been made to find ways to remove the noise without over-smoothing the data and removing/softening sharp topographic features that may be especially significant. (For example, the reader is referred to Falorni *et al.* 2005 and Stevenson *et al.* 2010). One of the most promising of these approaches is to use wavelet theory, (from the signal processing field), which analyses data using waves of different frequencies, to identify noise compared to genuine topographical variation.

Following a process presented by Falorni *et al.* (2005), a biorthogonal wavelet with five levels of decomposition was used for the current project, (with soft thresholding performed at each level, using the fixed-form, universal threshold). A comparison of the raw (upper) and de-noised (lower) DEM data, (using sample data from SRTM), is presented in Figure 3.64. As can be seen, this seems to have successfully maintained significant topographical features (such as the steep hills in the north-west) while smoothing out (i.e. removing “speckle” noise from) the flood-plain areas elsewhere.

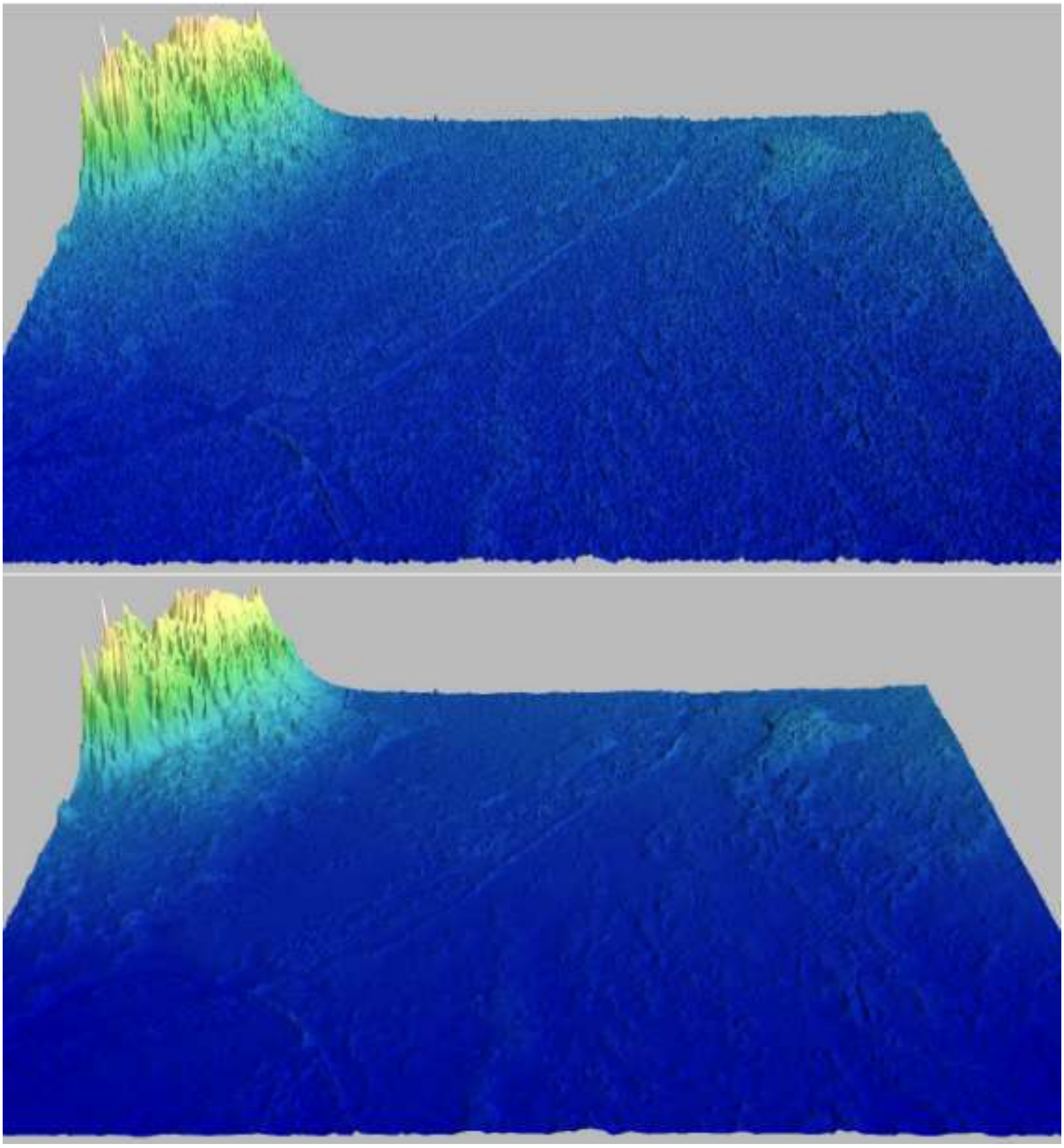


Figure 3.64: Comparison of raw (upper) and denoised (lower) DEM, showing that significant features (e.g. hills in upper-left corner) have been well maintained, while the flood plain areas have been effectively smoothed of noise, (using sample data from SRTM)

3.3.3.2 Hydrological filling

In the second pre-processing step, the denoised DEM was run through another irreversible process, whereby local depressions (so-called “pits”) were filled in, making it more suitable for hydrological applications. Without this step, significant amounts of rainfall-runoff would be retained in these local depressions and thus not contribute to the flows further downstream, which is likely to result in an under-estimation of the flash flood flows in streams and gullies, where the hazard is likely to be most significant.

Hydrological filling is illustrated, for a hypothetical cross-section of a slope, in Figure 3.65.

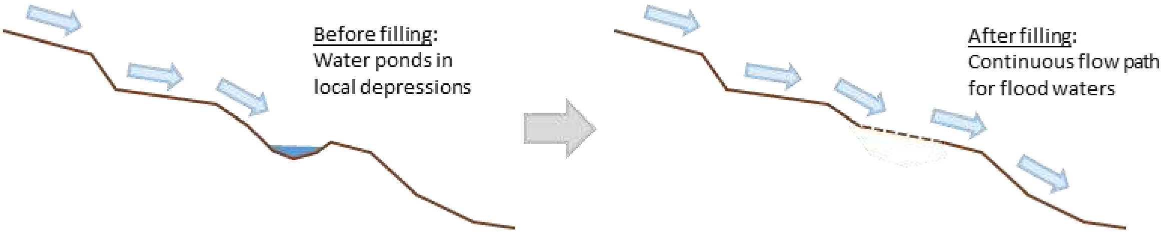


Figure 3.65: Illustration of effect DEM filling has on flows into/through local depressions

In order to accomplish this, the four-directional filling algorithm developed as part of the free Terrain Analysis Using Digital Elevation Models (TauDEM)[15] software package was used.

3.3.3.3 River carving

While the hydrological filling process described above is essential to remove local depressions from the DEM, (which would otherwise retain runoff flows, resulting in underestimated flash flood peaks in downstream streams/gullies), it can also cause excessive filling in the main river channels. This is especially true in very steep mountain valleys, such as those found in the hill districts of Uttarakhand.

For this reason, a final processing step was employed for the upstream parts of the catchments, which took as input the denoised and hydrologically-filled DEM, and then 'carved' the main rivers back into it. This was accomplished using the free and open-source Whitebox GAT application[16], which implements a hydrological carving method proposed by Lindsay (2016).

This composite approach (carving as well as filling) was found to be the best approach for the steep, mountainous terrain in the upstream parts of the state, whereas hydrological filling on its own was better suited to the flatter terrain in the downstream areas. Consequently, two sets of flash flood models were run, (one using a hydrologically-filled DEM and the other a fill/carve composite DEM), from which the appropriate results were selected for different parts of the state.

3.3.4 Derivation of roughness map from land use

Another important input to the flash flood models is a map of surface roughness, which will influence the routing times of overland flows, as well as their depth and velocity. For a hydrodynamic model of this spatial scale, standard practice is to derive a map of roughness values from a land use / land cover map, by relating different land use classes to Manning's roughness values based on reference tables sourced from literature. For this project, the reference table published by Kalyanapu *et al.* (2009) will be used, (itself based on a table originally proposed by McCuen 1998).

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[15] TauDEM: Available online at http://hydrology.usu.edu/taudem/taudem5/

[16] Whitebox GAT: Available online at http://www.uoguelph.ca/~hydrogeo/Whitebox/

As for the land use map, the Global Land Cover map produced by the ESA CCI (European Space Agency Climate Change Initiative)[17] has been sourced and processed for use in the flash flood modelling. This 300m resolution raster, which categorises land use / land cover into 38 classes and has been used in a wide variety of related applications all over the world, is presented for Uttarakhand in Figure 3.66.

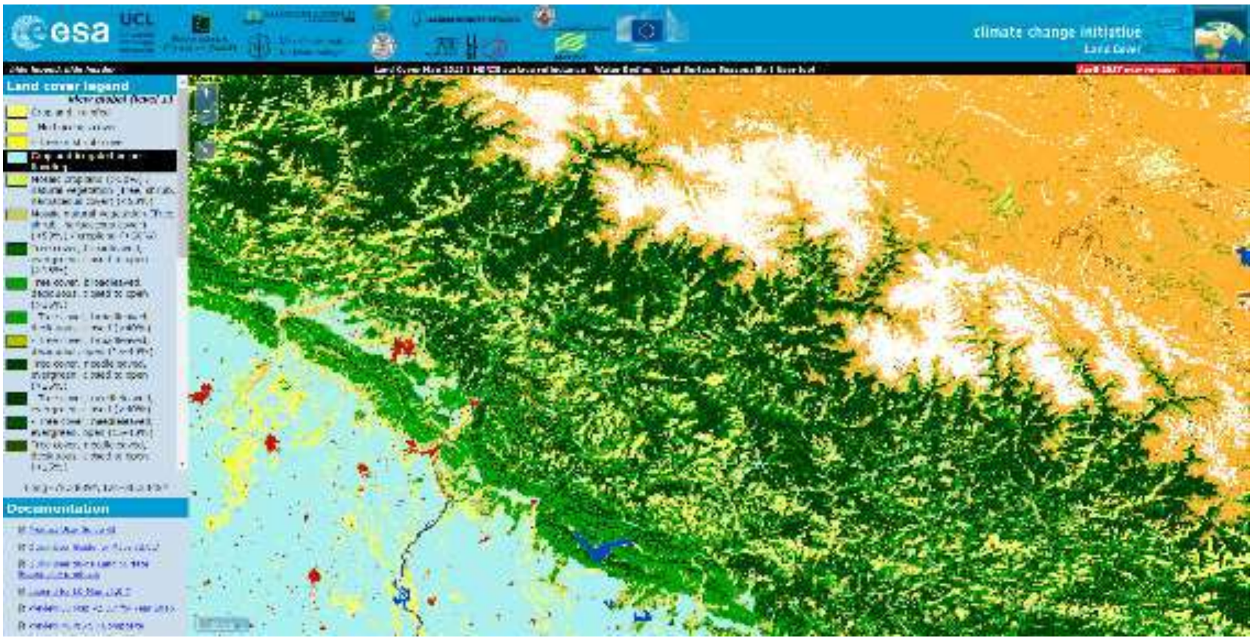


Figure 3.66: Screenshot of the ESA CCI Land Covermap over Uttarakhand, (taken from the online viewer at http://maps.elie.ucl.ac.be/CCI/viewer/index.php)

In order to derive a roughness value, (Manning's M), from the land use map, it is necessary to first relate each relevant land use class to a combination of the various surface types listed in Kalyanapu et al. (2009), and then calculate a weighted average for that combination. The results of this calculation are presented in Table 3.12 and as a map for the whole state in Figure 3.67.

Table 3.12: Roughness values calculated for ESACCI land use classes present in Uttarakhand

ESA CCI Land Cover class	Manning's M
Cropland, rainfed	5.71
Herbaceous cover	5.71
Cropland, irrigated or post-flooding	5.71
Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	5.88
Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)	5.56
Tree cover, broadleaved, evergreen, closed to open (>15%)	2.50
Tree cover, broadleaved, deciduous, closed to open (>15%)	2.50
Tree cover, broadleaved, deciduous, closed (>40%)	2.50

[17] ESA CCI: Available online at https://www.esa-landcover-cci.org/

ESA CCI Land Cover class	Manning's M
Tree cover, needle-leaved, evergreen, closed to open (>15%)	2.50
Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	3.13
Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	3.57
Shrubland evergreen	5.00
Shrubland deciduous	5.00
Grassland	6.67
Sparse vegetation (tree, shrub, herbaceous cover) (<15%)	5.00
Shrub or herbaceous cover, flooded, fresh/saline/brackish water	5.00
Urban areas	80.00
Bare areas	55.56

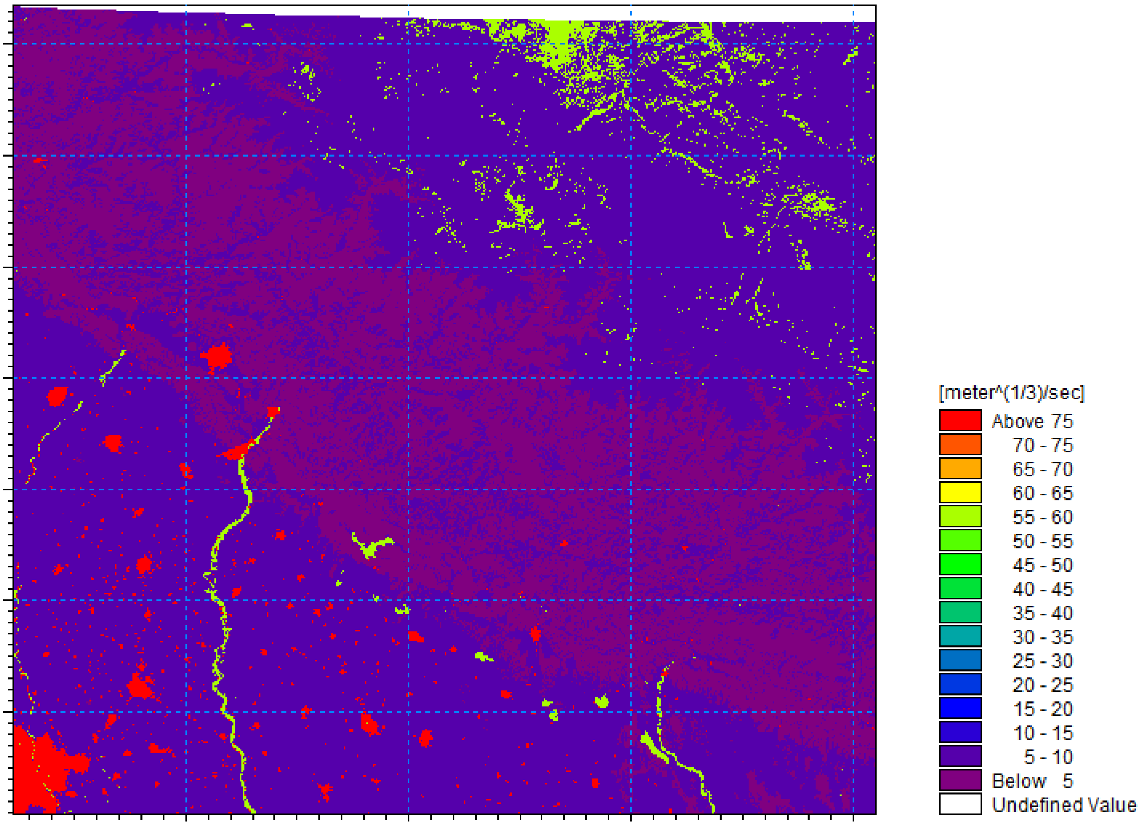


Figure 3.67: Roughness map for the state, as visualised within a MIKE SHE flood model

3.3.5 Post-processing of results to obtain flash flood intensity maps

As discussed in previous reports and presentations, the hazard posed by flash floods is due to the combination of flood depths and flow velocities, with the velocities being particularly important for some exposure types. For this reason, a variety of intensity measures are derived from the MIKE SHE flash flood model results in post-processing:

- Depth (**D**)

- Velocity (**v**)
- Energy head (**D** + $\mathbf{v}^2/2g$), where g is gravitational acceleration
- Flux ($\mathbf{Dv}^2$)

For every grid cell, each of the four intensity measures is calculated for each time-step of the simulation, in order to develop maps that show the maximum value simulated in that grid cell at any point during and after the rainfall event.

Sample images of typical results for these four intensity measures are presented in Figure 3.68. It is noted that since velocity (and velocity-derived) results are based on a simplified form of the shallow water equations, (diffusive wave approximation), they are presented in terms of indicative qualitative classes, rather than precise numeric values.

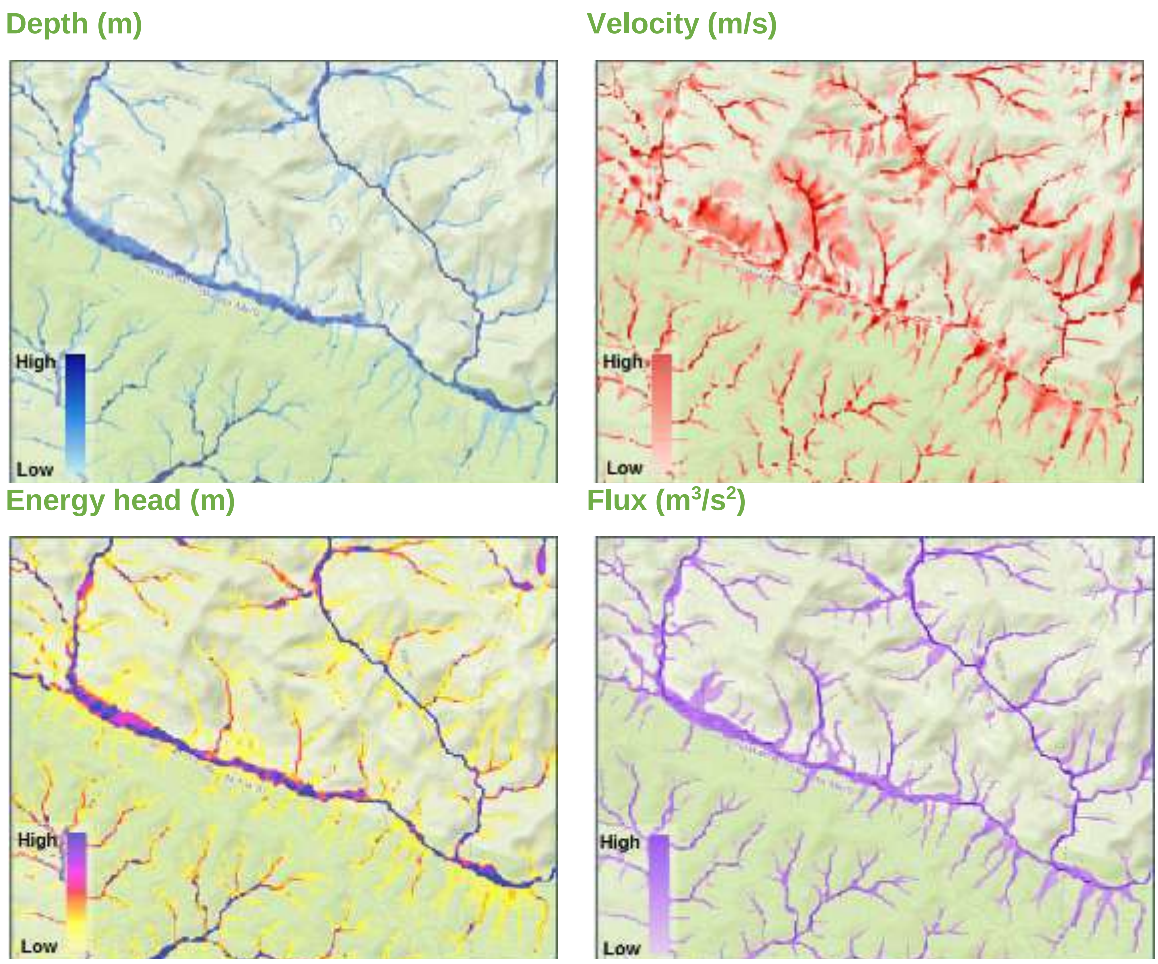


Figure 3.68: Sample results generated by the post-processing workflow

3.3.6 Tools and Software Used

The pre-processing, model simulation and post-processing use the following software:

- ArcGIS/QGIS for pre-processing of input grids/rasters
- MIKE SHE for hydrological and hydrodynamic simulations, (discussed in more detail below)
- Python/MIKE SDK (API) for post-processing results to derive hazard intensity maps

MIKE SHE is an advanced, flexible framework for integrated hydrological cycle modelling. It includes a full suite of pre- and post-processing tools, plus a flexible mix of advanced and simple solution techniques for each of the hydrologic processes included. MIKE SHE covers the major processes in the hydrologic cycle and includes process models for evapotranspiration, overland flow, unsaturated flow, groundwater flow, and channel flow and their interactions, as illustrated in Figure 3.69. Each of these processes can be represented at different levels of spatial distribution and complexity, according to the goals of the modelling study, the availability of field data and the modeller's choices, (Butts et al. 2004).

The MIKE SHE user interface allows the user to intuitively build the model description based on the user's conceptual model of the watershed. The model data is specified in a variety of formats independent of the model domain and grid, including native GIS formats. At run time, the spatial data is mapped onto the numerical grid, which makes it easy to change the spatial discretisation. This is an important considering for the current application, in which more than 100 catchment models must be set up and run in a time-efficient manner.

MIKE SHE is applicable at spatial scales ranging from a single soil profile, for evaluating crop water requirements, to large regions including several river catchments, such as the 80,000 km^2 Senegal Basin (e.g. Andersen et al., 2001). MIKE SHE has proven valuable in hundreds of research and consultancy projects covering a wide range of climatological and hydrological regimes, many of which are referenced in Graham and Butts (2006).

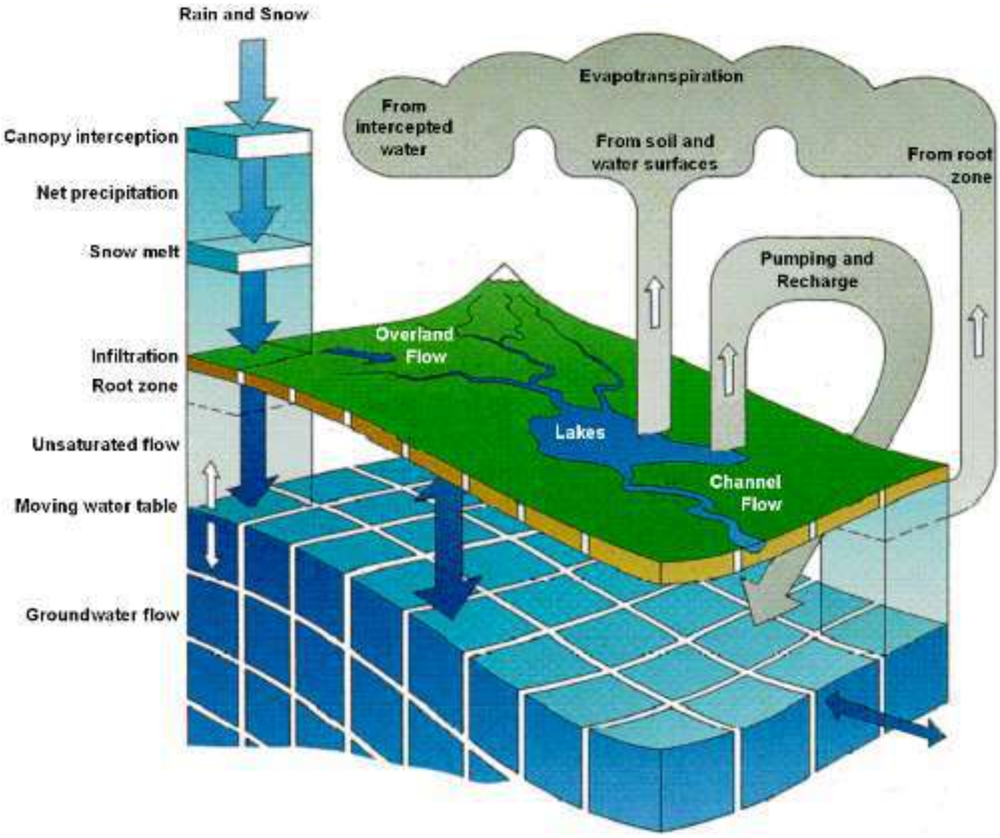


Figure 3.69: Hydrologic processes that can be simulated using MIKE SHE

3.3.7 Datasets Used for the Event Catalogue

The datasets used for the flash flood hazard modelling comprise a smaller subset of those already discussed for fluvial floods in Section 3.2.10. Although not technically a dataset, another important input to the flash flood modelling process for Uttarakhand has been CWC's "Flood Estimation Report for Western Himalayas – Zone 7", which allowed for the conversion of rainfall amounts associated with 24 hour duration storms, (of various return periods), to hourly time-series describing 6 hour storms of the same return periods.

Table 3.13: Collected data sets of relevance to the flood hazard modelling

Data	Format	Instrumentation	Scale	Source
Iso-pluvial maps	Maps	Rain gauges - interpolation	State	IMD
Catchment and drainage areas	Shape files	Derived from topography data	Sub-basin 300-800 sq.km	DHI Internal
10m CartoSat	Raster/Grid 10m	Stereographic	State	NRSC
30m CartoSat [1]	Raster/Grid 30m	Stereographic	State	NRSC (Bhuvan)

Data	Format	Instrumentation	Scale	Source
DEM [1]	Raster/Grid 30m	Radar	Global	SRTM
Land cover / use (USAC/NRSC)	Grid/Raster	Remote sensing	State	USAC / NRSC
Land cover / use (ESA CCI) [1]	Grid/Raster	Remote sensing	Global	ESA Land Cover

1 Freely-available alternatives to the preferred dataset on the row above

3.3.8 Limitations, Gaps, and Critical Assumptions

The main limitations, gaps and critical assumptions associated with the flash flood hazard modelling are as follows:

- Land use / land cover: The land use map developed for Uttarakhand by USAC and NRSC is of a very high resolution (1:10,000) and appears to be of good quality. From a project perspective, it is disappointing that this dataset has not been made available, with a coarser global product having to be used instead. Fortunately, this is not expected to have a significant effect on the flash flood modelling, (as opposed to the exposure layer development, where it is a more significant loss).
- Modelling: Two-dimensional hydrodynamic modelling over such a large spatial extent requires a careful balance between spatial resolution, model time-step and solution scheme, in order to complete all required simulations within the project's timeframe. This has been achieved by using a 30m spatial resolution for all initial runs, (subsequent to which, especially hazard-prone catchments may be rerun on the 10m DEM at a later date), a three-minute time-step (as discussed previously), and a simplified form of the shallow water equations (diffusive wave). This last point is perhaps most important, as it means that velocity results (and derived intensity measures) should be taken as indicative rather than precise predictions.

3.4 LANDSLIDE SUSCEPTIBILITY MODELLING

3.4.1 Background

The determination of landslide susceptibility is generally performed using heuristic, statistical, or correlative models and deterministic or stochastic physical-based models (Catani et al., 2005; Goetz et al., 2011; Ermini et al., 2005). The physical-based models are complex and need a large number of input parameters, including geotechnical parameters for modelling and calibration (Ruddell et al., 2013; Saltelli et al., 2004). The collection of those parameters required for physical-based modelling is not feasible in the study site, and reviewers of this project's Inception Report strongly recommended that they should also not be approximated.

The statistical assessment approaches generally model the relationship between the presence of landslides and the causal factors that may be responsible for its occurrence. There are many GIS-based statistical landslide prediction models available which have been used in many parts of the world. Felicísimo et al. (2013) conducted a comparative study among multiple logistic regression (MLR), multivariate adaptive regression splines (MARS), classification and regression trees (CART), and maximum entropy (MAXENT) to model the landslide susceptibility.

Conventionally, most of landslide susceptibility models were modeled with logistic regression which is simply by fitting s-shape logistic curve with favorable and non-favorable samples. But in case of scenarios like landslides, non-favorable samples are hard to define. Locations that have never observed a landslide are not a good estimation for a non-favorable sample for landslides, because non-occurrence of a landslide doesn't means they are unfavorable. There will be landslide in those locations in future. Regarding this issue, a maximum entropy model provides a general way for estimating the unknown target probability distribution only from favorable samples (Phillips et al. 2006). This has been used widely for species distribution modeling (Phillips et al. 2006).

The concept of entropy was based on statistical mechanics and information theory. More precisely, entropy is a measurement of the unpredictability of information content. Entropy can also be interpreted as the number of choices we have to select and describe an event (Shannon, 1948, 1951). It was first quantified by Claude Shannon in his 1948 paper "A Mathematical Theory of Communication" (Shannon, 1948, 1951).

$$\mathrm{H}(X) = \mathbb{E}[\mathrm{I}(X)] = \mathbb{E}[-\ln(\mathrm{P}(X))].$$

This brings us to the idea of maximum entropy which was explained by Jaynes (Jaynes, 1957a, 1957b), "the best probability distribution that can represent an unknown pdf subject to a set of testable information (expected values of different variables) is the one with the largest entropy". So, the estimated pdf should have the maximum entropy meaning the maximum amount of information derived from the controlling factors.

Based on our review, it was concluded that maximum entropy model has the highest prediction capacity among those models and thus it was adopted for this study. MAXENT is software tool that allow to perform maximum entropy modelling with various other tools (https://homepages.inf.ed.ac.uk/lzhang10/maxent.html). It's free JAVA based software which have been widely used in various fields such as computer vision, spatial modeling, species modelling, natural language processing and many other fields.

3.4.2 Methodology

The overall workflow for the analysis is illustrated in Figure 3.70, consisting of two major components. The first component (landslide susceptibility analysis) was carried out by fitting historical landslide data with relevant Environment Factors (Topography, Geology, Soil, Land cover, etc.) through the Maximum Entropy Model. In the second component, this landslide susceptibility analysis was extended to assess the effect of landside susceptibility on human settlements (landslide exposure assessment). This analysis was carried out for each district separately in order to get better insights into the primary contributing factors in each district.

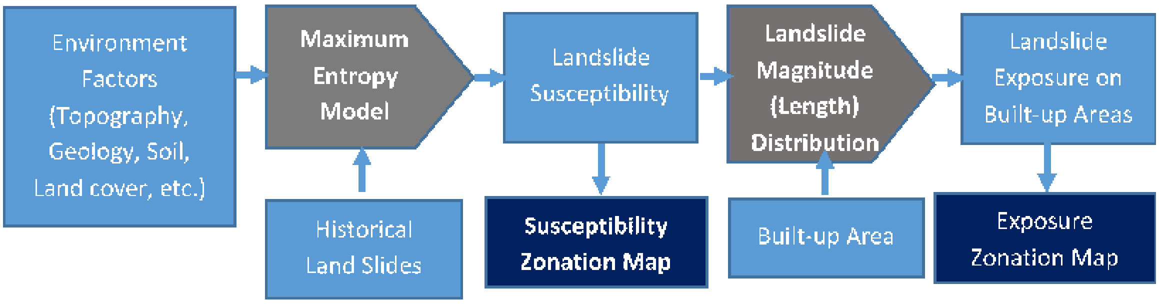


Figure 3.70: Landslide susceptibility and exposure overall workflow

3.4.2.1 *Landslide Susceptibility Assessment*

The Maximum Entropy analysis described above was used to delineate potential landslide areas based on landslide inventory points along with environmental layers such as slope, altitude, aspect, geology, soil, land use, rainfall, topographic wetness index, stream power index, slope-length factor, distance to faults, distance to roads, and other relevant layers. Figure 3.71 illustrates the landslide susceptibility modelling process.

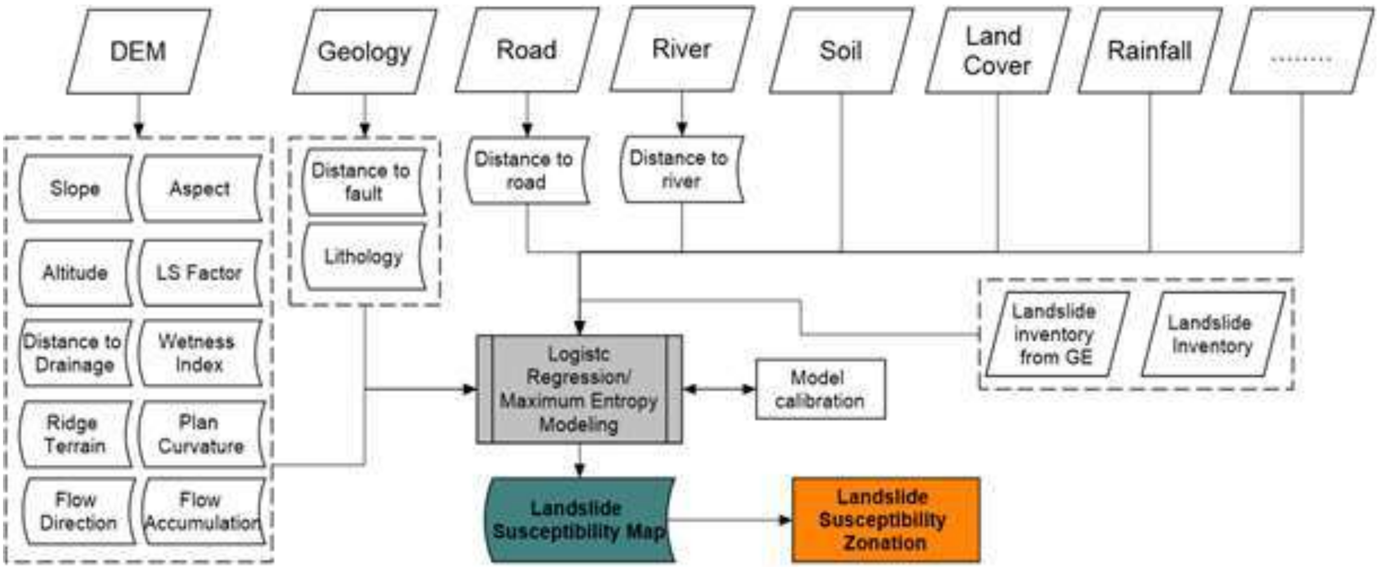


Figure 3.71: Landslide susceptibility modelling workflow

These landslide inventory points were generated through visual interpretation of Google Earth satellite imagery covering the entire state of Uttarakhand. Additionally, landslide inventory data from state government reports were also used as complementary inputs. Data from both sources were verified independently using Google Earth satellite imagery before inclusion in the model. All environmental layers were collected through the responsible state and central government authorities. Details of environmental layers and landslide inventory points are summarised in Section 3.4.4.

The derived landslide susceptibility values by the fitted maximum entropy model were then scaled using a logistic function in order to normalise the resulting susceptibility values between zero and one. The final landslide susceptibility zonation map was derived by dividing the resulting landslide susceptibility values into five classes by the equal interval method. These classes of landslide susceptibility zonation are as follows:

- 0.0 – 0.2 : No Susceptibility
- 0.2 – 0.4 : Low Susceptibility
- 0.4 – 0.6 : Medium Susceptibility
- 0.6 – 0.8 : High Susceptibility
- 0.8 – 1.0 : Very High Susceptibility

3.4.2.2 Landslide Exposure Assessment

Landslide susceptibility indicates the likelihood of a landslide occurring in any given spatial location in the study area. However, this does not directly address the question of what the impact of such a landslide on any surrounding built-up areas would be, which is obviously of great relevance when it comes to decision-making. Hence, the susceptibility for all the built-up areas was extracted to assess the landslide exposure on built-up area.

This assessment is complicated by the fact that landslides in the general vicinity of a given built-up area may also impact it, (rather than only high-susceptibility zones which intersect it directly). To address this issue, rather than taking pointwise susceptibility, spatially-averaged susceptibility is used for the exposure assessment. As one would expect, the susceptibility value of nearer pixels has more impact on a given built-up area than the susceptibility value of more distant pixels. These distance-based weights are derived from the Landslide frequency-area (length) distribution, which is developed from historical landslides in the state (Figure 3.72).

The frequency-area distribution of historical landslides is able to represent landslides of various magnitudes (Malamud, et al. 2004), and it represents the characteristics of the terrain in which landslides of different size are most likely to occur. Figure 3.72 illustrates an example of such a frequency-area distribution (Malamud, et al. 2004). Landslide inventory data from the Geological

Survey of India was used to prepare the landslide frequency-area distribution in this study. Most of the historical records described the landslides by length of landslide instead of area. Therefore, the lengths of historical landslides will be used to describe the landslide magnitude distribution over the state.

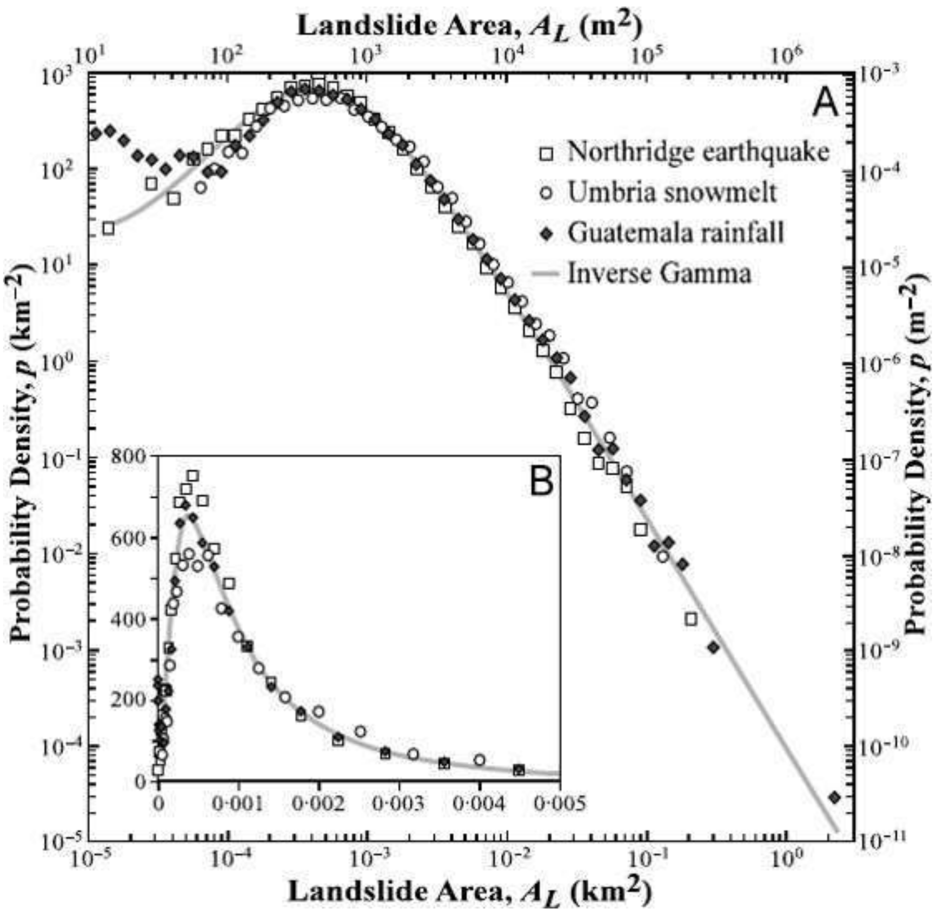


Figure 3.72: Frequency-area distribution of B. D. Malamud, et al. 2004 study

Finally, the impact of spatially-weighted landslide susceptibility on built-up areas is scaled linearly to a range between zero and one, and then divided into two classes (exposed and non-exposed) by the equal interval method.

- 0.0 - 0.5 : Not exposed
- 0.5 - 1.0 : Exposed

3.4.3 Tools and Software Used

The processing of GIS data was carried out using the following software:

- ArcGIS
- QGIS

- SAGA GIS package

Part of the landslide inventory was prepared using Google Earth.

An innovative web-based crowdsourcing application was developed specifically for this project, for the digitisation of built-up areas in the whole state.

The Maxent open-source software package was used to model the landslide susceptibility.

Landslide magnitude distribution and landslide exposure map preparation are prepared by MS Excel software.

3.4.4 Datasets Used for the Event Catalogue

The prominent datasets for the landslide susceptibility mapping are summarised in Table 3.14.

Table 3.14: Collected datasets of relevance to the landslide susceptibility modelling

Data	Format	Instrumentation	Scale	Source
CartoSat	Raster Grid 10m	Stereographic	State	USAC
DEM	Raster/Grid 30m	Radar	Global	SRTM
Geology	Shape files (digitised by AIT)	Survey	1 : 50,000	GSI
Fault line	Shape files (digitised by AIT)	Survey	1 : 50,000	GSI
Land cover / use	Grid/Raster	Remote sensing	Global	ESA Land Cover
Soil	Shape files (digitized by AIT)	Survey	National	National Atlas & Thematic Mapping Organisation
TRMM Rainfall	Raster/Grid, Time series	TRMM	Global	TRMM, NASA

The landslide inventory was compiled using several sources, including the interpretation of Google Earth satellite images. Table 3.15 shows the collected and interpreted landslide inventory datasets which were used for the landslide susceptibility analysis and landslide magnitude distribution.

Table 3.15: Collected and interpreted landslide inventory datasets

Source	No of events
Geological Survey of India - macro-scale (1:50,000) landslide susceptibility mapping - Detailed Log Sheets	328
Geological Survey of India - macro-scale (1:50,000) landslide susceptibility mapping - District wise reports	2,309
Uttarakhand Disaster 2013-I,II,III Volumes	26

Source	No of events
ADRC disaster database	1
Desinventar disaster database	114
Sub total	2,778
Interpretation of Google Earth	6,536

A map of the compiled landslide inventory is presented in Figure 3.73.

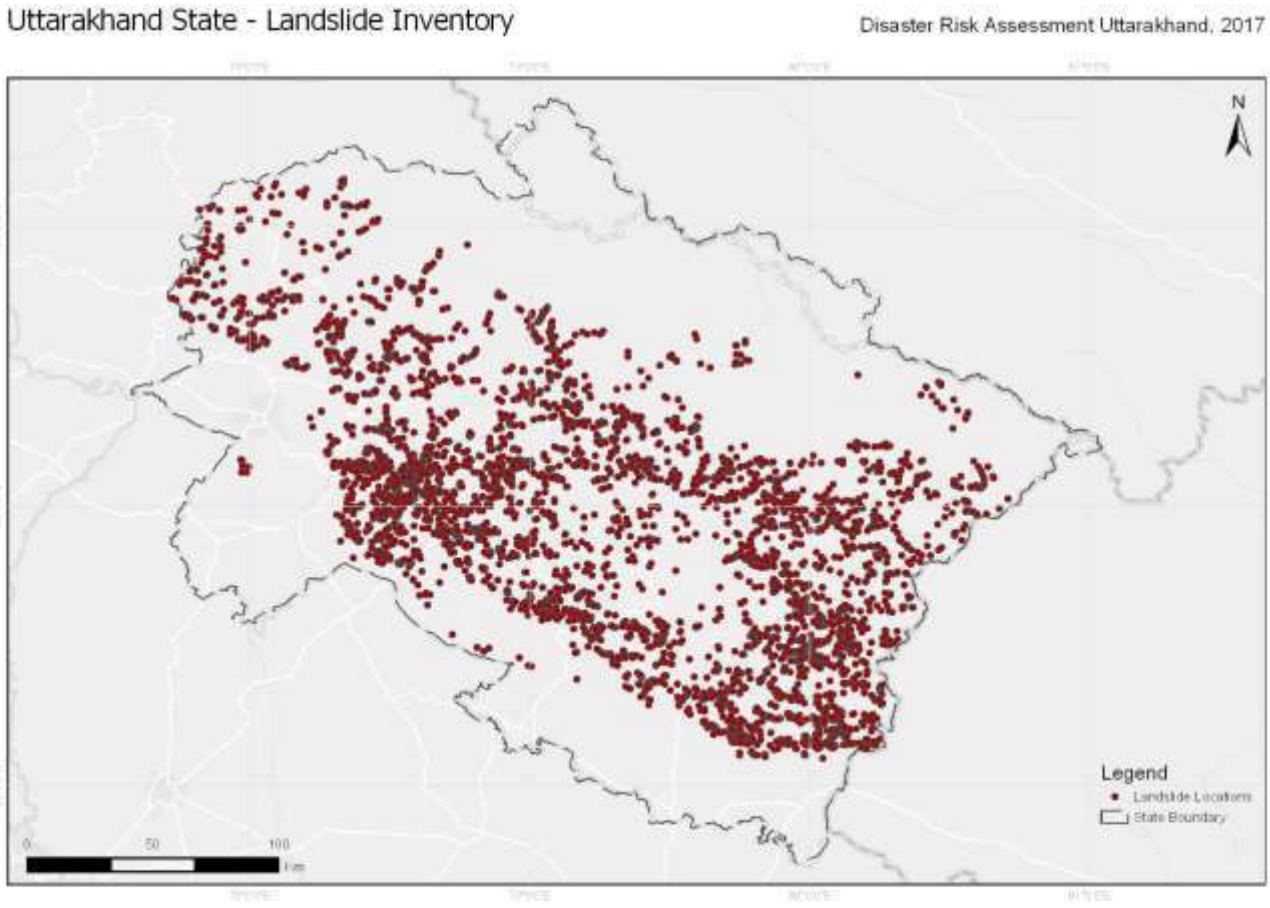


Figure 3.73: Map of the full landslide inventory collected

Based on the input datasets listed above, the pre-processed rasters which were developed as inputs to the Maxent model are presented in the following sections.

3.4.4.1 Slope

Slope is an essential parameter for landslide susceptibility studies, since landsliding is directly related to slope angle (Anbalagan 1992; Pachauri 1998; Clerici 2002; Saha 2002). Landslides mostly occur at certain critical slope angles (Gokceoglu, C., Aksoy, H., 1996; Uromeihy 2000; Dai, F.C., et al., 2001).

Slope calculates the maximum rate of change in value from that cell to its neighbours. Basically, the maximum change in elevation over the distance between the cell and its eight neighbours identifies the steepest downhill descent from the cell. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain.

Slope (degrees) = ATAN (√ ([dz/dx]2 + [dz/dy]2)) * 57.29578

The slope map presented in Figure 3.74 was generated based on the CartoSat 10m DEM.

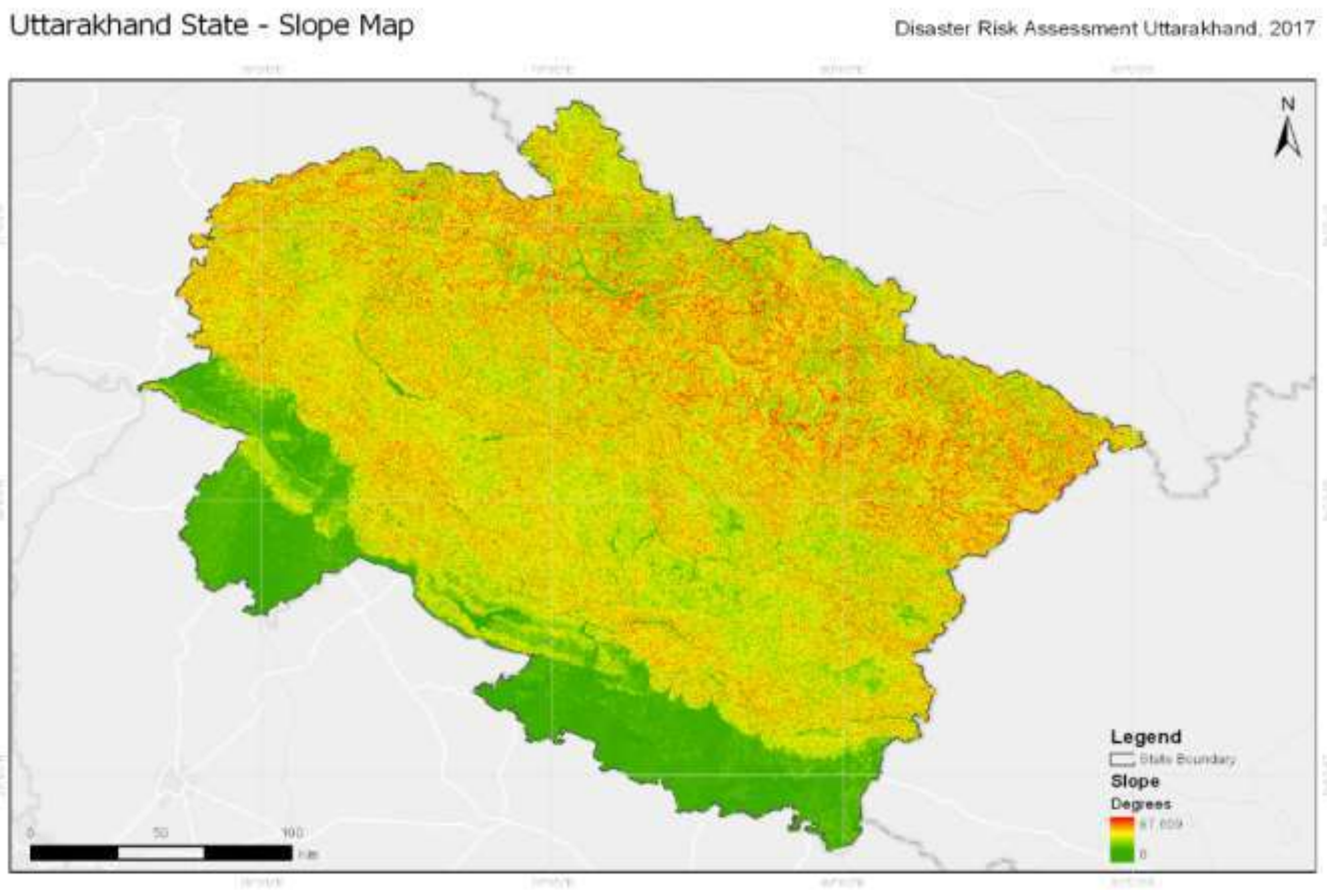


Figure 3.74: Slope raster used in the Maxent landslide susceptibility modelling

3.4.4.2 Aspect

Aspect is also considered an important factor in landslide susceptibility studies (Van Westen 1994; Carrara 1991; Maharaj 1995; Guzzetti 1999; Nagarajan 2000). Aspect-related parameters such as exposure to sunlight, drying winds, rainfall (degree of saturation) and discontinuities may control the occurrence of landslides (Gokceoglu, C., Aksoy, H., 1996; Dai, F.C., et al., 2001).

Aspect identifies the down slope direction of the maximum rate of change in value from each cell to its neighbors. Aspect can be thought of as the slope direction. The values of the output raster will be the compass direction of the aspect.

The aspect map presented in Figure 3.75 was generated based on the CartoSat 10m DEM.

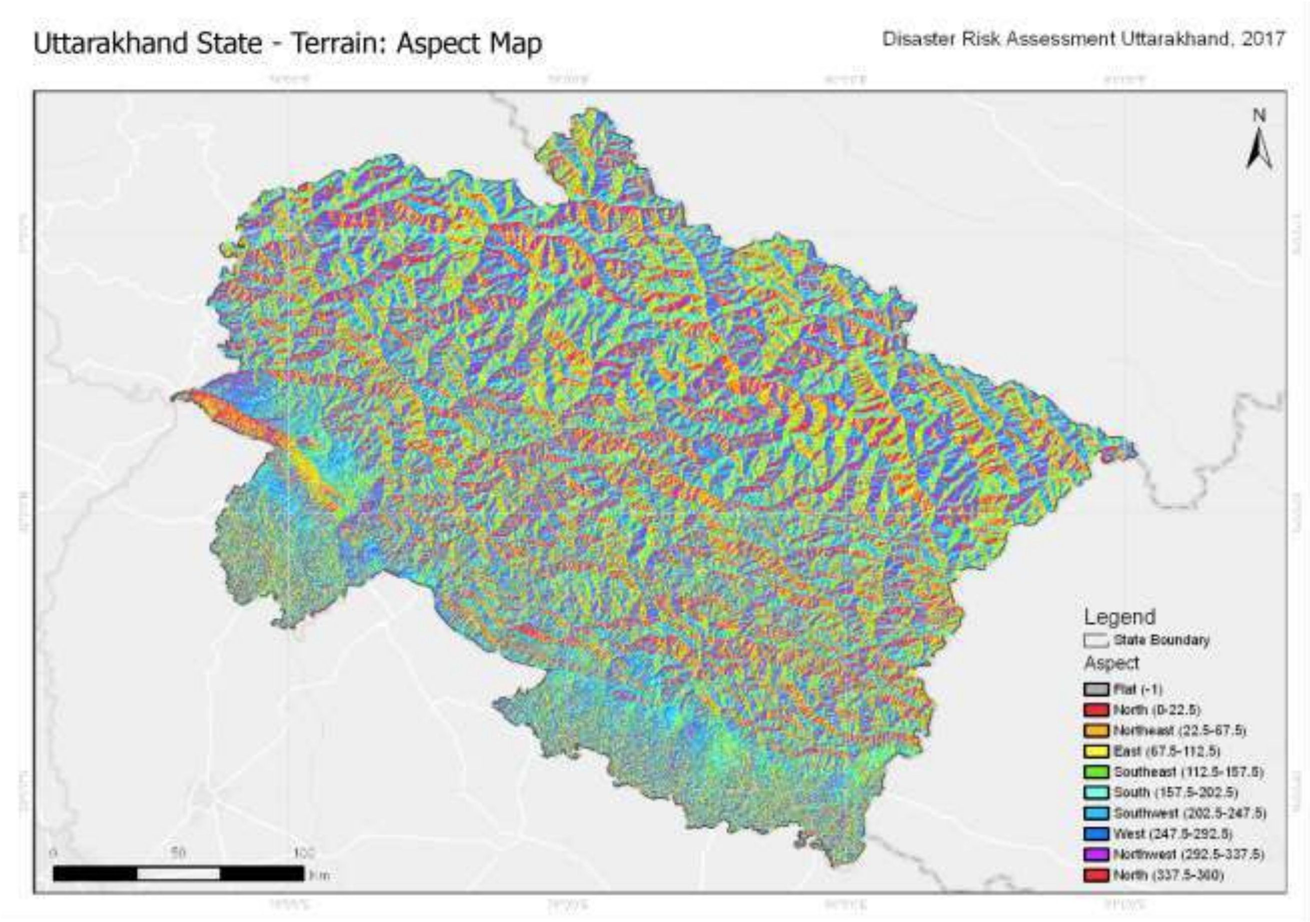


Figure 3.75: Aspect raster used in the Maxent landslide susceptibility modelling

3.4.4.3 Geology Map

Geology plays an important role in landslide susceptibility studies because different geological units have different susceptibilities to active geomorphological processes like landslides (Carrara, A., et al., 1991; Anbalagan 1992).

The geology of the area is a critically important component of a regional zonation of slope instability. Because geology influences the formation of soils, the types of vegetation and the hydrologic conditions, it is an important factor for slope instability. Geology refers to the composition of the underlying rock and the characteristics that influence the decomposition of those rocks. Weathering has a large effect on the soil physical properties that control land sliding such as texture, porosity and shrink-swell properties.

The geological map used for the Maxent susceptibility modelling is presented in Figure 3.76.

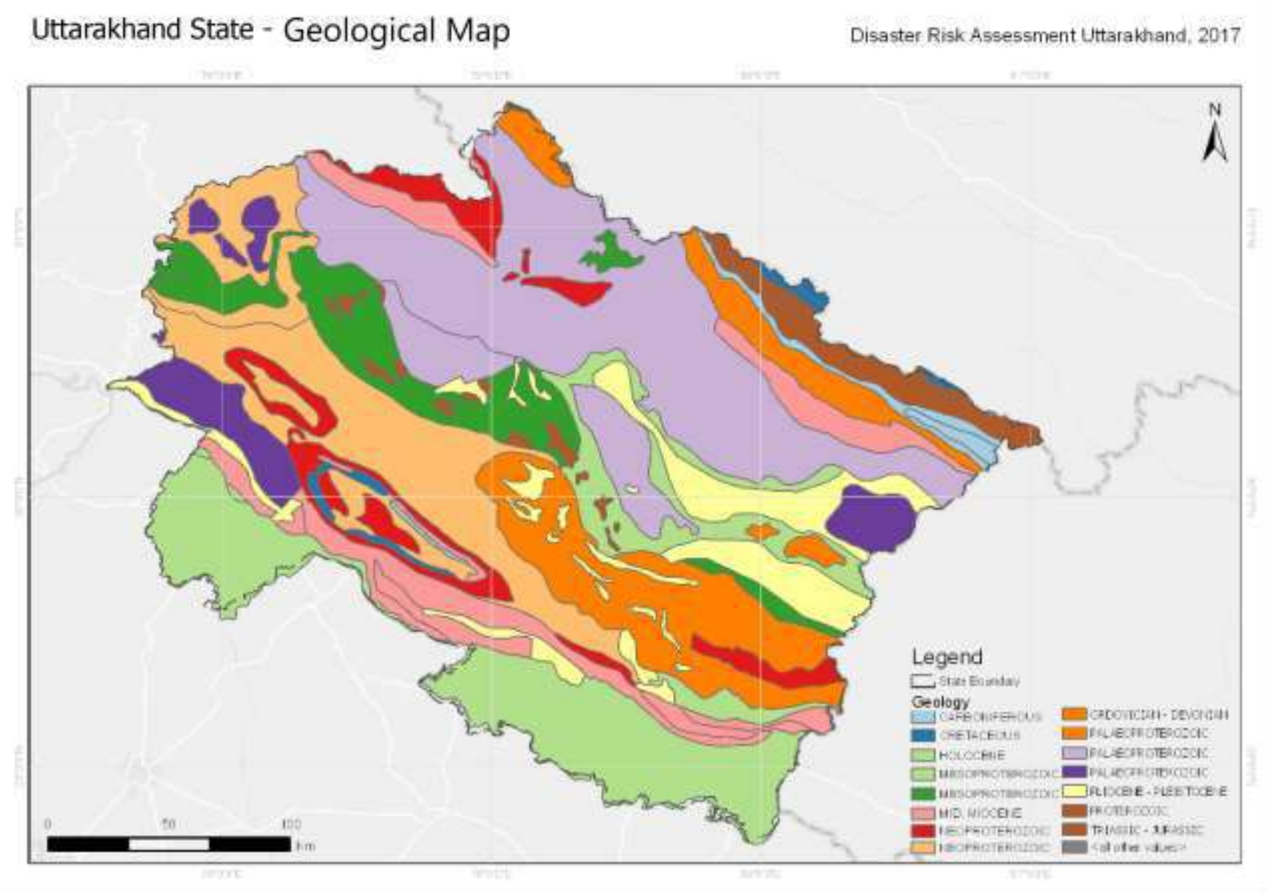


Figure 3.76: Geological map used in the Maxent landslide susceptibility modelling

3.4.4.4 Soil Map

The soil map used in the Maxent landslide susceptibility modelling in shown in Figure 3.77.

3.4.4.5 Distance to River

The raster of distance-to-river values used in the Maxent model is shown in Figure 3.78.

3.4.4.6 Distance to Road

The raster of distance-to-road values used in the Maxent model is shown in Figure 3.79.

3.4.4.7 Distance to Thrust

The raster of distance-to-thrust values used in the Maxent model is shown in Figure 3.80.

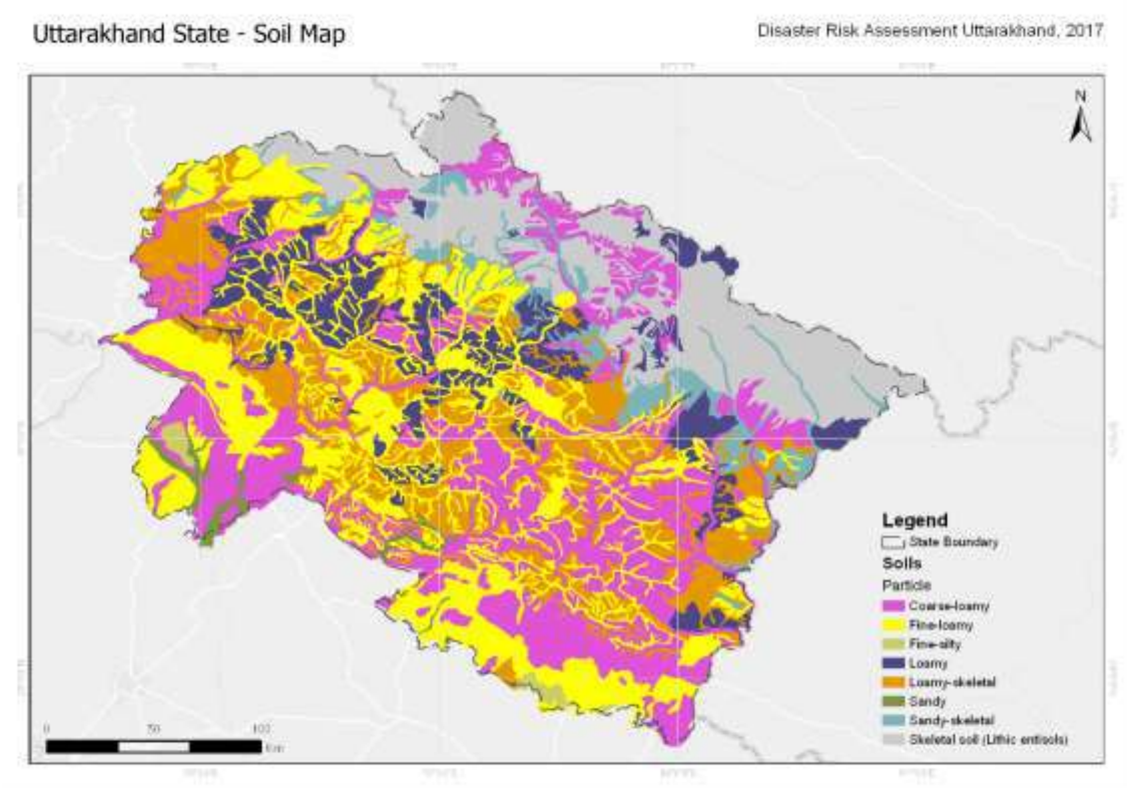


Figure 3.77: Soil map used in the Maxent landslide susceptibility modelling

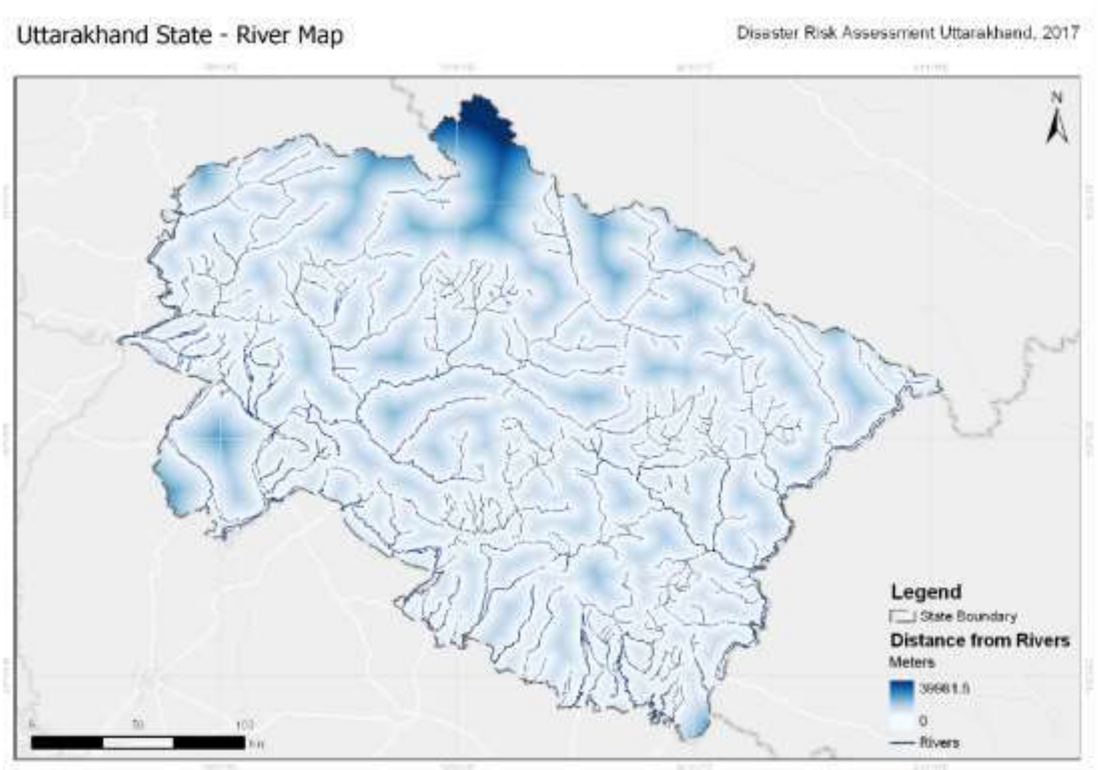


Figure 3.78: Distance to river raster used in the Maxent landslide susceptibility modelling

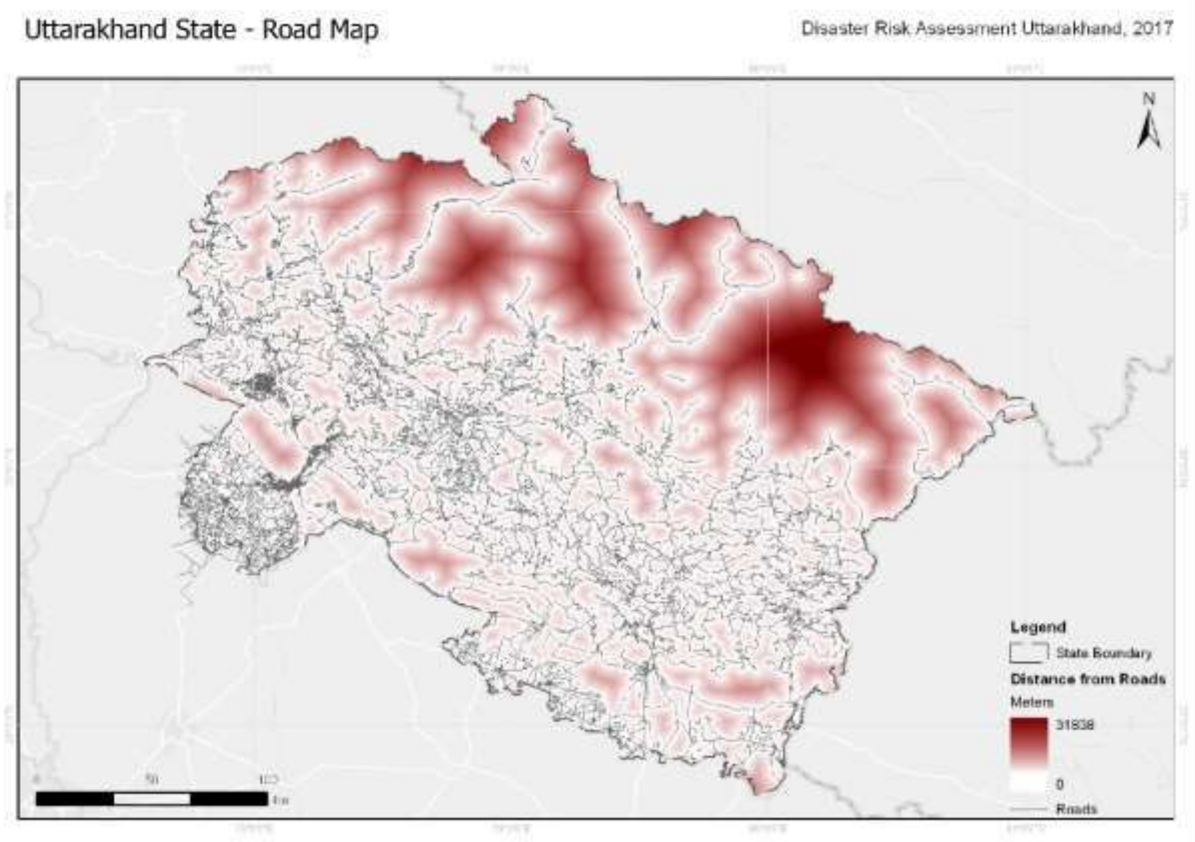


Figure 3.79: Distance to road raster used in the Maxent landslide susceptibility modelling

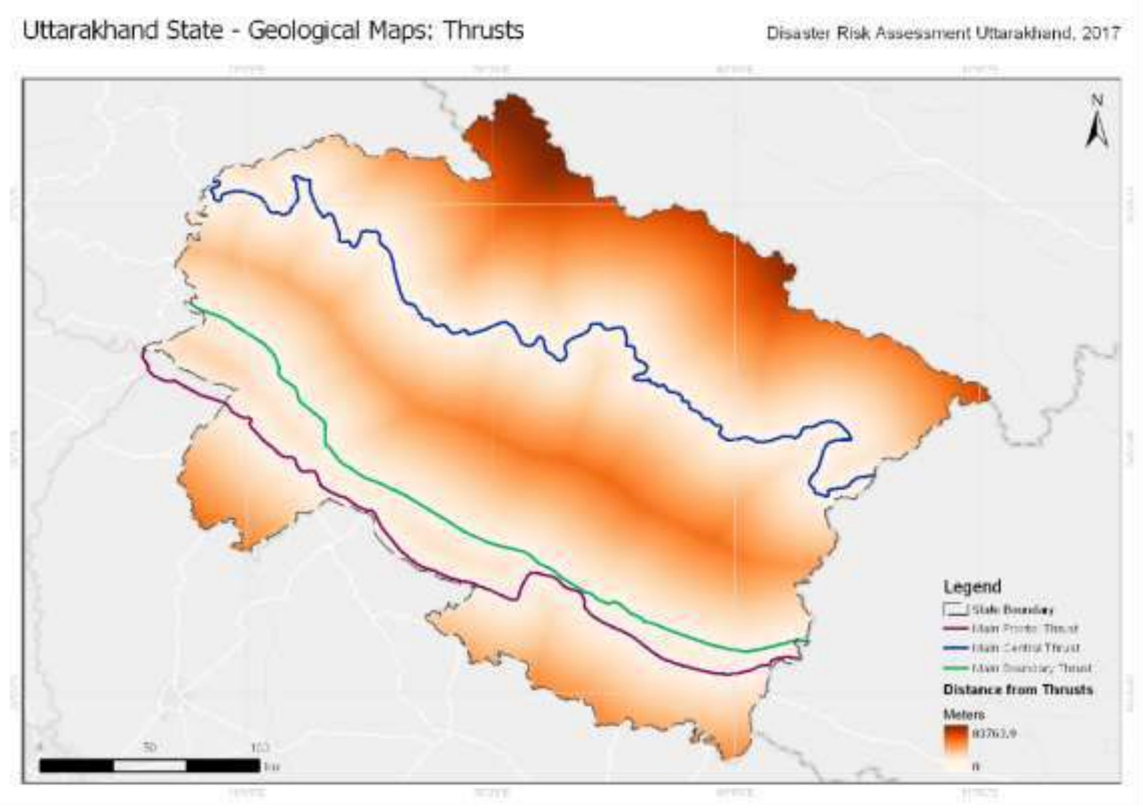


Figure 3.80: Distance to thrust raster used in the Maxent landslide susceptibility modelling

3.4.4.8 Distance to Fault

The raster of distance-to-fault values used in the Maxent model is shown in Figure 3.81.

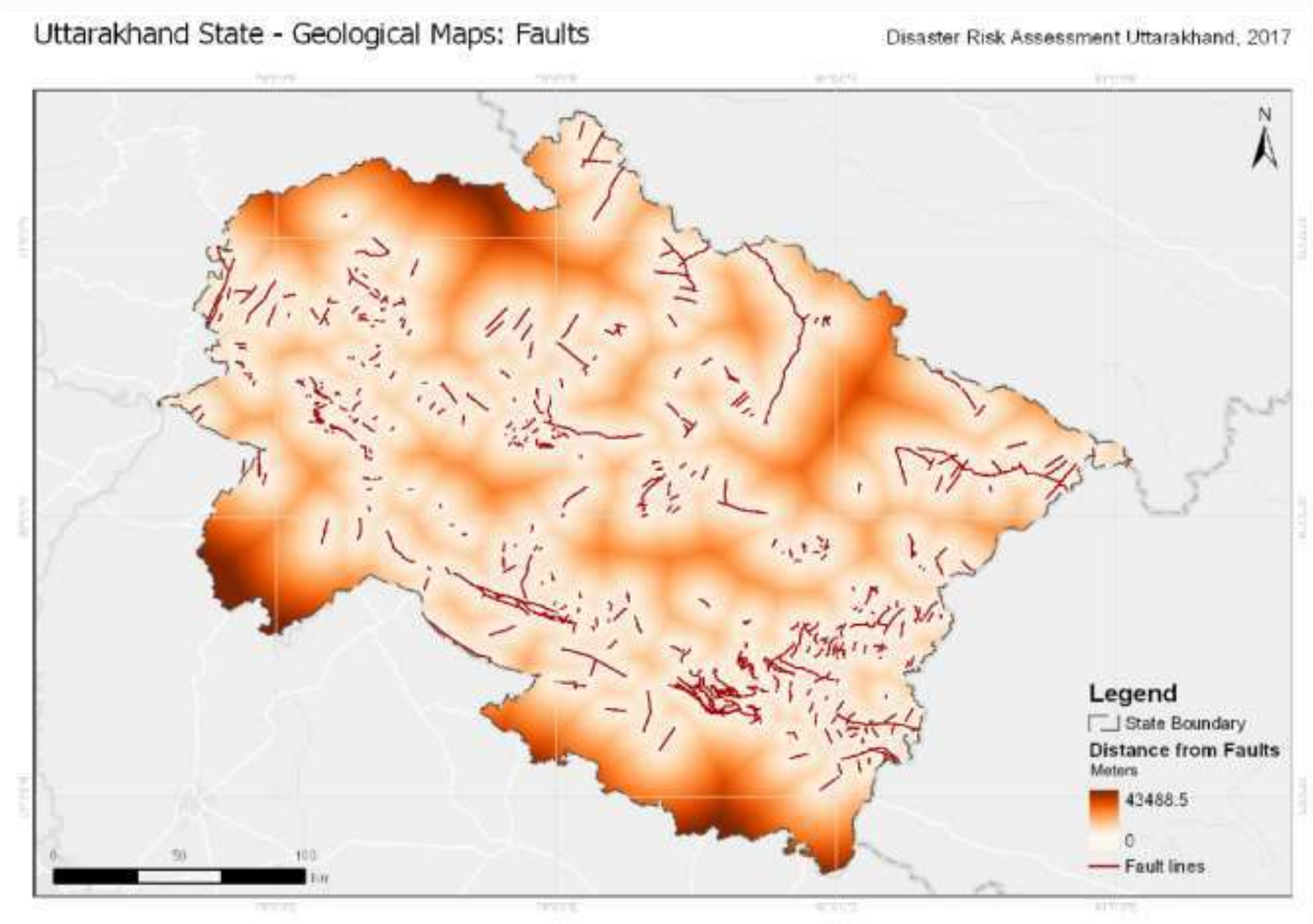


Figure 3.81: Distance to fault raster used in the Maxent landslide susceptibility modelling

3.4.4.9 Land use

The land use / land cover map used in the Maxent susceptibility model is shown in Figure 3.82.

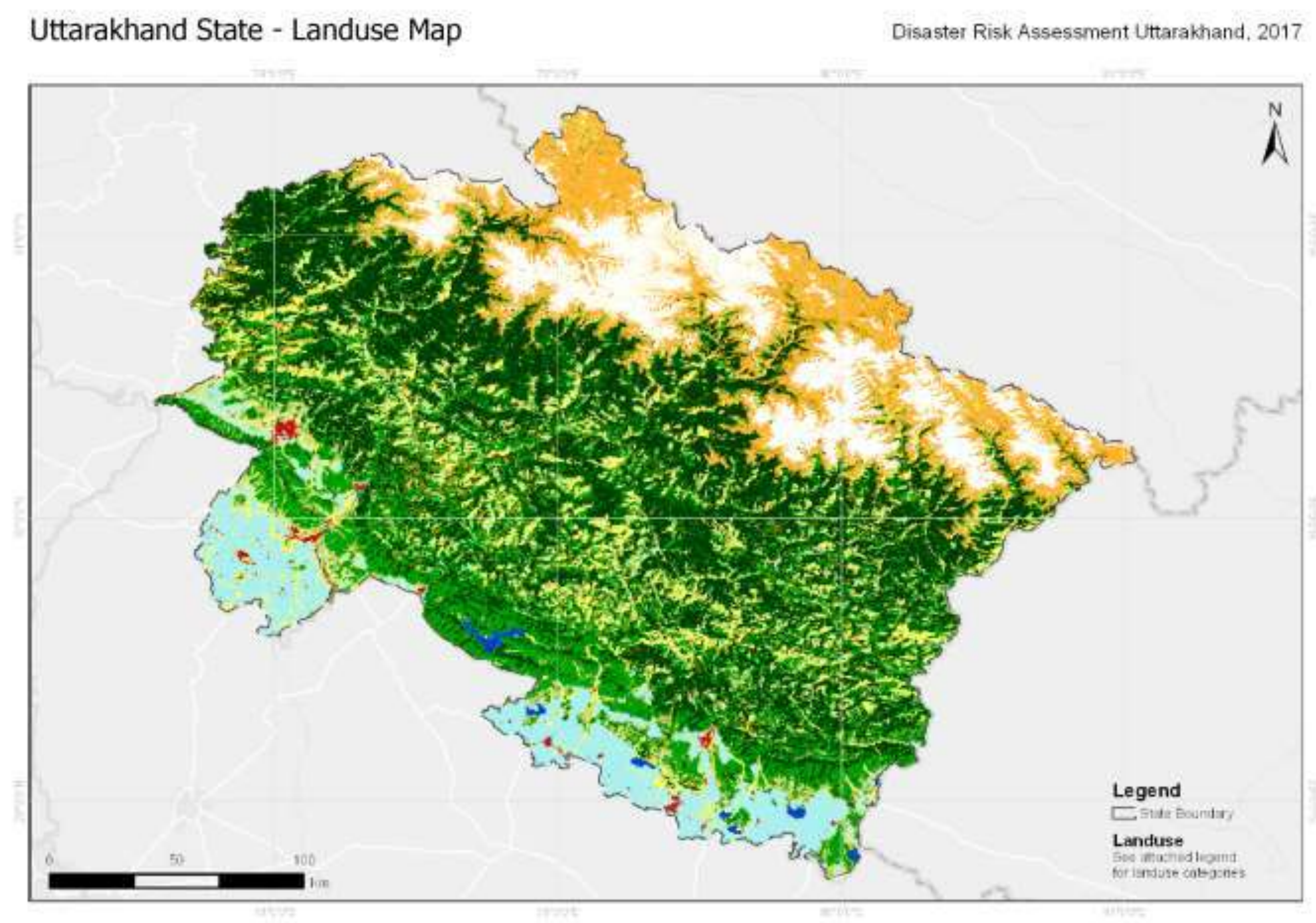


Figure 3.82: Land use raster used in the Maxent landslide susceptibility modelling

Figure 3.83 presents the legend for the land use map given in Figure 3.82.

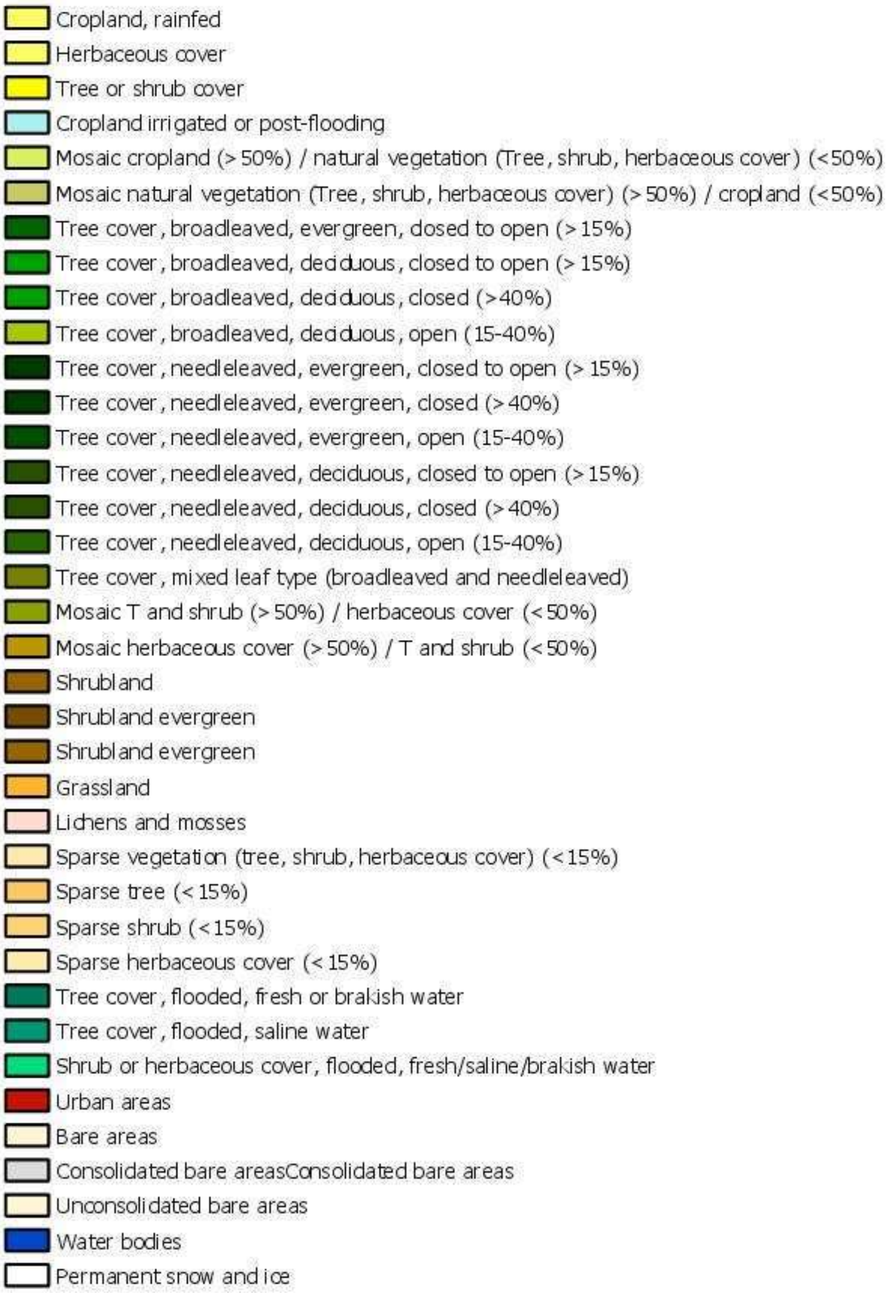


Figure 3.83: Legend for the land use raster used in the Maxent landslide susceptibility modelling

3.4.4.10 Average Annual Rainfall

The average annual rainfall raster used in the Maxent model is shown in Figure 3.84.

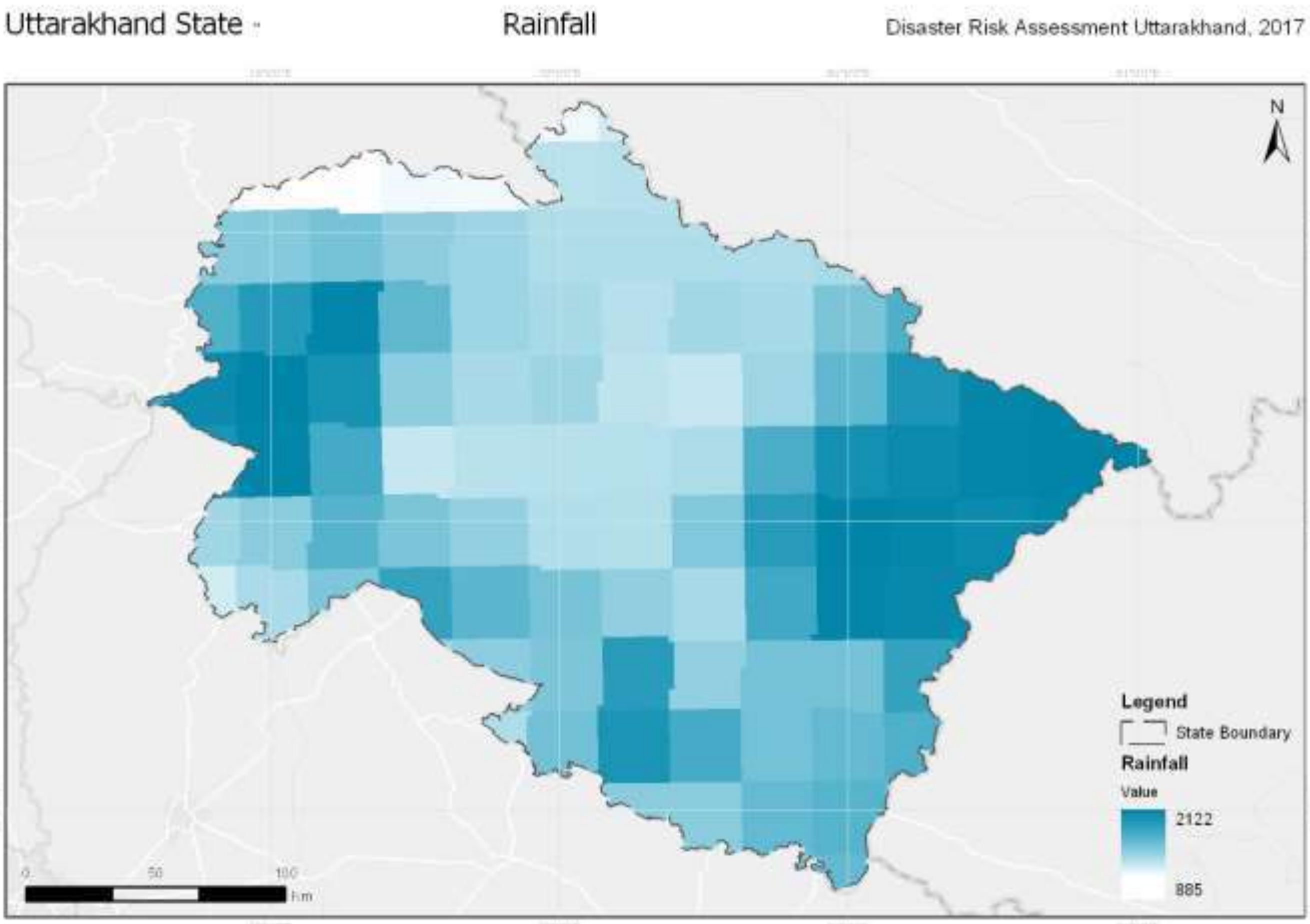


Figure 3.84: Average annual rainfall raster used in the Maxent landslide susceptibility modelling

3.4.4.11 Slope Length Factor

The slope-length factor (LS) is considered to be another important factor in landslide susceptibility modelling (Pourghasemi et al. 2012). LS factor represents the combined effect of slope and length. The well-known soil erosion model, Universal Soil Loss Equation (USLE) utilizes the LS factor to measure the sediment transport capacity of overland flow. The combined slope-length factor can be calculated by Moore and Burch (1986) study and easily derive in SAGA GIS toolbox.

The slope length factor raster used in the Maxent model is shown in Figure 3.85.

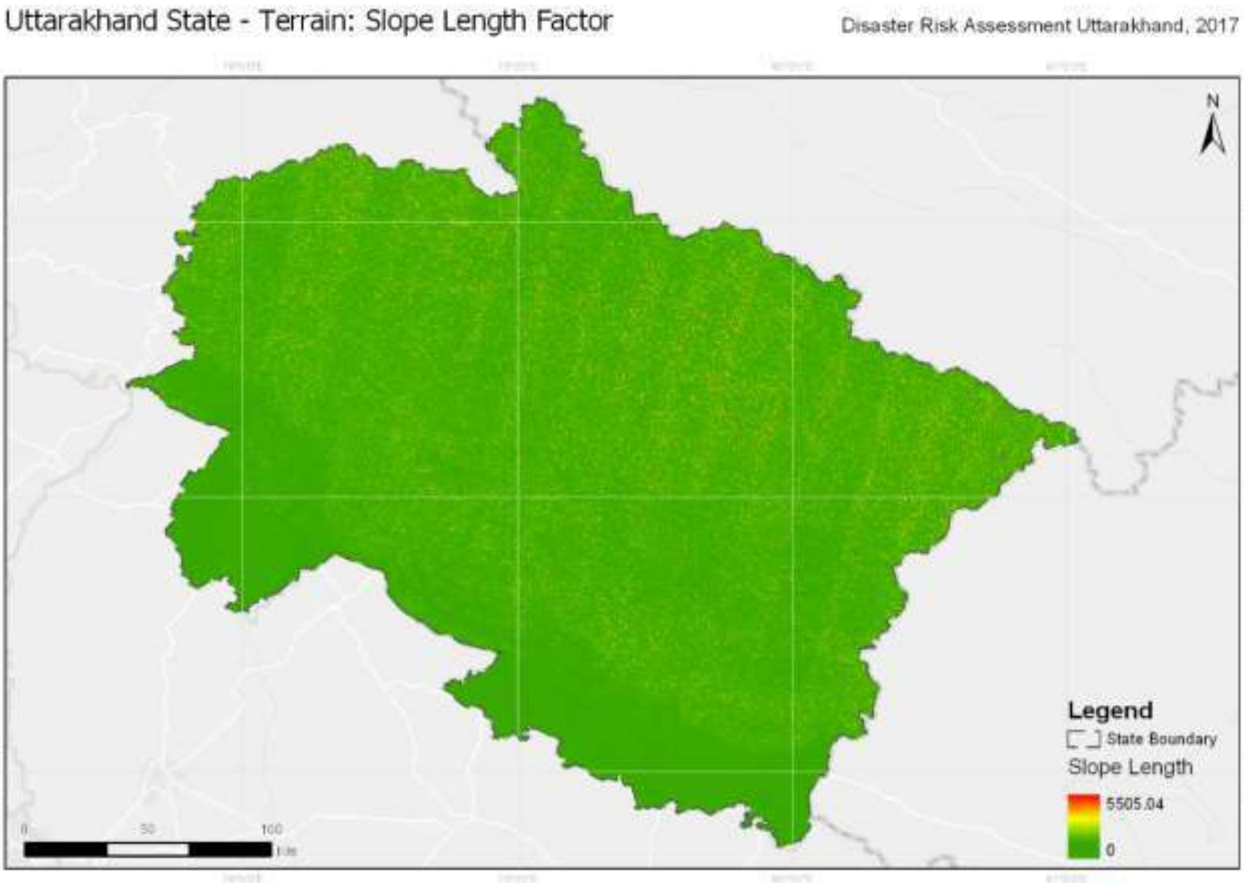


Figure 3.85: Slope length factor raster used in the Maxent landslide susceptibility modelling

3.4.5 Limitations, Gaps, and Critical Assumptions

The main limitations and gaps identified are listed as follows:

- Data: considerable effort has been devoted to collecting the most relevant datasets in the appropriate scale. However, some of the data (as such as land use / land cover) is in global scale which may limit the impact of those data in the landslide susceptibility analysis. The rainfall dataset used is in 25km scale, which obviously has an impact on the resolution of the assessment results.
- Modelling: The existing landslide model in CAPRA could not be used for this project due to the lack of spatially-distributed geotechnical parameters. Moreover, the approximation of those parameters based on literature or on other related layers (primarily soil or geology maps) was not advised by the reviewers of the Inception Report. Therefore, the statistical-based landslide susceptibility mapping method described above was introduced and then combined with the landslide magnitude distribution to model landslide hazard zonation.

3.5 INDUSTRIAL HAZARD ASSESSMENT

3.5.1 Introduction

This section summarises the approach to the hazard modelling. For specific details about the methodology, please refer to Volume 4 on the Industrial Hazard Assessment.

3.5.2 Summary of Approach

Facility level assessments have been undertaken for shortlisted industries with Multi Accident Hazard (MAH) status. We have focussed on explosions, hazards, and toxic emissions from the facilities and assessed the potential impact and exposure of such threats.

The approach is summarised as follows:

Step 1: Consult Relevant Agencies to Identify Hazardous Facilities

Step 2: Collect Available Secondary Data & Consult Shortlisted Industries to Confirm Operational Status.

Step 3: Visit all Operational Shortlisted Industries for Local Assessment

Step 4: Conduct ALOHA Model testing of Hazard

Step 5: Determine Exposed Building Stock and Population in Impact Zones

Step 6: Identify Priority Hazardous Facilities for Action

3.5.3 Data Collection

An example of the data collected about the storage containers at a specific facility is given in Table 3.16.

In this case it is an LPG container at a facility in Udham Singh Nagar. The storage containers of every facility posing a threat of chemical emission, fire, or explosion was profiled in this manner. The data collected provided critical input criteria for ALOHA modelling.

3.5.4 ALOHA Modelling

ALOHA stands for *Areal Locations of Hazardous Atmospheres* and it is a proven hazard modelling tool that is is used widely to plan for and respond to chemical emergencies.

The software allows you to enter details about a real or potential chemical release, and then it will generate threat zone estimates for various types of hazards. ALOHA can model toxic gas clouds, flammable gas clouds, BLEVEs (Boiling Liquid Expanding Vapor Explosions), jet fires, pool fires, and vapor cloud explosions.

The threat zone from a chemical or explosive hazard are shown on a grid in ALOHA, and they can also be plotted on maps in Esri's ArcMap, Google Earth, and Google Maps. The red threat zone represents the worst hazard level, and the orange and yellow threat zones represent areas of decreasing hazard.

Table 3.16: Example profile of a storage container at a facility

Hazardous Material	
Hazardous Materials	LPG
Storage Type	
Storage Type Tank, Drums, Carboys, Barrels, Bullet etc..	Bullet
Storage Type (Horizontal/Vertical)	Horizontal
Storage Type (Above/under Ground)	Above Ground
Unit Storage Size # (Tonnes)	15
Total Number of Unit Storages (Nos)	2
Storage Quantity	
Max.Qty Stored in plant (Tonnes/KL)	30
Unit Storage Dimensions (Tank, Bullet etc.)	
Length/ Height (m)	6.4
Diameter (m)	2
Volume (cubic meter)	16.87
Storage Outlet Nozzle Details	
Height of nozzle from ground (m)	1
Diameter of nozzle details (mm)	28
Dyke Dimensions	
Length (m)	NA
Breadth (m)	NA
Height (m)	NA
Storage Details	
State in which Chemical is Stored (Liquid/Gas /Solid)	Liquid
Pressure (bar)	1
Temp. (Degree Celsius)	15-20
Ambient Temperature During Year	
Maximum (Degree Celsius)	40
Minimum (Degree Celsius)	5

ALOHA allows the user to estimate the dispersion of a chemical cloud based on the toxicological/physical characteristics of the released chemical, atmospheric conditions, and specific circumstances of the release. ALOHA can estimate threat zones associated with several types of hazardous chemical releases, including toxic gas clouds, fires, and explosions.

Threat zones can be displayed on GIS maps to help users assess geospatial information, such as whether vulnerable buildings or communities (such as hospitals and schools) might be impacted by the release.

Typical outputs for ALOHA are illustrated overleaf in Figure 3.86.

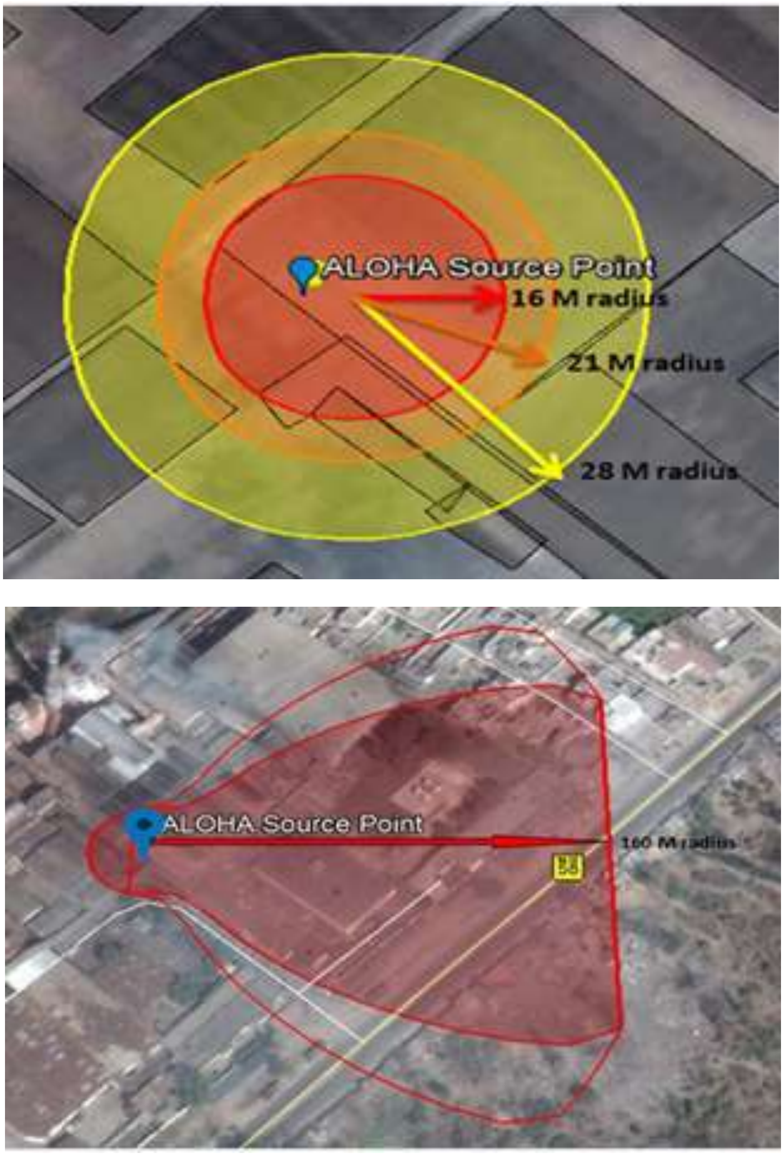
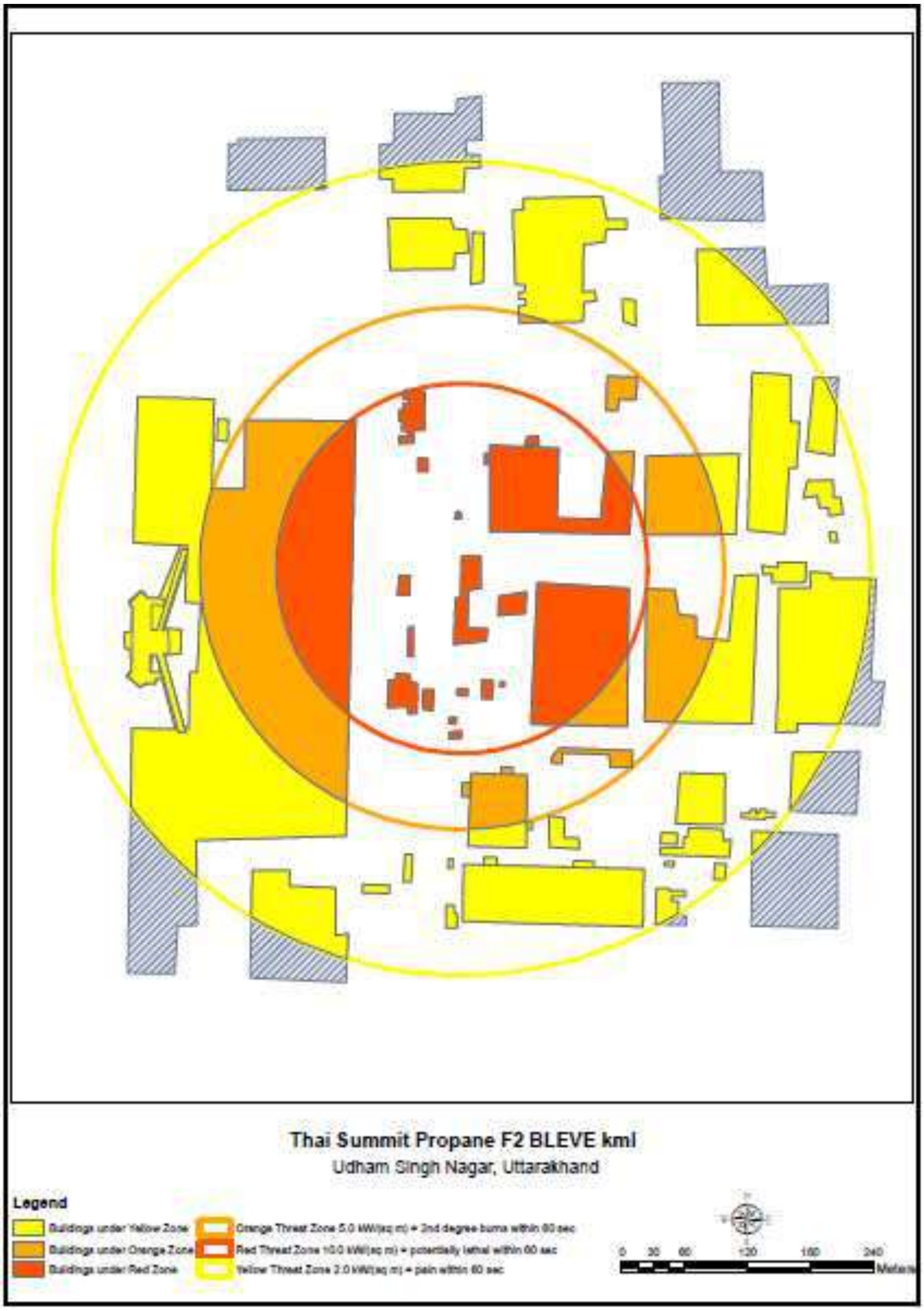


Figure 3.86: Typical Examples of Outputs from ALOHA (top: explosion area of concern; bottom: toxic cloud dispersion zone)

3.5.5 Assessment of Exposure

For each facility, the number of impacted buildings and people has been estimated within the different threat zones. This information is found in the appendices of Volume 4 and a typical output is illustrated here in Figure 3.87.



UDS134: Thai Summit Propane F2 BLEVE kml		
Color	**Total Area (sq.m) of Built up**	**Total Area (sq.m) of dispersion curve**
Red	36,961	98,753
Orange	43,792	98,166
Yellow	108,028	281,096

Figure 3.87: Example of Exposure Assessment for a Specific Facility and Scenario for a Propane Explosion.

3.5.6 More about ALOHA

ALOHA is not difficult to use and there are comprehensive support resources available. Here are some key resources.

Factsheet:

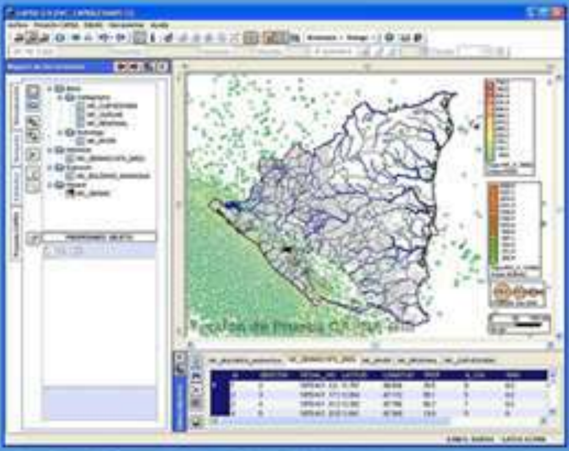
https://response.restoration.noaa.gov/sites/default/files/aloha.pdf

Technical Resources:

https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/aloha-technical-resources.html

Manual:

https://response.restoration.noaa.gov/sites/default/files/ALOHA_Tech_Doc.pdf



CAPRA
Probabilistic Risk
Assessment Platform

CHAPTER 4
Risk Database & Toolkit

4 THE RISK DATABASE & TOOLKIT

This section of the report introduces the DRA Risk Database and Toolkit; a collection of tools that have been deployed by this project and that will help the GovUk assess and manage risk on an ongoing basis. The toolkit includes CAPRA for risk assessment and a web based database for dissemination of maps and data. The toolkit offers great flexibility, and it will interface well with forthcoming Decision Support System proposed for the State of Uttarakhand under a subsequent phase.

4.1 INTRODUCTION TO THE DRA TOOLKIT

The Disaster Risk Assessment Toolkit ("The DRA Toolkit") is a key outcome of the project. It is comprised of several components that, together, empower the Government of Uttarakhand to disseminate risk information and to repeat and continually improve risk assessment over time.

The components of the toolkit are as follows:

1. CAPRA Team RC+ for risk computation
2. Online Risk Database accessible via the USDMA website
3. MIKE Hydro River and MIKE SHE for Flood Modelling
4. R-CRISIS for seismic risk
5. ArcGIS Script for Landslide Susceptibility Mapping
6. ALOHA for Industrial Hazard Assessment

With the DRA Toolkit, the State of Uttarakhand will be able to facilitate the inventory, organization, and presentation of various risk relevant information collated from different local state agencies and institutions beyond the data provided by the present study.

Only the MIKE suite is not license free. However, a license has been gifted to the DMMC under this project. All other components and license free and/or fully Open Source.

In agreement with the PIU (TA & CBDRM), the DRA-JV has enabled a solution comprised of world class risk modelling software coupled with license free online database for data dissemination and leading hazard modelling tools.

All manuals are provided under Appendix A.

4.2 TOOLKIT COMPONENTS

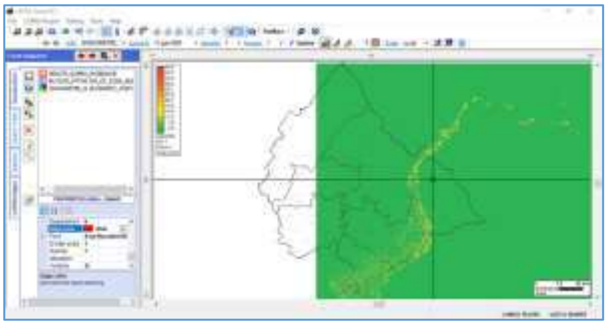
4.2.1 R-CAPRA for Risk Computation

4.2.1.1 About R-CAPRA

R-CAPRA is a tool and platform for probabilistic and deterministic risk assessment. It is open source and fully supported by ERN. The version deployed for the GovUK is fully compatible with R-CRISIS and RMS (one)©.

The risk metrics output from r-CAPRA studies are:

- Loss exceedance curve (LEC).
- Average annual loss (AAL).
- Probable maximum loss (PML).
- Pure risk premium.



The exposition, vulnerability and risk for al hazards are presented in a geographical information system, this helps decision-makers understand risk, estimate probable losses, and reconstruction costs, so they can assess disaster risk reduction strategies. Some applications of an R-CAPRA study are:

- Development, placing and operation of risk transfer instruments
- Development of the risk profile for a city, country or region.
- Cost-benefit evaluation of different loss mitigation actions.
- Emergency response action plan development.
- Land planning.

More information is available at https://ern.com.mx/web/capra_en.html and technical support is available via contacto@ern.com.mx

4.2.1.2 Modules of CAPRA

Specifically, the different modules of R-CAPRA are:

- Hazard Modules: It links to data of historical data, hazard extent and models to predict hazard frequency and intensity;
- Exposure Data: Accurate, up-to-date topographic maps, land use maps, asset maps, classification, valuation and location of critical infrastructure can be used by the system;
- Vulnerability and Damage Module: The vulnerability module includes software tools for the development of physical vulnerability functions for each hazard and class of asset considered. The vulnerability module can also be used to assign specific vulnerability functions to the exposed elements;
- Loss Module: This module describes and processes probabilistic losses at various user defined return periods for selected hazards;
- User-added Modules: Example are (a) Climate Change Scenarios – to process the probable loss characteristics over a modelled future climate change scenario; (b) rapid near real-time loss estimation – to estimate probable damage modelled on a specific hazard event such as a cyclone track or avalanche;
- User adaptation: DHI has experience in the use of CAPRA and is currently adapting DHI tools to the CAPRA tools.

4.2.1.3 History of the CAPRA Initiative

The CAPRA initiative started in January 2008, as a partnership between the Center for Coordination of Natural Disaster Prevention in Central America (CEPREDENAC), the United Nations International Strategy for Disaster Reduction (UN ISDR), the Inter-American Development Bank (IADB) and The World Bank as a means to raise awareness among client countries in Central America by providing them with a set of tools that would let them better understand the risk of adverse natural events.

The CAPRA (Probabilistic Risk Assessment) Program is an initiative that aims to strengthen the institutional capacity for assessing, understanding and communicating disaster risk, with the ultimate goal of integrating disaster risk information into development policies and programs.

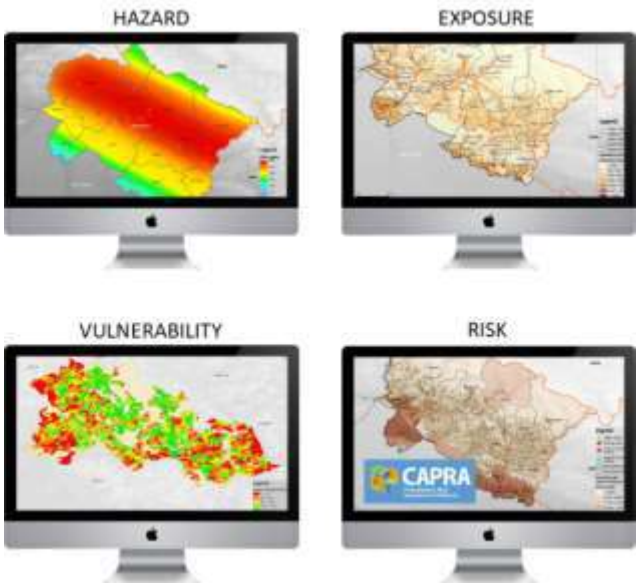
Under the CAPRA Program, government institutions and other agencies partner with The World Bank to address specific development challenges and meet disaster risk information needs through hands-on practical training and other complementary services.

The CAPRA Program is currently supported by the Spanish Fund for Latin America and the Caribbean (SFLAC), the Department of Foreign Affairs and Trade of the Australian Government, and the Global Facility for Disaster Reduction and Recovery (GFDRR).

4.2.1.4 R-CAPRA User Manual

The user manual for CAPRA-GIS is provided under Appendix A.

4.2.2 Online Disaster Risk Database



The online Disaster Risk Database (preferred application name) is a web application hosted securely on NIC Virtual Server that allows for the storage and dissemination of maps, data, and documents on the hazards, exposure, vulnerability, and risk for the entire state. In short, the system provides access to hazard, exposure, vulnerability, and risk maps and related documents and data. Content is comprised of maps, data, images, and documents (PDF, Word, Excel).

Users can view, query, and download maps, data, and docs and configure maps and print them. USDMA Administrators can logon to administer content, upload maps, docs, and data, and make content public or 'private' and only visible to specific agencies if necessary.

4.2.2.1 Design Strategy

The Risk Database is focused on data sharing and collaboration. It will facilitate the exchange of information between agencies and with the public. Authorised representatives can upload GIS files, spreadsheets, and documents and organize them as desired.

The DRA-JV deliberately developed the User Interface to resemble the recently upgraded USDAM website in order to provide a relatively seemless experience for users.

4.2.2.2 Key Features

The project terms of reference simply called for a GeoNode based application. However, whilst an excellent platform for many applications, GeoNode is limited in its capability for USDMA and it runs on a Linux operating system, which is not familiar to the administrators of the risk database. Therefore, in agreement with PIU (TA & CBDRM), the DRA-JV has implemented a license-free web application that meets contractual specifications and enables the USDMA to link the data files in to other future systems.

Key features of the online application include:

- Hosted in an NIC virtual environment with full scalability and redundancy.
- Fully compliant with NIC security standards.
- Compatibility with standard GIS formats and MS Office file formats

- User permissions management to restrict access to certain data amongst agencies or to provide Public access if required.
- Same development platform and full compatibility with the Uttarakhand River Morphology Information Management System (URMIS).
- Ability to store compliant metadata against any geospatial layer or data files uploaded to the system.
- Ability for other applications (for instance, the DSS) to access or "call" the maps on the geoserver via a web service.

4.2.2.3 Hosting

The Disaster Risk Database is hosted on a virtual server procured by DMMC from NIC. The server is administered by DMMC. Access to the DRDB is via the USDMA website at www.usdma.uk.gov.in

4.2.2.4 Specifications

The specifications for the virtual application server recommended by the DRA-JV are as follows:

Server Configuration:	1 VM with 04vCPU, 32GB RAM and 60GB Storage
Type of Server:	Web and Application Server
Platform:	Windows
Environment:	Production
Additional Storage (GB):	1,000 or 1TB
FTP Access Required:	Yes
VPN Access Required:	Yes

The application requires the following pre-requisite components installed and operational on the virtual server:

Webserver type:	7.5
.NET Framework:	ASP.NET 4.5
GeoServer version:	GeoServer 2.11.0 (www.geoserver.org)
Database specs:	PostgreSQL 9.3.0 (www.postgresql.org) and PostGIS 2.1.0 extension

- MIKE INFO 2016 1.6 (v2.1.6) – Provided by DHI
- Latest version of DokuWiki (www.docuwiki.net)
- PHP version 5.6 or later (www.php.net)

- FileZilla FTP Server v3.27.0.1 (www.filezilla-project.org)

4.2.2.5 User Manual

Refer to Appendix A for the User Manual for the Online Risk Database.

4.2.3 Hazard Modelling Tools

4.2.3.1 MIKE HYDRO RIVER for Floods

MIKE HYDRO RIVER is a proprietary produce from DHI Water & Environment that is the next generation of river system modelling tools, and the successor to DHI's well-known product, MIKE 11. It enables hydrologists to model a variety of situations related to river hydraulics, water quality, flooding, forecasting, navigation, as well as catchment dynamics and run off.

MIKE HYDRO River provides a modern, map-based and highly intuitive graphical user interface for river modelling. It builds on the long and successful history of MIKE 11 – one of the world's most well-proven and commonly applied 1D river modelling packages.

It provides the largest diversity in calculation features and add-on modules and enables you to conduct all required modelling activities within one modelling package. It enables seamless model couplings making MIKE HYDRO River perfectly suited for fully integrated applications.

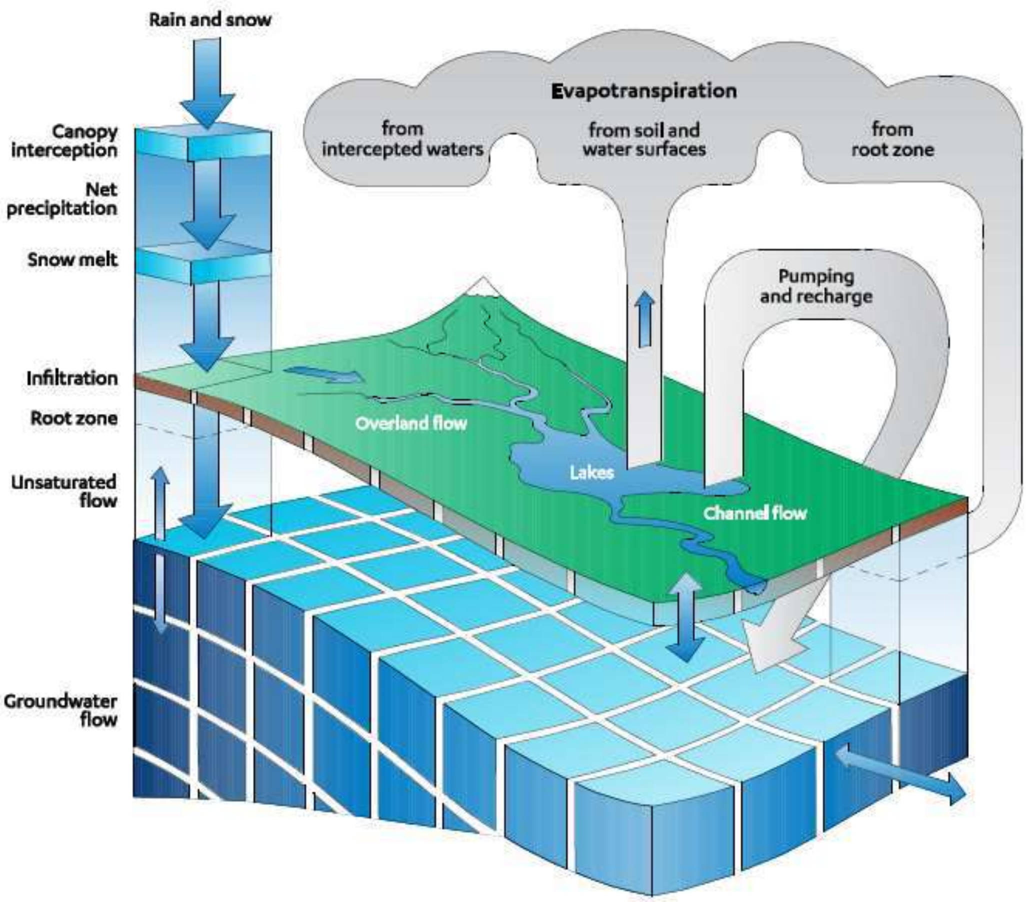
MIKE HYDRO River is the ideal software for:

- real-time flood forecasting
- dam break analysis
- reservoir optimisation including complex structure operations
- ecology and water quality assessments in rivers and wetlands
- flood analysis and flood alleviation design studies
- water quality forecasting
- sediment transport and long term assessment of river morphology changes
- salinity intrusion in rivers and estuaries

Additionally, optimal river modelling solutions often require integrated modelling, in which the river model interacts with surrounding flood areas or groundwater. MIKE HYDRO River is perfectly suited for fully integrated applications by seamless model couplings with other products like MIKE FLOOD and MIKE SHE.

4.2.3.2 MIKE SHE for Flash Floods and Catchment Modelling

MIKE SHE delivers truly integrated modelling of groundwater, surface water, recharge and evapotranspiration. No other tool or combination of tools can match MIKE SHE in terms of seamless integration of all the important processes of the hydrological cycle.



It is the ideal software for:

- integrated catchment hydrology
- conjunctive use and management of surface water and groundwater
- irrigation and drought management
- wetland management and restoration
- environmental river flows
- floodplain management
- groundwater-induced flooding
- land use and climate change impacts on groundwater and surface water

- nutrient fate and management
- integrated mine water management

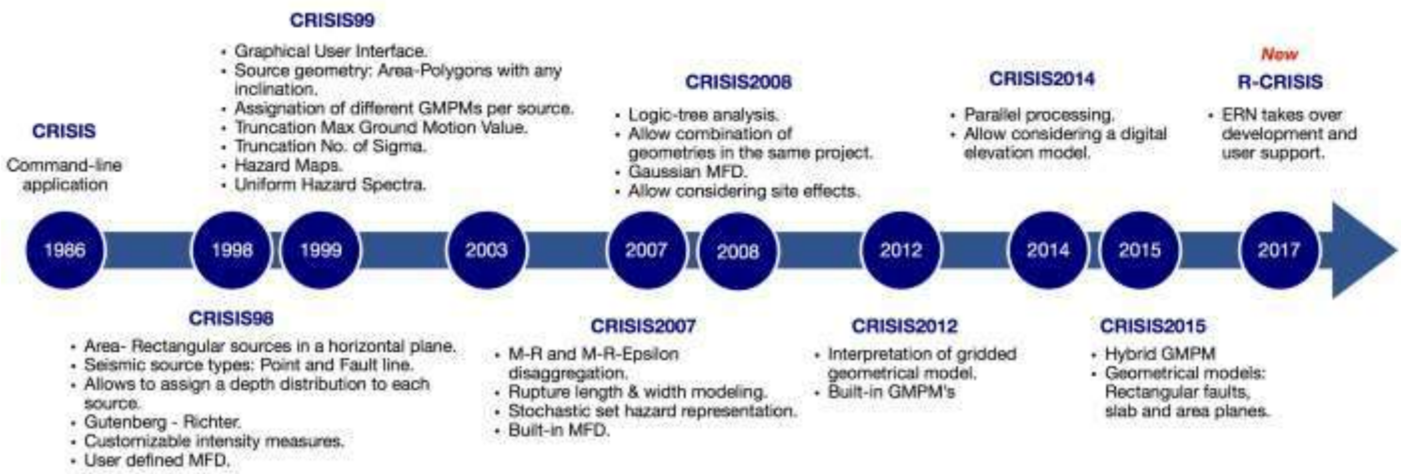
MIKE SHE is a flexible modelling framework that includes a range of numerical methods for each hydrological process. It has an advanced, conceptual, model-independent user interface with full water balance accounting for all hydrological processes. It is possible to combine the hydrological processes and numerical methods depending on the requirements of your application and the availability of data. All numerical engines in MIKE SHE are parallelised to make efficient use of available multicore resources.

MIKE SHE includes both a simple, semi-distributed overland flow method for rainfall-runoff modelling and a 2D, diffusive wave, finite difference method for detailed runoff and flood modelling. It can simulate detailed flooding based on fine scale topography in a coarser numerical grid as well as detailed two-way exchange with rivers.

4.2.3.3 R-CRISIS for Earthquakes

R-CRISIS

R-CRISIS is a Windows based software with the capability of performing probabilistic seismic hazard analysis (PSHA) using a fully probabilistic approach allowing the calculation of results in terms of outputs with different characteristics (i.e., exceedance probability plots, set of stochastic events). The first version of the program was launched in 1986 and since then several and continuous updates and improvements have been included to keep the program as a state-of-the-art tool. Originally developed using FORTRAN as programming language (Ordaz, 1991) without a GUI, it developed later into CRISIS99 (Ordaz, 1999). Since 2007 the program was upgraded in view of the advantages offered by the object-oriented technologies (i.e. Visual Basic.NET). In that version, called CRISIS2007, both the GUI and the computation engine were written in the same programming language. In 2017, Prof. Ordaz decided to continue the development and support of CRISIS through his company ERN, rebranding it as R-CRISIS.



4.2.3.4 Script for Landslide Susceptibility Modelling

There are mainly three phases in the landslide susceptibility modeling framework such as data preparation phase, landslide susceptibility modeling phase and landslide zonation phase. The whole process can be executed by free software for commercial GIS packages for basic operations. The Maxent model, the susceptibility modeling package which uses maximum entropy modeling technique can be download freely at https://github.com/mrmaxent/Maxent/. Figure 4.1 illustrates the overall landslide susceptibility modeling tool package

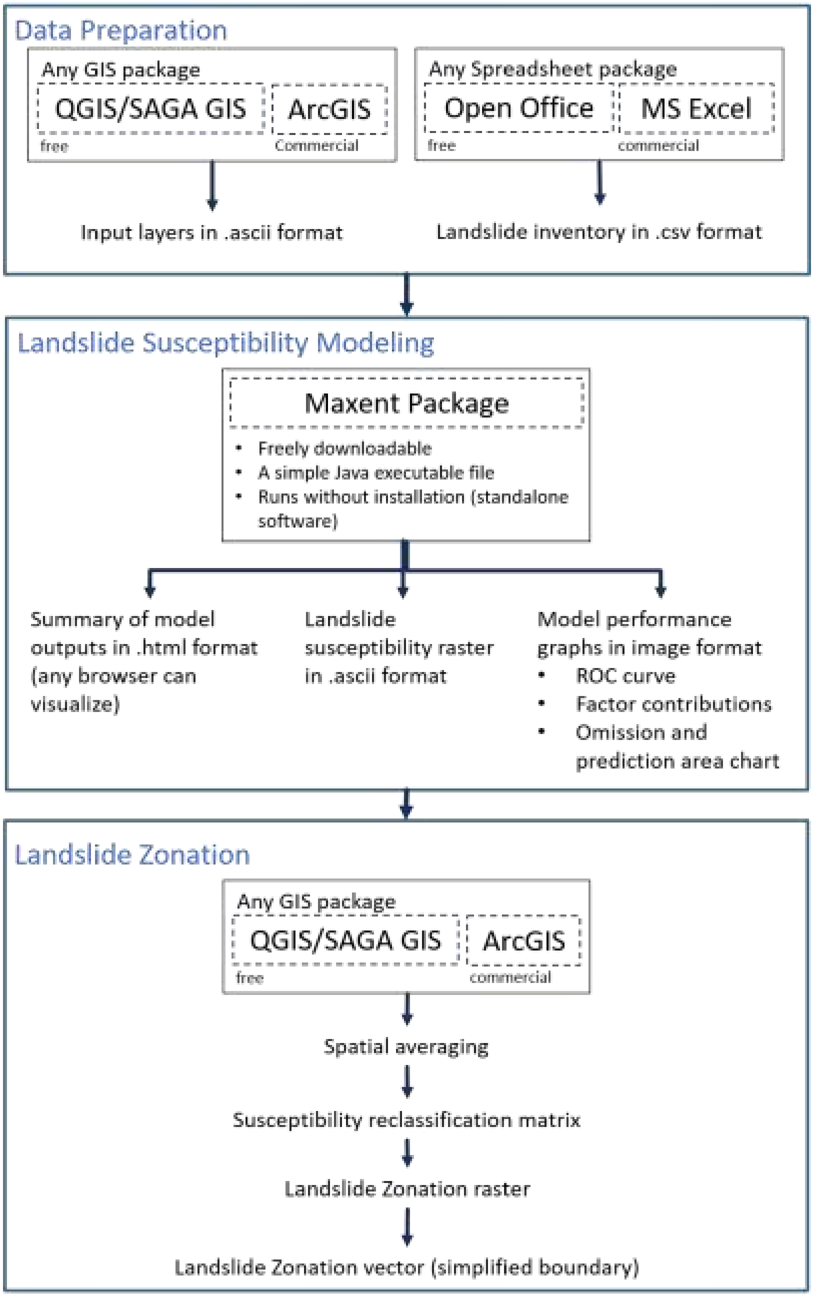


Figure 4.1: Overall landslide susceptibility modelling tool package

Data preparation for the Maxent model can be carried by free GIS packages like QGIS or SAGA GIS, and ArcGIS commercial software also can be used. Figure 4.2 shows how SAGA GIS packages has been used to generate some of landslide causal factors for the Maxent model.

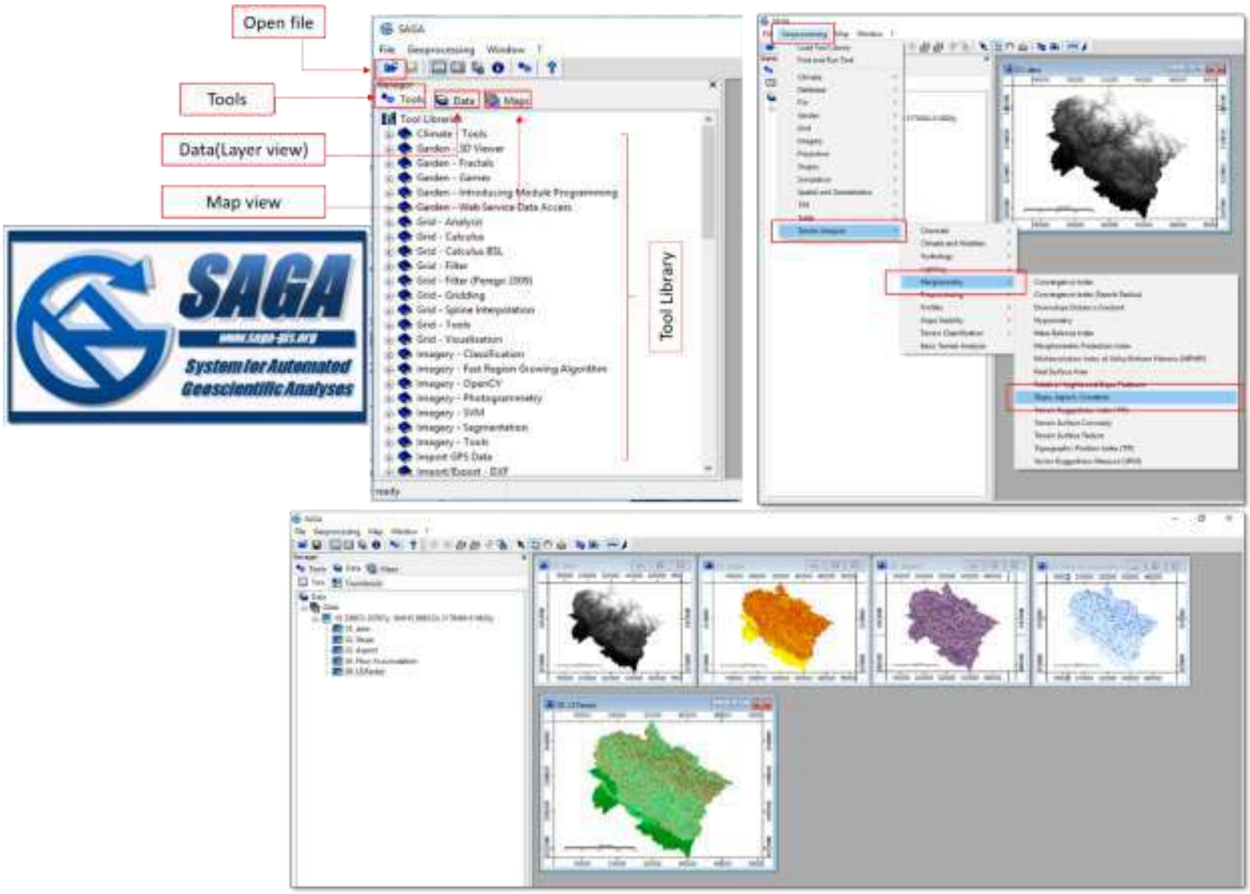


Figure 4.2: SAGA GIS package for data preparation

The Maxent software is a standalone package which could run without installation. It's also an open source which could be modified with specific need. The model execution has been conducted in district level where normal computer able to run and able to improve by DMMC staff in future. The new landslide inventory always can be incorporated and execute the model, eventually model will reach to better accuracy. If the USDMA invest on higher accuracy DEM, the data preparation steps could rerun to generate topographic factors like slope, aspect, LS factor from the new DEM and input the Maxent model. Figure 4.3 illustrates the Maxent model parameterization and execution.

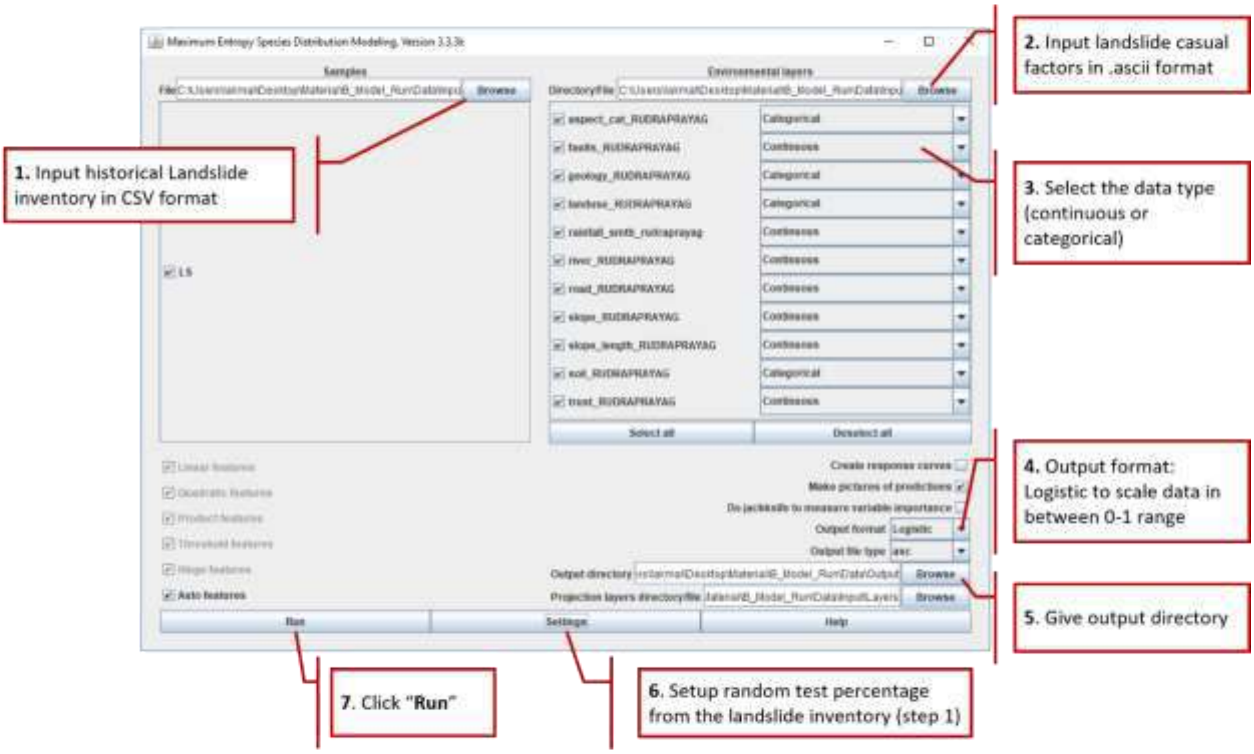
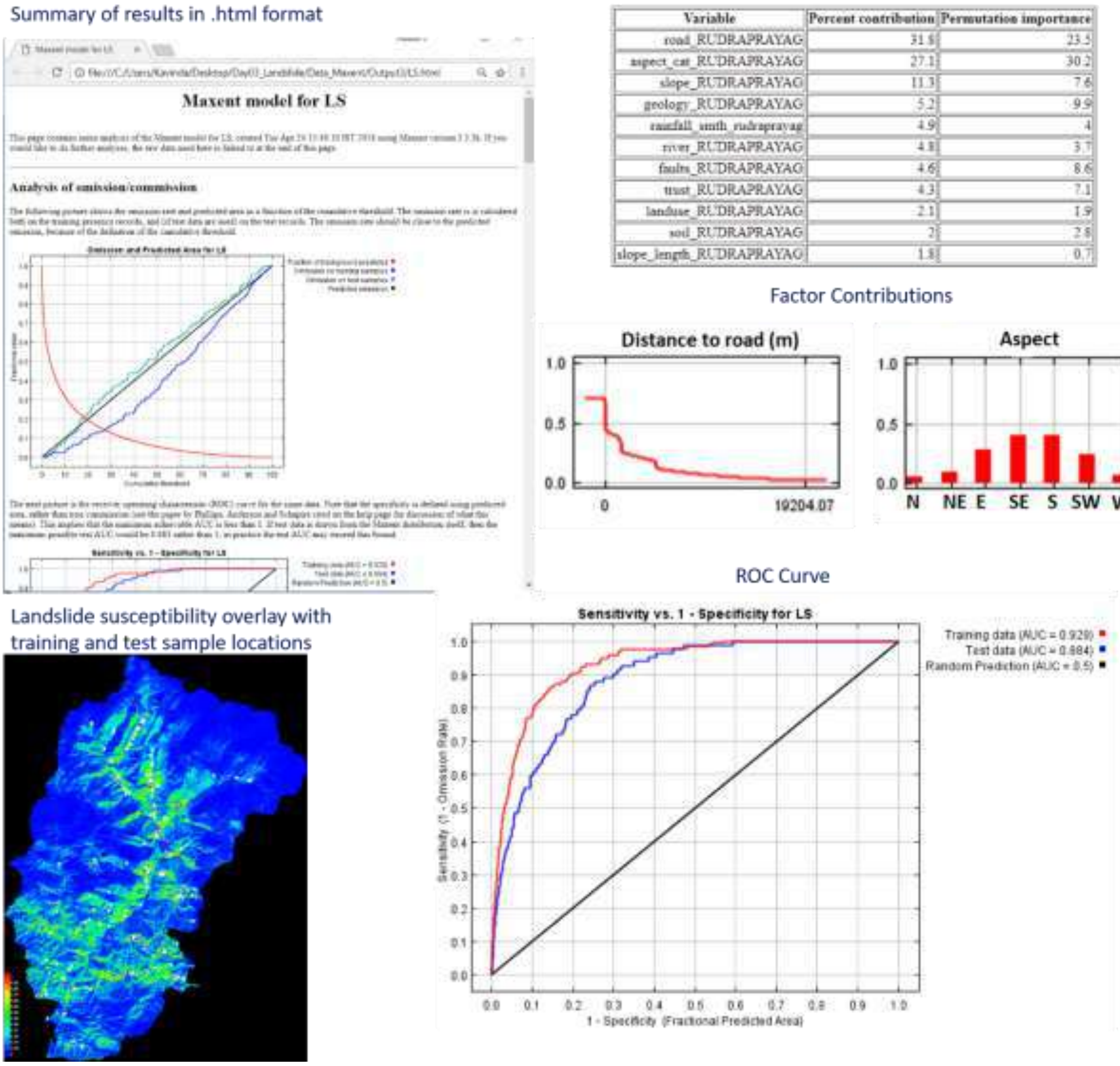


Figure 4.3: The Maxent model parameterization and execution

Figure 4.4 shows generated output by the Maxent model. All the inputs layers, intermediate results and all kind of outputs are compiles into a .html file which can be read by any browser. It also generates comparative description for all the generated output figures. Each and every output link to the original dataset by hyperlink which able to keep the track of model execution details in long run.



Variable	Percent contribution	Permutation importance
road_RUDRAPRAYAG	31.5	23.5
aspect_cat_RUDRAPRAYAG	27.1	30.2
slope_RUDRAPRAYAG	11.3	7.6
geology_RUDRAPRAYAG	5.2	9.9
rainfall_smth_rudraprayag	4.9	4
river_RUDRAPRAYAG	4.8	3.7
faults_RUDRAPRAYAG	4.6	8.6
tnust_RUDRAPRAYAG	4.3	7.1
landuse_RUDRAPRAYAG	2.1	1.9
soil_RUDRAPRAYAG	2	2.8
slope_length_RUDRAPRAYAG	1.8	0.7

Figure 4.4: Generated outputs by the Maxent model

4.2.3.5 ALOHA for Industrial Hazard Assessment

ALOHA (Areal Locations of Hazardous Atmospheres) is an open source and freely available desktop application designed to model chemical releases, fires, and explosions for emergency responders and planners.

Whilst useful for planning threat zones and understanding potential threats, ALOHA is specifically designed to produce reasonable results quickly and to be of immediate use to responders during an emergency. Key features of the package include:

- Minimisation of data entry errors by inbuilt crosschecking of the input values and warning the user if the value entered is unlikely or not physically possible.
- In built chemical library with physical properties for approximately 1,000 common hazardous chemicals so that users do not have to enter that data.
- Generates a variety of scenario-specific output, including threat zone pictures, threats at specific locations, and source strength graphs.
- Calculates how quickly chemicals are escaping from tanks, puddles, and gas pipelines—and predicts how those release rates change over time.
- Models many release scenarios: toxic gas clouds, BLEVEs (Boiling Liquid Expanding Vapor Explosions), jet fires, vapor cloud explosions, and pool fires.
- Evaluates different types of hazard (depending on the release scenario): toxicity, flammability, thermal radiation, and overpressure.
- Models the atmospheric dispersion of chemical spills on water.

ALOHA is part of the CAMEO® software suite, which is developed jointly by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA).

Once ALOHA's calculations are complete, users can choose to display a variety of graphical outputs.

A threat zone is an area where a hazard (such as toxicity or thermal radiation) has exceeded a user-specified Level of Concern (LOC). ALOHA will display up to three threat

zones overlaid on a single picture. The red threat zone represents the worst hazard.

The Threat at a Point feature displays specific information about hazards at locations of interest (such as a school).

ALOHA's threat zones can be displayed on maps in MARPLOT®, another program in the CAMEO suite.

ALOHA Factsheet:

https://response.restoration.noaa.gov/sites/default/files/aloha.pdf

Technical Resources:

https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/aloha-technical-resources.html

ALOHA Manual:

https://response.restoration.noaa.gov/sites/default/files/ALOHA_Tech_Doc.pdf

4.3 POST-PROJECT SUPPORT PLAN

Effective planning, response, recovery, and mitigation requires USDMA to have sufficient technical capacity to model, report, and monitor risks and to undertake effective risk based planning. USDMA presently lacks sufficient technical capacity for risk assessment and will require ongoing operational support in order to use the tools effectively and to embed risk based planning in to its operations. Additionally, District Officers and State Level Agencies will require additional training in risk assessment and reporting.

The DRA Terms of Reference require the DRA Consultant to develop a post project support plan for GovUk. Implementation of the support plan is under a separate engagement at the discretion of the GovUk. The GovUk will be responsible for preparation of the final plan and commercial contract relating to the support services.

4.3.1 Objectives of the Support Plan

The DRA-JV has developed and submitted a support plan that allows for local front-line support (Tier 1) and remote technical support (Tier 2). This plan is presented in Appendix H and is summarised here.

The objectives of the support plan is as follows:

1. To ensure that the technical staff of the USDMA and DDMC are able to use and benefit from the tools and techniques implemented under the DRA Uttarakhand.
2. To enhance the benefit of the systems in the districts and communities.
3. To support USDMA in establishing effective business processes for data management and data exchange amongst nodal agencies.

4. To enable the DRA consulting team to collaborate on the effective implementation of the DSS.

4.3.2 Recommended Duration

It is recommended that the support plan be implemented for a minimum of 12 months, with an option to extend support to 24 months if necessary. The scope of the support plan could be adjusted after 12 months to be based on the needs evaluated at that time.

4.3.3 Scope of Support Functions & Resourcing

The functions recommended under the support plan are as follows. We have segregated the functions in to critical and non-critical components. However, it is the recommendation of the DRA-JV that all functions are supported, including the non-critical components, in order to ensure maximum impact and value:

CRITICAL COMPONENTS

- Operational support for all tools in the DRA Toolkit, including CAPRA RC+, MIKE, and R-CRISIS 2017.
- Tech advisory and knowledge transfer on risk based planning and DRR
- Support for data management (collection, preparation, analytics)
- Technical advisory on data transfer to forthcoming Decision Support System (DSS) and compatibilities
- GIS operations (support and advisory)
- Advisory on risk computation and hazard modelling
- Technical and management reporting
- Procurement advisory as USDMA develops its suite of applications and infrastructure

NON-CRITICAL (OPTIONAL) COMPONENTS

- Advice on implementation of hotspot management strategies
- Additional and tailored training for USDMA technical staff & GovUK Administrators by key technical experts
- Support for coordination of Community Based Disaster Risk Management (CBDRM) plans and initiatives
- Support for District Level Capacity Building

The human resources recommended to support the functions (both critical and non-critical) are as follows:

CRITICAL	
• Locally based Tech and Operational Support	1 pax / FT
• Remote (national or international) support from Key Experts	
– Remote GIS & Risk Consultant	5 days per month
– Remote Key Experts in Risk	5 days per month
– Remote Key Experts in Hazard Modelling	5 days per month
OPTIONAL	
• Locally based CBDRM expertise	1 pax / FT
• 4 x 1 week Training Courses per annum (tailored)	
– Training Lead (prep & delivery)	6 weeks
– Training Support (prep and delivery)	6 weeks

4.3.4 Estimate of Annual Cost

The estimated cost and recommended annual budget is as follows:

Recommended Budget (12 mo):	Time:	INR	165 lakh
	Travel:	INR	45 lakh
	Expenses:	INR	16 lakh
	Total:	**INR**	**226 lakh**
Critical Components (only):	**Total:**	**INR**	**90 lakh**

4.3.5 Specifications of an Effective Support Service Provider

We recommend the following contractual requirements when procuring the support phase:

- The Consultant must have experience of implementing similar projects in India and have an established Global and Local network of institutes engaged in Disaster Risk Management.
- Local Tier 1 support presence highly recommended, but not necessary.
- Consultant must have experience of delivering risk assessment project using CAPRA on a scale similar to that completed in Uttarakhand.

- Sufficient ICT competency in the Consultant's organisation to advise on deployment of software.
- Ideally, the Consultant will have familiarity with the development environmental for the UDRDB Web Viewer and URMIS.
- The Consultant will have immediate access to staff highly skilled in probabilistic earthquake and flood risk assessment, assessment of landslide susceptibility, and staff experienced in industrial assessments.
- Consultant's staff to come from a firm, institute, or consortium that has completed similar work to the DRA Uttarakhand.
- Consultant organisation to be highly experienced in geospatial data management.
- Expertise in training and capacity building, with access to staff with experience in Community Based Disaster Risk Management and the application of risk reduction strategies.
- Experience of food modelling in MIKE or ability to model floods in alternative products, but generate adequate CAPRA input files for risk assessment.
- Consultant must have the technical ability to model EQ in R-CRISIS 2017 and to apply the landslide models developed under the DRA.

CHAPTER 5
Hotspot Risk Reduction Strategies

5 HOTSPOT RISK REDUCTION STRATEGIES

Fourteen (14) representative “hotspots” for risk have been identified through the process of risk assessments. There are 5 urban, 5 rural, a 4 tourism locations for which risk reduction strategies have been proposed. This section of the report introduces these hotspots and overarching risk reduction strategies recommended for Uttarakhand.

These have been developed as standalone documents to facilitate the dissemination and sharing of the strategies with the municipal, block, and district level agencies responsible for implementation of the strategies.

The outputs of the risk analysis for each of the blocks concerned is found in the State Atlas of Risk under Volume 3 of the project report.

5.1 OVERVIEW OF THIS COMPONENT OF WORK

A specified outcome sought from the Disaster Risk Assessment (DRA) of Uttarakhand is an assessment of flood and seismic hazards for critical urban and rural area "hot-spots" shown to have high vulnerability for the communities at risk. The specific objective set to address this task is: *To develop risk mitigation, planning and emergency response strategies for 5 urban, 5 rural areas and 4 tourist destinations exposed to earthquakes and floods*.

In considering these assessments, it is important to recognize that they not only address identified “hotspots”, but also are intended as case study templates for application to other similar locations across Uttarakhand. All areas within the State have some level of vulnerability in terms of potential loss of human life and property damage. The difference between sites is one of degree of impact, which is a result of the external factors gauging the strength or severity of a triggering event, the physiographic context and the nature of the planned and implemented hazard mitigations across the spectrum of planning and preparation, response and recovery capability within an area. The development of these Strategic Mitigation Strategies is seen as imperative for each area in the State.

Uttarakhand State is one of the most multi-hazard prone States of India. The State faces various types of natural hazards like the geological hazards of earthquake and landslide; the hydrological hazards of riverine, flash floods and glacial lake outburst floods; the meteorological hazards of hailstorms and cloudbursts; and the climatological hazards of droughts, forest fire, cold wave and avalanche. The frequency and intensity of most of the hydro-meteorological hazards are compounded by the climate change and its impacts on agriculture, horticulture, human settlements and human and animal health.

All these hazards have the potential to create risks of disasters when exposed to vulnerable physical, economic, social and environmental conditions. The physical vulnerabilities of Uttarakhand State include the unsafe stocks of private and public buildings and infrastructure that may not withstand the shocks of powerful earthquakes. The economic vulnerabilities are mainly the productive assets like industries, hydel power stations, reservoirs, tourism facilities, and transport infrastructure across the State. Any disruption of these facilities due to disasters may badly affect the economy of the State as well as the ability to respond and recover. The socially vulnerable groups in the State, like most of the States, are the rural and urban poor, the vulnerable women, children, disabled, aged etc. who suffer unequal burden of disasters. The delicate ecology and environment of the State further make it highly susceptible to the hazards of landslides, forest fires and flash floods.

In undertaking this task on "hot spots" consideration has been given to the impacts of events on residential and government buildings, transport infrastructure, livelihood, and/or critical infrastructure/ facilities. Based on the detailed impact assessments, we have developed risk planning, mitigation, and emergency response and recovery strategies for the identified hot- spots (such as land use planning, shelter siting, evacuation routing, seismic retrofitting, flood protection, protecting livelihoods, etc.).

5.2 WHY DEVELOP STRATEGIES?

Risk management is the process through which risk is evaluated before strategies are introduced to manage and mitigate the threat. In an ideal world, the risk management procedure follows a clear set of priorities in which the highest levels of risk are addressed first. However, in order to develop such a priority list, a detailed quantitative risk assessment of all relevant factors and processes is required.

This is a difficult task, not least because of the need to balance the relative significance of losses from high and low frequency events. Risk management itself is often considered to be focused upon the prevention, mitigation and preparedness elements of this cycle, although the other elements are also important. Prevention, which forms part of this cycle, is only to a limited extent achievable.

There is a paradigm shift underway in disaster management (and the allocation of associated government/donor funding), both in India and worldwide, moving from a primary focus on recovery and reconstruction to an emphasis on disaster risk reduction (DRR). This requires a detailed and holistic assessment of the risks present in a given geographical and socio-economic context, which may then be used to inform a process of risk management, reducing the impact of potential disasters in the future.

The present project focuses on the aspect of pre-disaster protection in the risk reduction cycle. However, this does not mean the other aspects of the cycle are neglected. Therefore, the basis of a risk management system will be developed that, in a later stage, may be expanded to act a basis for post-disaster recovery as well. For example, information generated for pre-disaster protection can be used (perhaps after adaptation) for pinpointing areas that most urgently require post-disaster recovery and for selection of effective and efficient post-recovery measures. Besides, due to the modular approach of the system, decision-making and action protocols for pre-disaster protection can be supplemented with protocols for post-disaster recovery.

The primary elements of pre-disaster protection are:

- Risk assessment: Involves the identification of a hazard, the accumulation of data and the preparation of loss estimates;
- Mitigation: Measures are taken in advance of disaster strikes, aimed at decreasing or eliminating the loss. Various long term measures, such as the construction of engineering works, insurance and land use planning are used;
- Preparedness & Resilience: Reflects the extent to which a community is alert to disaster and covers short-term emergency planning, hazard warning and temporary evaluation procedures plus the stockpiling of supplies.

Holistic management of risk identifies actions to be taken to reduce the impact of extreme events before, during and after extreme events and include preventive technical/structural measures as well as socioeconomic aspects to reduce vulnerability to hazards. It is important to note that disaster risk management and management of climate change impacts share the same objectives, presenting a major challenge and opportunity to bridge current disaster risk management efforts with climate change adaptation measures.

As the costs of damage from natural disasters continue to increase, the importance of identifying effective ways to reduce vulnerability to disasters becomes paramount. Government leadership at all levels form a cornerstone to disaster risk management, but frequently there is the expectation that this is where the full responsibility lies. While it is undeniable that Government has a role, we propose that a Public-Private-Community partnership approach more realistically leads to greater effectiveness in preparation and response, with a greater overall reduction in loss of live, property, and livelihood when a disaster does occur. All hazard mitigation strategies therefore need to be formulated on the premise that communities, the private and the public sector need to collaborate to reduce the risk from natural hazards.

The individual case studies/hotpot plans are built around the four key elements of the disaster risk management framework embodied in the Sendia framework:

1. Mitigation
2. Planning and preparation
3. Response, and
4. Recovery – short term and long term

These four elements need to be thought of as sequential, but also reiterative and thereby adaptive. That is, the sequence follows a well-defined and tested path, but there is the need for continues improvement in response to greatly improved data sets over time, as well as a learning curve reflecting successes and failure – what has worked, what has not, and how do we do better into the future?

The central theme of build back better encompasses this adaptive approach and applies not just to more resilient buildings, but also a more resilient Government, private sector and community adaptation. An added benefit of this learning, and recognizing the opportunity for improvements over time, is an increased ability to define and prioritize the actions that need to be taken from a strategic point of view.

It is important to acknowledge that Uttarakhand State has a state level DRM Plan as do the individual Districts within the state. These strategies do not seek to replicate these important documents, but rather to complement them. The strategies offered here are intended to address the above approach and are, therefore, not about specified actions, but rather ways to improve on existing strategies as well as proposing new ones.

Additionally, the strategies are deliberately succinct, and we ensure that they are implementable and with measurable benefits to the specific 'hotspot' and to the state as a whole.

5.3 DEFINING STRATEGIES VS PLANS[18]

A strategic plan is a plan of action designed to achieve a long-term objective or overall aim.

A Strategy is a planning tool developed with a long- term perspective. It provides a common vision and includes certain guiding principles and priorities. It needs to incorporate certain flexibility and periodic evaluation mechanisms to adjust course, evolve and adapt to changing circumstances, while continuing to provide guidance.

A Plan on the other hand provides the operational orientation for implementing the strategy. It defines specific goals to reduce risk together with priority actions and activities to achieve these

[18] Abstracted in the main from: Implementation guide for local disaster risk reduction and resilience strategies, UNDSIR 2018

goals. It goes into needed detail as it assigns roles and responsibilities, mobilizes resources and allocates budget. It also sets timelines, indicators, and mechanisms for monitoring progress.

An Action is a key step to be taken in concert with other actions also needed for the Plan to succeed.

It is not possible for this project to be prescriptive with respect to individual actions that need to be taken within each Division or Subdivision, Block or community. The development of these actions needs to be done in the context of the State and Divisional level plans and the key stakeholders and the development of these could be used as a key part of the resilience building process. Given the primary focus is on Mitigation and planning it makes more sense to focus initially on strategic needs as a basis for the required detailed planning and formulation of actions.

At the same time the 14 case studies are intended as models for other districts, sub districts block and communities to adopt in developing their own strategies and actions. Many of these strategies will be broadly applicable and can be directly adopted. By formulating the strategies first it becomes a much easier task to go forwards and then develop specific actions to address these strategies.

5.4 ACTS, REGULATIONS & GUIDELINES WRT DISASTER RISK MANAGEMENT

The following acts and guidelines set the context for the hotspot risk mitigation strategies and are pertinent in shaping the mandated response, recovery, mitigation, and planning activities for the state level government and its regional subsidiaries.

National level Acts & Plans

- National DM Act 2005
- National DM Policy 2009
- Compendium of laws on DM 2015
- National DM Plan 2016

National Guidelines by NDMA

- Guidelines on School Safety Policy 2016
- Guidelines on Hospital safety 2016
- Guidelines on Minimum Standards of Relief
- Guidelines on management of Earthquake 2007
- Guidelines on Management of Floods 2008
- Guidelines on Management of Urban Flooding 2010

- Guidelines on Management of Landslides & Snow Avalanches 2009
- Guidelines on Medical Preparedness & Mass Casualty Management
- Guidelines on incident Response System 2010
- Guidelines on seismic Retrofitting of Deficient Buildings & Structures 2014

National Guidelines under GoI UNDP DRM Program

- Model Guidelines for Development and Building Construction including Safety provisions for natural Hazards in Rural Areas – 2008
- Proposed Amendments in Town & Country Planning Legislations, including:
  - Regulations for Land Use Zoning
  - Additional Provisions in Development Control Regulations for Safety & Additional Provisions in Building Regulations/ Byelaws for Structural safety in Natural Hazards Zones of India – Vol-1(A)- for Municipal Councils - 2007

Uttarakhand State Acts/ Guidelines/ Regulations

- The Uttarakhand Building Byelaws & regulations – 2011 (Amendment 2016)
- The Uttarakhand Urban & Country Planning & Development Act 1973
- The Uttarakhand Flood Plain Zoning Act 2013

5.4.1 The Sendai Framework

The Sendai Framework for Disaster Risk Reduction 2015-2030 was adopted at the Third UN World Conference in Sendai, Japan, on March 18, 2015. It is the outcome of stakeholder consultations initiated in March 2012 and inter-governmental negotiations from July 2014 to March 2015, supported by the United Nations Office for Disaster Risk Reduction at the request of the UN General Assembly.

The Sendai Framework is the successor instrument to the Hyogo Framework for Action (HFA) 2005-2015: Building the Resilience of Nations and Communities to Disasters. The Sendai Framework introduced a number of innovations and a significant shift towards a strong emphasis on disaster risk management as opposed to disaster management, the definition of seven global targets, the reduction of disaster risk as an expected outcome, a goal focused on preventing new risk, reducing existing risk and strengthening resilience, as well as a set of guiding principles.

The Sendai Framework also articulates the following: the need for improved understanding of disaster risk in all its dimensions of exposure, vulnerability and hazard characteristics; the strengthening of disaster risk governance, including national platforms; accountability for disaster risk management; preparedness to “Build Back Better”; recognition of stakeholders and their roles;

mobilization of risk-sensitive investment to avoid the creation of new risk; and the resilience of health infrastructure, cultural heritage and work-places.

5.4.1.1 Sendai Framework Priorities

The framework has four priority areas:

Priority 1. Understanding disaster risk: To be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. Such knowledge can be used for risk assessment, prevention, mitigation, preparedness and response.

Priority 2. Strengthening disaster risk governance to manage disaster risk: Disaster risk governance at the national, regional and global levels is very important for prevention, mitigation, preparedness, response, recovery, and rehabilitation. It fosters collaboration and partnership.

Priority 3. Investing in disaster risk reduction for resilience: Public and private investment in disaster risk prevention and reduction through structural and non-structural measures are essential to enhance the economic, social, health and cultural resilience of persons, communities, countries and their assets, as well as the environment.

Priority 4. Enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction: The growth of disaster risk means there is a need to strengthen disaster preparedness for response, take action in anticipation of events, and ensure capacities are in place for effective response and recovery at all levels. The recovery, rehabilitation and reconstruction phase is a critical opportunity to build back better, including through integrating disaster risk reduction into development measures.

The strategies proposed here at the state and Divisional/local level take each of these priorities into account and have been developed around the four goals described below.

5.4.1.2 Sendai Framework Goals

Goal # 1: Increase Public Awareness on Local Hazard

Description: Increase public awareness and understanding, support, and demand for hazard mitigation.

Objectives:

- Heighten public awareness of the full range of natural hazards they may face.
- Educate the public on actions they can take to prevent or reduce the loss of life and/or property from all hazards.

- Publicize and encourage the adoption of appropriate hazard mitigation measures.

Goal # 2: Protection of Lives and Property

Description: Implement activities that assist in protecting lives by making homes, businesses, infrastructure, critical facilities, and other property more resistant to natural hazards.

Objectives:

- Advise public about health and safety precautions to protect from injury and loss.
- Warning and communication technologies to mitigate damage from natural hazards.
- Reduce damage to enhance protection of dangerous areas during hazardous events.
- Protect critical facilities and services.
- Ensure Emergency Services and critical facilities are included in mitigation strategies.

Goal # 3: Promote Resilient Communities

Description: Promote development in a sustainable manner/ dovetail DRR component in development planning.

Objectives:

- Incorporate hazard mitigation into long-range planning and development activities.
- Utilize regulatory approaches to prevent creation of future hazards to life and property

Goal #4: Promote Resilient Communities

Description: Promote development in a sustainable manner/ dovetail DRR component in development planning.

Objectives:

- Incorporate hazard mitigation into long-range planning and development activities.
- Utilize regulatory approaches to prevent creation of future hazards to life and property.

5.4.2 The National DRM Framework

India saw a shift from a predominantly relief-centric approach to a more holistic proactive approach with the responsibility being placed in the Ministry of Home Affairs in 2003, the passing of the Disaster Management Bill in 2005 and the adoption of the National Policy on Disaster Management in 2009. The subsequent development of Disaster Management Plans at a National, State and District level then followed.

The adoption of three landmark International Agreements in 2015 has had significant bearing on disaster management, i.e.

- Sendai Framework for Disaster Risk Reduction in March 2015;
- Sustainable Development Goals 2015-30 in September 2015; and
- Paris Agreement on Climate Change at the 2151 Conference of Parties under the United National Framework Convention on Climate Change in December 2015.

INDIA'S DRM PRINCIPALS

1 All development Sector must imbibe the principles of DRM
2 Work towards Risk Coverage from Household to SMEs to MNC to Nation States
3 Encourage greater involvement & participation of Women in DRM
4 Invest in Risk Mapping globally
5 Leverage technology to enhance the efficiency of DRM efforts
6 Develop a network of Universities to work on disaster issues
7 Utilize opportunities provided by Social media & mobile technology
8 Build on local capacity & initiatives
9 Ensure that the opportunity to learn from disaster not wasted
10 Greater cohesion in international disaster response

What has emerged out of these agreements is the need for:

> *… a sharper focus on preventing the creation of new risks, and places enormous emphasis on improving the governance for disaster risk reduction.*

Recognition of these important changes has seen the development of the National Disaster Management Plan (DRMP), 2016, by the National Disaster Management Authority (NDMA).

The Uttarakhand State Disaster Risk Management Plan (DRMP) now must be revised to reflect these changes also as does the District and Sub District Plans. These issues are addressed below as proposed key strategies along with a State Policy on Disaster Risk Management (DRM).

5.5 STRATEGIC PLANNING CONTEXT

In formulating these specific Plans consideration has been given to building on the Sengai Framework, the existing Actions Plans formulated at National level and by the Uttarakhand State and Districts, plus at a block or smaller level. As a result, key goals, strategies and actions are all formulated around best practice methods and build on the good work already in place within the State. Where they are seen to exist, gaps have been identified.

It is also clear that the individual sites cannot be considered in isolation from the rest of the State. The physiography of Uttarakhand means that communications and transport routes are very much defined by the topography. At the same time there are few all weather airfields and only one capable of servicing aircraft from outside of the region or internationally, (The Jolly Grant) as will be needed in times of Crisis. Other critical factors are road (and in some cases rail) access routes and communications facilities.

The second consideration is that a number of the strategies we have identified are common across all case study areas and reflect a Statewide need. As a consequence, there emerges a need to consider the role of the State in addressing these common strategic suggestions. While it is not part of the terms of reference for this study to address statewide policy and the associated strategies, we have included here reference to these requirements in synoptic form.

Hazards can be "holistic" to a great degree in terms of the types of dangers they represent and, as a consequence, the mitigations required can in many respects be similarly holistic. The strategies we are proposing are very much related to the need for solutions addressing mitigation of risk through forward planning and actions to build out or diminish the risks as well as accommodating more effective and efficient response and post event recovery. That is, to build resilient communities and infrastructure.

5.6 STRATEGY DEVELOPMENT APPROACH

The individual Strategic Plans are built upon the hazard risk analysis undertaken by the project and formulated around key elements of the DRM framework embodied in the Sendia framework.

The DRM process is sequential (cyclic) in order to allow adaptive improvement over time in order to *build back better*. It is also intended to incorporate a focus on pre-impact preparation through planning in order to <u>mitigate risk associated with incidents before they occur</u>. This approach has been adopted at the National level and is encompassed in ten national DRM principals.

While Response and Recovery are recognised as being reasonably short time-frame processes (hours and days to months), Mitigation and Preparation are seen as much more strategic processes over longer time frames (months to years). The National DRMP recognises three recovery periods after a disaster: a) Early – three to eighteen months, b) Medium – within five years and c) Long-term – within five to ten years. The concept of "build back better" points to continuous improvement in the mitigation and preparation process and its implementation, over all time frames as funds ands and resources come to hand, risk profiles change, and skills and mitigation outcomes are increased or realised. Continuous improvement represents a learning curve reflecting successes and failure – what has worked, what has not worked and how do we do better into the future?

Figure 5.1: Disaster Risk Management Cycle

By developing strategies around the separate phases of DRM and recognizing the opportunity for improvements over time it is possible to prioritize the actions that need to be taken. For each strategy presented here there is an initial list of key Actions include as the start of the process.

The strategies offered here are intended to aid the State, District and Sub District manager's as well as Municipalities, citizens, local authorities, businesses, private residents, and local NGOs, with the intent of driving a *ground up* approach within a State level *top down* policy context. The challenge is for all organizations and individuals to take upon themselves the responsibility of being prepared and being better able to offset the risks and manage the consequences of these disasters.

Information driving the Strategies includes a review of the existing District Disaster Management Plans to obtain a good overview of the state of practice for disaster management in the relevant district and a process of stakeholder consultation. This consultation has been important in obtaining an understanding of the current response resources available i.e. debris removal equipment, hospital beds, stock of medical, relief and food supplies, ambulances etc. to understand the State's capacity to respond to an emergency. Ideally be done across the entire spectrum of the relevant stakeholders i.e. government agencies, hotels, communities, private foundations, public and private hospitals etc. In order to begin preparing emergency response strategies and risk mitigation plans for the 14 hotspots we have used standard event scenarios and assessed plausible risks and damages in these hotspot areas.

Plausible impact scenarios for each hotspot have been developed in consultation with the wider stakeholder community likely to be impacted or a contributor to phases of the DRA process for the specific area. These scenarios provide descriptive accounts of what could possibly go wrong in the event of a disaster using the outputs generated by CAPRA and from the experience of the wider stakeholder community as obtained through focus group discussions and/or tabletop exercises. Using these two methods will ensure that the impact scenarios are realistic and inclusive.

What we hope has emerged from these discussions are best estimates of the plausible extent of damage for each of the hot spots considered. We will take these estimates and develop an emergent response strategy on how to address them best. Once we have an emergent strategy, we will circle back to all the relevant stakeholders and hold meetings / round table discussions with them to get feedback on the emergent strategy. We will revise the emergent strategy in accordance with the feedback and finalise the same in consultation with the PIU.

Data collected from the field, district line departments, State level departments, PIU (TA-CBDRM), DMMC, and research institutions in the State has also been used to develop the strategies. The DHI Joint Venture Team conducted the data collection and did the research and analysis facilitated district consultation workshops and public workshops and developed the final mitigation strategies.

5.7 IMPORTANCE OF EFFECTIVE MONITORING & EVALUATION

Within an adaptively managed cyclic process effective monitoring, evaluation and response, leading to changes in performance is a fundamental requirement as part of the process. Regularly presented figuratively as a cyclic process the DRM process, when managed to incorporate changes from feedback through effective monitoring and evaluation, then becomes cyclonic in nature.

Results based management (RBM) for the delivery of programmes is now a standard approach to delivery of UNDP projects

What then makes an effective monitoring and evaluation process? Determining adequate indicators of progress and success needs to be done using within realistic time periods and quantitative rather than qualitative measures. The needs to be an integral part of the formulation process and to do this we have adopted the approach taken in the application of logical frameworks (LogFrames) as used in many funding proposals and their management.

Effectiveness as a measurable impact from a strategy or action helps both identify and modify operations and processes to improve performance, but to also demonstrate this effectiveness to key stakeholders, thereby providing a measure of “success” and hopefully a commitment to continue funding. The most important of these stakeholders are the actual participants and frequently incentives are need to maintain their investment in the required activities. At the same time efficiency and effectiveness can also be appraised and changes made to increase both through the acquisition of additional resources or their reallocation.

The role of reporting back on a regular basis to key stakeholders can also have the very beneficial outcome of generating pressure for change if funding and political capital are both in limited supply. Annual Report Cards that provide a synopsis of progress in readily understood terms have been used to great effect in this way elsewhere.

5.8 HOTSPOT SELECTION

Monitoring and Evaluation

At the programme level, the purpose of monitoring and evaluation is to track implementation and outputs systematically, and measure the effectiveness of programmes. It helps determine exactly when a programme is on track and when changes may be needed. Monitoring and evaluation forms the basis for modification of interventions and assessing the quality of activities being conducted.

Monitoring and evaluation can be used to demonstrate that programme efforts have had a measurable impact on expected outcomes and have been implemented effectively. It is essential in helping managers, planners, implementers, policy makers and donors acquire the information and understanding they need to make informed decisions about programme operations.

Monitoring and evaluation helps with identifying the most valuable and efficient use of resources. It is critical for developing objective conclusions regarding the extent to which programmes can be judged a "success". Monitoring and evaluation together provide the necessary data to guide strategic planning, to design and implement programmes and projects, and to allocate, and re-allocate resources in better ways.

See: http://www.endvawnow.org/en/articles/331-why-is-monitoring-and-evaluation-important.html?next=332 as adapted from Gage and Dunn 2009, Frankel and Gage 2007

Frankel, Nina and Anastasia Gage. 2007. "M&E Fundamentals: A Self Guided Minicourse." U.S. Agency for International Development, MEASURE Evaluation, Interagency Gender Working Group,

5.8.1 Selection Process

The DRA project was required to complete an analysis and define mitigation at 5 Urban, 5 Rural and 4 Tourist Destination Risk Hot Spot Areas. The two Task Objectives are:

- To develop risk mitigation, planning and emergency response strategies for the 14 identified "hot-spot" areas
- To develop risk analysis relating to the tourism and agriculture sectors in Uttarakhand

To select hotspots we followed a process that:

1. examined historical and projected occurrence of hazards - all hotspots have previous records of disasters - minor, major or both human loss & infrastructure loss have been recorded;
2. selected areas that are growing or projected to grow reasonably rapidly. Increasing exposure is a key driver for the present and emerging risk profile in Uttarakhand;
3. computed and selected locations of high exposure and vulnerability to either earthquakes, floods, or both now and in future;
4. ensured that the selected locations are representative areas that serve as good case studies for applying strategies that can be transferred to other locations easily to scale up the process later;
5. attempted to ensure that the plains and hill areas are adequately represented because strategies differ and we wished to ensure good coverage; and
6. selected sites that have strategic significance within the classification of urban, rural, or tourism; for instance as gateways for tourism or clearly as areas of rapid urbanisation and agglomeration. Note that the selection process and selection was validated with stakeholders.

Given the current exposure or criticality of the locations selected, effective implementation of the strategies in these locations will measurably reduce the overall risk profile of the state and act as effective models for future strategic risk reduction elsewhere.

5.8.2 Chosen Hotposts

The selected case studies are shown in the following table (Table 5.1) along with their overall risk classifications for earthquake, flood, flash flood, and secondary landslide hazards (i.e. landslides potentially triggered by the hazard event). Figure 5.2 shows the location of the selected hotspots.

Table 5.1: Selected Hotspots for Strategic Planning for Risk Reduction

Category	Ref.	Location	Scope of Strategic Plan
Urban	U1	Haridwar City	Citywide and surrounds.
	U2	Dehradun City	Citywide and surrounds.
	U3	Rishikesh City	Citywide and surrounds.
	U4	Rudrapur and Haldwani	Conurbation connection the two settlements and surrounds.
	U5	Srinagar City to Karnaprayag	The entire corridor comprising and extending from Srinagar City to Karnaprayag.
Rural	R1	Bhatwari Block	Entire block and all settlements within.
	R2	Munsiari Block	Entire block and all settlements within.
	R3	Laksar Block	Entire block and all settlements within.
	R4	Narayanbagar Block	Entire block and all settlements within.
	R5	Ukhimath Block	Entire block and all settlements within.

Category	Ref.	Location	Scope of Strategic Plan
Tourism	T1	Joshimath City and Badrinath	Corridor encompassing the city of Joshimath and Badrinath, including the route to Badrinath.
	T2	Kedarnath	Area of tourist aggregations at entry to trek and along route corridor to the settlement of Kedarnath.
	T3	Mussoorie City	Citywide and immediate surrounds.
	T4	Nainital City	Citywide and immediate surrounds.

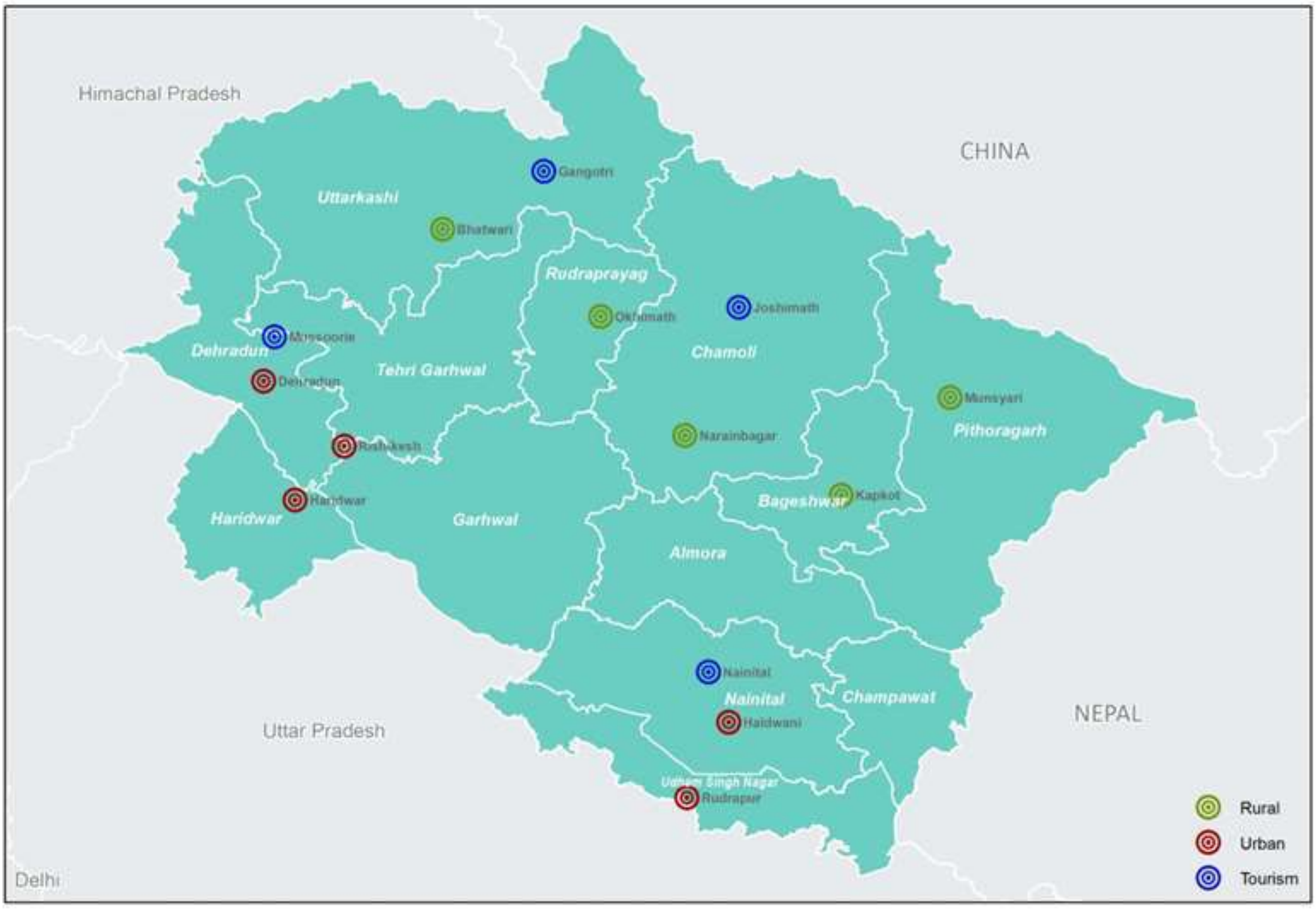


Figure 5.2: Location of the Selected Hotspots for Strategic Risk Reduction

The following tables summarize the risk profiles of the urban, rural, and tourism hotspots for strategic risk reduction. The reader is referred to the individual hotspot strategic plan documents for more information.

Table 5.2: Risk Summary of Urban Hotspots

Urban Hotspot	Risk & Hazard Profile			
U1. Haridwar City	EARTHQUAKE HIGH RISK	LANDSLIDES VERY LOW RISK	FLASH FLOODS NO RISK	FLOODS MODERATE RISK
U2. Dehradun City	EARTHQUAKE HIGH RISK	LANDSLIDES VERY LOW RISK	FLASH FLOODS LOW RISK	FLOODS LOW RISK
U3. Rishikesh City	EARTHQUAKE HIGH RISK	LANDSLIDES MODERATE RISK	FLASH FLOODS MODERATE RISK	FLOODS HIGH RISK
U4. Rudrapur and Haldwani	EARTHQUAKE HIGH RISK	LANDSLIDES NO RISK	FLASH FLOODS LOW RISK	FLOODS NO RISK
U5. Srinagar City to Karnaprayag	EARTHQUAKE HIGH RISK	LANDSLIDES VERY LOW RISK	FLASH FLOODS NO RISK	FLOODS MODERATE RISK

Table 5.3: Risk Summary of Rural Hotspots

Rural Hotspot	Risk & Hazard Profile			
R1. Bhatwari Block	EARTHQUAKE HIGH RISK	LANDSLIDES HIGH RISK	FLASH FLOODS HIGH RISK	FLOODS LOW RISK
R2. Munsiari Block	EARTHQUAKE HIGH RISK	LANDSLIDES HIGH RISK	FLASH FLOODS MODERATE RISK	FLOODS LOW RISK
R3. Laksar Block	EARTHQUAKE HIGH RISK	LANDSLIDES LOW RISK	FLASH FLOODS LOW RISK	FLOODS HIGH RISK
R4. Narayanbagar Block	EARTHQUAKE HIGH RISK	LANDSLIDES HIGH RISK	FLASH FLOODS HIGH RISK	FLOODS LOW RISK
R5. Ukhimath Block	EARTHQUAKE HIGH RISK	LANDSLIDES HIGH RISK	FLASH FLOODS HIGH RISK	FLOODS LOW RISK

Table 5.4: Risk Summary of Tourism Hotspots

Tourism Hotspot	**Risk & Hazard Profile**			
T1. Joshimath City and Badrinath	EARTHQUAKE EXTREME RISK	LANDSLIDES MODERATE RISK	FLASH FLOODS HIGH RISK	FLOODS NO RISK
T2. Kedarnath	EARTHQUAKE HIGH RISK	LANDSLIDES HIGH RISK	FLASH FLOODS MODERATE RISK	FLOODS NO RISK
T3. Mussoorie City	EARTHQUAKE HIGH RISK	LANDSLIDES HIGH RISK	FLASH FLOODS NO RISK	FLOODS NO RISK
T4. Nainital City	EARTHQUAKE HIGH RISK	LANDSLIDES HIGH RISK	FLASH FLOODS NO RISK	FLOODS NO RISK

CHAPTER 6
Training and Capacity Building

6 TRAINING AND CAPACITY BUILDING

This section of the reports highlights the training, capacity buildings, and stakeholder engagement activities completed under Component 6 of the study. The capacity-building programme was comprised of technical workshops, hands-on training, and orientation workshops in the Districts in order to engage officers in the process of data validation and risk management.

6.1 INTRODUCTION

A key component of the study has been effective engagement and capacity building with the Government of Uttarakhand on the development of the hazard, impact and risk information and the communication of the risk results.

The DRA JV initiated capacity building activities early in the project in order to maximize the opportunity of local stakeholders to familiarize themselves with the systems and to learn the concepts and techniques for risk assessment and risk based planning.

6.2 CAPACITY BUILDING ACTIVITIES COMPLETED

To achieve these objectives, the DRA-JV executed an engagement, training, and capacity building programme that extended beyond that required under the terms of reference.

The purpose of the training and capacity building plan was as follows:

a) To assist the DMMC and appointed participants to understand the risk assessment framework and tools so that they may maintain and take forward the outcomes after the conclusion of the project.
b) To convey the framework of disaster risk assessment and bring uniform understanding about hazard, exposure, vulnerability and risk assessment.

c) To enable the DMMC, state, regional and district disaster management and line departments to grasp the structure, function and application of the tools including their role in the contribution and exchange of data.

The amount of training and engagement exceeds the expectations of the Terms of Reference. Training plans adopted a systematic process of (a) subject introduction (b) exploratory and (c) intensive learning for all the training sessions covering the following topics:

- Disaster Risk Assessment Framework
- DRDB Data Base - architecture, structure, design, data uploading, updating and its application
- Web Viewer - Upload, download data and using data for modeling and GIS mapping purposes
- Customization of GIS Application for DRDB
- Modeling - flood, flashfloods, (Mike 11) landslides, earthquakes, industrial disasters - ALOHA
- Probabilistic and Deterministic Risk Assessment using model and mapping results.
- Modules for district and division level workshops
- Module for overseas exposure and training visit
- As part of the training, capacity building and government engagement, a series of state-level trainings regional and district level workshops organized during the project period from 7th July 2016 to 13 Sept 2018.

The training materials for these modules are placed in Appendix A. The inventory of training completed is provided in the table below.

Table 6.1: Inventory of Training and Capacity Building and Government Engagement events

No of Training / Workshop Days	Topic	No. of Participants
1d - 7 Jul 2016	Disaster Risk Assessment of Uttarakhand – Kick Off Orientation	115
	Class Room Training to DMMC and select District Disaster Management Staff:	
1d - 5th Oct 2017	Data Base Structure & Risk Assessment	12
1d - 6th Oct 2017	Risk Assessment (Hands On)	12
1d - 5th Jan 2018	DRDB Web Viewer and GIS (Hands On)	14
1d - 23rd Apr 2018	EQ Hazard Modelling	23
1d - 24th Apr 2018	Flood Hazard Modelling	19
1d - 25th Apr 2018	FF and LS Hazard Modelling	19
1d - 26th Apr 2018	CAPRA and DRDB Web viewer	18
1d - 27 Apr 2018	Probabilistic and Deterministic Risk Assessments	23

No of Training / Workshop Days	Topic	No. of Participants
  26th Nov 2016 28th Nov 2016 29th Nov 2016 1st Dec 2016 5th Jan 2017 6th Jan 2017 11th Jan 2017 2nd Mar 2017 3rd Mar 2017 9th Mar 2017 26th Mar 2017 29th Mar 2017	District Level Workshops on Disaster Risk Assessment & Data Validation Uttarkashi Nainital Bageshwar Chamoli Tehri Dehradun Almora Rudraprayag Pauri Haridwar Pithoragarh Udham Singh Nagar	DDMO, Line Dept and DM Office Staff 23 24 27 25 25 31 27 44 15 43 34 96
4th–10th April 2017	Technical Collaboration with IIT Roorkee on methods for hazard assessment and scaling of exposure.	20
  7th Mar 2018 9th Mar 2018	Division Level Workshops on Hotspots, Mitigation, and Risk Assessment 1. Nainital - Kumaun Division 2. Srinagar - Garhwal Division	 74 72
2nd May 2018	Technical Seminar on A New Perspective on Natural Hazards, Risk, and Insurance: A Knowledge Exchange with IIT Roorkee	80 (estimated) comprised of professors, guests, and students.
12th Sept 2018 13th Sept 2018	State Level Symposium to disseminate the findings of the Risk Assessment and hand over the DRDB to the State. Nodal Officers Workshop with DDMOs to orient Nodal Officers in DRDB, Risk Assessment and Application of models and GIS mapping	175 (Estimated) 25

Two (2) Senior Govt. Officials were also engaged in the World Bank and Global Forum of Disaster Risk Reduction (GFDRR) Understanding Risk Forum in Mexico in May 2018.

In addition to the aforementioned activities, we visited many state and district-level line departments in order to brief them on the initiative, create awareness, and to understand their data and capacity for effective DRM. Proactive engagement has been a strategic cornerstone of the project and its success.

6.3 APPROACH TO TRAINING AND CAPACITY BUILDING

6.3.1 Target Groups for Training and Engagement

The following are the target groups for the training, capacity building, and Government engagement.

Training and Capacity Building of DMMC and DDMOs: DMMC is entrusted to take forward the DRDB and the outputs / outcomes of the Disaster Risk Assessment Study in the Uttarakhand State after the conclusion of the project. It was, therefore, necessary that the training focused on the DMMC team to train them in the DRDB, hazard and risk modeling, and the use of GIS applications in Disaster Risk Assessment. This target group also comprised representatives of the District Disaster Management (DDM) Teams led by the DDMOs, because they play a key role in bridging the gap between the district and the state in assuring the correct information flow and participation of the key line departments; particularly for DRDB data inputs, updation, and its general application. Formal classroom methods were applied for all training sessions targeting the DMMC and the DDM teams.

Government Engagement: This target group was comprised of officials from the Disaster Management and all line departments at District, Region and State levels. The workshop method was applied to orientate and engage this target group. The Team Leader and team members have organized workshops at the district or regional headquarters in the state. Some workshops were organized in Dehradun, the State Capital. The activities for this group included:

- State Level Workshop for orientation in the Disaster Risk Assessment Studies in July 2016
- Symposium on Disaster Risk Assessment Studies where all line department officials were invited by the Secretary Disaster Management Department State Govt. of Uttarakhand.
- District Level Workshops held in 12 districts in the state under the guidance of the District Magistrate of each district, facilitated by the District Disaster Management Officers

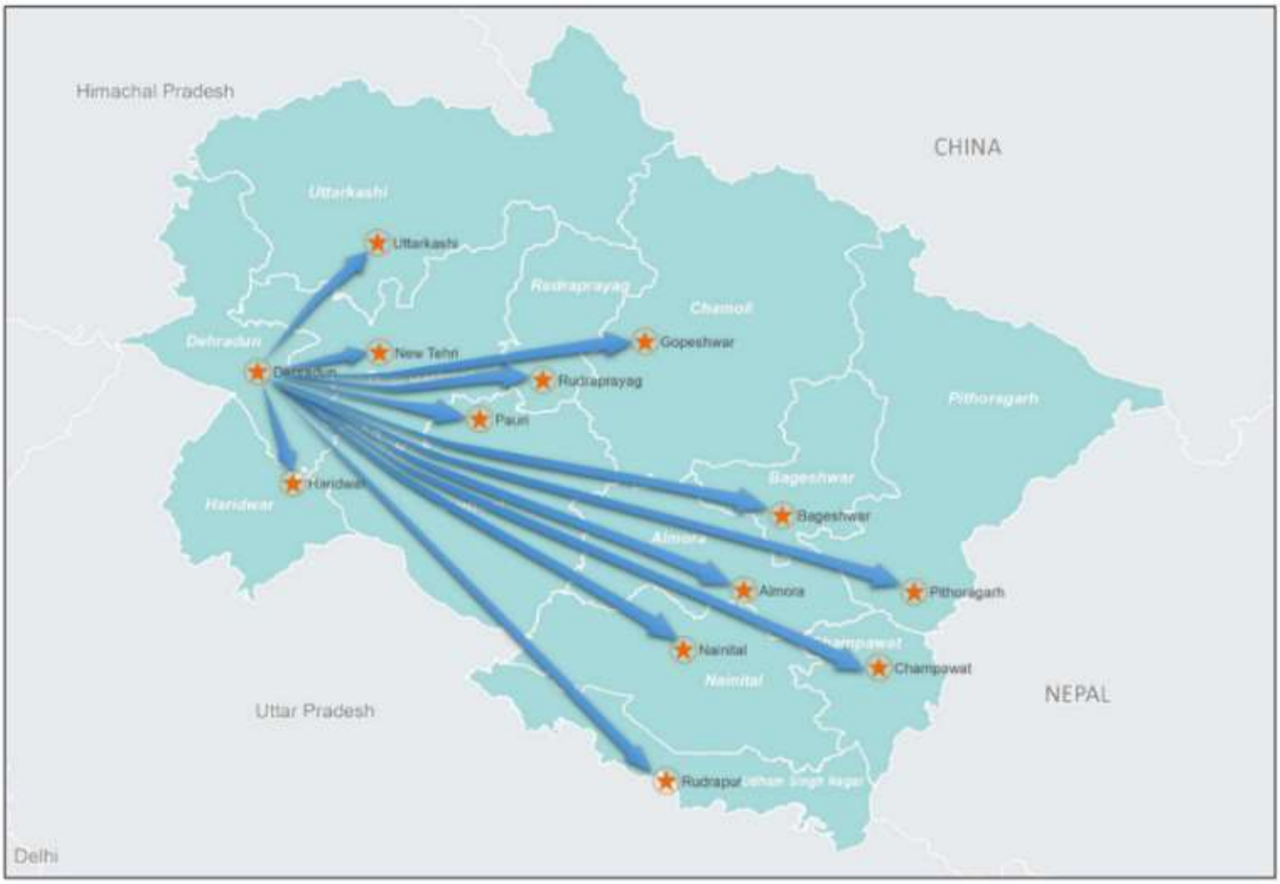


Figure 6.1: Locations of District and Divisional Level Workshops held under the DRA

- Division Level Workshops held at Nainital for the Kumaun Division and at Srinagar for Garhwal Division
- Overseas Exposure and Training: Participation of representatives of UDRP at the Understanding Risk Forum (Mexico 2018).
- Orientation and Training Workshop for the Nodal Officers belonging to key line departments in the state for familiarity with the DRDB. The training included know how of the web viewer application and database updating. The workshop in collaboration with the DMMC and District Disaster Management Office was intended to assure future real time data updating which is essential for disaster management planning, preparedness, response and monitoring.

In addition, local support staff and teams of the local collaborators such as TESRA Engineers, Shanti Kunj NGO were also trained in disaster risk assessment studies, enumeration skills in collection of data, use of a Smart Phone App for data collection and documentation. The DRA Team of Experts have also written research papers for dissemination of the methods, contents and useful findings of the studies under guidance and in consultation with the PIU. These are authored in collaboration with appropriate GovUk representatives.

In addition to these groups, the DRA Team also engaged and collaborated with staff from several institutions such as IIT Roorkee, Wadia Institute of Himalayan Geology, National Institute of Hydrology, Indian Institute of Remote Sensing, and the Uttarakhand Space Applications Centre (USAC).

6.3.2 Pedagogy

Care has been taken while designing the training packages keeping in mind the age group of the learners. It is a challenge to transfer knowledge to adult learners. Every possible attempt has been made to use methods acceptable and understandable to the adult trainees using maps, illustrations, examples, power point presentation, group exercises and case studies. All these methods appear to have cultivated interest of the trainees in the session as could be inferred from their active participation. Though technical jargon and technical concepts were included, the trainers have attempted to use easily understandable language in verbal and in written communication with trainees.

6.3.3 Resource Agencies & Trainers

The following agencies have provided the Trainers, all of whom have been highly qualified and experienced in their field of specialization:

- DHI Singapore - Framework for Disaster Risk Assessment, Flood Modelling, and use of the disaster risk database
- ERN Mexico - CAPRA Modelling and Seismic Hazard and Risk Assessment
- AIT - Asian Institute of Technology, Bangkok – Landslide Susceptibility Modelling
- Earth Observatory, Singapore – Orientation in Seismic Hazard Assessment

6.3.4 Training Guide and Handouts, Presentations, and Sample data

For each training session, suitable training material was provided to each of the participants. These handouts and training materials are available under Appendix A.

6.3.5 Feedback

The trainee feedback was requested at the end of each of the above workshops and training sessions. The feedback was positive and the trainers received very active and enthusiastic response from the participants.






6.3.6 Assessment of impact of the training and capacity building

The Disaster Risk Assessment Team has outreached to 800+ participants in the Uttarakhand state with training, workshops, capacity building and Government Engagement.

The outreach of training and capacity building was spread throughout the State and covered 12 districts (a workshop could not be organized at Champawat District HQ), both divisions of Kumaon and Garhwal, and workshops at State level with the participation of the DMMC and District Disaster Management teams.

CHAPTER 7
Strategic Opportunities

7 RECOMMENDATIONS AND STRATEGIC OPPORTUNITIES

Uttarakhand is developing rapidly and has an aspiration to grow its economy substantially. This is admirable, but sustainable development is not possible in this context without effective disaster risk reduction and Uttarakhand must build its resilience.

This section of the report introduces a number of strategic opportunities for Uttarakhand to ensure that the state increases its resilience and is recognised as a leading state in the domain of disaster risk management. It is not an exhaustive plan, but rather a set of recommendations drawn from our team's experiences in Uttarakhand that are relatively straightforward to implement with sufficient funds and coordination and, collectively, will reduce risk across the state over time.

7.1 INTRODUCTION

Here we present recommendations and strategies that we encourage the State Government to commit to in order to improve community resilience and reduce risk across the state. We limit the strategies to those most relevant to risk assessment and risk reduction, and these are by no means exhaustive.

There are many opportunities for strengthening disaster risk reduction in Uttarakhand, but it requires appropriate financial and governance arrangements to be in place and for effective enforcement of existing and emerging regulations.

We have grouped recommendations in to **Seven (7) priority themes**, namely:

1. Improvement of Capacity to Undertake and Apply Disaster Risk Assessment
2. Improvement of Disaster Risk Awareness & State Level Capacity for DRR
3. Enhancement of State Level DRM Policy and Planning
4. Reduction of Seismic & Landslide Threat to People & Infrastructure
5. Reduction of Fluvial and Flash Flood Threat to People & Infrastructure
6. Reduction of Social Vulnerability
7. Implementation of Strategies to Reduce Threat to Tourism Sector

Here we present recommendations that, if implemented under the GovUK's ongoing programme of work, would reduce risk notably and develop resilience. It is not an exhaustive plan; rather we aim to introduce key strategic initiatives that together improve risk assessment and reduce risk, significantly, across the state.

In considering the individual case study sites ("hotspot plans"), it has become clear that many of the strategies we are proposing are applicable across all the sites and, hence, are most likely relevant across the entire State. At the same time, we could see that the successful implementation of these and other site-specific strategies is going to be dependent on State level processes. We have presented here recommendations reflecting both of these needs.

Lessons Learned

From Bahadur, A., Lovell, E. and Pichon F. (2016))

Overall, this research finds that while the SDMPs provide a good basis for coordinating disaster risk reduction and management at the state level, they would be strengthened if they:

- clarify the division of responsibility among the nodal institutions charged with managing disaster risk
- consider all stages of the disaster management cycle equally, as opposed to their current emphasis on response and relief after a disaster
- consider new and innovative models for financing risk management
- mainstream disaster risk reduction across all the relevant sectors and departments at the state level
- adequately incorporate the socioeconomic vulnerability of different groups, such as women and the very poorest people, into vulnerability assessments
- consider the additional risks that climate change will bring to vulnerable populations
- produce baseline assessments and data to track future progress in disaster risk reduction
- align more closely with the Sendai Framework.

The Government of Uttarakhand has released its comprehensive State Disaster Management Plan in 2015.[19] The Plan covers the entire cycle of disaster risk management – the pre-disaster phases of prevention, mitigation and preparedness as well as post-disaster tasks of response, recovery and reconstruction and is based on the premise that disaster management is not the job of a single department or agency of the government; it is the joint responsibility of all the departments and agencies.

The Plans provide a framework for participation and contribution of every stakeholder – the departments and agencies of the State Government; the specialized agencies of the Government of India; the scientific, technical and academic institutions; the business and the corporate sector; the media; the civil society; and above all the communities living in the rural and urban areas of the State. However, Badadur et al (2016) in their review make the point that the existing DRM plan has a strong focus on "response and relief" and this was evident to us also in our discussions with District and Sub District managers. The State Strategies proposed here take into account the new 2016 National DRM Plan and the findings of Badadur et al (2016).

[19] Bahadur, A., Lovell, E. and Pichon F. (2016) *Strengthening disaster risk management in India: A review of five state disaster management plans*. Climate & Development Knowledge Network Report. CDKN: London, UK

One of the drivers for a response and immediate recovery focus is the well documented cycle of relief payments that drive annual project based budgeting at the District and Sub District level as well as with business and community members. A precedent for compensation has been long established resulting in a response cycle driven by political and institutional inertias as a result of this being the norm for decades, coupled with a lack of any non-response funding that is focused on risk reduction mitigation. Bahadur et al 2016 make the point that there are strong political and financial disincentives for engaging in risk reduction, because delivering response and relief following disasters is seen as yielding a political benefit that the intense public and media scrutiny after a disaster automatically leads to a higher priority being given to response as distinct to reduction. One government officer spoke to us in referring to this process as the disaster response "business" where all parties benefit financially and hence these financial and political benefits are strong disincentives to change the system.

A key strategy is the proposal that the State adopt an annual assessment and adopt a reporting process on the status and progress made in implementing the strategies in taking the respective DRMP forwards. If formulated as a report card then this can be used as both a governmental and Institutional device to drive mitigation, planning and preparation processes and yielding political and funding benefits to support the continuation of the process.

7.2 PRIORITY 1: IMPROVEMENT OF CAPACITY TO UNDERTAKE AND APPLY DISASTER RISK ASSESSMENT

The following recommendations are specific to improving the process of ongoing risk assessment at state and more localized scales. We also include recommendations that will help the uptake of probabilistic risk assessment (PRA) in to planning practices for all line agencies. The data improvement strategies emphasize the ongoing improvement of data on exposure (portfolios) and vulnerability functions.

Recommendation	Drivers	Outcomes	KPIs
USDMA to commit resources and a budget to update the risk assessment results and state level Atlas every 3-5 years (5yr max).	The Atlas and data online will go out of date. It has a "shelf life".	USDMA regularly updates the Atlas on online risk data to ensure that the information stays current and valuable.	Atlas and online database is refreshed annually and fully revised every 5 years (max).
Ensure that the USDMA establishes MoU for regular exchange of relevant infrastructure data from line agencies.	An increasingly accurate database of the inventory of infrastructure can determine the accuracy of the assessment of expected losses.	Inventories of assets and infrastructure are maintained, accurate, and reflect the key information required for the risk assessment (replacement cost, occupancy, and typology).	Inter-agency MoU established within 6 months with clear standards applied for data exchange.

Recommendation	Drivers	Outcomes	KPIs
USDMA must increase its technical capacity for risk assessment.	Without adequate technical leadership capacity and understanding at USDMA, there cannot be effective application of the data tools of risk assessment.	USDMA is able to operate, maintain, and fully understand and apply the tools and resulting datasets arising from probabilistic risk assessment.	Effective implementation of resourcing plan to ensure USDMA develops and sustains the desired capacity.
Invest in capacity building programme for line agencies to help them enhance their infrastructure data and use of risk information in their respective plans.	Line agencies lack understanding of the probabilistic tools and how they can apply the results in their planning.	Line Agencies are using risk in their planning and also contributing effectively to the assessments undertaken by USDMA.	Targeted capacity-building programme for line agencies to run for 12 months (minimum). Sustain an ongoing capacity-building programme.
Urban development authority should integrate risk based planning in to the urban planning process.	Standards of urban planning in urban areas are generally poor and the planning process does not quantify the changing risk or exposure as urbanization continues.	Every masterplan has an assessment of the risk associated with the future state of the urban development.	Masterplans are mandated to have a risk assessment completed to determine the future expected losses due to urban development.
Masterplans for all major urban centres should be updated regularly (every 5 years) and give a projection of growth (planned and unplanned). USDMA to be involved in masterplan review process.	Presently, masterplans and maps representing future development and not accurate for most of the major urban centres/municipalities.	Every masterplan is updated regularly and maintained in geospatial format.	Gov't Uk to mandate the creation and updation of masterplans for all major urban centres in the hills and plains.
Gov Uk to invest in high resolution LiDAR or satellite derived DEM that is 5m resolution minimum, and accurate (verified) for locations of high human density and exposure to flood risk and/or steep landslide prone slopes.	An accurate and high resolution DEM is required for the locations of greatest risk (hotspots). This will greatly enhance the ability to map and zone flooding and landslide susceptibility.	Improved models due to more accurate DEM.	DEM procured and applied in the remodeling of landslide susceptibility within 18 months. Reapplied for flood modelling within 5 years.
The forthcoming Census 2020 is fully digital. There is an opportunity to use the census to collect information useful for DRR.	Presently the 2011 census is the authoritative dataset covering the whole of Uttarakhand, but it lacks some easy to collect data that would help state level risk assessments (for instance, building storeys)	The Census 2020 digital data can be easily integrated in to the exposure data sets and help re-project vulnerability.	Refinements defined and incorporated in to Census 2020.
NDMA to assist and support mainstreaming process in Uttarakhand	Gov Uk presently lacks capacity to apply the outcomes of the risk assessment fully.	USDMA is fully able to apply risk based planning and tools on an ongoing basis.	NDMA to support and encourage appropriate resourcing and investment in Uttarakhand to sustain the project outputs.
NDMA to develop guidelines on the use of probabilistic risk assessments in government.	This would help disseminate the lessons learned from other work.	States are aware of the potential and limitations of PRA.	Guidelines developed within 12 months.
IIT Roorkee and NIDM to collaborate on development	Presently there is no standard catalogue of	Such a catalogue would help mainstream and broaden the	Catalogue initiated in 18 months and maintained on

Recommendation	Drivers	Outcomes	KPIs
of catalogue of vulnerability functions for application in risk assessments in India.	library of vulnerability functions for probabilistic risk assessment that can be applied elsewhere in India.	use of PRA across India and allow for comparability between results across states.	annual basis. All states to have access.

7.3 PRIORITY 2: IMPROVEMENT OF DISASTER RISK AWARENESS & STATE LEVEL CAPACITY FOR DRR

The following recommendations are intended to help the Govt Uk improve the awareness of risk across communities and help promote self-resilience and to create a risk aware community. This is a critical aspect of building resilience.

Recommendation	Drivers	Outcomes	KPIs
Develop and implement an ongoing and financed public education/awareness campaign for emergency preparedness & hazard mitigation	There is too little awareness of risk and risk preparedness in the most exposed urban and rural communities.	A successful "marketing" and multi-channel and awareness raising campaign would create more awareness and preparedness in the community.	Target mainstream media with simple message in 2019. Target schools and universities in 2019-2020. Establish annual social and education event to raise money and awareness from 2020 onwards.
Increase the number of Community Emergency Response Teams (CERTs)	CERTs reduce the burden on the state for response and recovery and can be very effective in saving lives and supporting preparation activities. There are too few in Uttarakhand,	CERTs established and fully operational in major urban areas in hills and plains.	Establish 5 per annum until full coverage is achieved for all urban centers and larger settlements.
Develop & modify Disaster Management/Evacuation Plans with the involvement of Community & line depts.	Community awareness of evacuation procedures and plans is very low.	Community is aware of the plans and feels engaged in the development of disaster management plans at the community level.	Target 5 critical locations per annum and engage community through newly established CERTs or other appropriate channels.
Target tourism sector and develop hotel and guesthouse information packs for distribution throughout the state. Run training for hospitality staff.	Presently tourists are unaware of the risks and response procedures.	A higher proportion of tourists who are aware of the response procedures and how best to look after themselves in the event of a catastrophe.	Establish multichannel awareness and capacity building campaign for tourism sector and implement in Haridwar, Nainital, Mussoorie, Dehradun and 5 other major hill tourism destinations from 2020.
Strengthening DM Institutions	In order to ensure that the DM Institutions are able to function sustainably at all levels; the first activity should be to develop a human resource plan for	DM institutions throughout Uttarakhand are sufficiently strengthened to assess, manage, and mitigate risk in the face of uncertainty and changing conditions. They	Initiate 3-year institutional capacity building programme under the Chairmanship of the Chief Secretary. Aim to initiate in 2019.

Recommendation	Drivers	Outcomes	KPIs
	the State Administrative Institute, State Police Academy, Patwari Training College etc. Further, a comprehensive capacity building program will be supported to develop the functional specialization of SDMA & DDMAs and train officers in the required skills for risk assessment, preparation of DM plans and preparedness activities, mitigation/ risk reduction efforts as well as response and recovery actions (including SOPs).	possess the funding and resources.	
Capacity Building of PRIs in DRR through State Institute of Rural Development (SIRD)	In DRR, the community & local administrations play a vital role as they are also the first responders during a disaster. As per the DM Act 2005, PRIs are entrusted to act as a Co-Chairman of the DDMAs. This activity would support the capacity building of PRIs by rolling out training pilots through ATIs & SIRD (State Institute of Rural Development) and also through training of PRIs members.	All PRI are trained through active participation in a tailored programme administered and delivered through the SIRD.	Establish training course in 2020. Mandate participation for all new PRI.
Establishment of Centre of Excellence for DRR in Himalayan States	The Centre will pursue implementable research for protecting human lives, properties & cultural & natural heritages from disasters. It would be assessing the threat of disasters & make the information available to the policy makers & implementors to ensure that the same is incorporated in effective development planning. It would document traditional disaster mitigation strategies & techniques prevalent in the region & will test & upgrade these & propagated. It would bring forth awareness amongst	The DMMC is dedicated to the cause of all disaster management related issues. Since its creation, the center has been working dedicatedly for bringing forth awareness amongst masses on various disaster related issues & propagating disaster safe technologies, capacity building, planning, organizing, data collection & analysis, hazard & risk analysis, post disaster review & reporting. This can be upgraded to Centre of Excellence in DRR.	State Centre of Excellence to be established by 2024.

Recommendation	Drivers	Outcomes	KPIs
	the masses regarding the threat of disasters & used different modes of communication for spreading the knowledge on simple mitigative strategies, CBDRM etc.		
Development of Human Resource in DRR	In order to ensure strong institutional capacity for DRR in state of Uttarakhand, it should be emphasize human resource development by providing skill development, specialized and professional education.	The State of Uttarakhand has a large number of ex-service men. Apart from these the Home Guards, National Cadet Corps (NCC) & the National Red Cross Societies are a great resource for disaster management in the state that needs to be utilized much more effectively. The activities can provide added value by building the specific capacities of these human resource.	To be determined.
Promote Equity, Social Inclusion & Women Empowerment	The State should develop its interventions for including marginal & vulnerable groups. It should promote the principles of equity, social inclusion & women's empowerment. It should emphasize women's empowerment with focused allocation of resources required for increasing their access to skills & for improved risk management. Similarly, identify socially & economically vulnerable groups for targeted interventions.	Communities are aware of their vulnerabilities & adequately prepared to manage & reduce disaster and environmental risk.	Establish state wide programme in partnership with NGOs by 2023 that targets urban and rural hotspots (high and growing population or threat) to promote social inclusion and woman's empowerment, with an emphasis on livelihoods resilience.

7.4 PRIORITY 3: ENHANCEMENT OF STATE LEVEL DRM POLICY & PLANNING

The following table presents recommended state level planning and policy related enhancements that would contribute to effective risk reduction across the State.

Recommendation	Drivers	Outcomes	KPIs
Review current building standard compliance and develop	Enforcement of the most current Building Codes Standards to protect the built environment in	Effective compliance to building codes and statutory planning zonation diminishes	Complete review and identification of mechanisms

Recommendation	Drivers	Outcomes	KPIs
mechanisms to strengthen levels of compliance. At the same time review statutory planning processes and enforce both to protect the built environment and to minimize exposure to disaster risks.	the City is required as is retrofitting. Similarly the State has amended building byelaws and the Town & Country Planning Act, however due to non-compliance/ or lack of enforcement by the concerned authorities, the habitation of unsafe/high risk areas is expanding.	the disaster risks for many in the community	for improved enforcement within 12 months. Introduce stronger enforcement and penalties in to Dehradun and Haridwar as top priority within 18 months.
Develop a State Policy on Disaster Risk Management that reflects the revised National focus and the need for funding to review and implement DRM mitigation and planning as key areas to focus	As yet Uttarakhand does not have a Policy on Disaster Risk Management the State Disaster Management Plan cannot be effectively acted upon by State Agencies as funding allocations are not being made in a way to reflect the existing Plan and the need to have a funded commitment for mitigation panning to build disaster resilience[20]	A overall more effective DRM Plan and DRM outcomes through resilience planning and capacity building leading to significant reduction in loss of life, impacts on infrastructure and cost savings in response and	Formulation and adoption of the adoption of a DRM Policy by close of the next Parliamentary sitting
Review other State Plans and consult with these States in preparing the policy and the revised DRM plans at State, District and sub district level.	Other states are already well advanced and being innovative. E.g. Assam has proposed livelihood, lifestyle and health factors as a district level capacity to respond; Gorakhupur has instituted a planning process leading to a climate smart district management plan aligned to different department's needs, priorities and capacities.	A DRM Policy and Revised DRM plans that are cutting edge and well founded in other States experiences leading to a best practice outcome and hopefully a more efficient and effective result with respect to mitigation planning and response.	Annual hosting of a between States workshop to share experiences with regard to mitigation, planning and preparation
Develop a mainstreaming approach across all Departments to addressing DRM, climate change and the sustainable growth of the State	There is a need to ensure that all relevant Departments have DRM and the associated sustainability and climate change issues built into their policy development and annual planning and budgeting cycles such that these are seen as mainstream business activities.	Long term sustainability, climate change adaption and disaster risk reduction within the State leading to overall reductions in expenditure through systematic planning and a reduced	Include DRM Planning and implementation as an annual reporting list item requirement by all agencies
Through the DRM Policy empower a single agency to lead the engagement and coordination of Departments in the delivery of "whole of Government" integrated DRM plans	Silo compartmentalization is common in all Governments and difficult to overcome. With respect there is a particular need to overcome this inertia in generating an integrated approach as=cross all of Government	Improved sustainability, climate change adaption and disaster risk reduction within the State leading to improved government efficiency and effectiveness.	Agency to organize across all Departments bi annual planning and response exercises designed to assess both mitigation effectiveness and response capability

[20] From the State perspective, disasters represent a critical risk in promoting and planning for the growth of the state. In the presentation of the 2022 Vision for the State DM is not a consideration.

Recommendation	Drivers	Outcomes	KPIs
Develop funding of mitigation planning processes as an annual and ti-annual budget line item to break the cycle of recovery based project funding for all Departments.	The core of present Government funding is dispersed based on recovery "projects" with little if any allocated to mitigation and planning.	Adequate and non-response based funding will result in mainstream mitigation and planning within the state.	Annual budget submissions based on triannual plans for mitigation and planning. Annual reporting on progress in delivery of changes and improved resilience.
Undertake annual reporting using a report card format on the status and progress made in implementing the revised State DRMP.	A report card process on an annual basis serves to provide transparency and accountability to all stakeholders. While some sectors find this difficult at first the benefits are that it can lead to significant investment buy in by all sectors of 7he stakeholder groups.	An annual report card that shows progress in delivering on a DMP approach as part of the mainstream processes in Government.	Annual report card completed and distributed every 12 months within the 3-month period following the close of the year.
Reduce both preparation and mitigation costs through financing partnerships with insurance companies and Banks.	There is a need to create incentives for bank loans and insurance cover opportunities through public-private partnerships in order to reduce overall Government expenditure, particularly in the form of compensation, thereby changing community and business expectations with respect to compensation based funding and a lack of mitigation and planning.	A change in expectations of government Departments, civil society and the private sector around the business of recovery financing by government. Overall cost savings to Government.	An annual progressive increase in uptake of private funding and insurance to cover DRM against specific targets set.
Include climate change as a specific consideration in the mainstream development of DRM mitigation and planning by all Departments.	There is mounting evidence that climate change is already having a direct effect on the frequency and severity of disaster incidents in Uttarakhand and India more generally.	Better DRM and more resilient sustainability of economic and social development within the state.	Ongoing over 36 months to build capacity in line agencies for climate readiness. Success criteria is that line departments all consider climate change effectively in their long term planning.
Include a State-wide census operation to support the national census data collection. This would include a much-detailed data collection to understand the age bifurcation of the population and also develop a health index of the state.	The exact bifurcation of age of children in the census e.g.: 0 to 6 y/o, 6 to 14 y/0, 14 to 18 y/o and 18 to 25 y/o will give the state government a detailed understanding of the most vulnerable populations in the state amongst the children and an understanding of the target group to inculcate disaster management training for.	The local government officials will have a database to understand the number of young population in their areas who can be trained as disaster management experts developing a self-sustained community. The detailed bifurcation in the data collection will help future disaster risk assessment studies to collate better data and analyze accurate risk and vulnerability indices	Data recording to be taken up alongside national census for 2021 and all census data collections moving forward.
Reduce Social Vulnerability through a proactive approach to strengthen the socio	It is only through a proactive approach to improving social and economic standing of, their access to education, medical	Community empowered for improved disaster risk management as a result of	To be determined.

Recommendation	Drivers	Outcomes	KPIs
economic standing of all communities in the State	care and infrastructure that it is possible to diminish vulnerability and improve resilience. Noting that most studies show that in extreme natural events the most vulnerable are more likely to be adversely affected, they are the most likely to be susceptible and less likely to recover from the impact of hazards.	their improved social and economic circumstances	
Establish baseline assessments and KPIS to track performance in delivering on Policy – reporting to Parliament on an annual basis.	Presently there is little accountability through to the National Government on progress on policy development and implementation.	State Government reports annually against a predetermined set of KPI for DRR and enhancement of DRM.	Establish KPI in 2019-2019 and implement annual reporting to Central Government from 2021.
Enforce/popularize Multi-Hazard Resistant Construction Technology	The uptake of hazard resistant construction can be accelerated.	All new construction is to code and a higher proportion of new builds adopt multi-hazard resistant construction technologies.	Establish clear policy on the use of such technologies for adoption and enforcement from 2020. Promote availability of such techniques to the public through multi-media awareness campaign. Target construction companies and ensure all new construction contracts incentivize such approaches.
Integrate Hazard Mitigation Plans in to existing development programs.	Presently hazard mitigation plans are not an integral part of sector or urban development plans.	Resilience of expanding communities and infrastructure will be increased if hazard mitigation is considered as a mandatory component of all development plans.	Establish clear policy directive in 2019 for hazard mitigation to be an integral part of all planning.
Promote non-Structural Mitigation measures in Schools, Homes, Offices, Business centers etc.	There are clear opportunities to reduce risk through the wider uptake of non-structural mitigation measures in schools, colleges, offices, and centres of business.	Community resilience, risk awareness, self-reliance, and preparedness is enhanced through wider uptake of non-structural and inexpensive mitigation measures.	State level plan for this to be developed and put forward for funding in 2020.
Establish the legal Framework for making infrastructure flood resilient.	At this time it is not mandatory to obtain clearance for construction plans of infrastructure in flood prone areas from State's Irrigation/ Flood Control/ Water Resource Dept. with regard to their safety against floods	Enforce mandatory standards for flood resistant infrastructure.	Target policy development in 2019 and initiate district level enforcement in Haridwar and Udham Singh Nagar in the first instance by 2022.

7.5 PRIORITY 4: REDUCE SEISMIC & LANDSLIDE THREATS TO PEOPLE AND INFRASTRUCTURE

7.5.1 Background

Uttarakhand is within the most seismically active region of India. Many events of M5.5 or more have struck the region since 1900. The Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT) are the main active features in Uttarakhand. During the period 1990 to 2006, more than 23 000 lives were lost due to six major earthquakes in India, which also caused enormous damage to property and public infrastructure.

The occurrence of several devastating earthquakes in areas hitherto considered safe from earthquakes, indicate that the built environment in the state is extremely fragile and the ability of preparedness and effective respose to earthquakes is inadequate.

7.5.2 Earthquake Resilience

A disaster-resilient nation is one in which its communities, through mitigation and pre-disaster preparation, have developed the adaptive capacity to maintain important community functions and recover quickly when major disasters occur.

The ability of a community to recover from such a disaster reflects its resilience.

In order that block level communities could be more resilient, support from both district and state level is required. The communities should consider developing multi-tier resilience, goals and strategies. The resilience involves both pre-disaster mitigation (activities to reduce the amount of loss in an event) and the ability to mute post-event losses and rapidly recover from an event.

Resilience should allow for systemic change, especially in low-probability, high-consequence events. Resilience does not necessarily entail a return to normal or pre-disaster conditions. Reducing future risk should also be a goal of recovery activities.

Table 7.1: Resilience applications to social, ecological, physical and economic recovery by time-period (NRC 2011)

Time scale	Emergency response	Health & Safety	Utilities	Buildings	Environmental/Ecological	Economic
Immediate < 72 hours	Tactical emergency response	Deal with casualties/Reunite families	Use of emergency backup systems	Remove debris	Limit further ecological damage	Maintain supply of critical goods and services

Emergency 3-7 days	Strategic emergency response	Provide mass care	Begin service restoration	Provide shelter for homeless	Remove debris	Prioritize use of resources/substitute inputs/conserve
Very short 7-30 days	Selective response	Fight infectious outbreaks	Continue restoration	Provide shelter for homeless	Protect sensitive ecosystems	Shore up or override markets
Short 1-6 months	Assist in recovery	Deal with posttraumatic stress	Complete service restoration	Provide temporary housing and business sites	Deal with ensuing problems	Cope with small business strain
Medium 6 months–1 year	Reassess for future emergencies	Deal with posttraumatic stress	Reassess for future emergencies	Provide temporary housing and business sites	Initiate remediation	Cope with large business strain/recapture lost production
Long >1 year	N/A	Reassess for future emergencies	Mitigation for future events	Rebuild and mitigate	Mitigate for future events	Cope with business failures/mitigation

7.5.3 Earthquake-Resistant Design and Construction of New Structures

All new buildings should incorporate earthquake resistant features. Existing buildings must be constructed using earthquake resistant design or implementing retrofitting techniques. Local masons should be trained and incentivized for the use of retrofitting techniques and earthquake resistant construction technology. Simultaneously indigenous techniques of building construction should be promoted.

The construction of these structures is presently unregulated and is adding to the numbers of vulnerable structures. Currently, construction in rural areas is not governed by bye-laws such as those developed for the municipal and urban areas. State governments must develop suitable bye-laws for rural areas where most buildings are non-engineered, keeping in mind the local conditions, and extend them to the rural areas, especially on priority in high-risk areas.

7.5.4 Seismic Retrofitting Strategies

Retrofitting is a complicated process that requires time, specialized personal, and economical resources. However, due to the importance of the structure, such process must be carried out strictly.

Many authors have developed test in several structural types in order to know the positive effects that simple retrofitting techniques have in those structural types. Unfortunately, when applying simple retrofitting techniques (mainly in non engineering structures, such as rubble stone or adobe structures) it is not possible to know the resultant performance level, however, the seismic vulnerability will be decreased largely.

The DRA project team have developed a comprehensive set of guidelines on retrofitting techniques and options for the various building typologies and critical infrastructure in Uttarakhand. This guideline document is available under Appendix B.

7.5.5 Regulation and Enforcement

State governments must establish the necessary techno-legal and techno-financial mechanisms to ensure that all the stakeholders like builders, architects, engineers and government departments, responsible for regulation and enforcement adopt earthquake-safe constructions practices and provide seismic safety in all design and construction activities.

The lack of easy availability of the seismic safety codes and standards, has been frequently cited as one of the major factors responsible for the poor implementation of earthquake-resistant construction practices.

State governments must update the urban regulations by amending them to incorporate multi-hazard safety requirements. State governments will review, revise and update the urban and rural planning acts.

Rural and semi-urban areas account for most of the total building stock in Uttarakhand. The construction of these structures is presently unregulated and is adding to the numbers of vulnerable structures.

Case study: Building back better with under a 'beneficiary driven' scheme

In a housing scheme of large magnitude following a significant disaster where construction of many thousands of houses at a low cost (Rs. 25,000/- each?) is required, a scheme of owner driven construction with overall technical guidance and delivery mechanism of the chosen construction materials has shown to be highly effective. The best example in India of the construction of more than 2,00,000 houses under a 'beneficiary driven' scheme was adopted in Gujarat after the Bhuj earthquake wherein, the following mechanism was used:

- *(i) The funding was given to the beneficiaries through bank accounts in the joint names of husband and wife in three stages, 40% advance, 40% when the construction was completed upto plinth /door lintel level and 20% when the construction was complete upto the eve level band.*
- *(ii) (ii) Technical guidelines were made available for various types of construction and technology options, also permitting variation in the house plan to suit the beneficiary's requirement.*
- *(iii) Enough Junior Engineers were trained in the construction technology to guide, supervise and monitor the construction as it proceeds upwards and verify the level of construction and the technology adoption for releasing the next installment.*
- *(iv) Training of masons in the art of Disaster resistant construction through the trained Junior Engineers/Non-Governmental Organisations. Such Masons once trained will become an asset to the construction industry in the State. 4*
- *(v) Material banks were created by the Government where cement and steel bars were made available at cheaper rates through waivers of the duties on such materials for strict use in the rehabilitation/reconstruction work.*
- (vi) *Third party audit was adopted to check the quality of construction and proper use of technology by an independent organization appointed by the Government. It may be mentioned that with all these measures, the*

7.5.6 Public Awareness

One of the most challenging tasks in earthquake preparedness and mitigations is the sensitization of all stakeholders to the prevalent seismic risk and educating and training them to participate in earthquake preparedness.

If the community recognizes the importance of incorporating seismic safety measures in the construction of residential buildings, tremendous gains can be achieved in earthquake mitigation.

The State governments and knowledge institutions such as the IIT's and National Institutes of Technology, in collaboration with professional bodies of engineers, architects and urban planners initiate programs to sensitize their members on the importance of undertaking earthquake-resistant design and construction practices.

Earthquake preparedness will include the formulation of family and community contingency plans. Mock drills can be conducted for industrial units, officers, schools and hospitals, as well as for specific urban and rural areas to create greater public awareness.

7.5.7 Earthquake Response

To augment the capacities of the states, all state governments will raise, from within their armed police force, adequate strength of personnel for the SDRF with appropriate disaster response capabilities. In addition, the police, fire services, Home Guards and Civil Defence must be strengthened and upgraded to have adequate capacity to respond effectively to disasters.

Deployment of the Indian Armed Forces for post-earthquake response work will be resorted to only as the last option.

Specialised heavy earthmoving equipment and search and rescue equipment are required immediately following an earthquake to clear debris and to carry out search and rescue of trapped people from collapsed structures. State governments will compile a list of such equipment and identify suppliers of such specialised equipment and enter into long-term agreements for their mobilisation and deployment in the event of an earthquake.

7.5.8 Early Warning Systems

Not all hazards can be halted, avoided or predicted accurately, thus an early warning system in place is necessary to warn communities and government officials of an imminent natural event, so that immediate protective steps can be taken, population can move to safety and hazardous facilities or constructions can be evacuated.

An earthquake early warning system could provide up to tens of seconds of warning prior to shaking arrival. The time required to detect and issue a warning for an earthquake is dependent on several factors, such as:

1. Distance between the earthquake source and the closest seismic network seismometer (station). It takes a finite amount of time (3–4 miles per second) for the first seismic waves to travel from the source (e.g. the point on a fault that is breaking) to the seismic station. Therefore, the closer a station is to where an earthquake begins, the more rapidly the earthquake can be detected. Accurate detections often depend on multiple ground motion measurements from more than one station; so, increasing the density of stations near the fault can improve detection times.

2. Transfer of information to the regional networks. Data from multiple stations is collected and analysed by the regional seismic networks, so ground motion information must be transferred from the station to the processing centre. Existing networks use a variety of methods to send data back to the server to improve robustness, including radio links, phone lines, public/private internet, and satellite links. In addition, delays from packaging and sending the data from the station must be minimized to provide useful warning times.
3. Detection and characterization of an earthquake. Ground motion records received from the stations in real time are used to detect an earthquake and rapidly determine an initial location and magnitude of the event. Earthquakes can continue to grow in size over many seconds (the larger the earthquake generally the longer it takes to get to the final size), so magnitude estimates can also change through time as the evolving earthquake is tracked.
4. Shaking intensity threshold used to issue an alert. Alerts are issued for a region when the expected ground shaking intensity is above a minimum threshold. Alerts can be provided more quickly for low thresholds of ground shaking because the system doesn't need to wait as long for the earthquake magnitude to grow (larger earthquakes produce high ground shaking intensities).

7.5.9 Dissemination of Earthquake Information.

Dissemination of information and education of population by local disaster management authorities is a practice that must be implemented with focus on the actions that population must do when an earthquake occurs. For example, the following figure shows a portion of a leaflet prepared by the Japan Meteorological Agency describing simple instructions on how to react when an earthquake alert is received (National Research Council, 2011). This kind of educational material will help population to know the main ways to react in case of an earthquake event.

7.5.10 The Risk Ranking System Applied Under This Study

For the ranking we can consider the median value for each district/block of the Peak Ground Acceleration for a return period of 475 years.

Applying Hazard classes is very arbitrary and complicated because we cannot say if some place is in a low or medium zone. According to some references (USGS and Anand Joshi, 2000), they relate to the intensity of acceleration of PGA and the Mercalli Modified intensity which has 12 classes, here we have adopted a more simplified scale for the hazard classes based on these references as seen in the table below.

Table 7.2: Scale of Earthquake Intensity

Class	PGA	Intensity
1	< 10	Very low
2	24.04	Moderate
3	46.68	Strong
4	90.64	Very strong
5	176.00	Severe
6	341.75	Violent
7	> 660	Extreme

7.5.11 Strategies for Reducing Landslide Risk

The annual cost of landslide is high and exposure is increasing over time. The minimisation of landslide risk is achieved through reliable risk reduction studies and prioritization policies.

This section bullet points a number of general short, medium term, and long-term strategies that might be adopted across the state to reduce the risk from landslides.

Short-term, low-cost strategies can include:

- Develop education and public outreach to engage adjacent landowners to improve slope management practices.
- Continue low-cost mitigation options, such as maintenance of slide fences, ditches and other drainage facilities, in all hill districts near priority roads or where settlements are encroaching.
- Explore possibility of providing a drainage improvement incentive, such as reduced permit fees to adjacent landowners (limited duration).
- Develop detailed landslide hazard maps to assist local agencies in the development of land use regulations on steep slopes.

Intermediate strategies can include:

- Design and construct up to 10 projects in high-priority landslide areas from 2019-2025 to mitigate landslide problems and improve safety and service reliability.
- Develop detailed zonation maps for all major hill towns and access routes.

- Warn and inform owners of property in susceptible zones.

Long-term strategies can include:

- Develop an enduring management system to prioritize and implement slope stabilization projects.
- Continue community education and public outreach. Educate communities about unsafe building practices.
- Develop a permit process for improvements to private residential land adjacent to and/or above the track area, and identify a funding source or sources to implement improvements.
- Optimise design of containment structures and evaluate effectiveness of stabilization measures for shallow slope failures.
- Consider acquisition of long-term maintenance/construction easements on adjacent property in landslide-prone sections to improve opportunities to implement best-suited mitigation measures (Note that this long-term strategy would require additional funding.)
- Consider relocation and demolition of properties and communities in high and extreme landslide prone zones.
- Explore justification for further public investment, recognizing that a significant increase in capital investment will be required to significantly reduce landslide-related closures.

7.6 PRIORITY 5: REDUCE FLOOD THREAT TO PEOPLE AND INFRASTRUCTURE

7.6.1 Background

This section presents a general overview of flood risk, discusses the first principles upon which most mitigation strategies are based, and outlines a number of specific measures that may be relevant to Uttarakhand's flood risk hotspots. For further detail, the reader is referred to the references provided, with the overviews by Verwey *et al.* (2017) and Jha *et al.* (2012) particularly recommended.

It is important to accept from the outset that total protection against flooding in flood-prone areas cannot be guaranteed: this is neither possible nor desirable (the required investments would not be cost-effective). Just as people accept other risks in everyday life, such as traffic accidents, it should be accepted that "living with floods" is unavoidable in certain areas. However, this risk must be carefully assessed and mitigated as far as is practicable and economically viable, with the residual risk accepted and well communicated on the basis of cost-benefit analyses and socially-acceptable principles.

Recognising the inevitability of continuing flood risk is particularly important in Uttarakhand's context, given the unique constraints imposed by its geography, particularly the limited land availability in many towns/villages (squeezed in between steep mountain slopes and high-energy rivers) and the scale and slope of its river basins. This is not to be fatalistic about flood risks though, there is still much that can be done to bring the existing risk down to more acceptable/manageable levels.

A wide variety of mitigation strategies exists for floods, the applicability and cost-effectiveness of which will vary widely from place to place, depending on particularities of the local hazards, exposure and vulnerability. Put simply, there is no one-size-fits-all approach – the optimal solution for a particular hotspot will depend on careful analysis of all three factors.

The figure below shows how a combination of mitigation measures (including structural and non-structural) might be deployed in a particular hotspot to gradually bring down the initial risk (the left-most column) to a level that might be considered acceptable (the right-most column). This figure illustrates two important principles: that it is generally possible to significantly mitigate flood risk (through a site-dependent selection of structural and non-structural measures), and that some 'residual risk' will always remain, which must be well understood and clearly communicated to all.

Figure 7.1: "Bringing down the risk" – an illustration of how a selection of mitigation measures progressively reduce flood risk from an initial high to a more acceptable level (moving from left to right) (Source: Verway et al. 2017)

The specific measures selected for each hotspot will depend on which combination of measures is judged to be most practicable, efficacious and also cost-effective. Generally, the more investment (of funding and effort) put into flood mitigation, the further the risk may be lowered. However, at some point, as mitigation efforts to cope with increasingly extreme events become more and more expensive, the economic return on these investments will no longer be justified.

It is difficult to determine where that optimum investment is to be found, defined in terms of the return period of the event up to which mitigation measures should be designed to cope with. This optimum varies from location to location and depends on flood hazards, economic activities, and the human lives at stake. Figure 7.2 illustrates how the optimum level of flood investment for a very high-risk area might be estimated. The black line shows the cumulative cost of implementing mitigation measures to cope with increasingly extreme events (moving right along the x-axis), the red line shows the average annual losses associated with the same range of events, and the blue line can be thought of as the sum of the other two.

The figure demonstrates that a “do nothing” option in flood management is not attractive, as small investments that mitigate against the most frequent floods – usually investments in structural measures – already lead to a substantial rate of return on investment. (In other words, the cost of preventing losses due to the most frequent flood events is significantly lower than the losses that would otherwise result from those events.) However, the figure also illustrates that beyond an optimum investment point, further investments become less attractive. This means that there will always be a residual flood risk that has to be accepted on the basis of cost-effectiveness. Here the value of non-structural investments is particularly important, as flood forecasts and emergency support information can considerably reduce losses from hazard events that can’t be fully prevented.

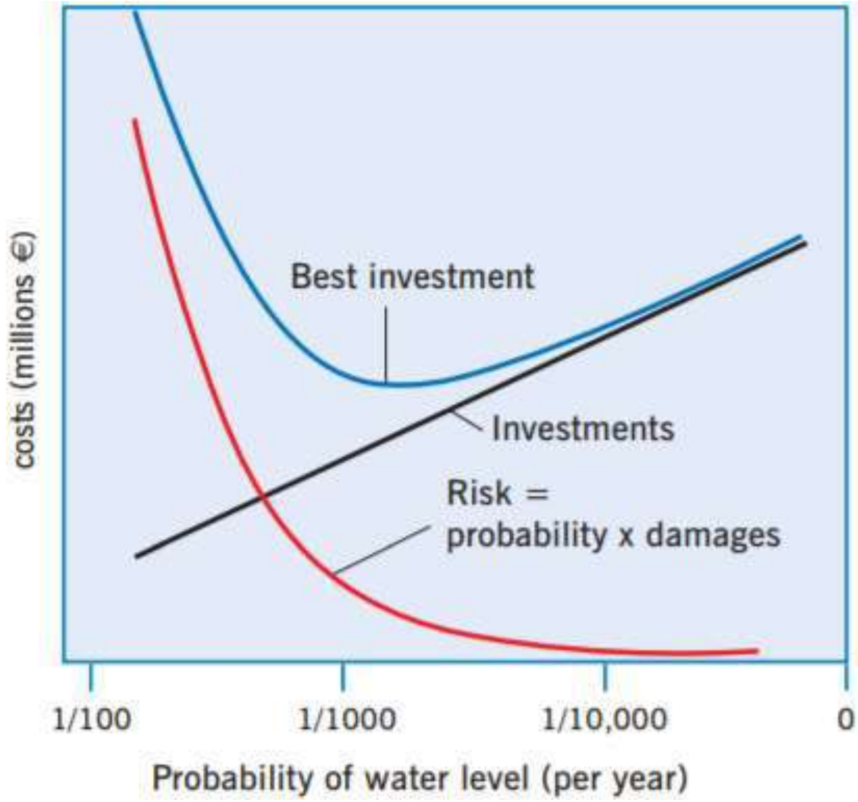


Figure 7.2: Illustration of approach to estimate optimum level of investment (in terms of the return period flood event for which measures should be designed to cope) on the basis of a cost-benefit analysis (Source: Hoogheemraadschap van Rijnland 2009)

However, while it is certainly useful to assess proposed flood risk management measures in economic terms (such as the cost-benefit analysis discussed above), the final decisions made by policy makers, urban planners and technical specialists must also consider broader issues. These include the impact of measures on environmental degradation, biodiversity, equity, social capital/capacity, and other potential trade- offs. Especially in this period of rapid urbanisation and climate change, decisions weighing up all of these factors must also account for the large uncertainty associated with future flood patterns and exposure distribution (Jha *et al.* 2012).

This adds a further element to the decision-making process, which needs to be robust against these uncertainties. Cost-benefit analyses should therefore aim to find combinations of measures that are predicted to perform well for a wide variety of future scenarios (i.e. robust to future uncertainty), as illustrated in Figure 7.3. This leads to a preference for flexible and so-called "no regret" approaches that will include measures that will be cost-effective regardless of changes in future flood risk.

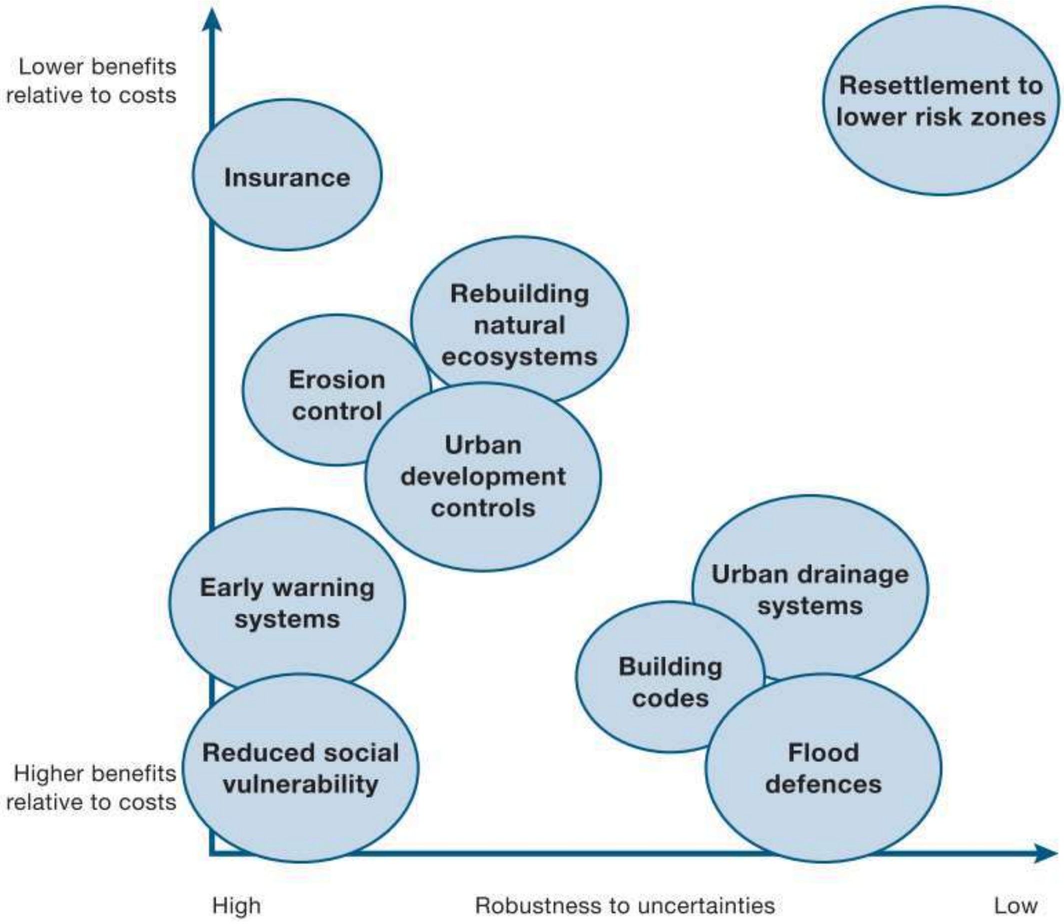


Figure 7.3: Example of a cost-benefit analysis of flood risk mitigation measures which also accounts for each measure's robustness to uncertainty (Jha *et al.* 2012)

A final general point to make is the need for integrated studies in flood risk management, ideally covering the entire river basin under consideration, which is particularly important when strategies for isolated hotspots are being drawn up. Integrated studies are important because flood risk management interventions have impacts outside the areas where they are actually implemented. In river basins, nearly all the interventions that are feasible have impacts (positive and/or negative) in the downstream direction, and the negative impacts should be included in the cost-benefit analysis for the proposed project and ideally compensated for in some way. Integrated studies are also important because flood management interventions generally have impacts on many other aspects of river basin management, such as environment, agriculture, drought, hydropower, etc.

7.6.2 General flood risk mitigation strategies

As illustrated in the previous section, investments in structural and non-structural flood management can be thought of as providing an attractive economic rate of return, up to a certain optimum investment level. Decisions regarding the flood hazard severity (in terms of return period) that mitigation measures should be able to cope with and the specific measures to be used should be based on flood hazard mapping and risk assessments (such as those developed during the current study), as well as estimates of the extent to which possible interventions (structural or non-structural measures) can reduce losses.

This section will explore the basic principles upon which most flood mitigation measures are based, with specific measures discussed in more detail in each sub-section. Given that flood risk is a product of hazard, exposure and vulnerability, it follows that reductions in flood risk might be achieved by reductions in one or more of each of those three aspects.

As the figure below suggests, structural mitigation measures generally target the hazard aspect (attempting to reduce peak flows and water levels), while non-structural measures are more often concerned with reducing exposure and/or vulnerability instead. While structural measures have traditionally been the main options in the flood risk manager's 'toolbox', the value of non-structural measures has been increasingly recognised in recent years.

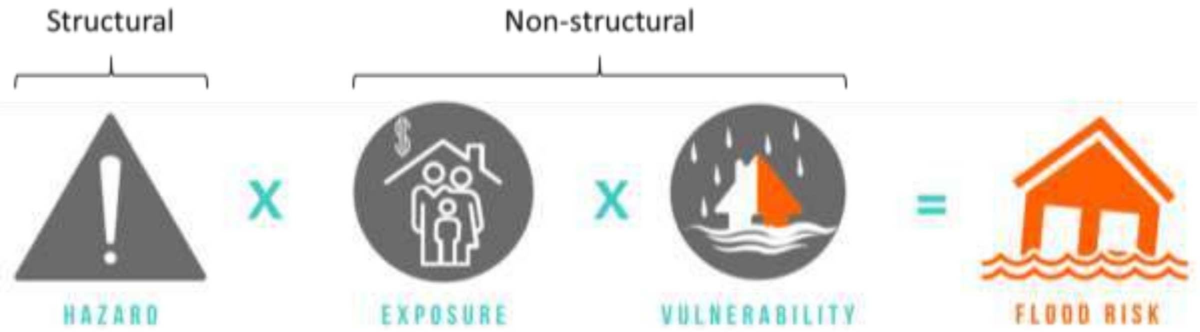


Figure 7.4: Structural mitigation measures often target the hazard component of flood risk, while non-structural measures work by reducing exposure and/or vulnerability (Verway *et al.* 2017)

No single mitigation measure or approach will be a panacea for all flood risk contexts. Instead, an effective flood risk mitigation strategy is always site-specific, using a proactive approach that carefully assesses risk in advance and then selects whichever structural and non-structural measures are judged likely to be most effective in that particular location. This assessment should be undertaken in an integrated manner, ideally considering the whole river basin and all of the various factors influencing the hydrological cycle and exposure distribution within it.

Figure 7.5 illustrates such a river basin-scale view, accounting for a wide variety of factors influencing flood patterns (such as upstream infiltration and groundwater management), structural measures that might be employed to reduce associated hazards (such as reservoirs for flood storage and urban barrier systems), and non-structural measures that could reduce how exposed and/or vulnerable people and economic assets are to flood events that still take place.

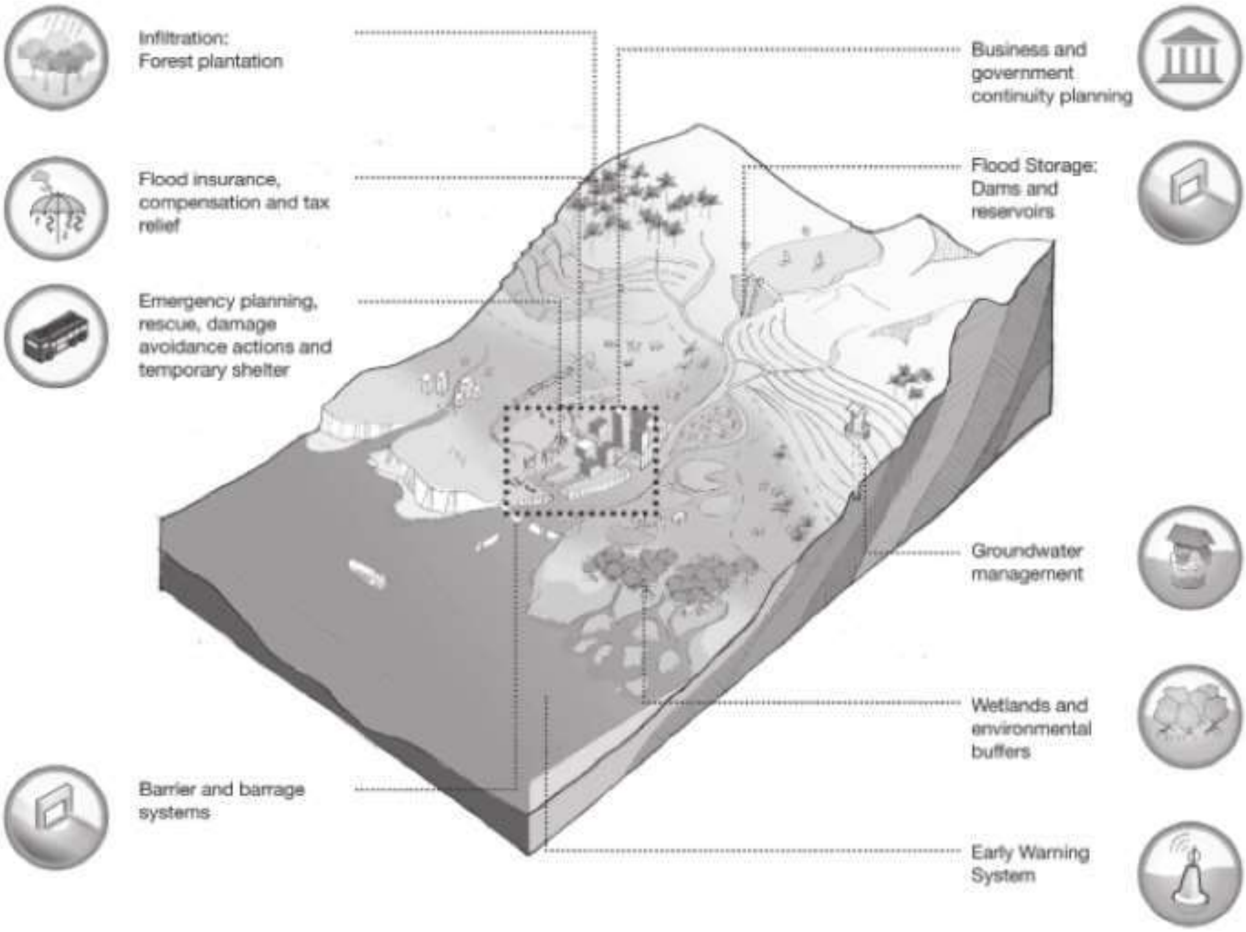


Figure 7.5: Overview of flood risk mitigation options at the river basin scale (Jha *et al.* 2012)

7.6.3 Hazard reduction strategies (primarily structural)

All measures aimed at reducing flood hazards (primarily structural solutions but also some non-structural options) have as their primary objective the reduction of peak discharges and peak flood levels at the site of interest. This is generally achieved through two main approaches: 1) adding flood volume retention storage at or upstream of the hotspot to delay storm water runoff and flood wave propagation, and 2) increasing the flow conveyance capacity of channels in and immediately downstream of the hotspot (or diverting floodwaters around it entirely).

7.6.4 Flood volume retention measures

Considering the first of these approaches, Figure 7.6illustrates three ways in which storm water runoff might be delayed, by providing additional storage volumes for floodwater using floodplains and reservoirs (offline and in line). In each of these three cases, the before-and-after hydrographs show clearly the expected attenuation of the flood peak. (Note that the other mitigation measure shown here - erecting flood embankments along the river - does not have such a pronounced impact on the hydrograph, and in fact is likely to result in even higher peaks immediately downstream of the hotspot than would otherwise be expected).

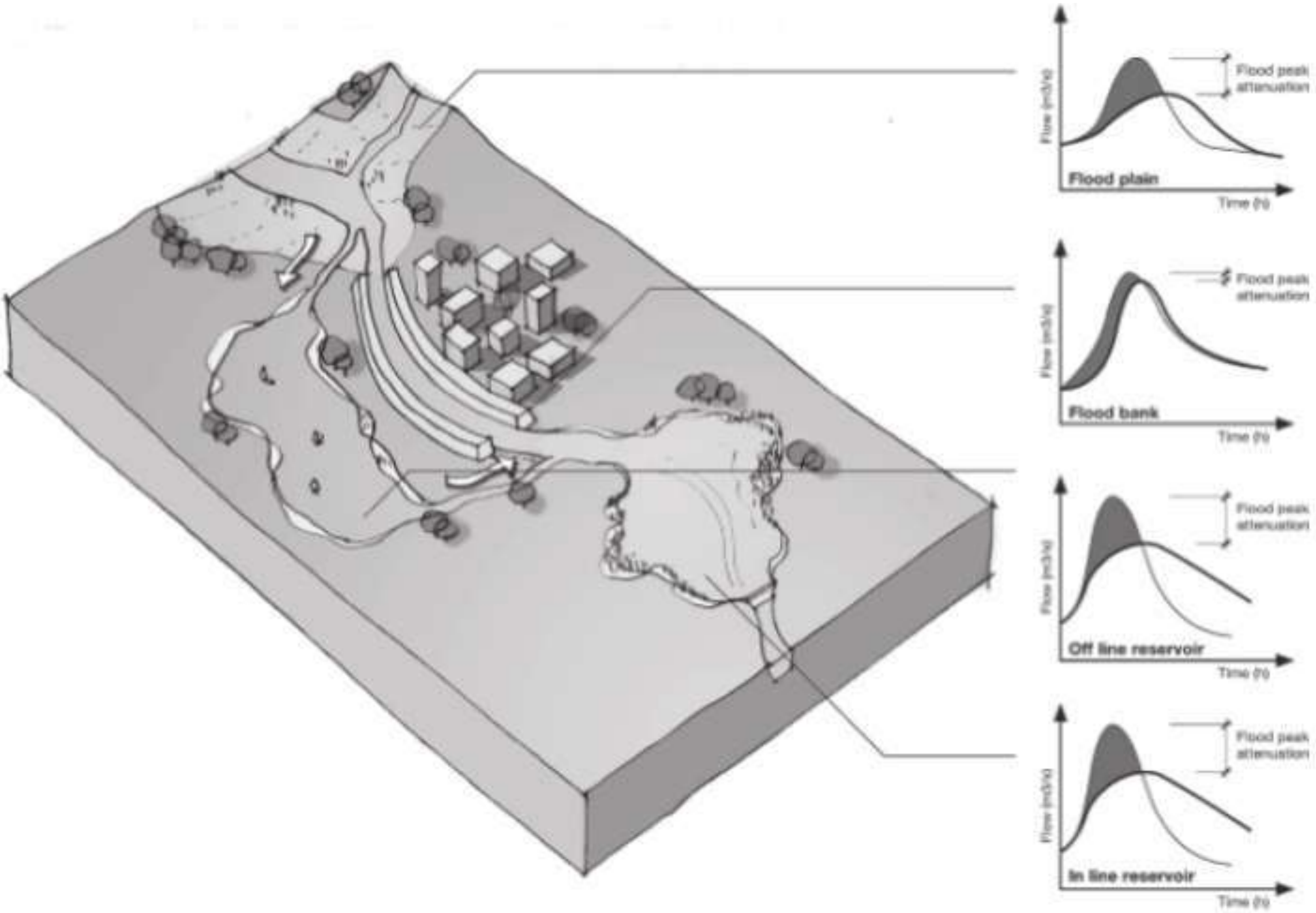


Figure 7.6: Attenuation effect of storage and conveyance measures (Jha *et al.* 2012)

Creating flood retention storage in river basins has two important effects: it reduces the speed of flood wave propagation (giving downstream communities more time to prepare for upcoming floods), and it reduces flood peak discharges and flood peak water levels in the downstream direction. (Note however that there may be exceptions to this rule: for example, if changes in the arrival time of flood peaks from different river tributaries result in a superposition of the flood waves at a sensitive location.)

As noted briefly above, adding retention storage along a river is most effective at reducing flood risk if it is installed either upstream of the area to be protected or at the hotspot location itself. Large-scale measures of this type that are most relevant to Uttarakhand include constructing reservoirs in upstream river basins or optimising the impact of existing ones, by adjusting their operating rules in favour of flood protection objectives (noting that these will tend to compete with those relating to irrigation provision and/or hydropower generation).

On a smaller scale (for example, in urban environments subject to localised flooding), the effort to apply the same principle (delaying storm water runoff) involves searching for micro-storage options. This has led to the concept of sustainable urban drainage systems (SUDS). The use of a large number of small-scale interventions in the urban environment, such as the mobilisation of emergency storage on parks and playgrounds, reduces the speed of runoff and reduces peak flows in the drainage system. However, although these solutions are multipurpose and usually demonstrate clear co-benefits, it appears unlikely that sufficient space exists for their implementation in most urban areas in Uttarakhand.

7.6.5 Increasing conveyance capacity

The second approach to reducing peak flood levels is to increase the conveyance capacity of the river/drainage system or to divert floodwater around sensitive areas. Increasing flow capacity (for example, by widening/deepening channels, constructing embankments that constrain flood flows to the main river channel, or using smooth bank materials for engineered channels) has the effect of reducing water levels (in the protected area) for a given discharge. Depending on the specific measure implemented, this is most effective if implemented directly at the hotspot to be protected (preventing or at least lowering flood depths there for a given discharge) or just downstream of it (allowing the flood volume to be released faster out of the flooded area).

A significant drawback to this approach is that it results in even higher downstream peaks than would otherwise be encountered (because water that would otherwise have spilled the river banks and spread laterally, is now retained in the main channel and conveyed within it). This is obviously not such an issue in coastal cities, where the creation of capacity to convey the flood peak flows without overtopping the river banks is often a cost-effective measure. However, for hotspots strung along a long river network - such as those under consideration in Uttarakhand - it must be borne in mind. If this approach is implemented here, care should be taken regarding any adverse impact on nearby downstream exposure and ideally compensated for (e.g. by providing floodplain storage downstream of the hotspot, in a location where exposure is low and controlled flooding will have little impact).

Despite these limitations, embanking flood-prone areas is often the most cost-effective way to protect communities locally and remains a valuable option in the flood risk manager’s toolbox. It is nevertheless good practice to study potential negative impacts, as this type of measure usually increases flood risks downstream. The reduced “room for the river” will lead to faster flood propagation downstream and higher peak flows, which may threaten downstream settlements, embankments or infrastructure such as bridges. Therefore, it is good practice when embanking to implement compensatory measures, such as additional retention capacity elsewhere.

7.6.6 Exposure/vulnerability reduction strategies (primarily non-structural)

Another approach to reducing the overall flood risk is to reduce its exposure and/or vulnerability components. This is generally (although not exclusively) achieved using non-structural measures, which focus primarily on reducing the vulnerability of people, assets, and economic values in the flood- prone area (or moving the exposure out of harm's way entirely). Although these measures generally don't prevent or even reduce the flood itself (i.e. the hazard component remains unchanged), they can nevertheless have significant impacts on the losses incurred by that flood. For this to happen though, it is critical that the community at risk is fully engaged and that citizen preparedness is encouraged. Therefore, clear, widespread and repeated communication of the flood risk and the mitigation measures available and/or encouraged is necessary.

An added advantage of non-structural measures is that they are often more cost-effective than structural measures (although this can be harder to assess/quantify), and frequently have multiple benefits above and beyond their flood management role. In any case, given that full flood protection by structural measures is not realistic (meaning that complementary non-structural measures are always needed to help cope with the inevitable large flood events), a good flood risk mitigation strategy should always have a good balance between measures of both types.

An under-appreciated point is that the higher the level of structural flood protection that's implemented in a hotspot or river basin, the more need there usually is for complementary non-structural measures (contrary to what might be expected). This is particularly the case in areas where significant exposure (human or economic) in a flood-prone area is protected by massive embankments (or other structural protection), lulling local residents and businesses into a false sense of security. When a flood does occur (as it must eventually), they are likely to be unprepared and losses to be significantly higher than they might've been if the embankment protection had been supplemented by continued awareness-raising and evacuation exercises.

The following sections present a number of specific non-structural measures which may be of relevance to the various flood hotspots around the state of Uttarakhand. Note that these and more are discussed in great detail in Jha *et al.* (2012).

7.6.7 Raising awareness of flood risks

Flood risk awareness is the cornerstone of non-structural flood risk management, as most if not all other non-structural measures are predicated on all stake-holders recognising the risk and also that mitigation is both possible and effective. Awareness may be naturally high in areas which flood often but low in others where floods tend to be low frequency but high impact, or where many residents may be transient and don't have a long-term memory of past events (such as slum areas along river banks).

Awareness-raising is often accomplished via events at schools and community or religious centres, but can also be broadcast via television, radio, advertising, text messages, street theatre, social media, promotion by celebrities and vehicle-mounted loudspeakers (ICDO 2009). Past efforts suggest that the main targets should be:

- To trigger local debates around flood risk issues relevant to that specific community; and
- To focus on risk which can be at least partially mitigated against and highlight the practical actions that can be taken

If possible, these awareness-raising efforts might also include information on how best to protect individual and public health during and after a flood, looking at basic hygiene, water treatment, preventing contamination of water and food sources, etc. This has been shown in other countries to help prevent the outbreak of water- and vector-borne diseases in temporary shelters following disaster events, which can significantly exacerbate flood impacts.

An additional method of raising (and sustaining) awareness of flood hazards is to build visual cues into the landscape, such as marking previous flood levels on buildings, bridges, poles, etc. These serve as a useful reminder to local residents, who are otherwise likely to gradually forget the severity of past events as time passes. Figure 7.7 presents some simple examples from around the world.

Figure 7.7: Examples of visual reminders of flood levels, in Germany (left & centre) and the UK (right) (Source: http://floodlist.com/dealing-with-floods/flood-high-water-marks)

7.6.8 Forecasting, early warning and information systems

One of the most important non-structural components of an effective flood risk mitigation strategy is the timely provision of accurate and actionable information support before, during and after a flood disaster. A good flood forecasting and early warning system (such as the example shown in Figure 7.8) is an essential part of this. As flood forecasts becoming increasingly accurate (given the greater availability of data and ever-increasing computational power), they can support planning and – particularly for large river basins such as those in Uttarakhand – provide sufficient lead time for significant reductions in flood damages and losses.

The four main essentials for an effective early warning system are as follows (Jha *et al.* 2012):

- Detection of conditions likely to lead to flooding (e.g. rainfall, rising water levels, snowmelt, etc)
- Forecasting/modelling of the flood hazards likely to result from those conditions
- Appropriate broadcast of clear warnings via locality- and recipient-relevant messages
- Subsequent response to the warnings, following pre-prepared emergency plans

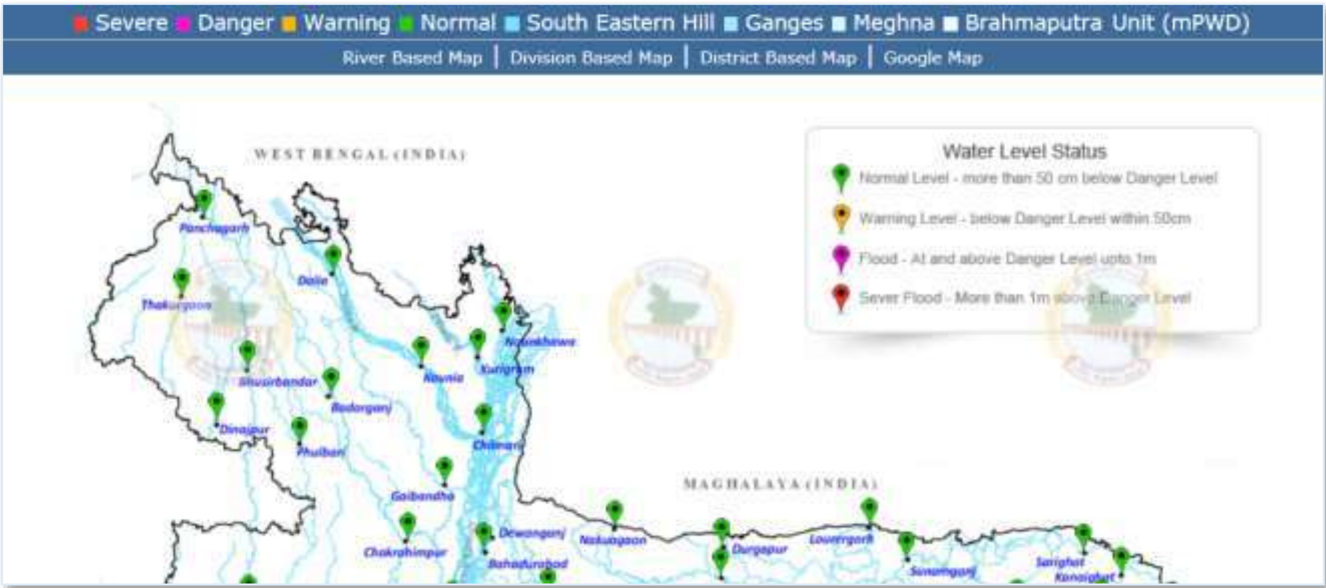


Figure 7.8: Screenshot from Bangladesh's "Flood Forecasting and Warning System" (http://www.ffwc.gov.bd/)

To complement flood forecasting, there is also a need for a good information system (dealing with critical infrastructure, evacuation routes, shelter etc.) to enhance preparedness, support early warning during flood emergency operations, and to coordinate and inform post-disaster recovery efforts.

7.6.9 Land use planning and flood zoning

Particularly in urban areas, the control of development through the incorporation of flood zoning into land use planning can reduce flood risks by allowing natural processes to occur, such as storage or the flow of floodwaters across the floodplain and reducing the exposure of communities and economic assets to the hazard. Conversely, a lack of guidance may put communities at risk through inappropriate development that puts people/assets at risk in flood-prone areas, prevents natural processes and intensifies the flow of water through increased hard surface areas.

Flood zoning by likely hazard can also inform building codes, such that any developments planned in flood-prone locations (despite the risk) should have to follow appropriate standards, including the use of flood-resistant building materials, building thresholds of a sufficiently-high level, etc.

However, the difficulty in implementing and enforcing these approaches within Uttarakhand's context is acknowledged, given the rapid rate of development in urban areas, the limited land available in many places (particularly in the hills) and – to a lesser extent – the possibility of bribery/corruption to circumvent regulations.

7.6.10 Flood insurance and other risk financing

Insurance and other risk financing measures have two main purposes in flood risk mitigation. Firstly, to offset financial risk from flooding, by supporting the post-flood recovery of those affected without placing excessive financial burdens on them. The advantages of flood insurance are clear, as recovery can be expedited, and funds are not diverted from other priorities such as development. Particularly for low frequency but high impact events, insurance spreads the risk of financial loss, centralises the holding of disaster reserves, and should therefore be a more efficient method of financing disaster recovery. Governments are increasingly considering insurance as a risk management option, to the extent that reinsurers such as Munich Re expect insurance in developing countries to be a major opportunity in the twenty-first century (Spranger, 2008).

The second (and indirect) benefit of flood insurance and other risk financing schemes is to reduce risk, due to the need for detailed and accurate risk assessment studies and associated incentives which encourage risk mitigation (Cummins and Mahul 2009; Kunreuther 2002). If risk is correctly assessed and priced, then the incentive to mitigate risks exists via premium pricing. Many insurance contracts also (implicitly or explicitly) require the policyholder to undertake reasonable risk reduction and mitigation activities.

Other risk financing schemes can also be used to support reduced vulnerability in future. For example, post-disaster compensation can be targeted to prioritise resilient reconstruction, whilst tax schemes have the potential to influence many aspects of reconstruction, including the use or set aside of flood-prone land.

7.6.11 Disaster response plans

It is crucially important to recognise that even after the implementation of an appropriate set of structural and non-structural mitigation measures, some residual flood risk will always remain. Thus, it is essential to plan for how to deal with flood events that exceed the measures in place and their likely aftermath. This involves multiple activities that can be included as part of a flood emergency plan, including but not limited to the following:

- Emergency planning: identify internal and external organisations, establish clear command structures and roles/responsibilities, and facilitate inter-agency cooperation
- Damage avoidance: establish actions that can be taken if sufficient lead time is available (e.g. installing temporary flood barriers, moving property to higher levels, etc)
- Evacuation and rescue: Initial efforts will depend on existing resources (transportation, fuel, food, safe high ground nearby, rescue equipment, etc), so these should be identified in advance

7.6.12 Other Actions

There are many other non-structural mitigation measures appropriate to flood risk. A few more are summarised briefly below, while the reader is referred to Jha *et al.* (2012) for further types and numerous examples/case studies that illustrate how they've been used in other countries.

- Business and government continuity planning (BGCP): Assess the ability of government, the private sector and individuals to continue delivering their most critical services during and after a disaster and address any weaknesses identified.
- Solid and liquid waste management: Solid waste frequently blocks drains and fills local depressions, exacerbating flood hazards, while poorly-handled liquid waste can result in water/food contamination and contribute to post-disaster disease outbreaks.
- Flood recovery and reconstruction: This should aim to ensure first that normal life/operation of the affected area can resume as soon as possible (despite ongoing reconstruction), that full reconstruction doesn't take too long, and that communities "build back better" wherever possible.

7.6.13 Summary of potential flood risk mitigation strategies

Based on the flood risk mitigation principles and broad strategies discussed above, Table 7.3: Summary of potential flood risk mitigation strategies by type & primary objective summarises a wide range of measures, in terms of type (structural and non-structural) and also their primary objective (targeting either the reduction of flood hazards or of exposure/vulnerability).

Table 7.3: Summary of potential flood risk mitigation strategies by type & primary objective

Type	Primary objective	Measure
Structural	Reduce hazards (using flood volume retention)	Construction of reservoirs Allowing river to reclaim floodplains Creation of pumped storage
	Reduce hazards (by increasing conveyance capacity)	Increase channel conveyance capacity Construct dikes/embankments Construct diversion canals

Type	Primary objective	Measure
		Temporary flood defences
	Reduce exposure and/or vulnerability	Construction of floating houses or houses on stilts
		Construction of flood-proof buildings Construction of elevated highways Elevation of terrain in new urban developments
Non-structural	Reduce hazards	Reforestation of river basin Improved operating rules for upstream reservoirs Enhanced infiltration in river basin Rules for agricultural practices
	Reduce exposure and/or vulnerability	Forecast & early warning systems Land use planning & regulations Building codes + enforcement Property acquisition & resettlement of people Raising flood hazard awareness Disaster response plans Post-flood recovery services Flood insurance

7.6.14 Reduction of Flash Flood Risk

Flash flooding can be caused by intense rainfall events (cloudbursts) can be very localized and occur in remote, isolated and inaccessible areas. Events can be very unpredictable and of extreme magnitude: economic impacts are nearly impossible to mitigate in many case so there focus should be on minimizing human losses.

- The warnings do not necessarily need to rely on real-time hydrological modelling. Hydrological analysis could be used to define trigger levels of rainfall intensity that could potentially lead to either direct flash flood or landslide that might subsequently to dam break type of flooding. The system needs to be integrated with local knowledge and communities involved in the development and operation.
- Response enhanced with local supply (food, health) stored locally
- Evacuation routes clearly defined and emergency response communicated to the public through education, leaflet, signs, locals or in transit
- Data and scenarios: the discharge data (SHP) provided can be used to identify the nearest intensity at a specific location for a specific event. Discharge could be established locally in a

post event scenario by looking at water level and previously established rating curves. The provided discharge data in the DB give a very large range of possible scenarios that should cover any hydrological conditions including very unlikely events

- Risk transfer: Micro-insurance could be established for flash flood (ideally pooled with other states – Himachal Pradesh…) – the correlation between flash flood is still high (exposure and risk concentrated in the Ganga river basin)
- Slower onset of events: traditional flood forecasting useful. Warning, education, communication and evacuation routes to be communicated particularly to the most vulnerable communities living in the most exposed areas and transient tourists -> Preparation and response are critical for those population groups
- Larger floodplains = water level variations between events RP lesser than in the mountains. Higher quality DEM data would help increase the accuracy of zoning. Higher rainfall accuracy less important (law of large numbers: larger catchment -> error averaging across space) than terrain accuracy.
- Walls and large structural measures should be used with caution as structures can fail. Localized flood proofing of buildings should be required in flood prone zone (protected by wall or not).
- Data and scenarios: same as above
- Risk transfer: flood risk transfer mechanisms needs pooling with many other states to be potentially viable

Dehradun:

- Flash flood early warning system as for the mountains, but impact less important (lower velocities and discharge expected)
- Zoning very important (high exposure – low magnitude events) as well as flood proofing
- Wall structures combined with building flood proofing (ideally avoid walls and favour planning (do not build here) or local proofing (flood events are short duration) to avoid transferring the problem from one place to the other.

Case study: Building community capacity for flash flood risk management.

Four flood early warning systems were installed in four flood-prone villages in the upstream section of the Jiadhal Rive

These villages were selected for their proximity to the foothills in the upstream section, cooperative villagers, and accessibility during floods. The instrument used in the early warning system was a simple flood alarm device consisting of a flood gauge and a rain gauge calibrated with risk levels by consulting the villagers.

The installation and maintenance of this system is simple enough to be handled by the community. The members of the family hosting the instruments and other selected individuals in each village were trained to install, operate, and maintain the flood warning system as well as to interpret the warning sirens. A home light unit that works on LED, along with a mobile phone and charger, were given to each host family.

The flood warning instruments installed by the project have provided communities with early warning of flash flood waves on six occasions between August 2010 and August 2011. In each of these flood events, the flood alarms woke villagers during the night or early morning drawing their attention to the rising water level. The villagers remained alert and disseminated the flood information to downstream areas using mobile phones. As a result, the downstream communities had lead-time of one to one-and-a-half hours to move people and valuables to safe areas.

During the flash flood that occurred on the night of 25 August 2010, the flood warning system implemented under the project enabled the people of the village Dihiri to save livestock (mainly pigs and some poultry) worth about USD 3,500 and other valuables.

Source: Partha J Das in Shrestha, AB; Bajracharya, SR (eds) (2013) Case studies on flash flood risk management in the Himalayas: In support of specific flash flood policies. Kathmandu: ICIMOD

See: https://unfccc.int/climate-action/momentum-for-change/information-and-communications-technology-solutions/community-based-flood-early-warning-system-india

7.7 PRIORITY 6: REDUCTION OF SOCIAL VULNERABILITY

7.7.1.1 Reducing Vulnerability

There is a need for reducing vulnerabilities and putting more emphasis on recovery from disasters to mitigate future risks and to reduce the causal factors of disaster. Prevention, mitigation and preparedness are less costly than disaster relief and response. This requires multi-stakeholder and multi-sectoral planning when investing in disaster risk management as a means of building disaster-resilient societies. Disaster risk management strategies are for prevention of new disaster risks, reducing existing disaster risk and managing residual risk. In this way, these strategies contribute to the strengthening of resilience and reduction of disaster losses. The purpose is not just looking at the impact of disasters but also at what makes communities vulnerable to multiple shocks and stresses before disasters occur.

Thus comprehensive vulnerability assessment is significant to aid and ensure the safety and wellbeing of communities, as it can assist with all phases of the disaster management cycle. Knowing the location of vulnerable communities more effectively targets and supports community-based efforts to mitigate and prepare disaster management interventions. Vulnerability is only one component of a larger equation that also includes the hazards itself, fragility of physical infrastructure, and community assets or other resources that may help to reduce the effects of the hazards. Comprehensive vulnerability assessment assigned to spatially identify vulnerable populations helps more completely understand the risk of hazards to vulnerable population, and to aid in mitigating, preparing for, responding to, and recovering from disasters.

7.7.1.2 *Understanding Vulnerability*

In assessing disaster risk vulnerability can have several meaning or contexts, e.g. the loss of life or injury, loss or damage to assets and infrastructure, economic impacts, and usually there is course a political dimension as well. Therefore, by defining the vulnerability just with the structures, the effect on the individuals and communities cannot be assessed properly. For example, although the building is seen in unsafe condition in any earthquake, it is the inhabitants of that building who are vulnerable. In managing these risks there are structural and non-structural remediation and mitigation. All of these concepts though are driven by the underlying issue of vulnerability. This is reflected in the normally accepted definition of vulnerability which is; "t*he characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impacts of natural or man-made hazards*"[21]. This definition scales people as being anything from an individual to a group be it a family, community, panchayat through to a State or Nation. Vulnerability in these terms has two facets. The first is the external attribute of risk, shock or stress to which an individual, household, community etc. are subject to; and the second is the internal which is emotional inability, defenselessness, that comes with the need to deal with damaging loss.

In short, individuals or communities that may face the same risk will not be equally vulnerable, some people experience higher levels than others. Thus, the term 'vulnerability' is to mean those who are more at risk and are at the worse end of the spectrum. It has a time dimension built into it, it is not just as what happens to life and property at the time of hazard event, but the future damage and loss that must also be considered. Strongly vulnerable groups are those that find it

[21] International Federation of Red Cross and Red Crescent Societies, (2000)

hardest to reconstruct and overcome following disaster, and this in turn makes them more vulnerable to the effects of subsequent hazard events.

The identification of the community's vulnerability gives a clear picture of at risk and susceptible groups, which can be called vulnerable groups. By identifying these vulnerable groups, better disaster management strategies can be developed, preparedness plans can be undertaken and better public awareness interventions can be developed in the pre-disaster phase. Besides, for during- and post-disaster interventions, the resource allocations can be organized fairly considering the vulnerability level of the communities.

7.7.1.3 Increasing Community Resilience

In addressing the issue of reducing vulnerability it is important to recognise the idea that the ability of people to resist and recover from a disaster depends not only on the magnitude of the events, but also on their social and economic conditions, such as their education, health and income levels, availing the basic amenities and access to essential services, resources and connectivity. The impacts of a natural event upon a population vary considerably depending on the socio-economic attributes of the people exposed to it. Disaster marks the interface between an extreme physical phenomenon and a vulnerable human population. It is of paramount importance to recognise both of these elements. Without people or and exposure there is no disaster. The two elements are basic to an explanation of an increase in the occurrence of disaster[22]. The vulnerability that leads to disasters is much more than normal environmental events and it refers to the socio-economic and demographic factors that affect the resilience of communities. Most studies show that in extreme natural events the most vulnerable are more likely to be adversely affected, they are the most likely to be susceptible and less likely to recover from the impact of hazards[23].

The disaster risks can be extensive and intensive, frequent and rare, sudden and slow-onset, from natural causes i.e. geological, meteorological, hydrological and climate-related; and man-made i.e. technological and environmental degradation. A multi-hazard approach is to be considered that recognizes that they can be sole, with sequential, accumulative and or interrelated effects.

In addition, it is also important to recognise that, as with all aspects of the disaster management programme process, mitigation and preparation play a major role in increasing community resilience, i.e. reducing vulnerability. The preparedness for any threat is important, which decrease the destructive effects of it for the communities and shortens recovery. The disaster risk management and disaster resilience should not be seen as a stand-alone set of activities but as a means of bridging the gap between development and humanitarian programmes as well as a means

[22] Barry E. Flanagan, Edward W. Gregory, Elaine J. Hallisey, Janet L. Heitgerd, and Brian Lewis, 2011; A Social Vulnerability Index for Disaster Management

[23] Phil O' Keefe, Ken Westgate and Ben Wisner argue the case that disasters are more a consequence of socio-economic than natural factors. Taking the naturalness out of natural disasters, 1976

of mainstreaming socio-ecosystem thinking within overall approach and regular programme activities. Building disaster resilience, rather than disaster risk reduction alone, is that a disaster resilience approach as a holistic concept includes both ‘traditional’ disaster risk reduction concepts such as mitigation, prevention and preparedness, but also encompasses approaches for resilience-oriented response and recovery interventions in the aftermath of disasters.

7.7.1.4 Vulnerability in Rural Environment

Vulnerability in rural settlements is defined as characteristics or qualities within social systems that create the potential for loss or harm. Since it is difficult to measure vulnerability in relative terms, one of the most common approaches for performing a vulnerability assessment i.e. the use of a set of composite proxy indicators is adopted. Here, there as a general consensus within the secondary literature about some of the factors that influences the vulnerability of populations. These include pre-existing characteristics of populations and economies such as age, gender, marginalised group, housing, availability to resources, and affordability to household basic amenities. Other characteristics include the level of access to education, healthcare, communication, connectivity, institutional resources and access to services, and geographical terrain- village elevation and slope. The other things being equal, generally the most vulnerable people in rural settlements are likely those living at the margins who are most susceptible to risk and uncertainty. Marginality in this context is considered in various ways as: socio-economic—people who, for social or economic reasons, are outside the mainstream and geographic— people who live in very isolated locations and who as a result are often socio-economically marginalised.

The larger part of the Uttarakhand state is characterized by a difficult terrain, undulating topography, remote and inaccessible villages, sparse population, tiny land holdings, an agriculture based economy and weak infrastructure. Unsafe conditions in mountains are commonly attributed to inaccessibility, isolation, backwardness and fragility. The region is rich in beauty and natural resources, however improper use of these resources and rapidly growing populations has thwarted its development and consequently certain rural areas are technically backward and economically poor. There are certain villages only accessible after a hard day of walking, and numbers of villages are very difficult to access during the rainy season, thus creating difficult conditions for humanitarian and development assistance. The vulnerable rural settlements in hill region districts are in strong contrast to plain region districts, living condition being extreme, women carry an important share of workload in the villages. In recent years riverside road alignments have been preferred over ridge alignments, where road go, people, homes, shops and business follow and habitations along riversides roads become unsafe. Increasingly people also move to relatively lower Himalaya areas for schooling and job opportunities. Migration coupled with socio-economic differentiation is re-configuring people’s vulnerability to natural hazards.

The inter district inequality in infrastructure leads to increasing disparities in terms of income and livelihood between hills and the plains. Low levels of income not only result in low levels of consumption and materials deprivation, but also constrain human potential by restricting access to education and health facilities, thereby creating a vicious cycle of poverty, which increases the vulnerability to any event of hazards. Historically mountain communities have developed certain resilience and coping strategies by drawing on a keen knowledge of their habitats. However, as the socio-economic contexts change, especially those driven by outside forces, so too have communities' abilities to grapple with conditions.

7.7.1.5 Vulnerability of Urban Environment

Factors contributing to social vulnerability in urban settlements are similar to those in rural settlements on terms of the relevance of social and economic conditions, but the effect of these are expressed in a very different way. In urban areas the man-made environment itself, the infrastructure support and the substantial increases in population density overall contribute in a way not seen in the rural environments of Uttarakhand.

In recent years Uttarakhand has experienced rapid urban growth due to population increases from rural migration, the emergence of rural growth centers, the development of tourism, improved access to markets, and the lack of effective land use policy, leading to land use intensifications and depletion of natural resources. In the 10 year period between 2001 and 2011 urban towns have increased from 86 (Census of India 2001) to 116 (Census of India 2011) and a 30.23 per cent growth in numbers. In 2011 more than 3 million people lived in these fast growing and emerging urban towns, and the numbers of semi-urban areas like centres have increased many folds as well. Consequently, there has been tremendous increase in density, intensity and complexity of urban settlements leading to changes in land use from agriculture lands (and forests/ other lands) to residential, commercial, and institutional areas.

The state has limited arable lands and yet the agriculturally productive peri-urban areas are now being encroached by speedy urbanization. Moreover, rapid urban growth, largely informal, unplanned/ squatter settlements, has disrupted natural resources. Depleted forests and biodiversity, increased risks of natural hazards and potential to disasters in urban areas as well as in their peri-urban zones, and greater vulnerability of mountain inhabitants are increasingly evident. The open spaces (forests areas, water bodies/ rivers beds/ rivulets are being squeezed because of encroachment of urban expansions, squatters/ slum dwellers, and/ or used to dump solid wastes.

In the event of a sever hazard in these environments, the resulting devastation may be sever as most buildings are not expected to stand up to a quake as a result of the extent of modern construction without engineering input and meeting of building codes. The unsafe conditions are the specific forms in which the vulnerability of population is expressed in time and space in conjunction with hazards, people having to live in hazardous locations, being unable to afford safe buildings, lacking effective protection by the state.

Rural–urban migration for better employment opportunities, health and education services, etc. are largely the reason an urbanisation process resulting in land pressures as migrants from outsides move into already overcrowded towns. The new arrivals, particularly of low-income families have little alternative other than to occupy unsafe land, construct unsafe habitations, live within squatter settlements, and/or work in unsafe environment. Slum dwellers often incur greater risks from natural hazards as a result of having to live in very closely-built structures which can disturb natural land drainage patterns and water course. The marginalised communities may have little choice but live in poorly constructed housing as urban squatters at unsafe sites. For them, natural hazards are usually subordinate to other basic survival needs and to human sources of risk and vulnerability

7.7.1.6 Conclusion and Recommendations

The following is abstracted from the social vulnerability assessment under taken by Negi (2018) for the DRAU project.

The vulnerability of people/ community or region is inseparably linked to the social, cultural and economic processes of development and the environmental transformation of the state of Uttarakhand. The variations of vulnerabilities classes at settlements level (both rural and urban) illustrated that they are the product of social development or inadequate development; reflect deficits, shortages, inequalities or disruptions within socio-economic development in the region.

By and large the vulnerability is determined by social systems and not only by the severity of natural forces or events. Poverty and lack of employment opportunities, access to health and education, basic amenities, access to services and resources are important concerns of the rural communities, and this has been manifested in large-scale migration from the rural to urban areas. Moreover, it reduces the socioeconomic resilience of communities against hazards and emergency situations in both environments.

Uttarakhand is inherently fragile to natural event led disasters such as cloudbursts, landslides, flash floods, floods, glacial lake outbursts and earthquakes. Climate change is also increasing the frequency of such natural events. What must now be dealt with to prevent worsening the situation it to mitigate impact from unregulated, unscientific, unsafe and unplanned infrastructure development and road construction, hill slope cutting, deforestation, encroachment to river flood plains, water streams, and infrastructure projects built in the fragile zones, concrete houses without proper measures, and other regulatory checks and balances.

The opportunity exists for disaster risks to be minimized by use of indigenous knowledge and modern technological interventions. To safeguard against accelerated degradation and improve the living standard of vulnerable communities, there is need to address area specific issues through systematic and affective integration of the ecosystem service and development. The ever present threat from devastating landslides, earthquake, flood etc. remains unless replicable and area specific development policies are brought to bare.

It is a firm conclusion here that explicit priority be given to the involvement of multi- stakeholders in strengthening the capabilities of state, district, block and community. This conclusion is entirely consistent with emerging global values and thinking as to how community resilience can become a major factor in reducing social vulnerability.

The coordination and corroboration of the relevant organizations/ institutions, NGOs/ CBOs will be important in terms of sharing expertise, experience and resources of scientific and technical knowledge base, information/ data on hazards and disaster risks, disaster mitigation planning and management etc. beside the community participation. The possibility exists of enlarging the coordination consortium to involve various organizations/ institutions increases the potentialities of reaching sustainable solutions when dealing with complex disasters, and further strengthens the existing institutional framework for disaster management at State, Districts, Blocks and community levels. See for example UNEP 2008.

The community, as the stakeholder and recipient of the direct impact of disasters, need to be involved in the process of decision-making and implementation of activities. Community empowerment for disaster risk management demands their participation in risk assessment, mitigation planning, capacity building, participation in implementation and development of system for performance monitoring which ensures their stake.

The micro mapping of hazards profile and anecdotes historical timeline, seasonality of natural hazards prepared by community people can be a vital repository for disaster risk management and strategic planning. The participatory risk assessment will provide the community and support role-players with disaster risk specific baseline data that should be integrated into the USDMA Disaster Risk Data Base (DRDB) and used in Disaster Risk management planning for development planning purposes. This could be seen as risk reduction programmes designed primarily by and for the people in disaster-prone areas. It has been shown from past assessments that disaster mitigation using government and institutional interventions alone is insufficient because they pay little attention to addressing the community dynamics, perceptions, knowledge and the likelihood of being first responders. Stakeholder acceptability of structural and non-structural innovations e.g. methods and techniques, should be taken into account in the interests of project sustainability. In addition, promotion of self-organisation by the affected population and consideration of traditional and local knowledge are of fundamental importance for sustainability. Based on the recognized local needs, existing policies and institutions with a more participatory approach, should aim to strengthen effective coping mechanisms to enhance the resilience of communities.

7.7.1.7 Strategies for Reducing Social Vulnerability

The following are presented as overall strategies to address social vulnerability. They represent the social context for the broad statewide strategies presented above. At same time, many of the strategies proposed here transcend levels of governance and are relevant, not just at a state level but right down to an individual village level. These strategies are based upon the paradigm that disasters are a product of the social, political, and economic environment within in which people find themselves as distinct from the natural environment, and this is because of the way these factors structure the lives of different groups of people. Perception may also play a role in community resilience and differences in perception and response, coupled with differences in people's socio-economic characteristics and circumstances, result in a wide range of vulnerability in any community. Vulnerability to any external changes is mediated through certain inherent preconditions, like those of resource availability, infrastructure availability and institutional access, and hence varies within a community. Social aspects of risk interpretation must be recognised if risk is to be effectively managed, and community participation in the practical management of the problem faced is a vital component of this approach.

Recommendation	Drivers	Outcomes	KPIs
Mainstreaming Disaster Resilience- into all sectors development plans and programmes, schemes, to avoid duplication and ensure unified and efficient use of existing capacities and resources.	Mainstreaming disaster resilience is especially important in integrated planning as this is where to bring in non-traditional emergency actors, looking beyond disaster management authorities, to include all sectoral agencies and other actors who are involved in addressing the underlying causes of natural disasters.	Disaster risk management more inclusive in sectoral planning and adequate resources allocated for implementation. The communities and local authorities coordinating for ensuring the application and replication of best practices, strengthening the sustainability of disaster risk management actions and encouraging a multiplier effect.	Disaster risk management is the integral part of all the sectoral development plan. Disaster risk management programme at the sectoral level improved. Hazard information integrated into sectoral development planning and programmes.
Increase Access to Basic Services- road communication, telecommunication network, drinking water, sanitation, electricity, health, education, etc.	Properly accessible provision of basic services constitutes significant factor in disaster risk management. Inadequate basic services are obstacles to development and innovations. Communities with spatial and institutional marginalization lack resources, knowledge and experience in risk preparedness and response.	Development of basic services infrastructure and facilities drinking water, electricity, road and communication, banking facilities, health and education etc. Promotion of appropriate technology at low cost and environment friendly e.g. use of water power mills in generating hydropower.	Availability of adequate basic services and accessible to communities.
Micro-zonation and Micro-mapping- of previous and upcoming hazard prone areas and its origin causes, ground characteristics,	As part of a resilience approach, micro-zonation and micro-mapping can be deployed to aid local level planning, increase community awareness of the hazards they face and ensure	Development of topographical hazards maps and resources maps at settlements level using satellite imagery/ GIS technology, rapidly collect	Detail mapping at settlement levels with anecdotes historical/ timeline data on natural events/ hazards. Community based repository

Recommendation	Drivers	Outcomes	KPIs
vulnerability and integrated risk, historical qualitative or anecdotal information/ data with the help of modern science and local public.	more targeted interventions that reduce the risk of disasters.	primary and secondary data to facilitate inter-agency coordination and decision making.	at settlement level is developed.
Building a Culture of Risk Management- Strengthening communities' capacity to prepare for disasters, shocks and stresses and implement timely responses. The skills and resources needed in order to scale-up and react to the crisis.	Despite mitigation measures, communities coping capacities might be overwhelmed following a shock event. Strengthening local governments' and communities' capacity to prepare for disasters, shocks and stresses and implement timely responses is vital.	Disaster risk management structure operating in place for resilience-oriented response and recovery interventions in the aftermath of disasters, emergency response and relief activities to save lives, reduce health impacts, ensure public safety and meet the basic needs of the people affected.	Skills and resources and standard operating procedures in place at all levels. Communities are mentally well prepared and strengthened.
Promote Natural Resource Management through adoption of practices that maintain the long term ecological and biological integrity of natural resources to strengthen resilience.	The region is eco-sensitive; man-induced changes i.e. road construction, building construction, hydro power, etc. have larger implication on natural resources. Vulnerability of the region exacerbated as anthropogenic interventions triggering of disaster which inflicts irreversible damage to ecology of the region, besides property and loss of life simultaneously.	Land use policies can be counted among the potential agent of land use change in the region. A land use programmes/ schemes guidelines implemented and decides the nature of present and future land use pattern for a better environmental system to live. The programmes and schemes to address area specific issues through systematic and affective integration of the ecosystem service and development.	A coherent land use policy in place or of environmental guidelines and regulatory oversights sensitive to mountain needs and contexts.
Sustainable and Diversifying Agriculture and Alternative Livelihoods- to increase agricultural productivity, including cluster approach, animal husbandry, horticulture, organic farming, floriculture, tea plantation, herbal, medicinal and aromatic plantation, forestry, fishery and aquaculture, handicrafts subsectors, etc.	Very low percentage of area is irrigated out of the net shown area mainly because of the hilly terrain. Yet these areas can also be considered sensitive, as any changes in rainfall will have a direct impact on cropping patterns.	Diversified agriculture practices in the region, various supportive/ promoting schemes and programmes implemented	The augmentation of agro produce and a significant increase economy.
Building Back Better- Restoration and improvement of facilities, livelihoods and living	In order to address root causes of vulnerability and future risk, including ensuring that homes and infrastructure is rebuilt in a	Construction of homes away from areas of hazards prone/ unsafe place and ensuring that basic facilities are	Safer and Fairer housing, basic amenities, and livelihoods resources in the regions.

Recommendation	Drivers	Outcomes	KPIs
conditions of vulnerable communities, hazards prone areas including efforts to reduce disaster risk factors.	way that it will not be impacted by future hazards.	protected from the impacts from hazards.	
Instituting incentives- Remove unsafe buildings and buildings on unsafe sites or, more probable, to upgrade their level of safety; to encourage future development on safer sites and safer methods of construction.	The buildings and settlements unsafe, due in part to the lack of enforcement of building regulations. The combination of this rapid and unregulated growth increases disaster risk, threatening existing and planned investment and, ultimately, the future of the residents in the region.	Established institutional mechanism and financial incentives for encouraging safe building at safe sites. Updating and enforcement of safety standards and construction codes. Rehabilitation and reconstruction planning. Increased public private investment in risk reduction.	All building/ housing are safeguarded and protected.
Strive for Sustainable Habitat Sensitive to Mountain Needs and Context- Planned urbanisation, peri-urban/ semi-urban areas, and promote appropriate building technologies for rural habitation, in order to reduce environmental hazards, collateral damages, human sources of risks and vulnerability.	Increasing population linked with accelerated urbanization has detrimental impacts on land resources. Where roads go, people homes, shops and businesses follow. Habitations along roadsides and or riversides peri-urban areas become unsafe. The marginalized population, whether urban or rural, build on the only lands available to them on unsafe slopes, cheapest sites at risk from a variety of natural hazards. The rural housing is transforming to urban like housing of unregulated RCC structure.	Sustainable Habitat programmes/ schemes supported with geo-technical and risk consideration in land use and habitation planning. Promotion of earthquake resistance housing in rural and urban areas. Training and capacity building programmes for local masons to build safer houses. Replication and application of good case and examples.	Habitat policy in place. Housing improvement and human settlement relocation from hazards prone areas.
Promote Tourism- for leisure, religious, cultural, adventure, nature and wildlife, as it can be biggest source of employment and it also creates linkages for local area development.	The region is rich in natural beauty with a unique mountain environment as well as rich historical and cultural assets, and tourism as a major opportunity to create jobs. However, the issues that hinder the effective marketing of the state as tourism destination are lack of awareness of Uttarakhand as a tourism destination, development and operational issues.	Tourism development in an environment sustainable manner to meet wide and diversified demand for tourism in the region from both domestic and international markets in terms of content and standard of facilities and utilities to attracts tourists for pilgrimages, cultural tourism, nature tourism, adventure tourism, wildlife tourism, eco-tourism, and amusement and leisure tourism.	Safer tourism in the regions, basic operational facilities e.g. transportation, accommodation and sanitation at tourism locations.
Effective Legal Framework- regulations/ laws, executive orders, and other legal instruments that set the ground rules for governmental and non-	Disaster management is supposed to fall within the exclusive legislative competence of the states with the central government having no or very limited say in the matter. The state is fairly deficient on having a	Developed policies, regulations based on information reviews that are drawn on to establish appropriate courses of action; legislation identifies explicit decisions about how a	The comprehensive framework of policy, along with legal and institutional arrangements is in place.

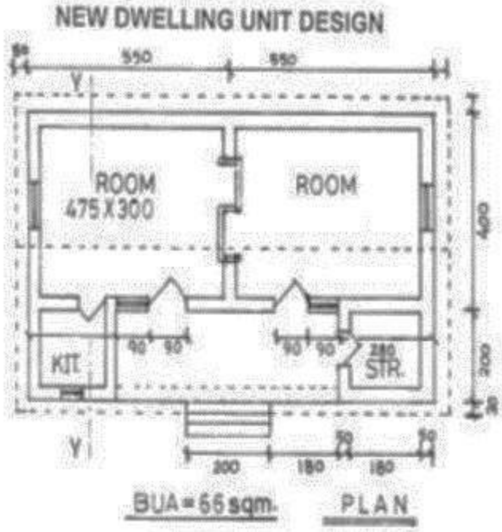
Recommendation	Drivers	Outcomes	KPIs
governmental activities related to disaster management.	comprehensive constitutional-legal framework of disaster management, and continue with the relief-centric policy without any innovation or improvisation in the policy of disaster management.	particular policy will be conducted and legitimizes those actions; and institutional arrangements identify specific agencies and their relationships for carrying out the missions and duties associated with the policy.	
Demystify the myths though Behaviour Change Communication- to change prevailing attitudes, practices and prevent/ mitigate harm from hazards and reduce disaster, prepare the population before a disaster, disseminate information during disasters and aid subsequent recovery.	People perception of risk is not adequate with the assessed risk, the coping attitude is mainly fatalistic as it refers to God's decision and there's nothing that can be done against it. People, even when they have properly identified the hazard that can affect their community, believe they cannot influence and mitigate it because it's attributed to a "*devik aapda*" (divine intervention), and people perceived that it happens once awhile, and do not fully appreciate the threat level that the hazards pose.	Community awareness and sensitization programmes on disaster risk assessment and management. Combining experience, expertise and long-standing community relationships, local NGOs/ CBOs, and resources of scientific and technical knowledge base, information/ data on hazards and disaster risks, and support capacity building for community resilience.	Community preparedness and trainings activities. Strengthened and sustained capacity for a culture of safety and community resilience

7.7.1.8 Case Study: Building Back Better - Community Based Earthquake Resistance Rural Housing in Uttarakhand Hills (by Mr. Ravinder Singh Negi, July 2018)

A village Aungi in Uttarkashi district was rehabilitated at a complete new site following the earthquake of October 20, 1991. Most of the houses in village were damaged, but Aungi was left uninhabitable because of the post-earthquake risk of rock fall. Houses suffered rear wall bulging, partial collapse and delaminating of stones wall masonry. Single RCC roofed house suffered severe cracks and some new houses suffered corner damage and collapse of some walls. Though Aungi did not suffer any deaths the neighbouring villages of Maneri, Didsari, Jhamak and Sainj within the epicentre tract suffered severe damage and loss of lives - more than 200 deaths.

The villagers exploring alternate sites on which they could relocate the village. With the assistance of a NGO (CASA), an assessment was done by villagers drawing on their long experience of site quality, especially micro-climate, pest-proneness, and access to natural resources. This was combined with a detailed technical assessment of geological risks, site development costs and other environmental factors. Detailed discussions were held with members of various community groups. The community then chose the best plausible option, close to the existing village so the same amenities could be used.

The complete village was reestablished at the new site with proactive participation of villagers, promoting local building materials with appropriate technology adoption for constructing earthquake resistance houses. Altogether 53 housing units were constructed with variation of three, two and one room house units according to the number of families they had to accommodate.



The foundation was tied to the plinth beam and plinth beam tied to RCC columns at the corners which in turn were tied to the lintel beam. Foundations were designed taking the form of a human foot and in the case of natural disaster the wall would tend to fall to the outside.

The supporting roof truss anchored in lintel beam and wall sandwiched between plinth beam and lintel beam. The walls are made of stone laid in mud mortar further tied up by systematically laid thru stones with bands of concrete at various strategic levels. Heavy timber rafters support the CGI roof on top.

Retaining walls in stone masonry, provided with weeping holes, longer thru stones at 0.9mt intervals in alternate courses bound the wall. The concrete cast corner was designed with 2 off x 12mm diameter vertical bars. Lintel beams were laid with MS bolts to tie door and window chowkats and the wooden truss frame. Local masons were trained on these earthquake resistant construction techniques so that community could benefit in the longer term.

The site visit in December 2017 showed that houses constructed in 1991-92 to be in good condition and now occupied by the next generation from the village communities. In terms of the plan as well as the choice of materials, these houses are the nearest to their traditional counterparts, both in terms of orientation and spatial relationships. Living rooms are arranged in a row, all entered from the veranda in the front, apart from these, a kitchen and store has also been provided.

7.8 PRIORITY 7: IMPLEMENT STRATEGIES TO REDUCE THREAT TO TOURISM SECTOR

7.8.1 Background

It is recognised that, if properly managed, tourism has the potential to make a substantial contribution to the achievement of the United Nations' Millennium Development Goals. It is also important to recognise that economic considerations, rather than social and environmental considerations, constitute the dominant force directing tourism development, policies and promotion (UNEP 2008). What this means for many countries, particularly with developing transitional economies, is that the very natural and social assets that attract tourists could very well be sacrificed in the process.

Natural disasters, frequently exacerbated by manmade interventions in the landscape, can cause significant direct and indirect impacts on the growth of tourism and the loss of significant income as a result (see Box below on Nepal's 2015 earthquake).

Tourism features as a prime element in the Uttarakhand Vision 2022[24]. The two goals are:

- Promote the state as a global tourist destination by showcasing its spiritual, cultural and adventure tourism.
- Target 0.5 million international tourists by 2022.

Inflow of foreign tourists into the state increased from 101.97 thousand in 2014-15 to 105.88 thousand in 2015-16.

Uttarakhand is a well-renowned religious and wildlife tourism destination. In 2015-16, a total of 319.06 lakh tourists of which 1.12 lakh were foreign visitors.

There are 21 destinations in Uttarakhand that have the potential to become major tourist destinations. These places include Jageshwar, Baijnath, Saat Taal, Bhimtal, Patal Bhuvaneshwar, Chakori, Someshwar, Pithoragarh, Chakrata, Roopkund, Hanaul, Anson Barrage, Harshil, Dhanaulti

[24] IBEF Brief Uttarakhand May 2017 www.ibef.org

and Dayara meadow. Jauljiwi in Kumaon and Tons in Garhwal division are planned to be developed as adventure tourism destinations.

Uttarakhand Tourism Policy, 2016 was launched in 2016, which aims at developing the state's image as a safe, secure and friendly destination for tourists.

There are numerous avenues for recreation in the state, particularly in key cities such as Dehradun, Nainital & Mussoorie. There is a botanical museum in the Forest Research Institute at Dehradun. The Indian Military Academy has a museum, library, war memorial, arms & ammunition, shooting demonstration room, & an 18-hole golf course. There is another popular golf course in Ranikhet. There are several heritage hotels such as the Chevron Rosemount, Chevron Fairhavens & the Ramgarh Bungalows. There are numerous unique entertainment and adventure avenues including wildlife resorts such as Solluna resort in Nainital, Quality Inn Corbett Jungle Resort & Tiger Camp: Camp Forktail Creek in Jim Corbett Park.

The Nepal April 25, 2015 Earthquake

Nepal's tourism sector has suffered losses worth Rs 44 billion in the aftermath of the devastating earthquake and its aftershocks. The casualties were over 8,790 and 22,300 people were injured. It is estimated that lives of eight million people (almost one-third of the population of Nepal), have been impacted by these earthquakes. Thirty-one of the country's 75 districts have been affected, out of which 14 were declared 'crisis-hit' for prioritizing rescue and relief operations; another 17 neighboring districts were partially affected (NPC, 2015: 11). Among all of the other challenges in the development of tourism in Nepal, the natural disasters are the major challenges to be faced (Kunwar, 2015: 24).

These disasters have heavily damaged the infrastructure of tourism in Nepal, affecting not only the mountaineering, trekking and tour businesses, but also, many cultural heritage sites, shrines, pagodas, temples and archaeological sites-properties over hundreds of years old (Ghimire, 2015)

The overall impact of the earthquake on the tourism sector goes beyond the 14 affected districts in terms of a sharp fall in the number of tourists. The negative repercussions of the disaster are likely to translate into a reduced number of tourist arrivals over the next few years, reduction in tourist spending per day which will significantly affect revenues. Other nations that have experienced similar disasters have generally taken several years to recover fully with regard to tourist arrivals. It is estimated that the overall impact of the earthquakes on the Nepali tourism industry will be a reduction of about 40 percent on average over the next 12 months, and a 20 percent reduction in the next 12 to 24 months (NPC, 2015).

Abstracted from Him Lal Ghimire 2015 Disaster Management and Post-quake Impact on Tourism in Nepal, Journal of Tourism and Hospitality (Vol. 7),pp:37-57

To this end complimentary goals are expressed with respect to increasing power, roads and communications.

7.8.2 Types of Tourism

In considering tourism in Uttarakhand the clear distinction needs to be made between the principal types, namely:

- Pilgrimage
- Cultural

- Natural Beauty
- Adventure & Sport
- Wildlife
- Eco-tourism
- Amusement and Leisure

The term tourism industries include those industries that typically produce tourism characteristic products; it is equivalent to the more colloquial term "tourism sector". The following list identifies such industries:

- Accommodation for visitors
- Food and beverage serving activities
- Railway passenger transport
- Road passenger transport
- Water passenger transport
- Air passenger transport
- Transport equipment rental
- Travel agencies and other reservation services activities
- Cultural activities
- Sports and recreational activities
- Retail trade of country-specific tourism characteristic goods
- Other country-specific tourism characteristic activities

7.8.3 Tourism Related Risk Reduction Strategies

> *Promotion of effective disaster preparedness in… tourism destinations is a governmental function yet requires the participation of all at the destinations.*
>
> ***UNEP 2008***

It is important to recognised that tourism from the DRM point of view needs to be considered in terms of individual destinations and the way people travel to and from these. Even so, leadership in this regard has to come from Government, the industry is a key stakeholder but is not likely to undertake a whole of system approach to the management of the problem. Moreover, policy and regulations may need to be enforced as it has been demonstrated elsewhere that short-term commercial imperatives will frequently overtake long-term benefits to the whole economy and society at large.

Disaster management needs to be systematic and positive in approach DMP should promote collaboration between public, private and community stakeholders and seek proactive responses to perceived threats. Adopting strategies that are positive, integrating and allow changes with changing circumstances is important.

DRM is undertaken as five basic and sequential tasks (UNEP 2008)

1. *Identifying hazard risks:* analyzing hazards resulting from a natural or manmade event, along with an understanding of the full range of probable effects and consequences.
2. *Assessing a community's vulnerability to the risk:* a community's vulnerability may be measured in terms of its size, geographic location, economic status, level of organization, and available resources; infrastructure, and response capability, among other factors. Its vulnerability will therefore depend upon the level of exposure and its capacity to adapt, respond to or recover from the hazard.
3. *Developing a preparedness and mitigation plan:* a plan will be required to address any institutional or systemic weaknesses, which could limit the destination or community's ability to mitigate disaster risks.
4. *Implementing the plan:* implementation may be simulated to ensure that the plan is workable during real disaster conditions. It is also important to document the lessons learned from the exercises in order to assemble a databank of learning, experience and information.
5. *Monitoring, evaluating, revising and updating the plan:* the information assembled provides essential learning for revising and updating the plan, correcting any areas of weakness or ineffectiveness, reallocating resources

These elements are not static, but revolve around a continuous cycle of activity and interaction among the responsible and collaborating agencies. For such groups a common objective to reduce the probability for disaster occurrence is important. This framework is used in developing strategies for the hot spots.

With tourism there needs to be very specific data brought to the process. For example, when managing tourism disaster risks, the need to include the tourism value chain in the planning and organization process. This needs to be understood so that all aspects of the DM plan can build the necessary links to the other relevant sectors and the broader community.

In the case of the Uttarakhand hotspots and elsewhere there is more than one tourism type as a result there is more than one value chain that needs to be considered.

There needs to be a continuous cycle of activity and interlocution among the responsible and collaborating agencies, united by a common objective to reduce the probability for disaster occurrence

In preparing a Tourism DM plan for individual locations the following key strategies need to be adopted.

7.8.3.1 Mitigation

Recommendation	Drivers	Outcomes	KPIs
Establish a Tourism Disaster Management Committee (TDMC).	The TMDC needs to include relevant government agencies, police fire and health representatives, the Army, highway construction, Dam construction, hotel association, tourist operators, restaurants, All India Radio, Met office, Water Commission, Gram Panchayat representatives, community tourism representatives.	A TDMC with responsibility to ensure a TDMP is formulated, understood and implemented with an obligation to report to the respective city/ward and state government.	A committee established and appropriate TOR agreed and signed off on within 6 months.
Establish a TDMC funding arrangement and resourcing to undertake technical aspects of the work	The formulation of the HIPTR is going to be a specialized set of tasks that will require skills not already available in administration – GIS, community consultation, undertaking a range of survey and economic evaluation. Specialist traing may be required.	A funded and resourced task team to undertake key elements of data collection, analysis and plan preparation.	A five year funding plan to be established within 6 months of TDMC inception. Recruitment/contracting of key personnel within 3 months of TOR being signed
Develop a Hazard identification Prioritisation and Tourism Risk (HIPTR) assessment by mapping of hazard areas against tourist areas, activities and movements (vulnerable populations), to derive a level of exposure and value chain for each of the tourist categories[25]	The development of a knowledge management system and it being held current is an important first step. The DRMA data portal is prime source for some but not all of the data required. A series of surveys will be required. Risk mitigation and management options need to derived	A risk assessment of which tourist, where and when they are exposed, as well as the expose of the relevant service industries and secondary suppliers	HIPTR to be drafted within 6 months of the TOR being finalized
Develop a specific Hazard identification Prioritisation and Pilgrimage Risk (HIPTR) assessment to deal with large numbers involved in both the Chardhams of the Himalayas and the melees.	There is a fundamental issue with pilgrims that comes out of the sheer numbers involved. Mass movement is a critical issue at all the temples and within the urban areas associated with bathing. Panic will be a major issue should a large hazard event occur and crowd control will be paramount as a first response capability in this situation, as will provision of medical services.	An analysis focused on the temples, waiting areas and bathing areas around managing congestion, choke points and potential solutions.	HIPPR to be drafted within 6 months of the TOR being finalized

[25] There is a need to understand the risk profile in terms of loss of life and assets but also any additional risks including risks to tourism resources (e.g. biodiversity, water supply), plant and infrastructure (e.g. coastal resorts), business risks (e.g. supply disruptions, changes in insurance coverage), or market risks (e.g. changes in competitiveness through increased transportation costs).

Recommendation	Drivers	Outcomes	KPIs
Develop a Tourism Disaster Management Plans (TDMP) at all levels of jurisdictions, across departments, the industry and communities.	A TDMP is the basis on which all forward planning for mitigation a preparation is based. Risk mitigation and management options need to be assed and adopted	A well prepared and tested DMP that is regularly reviewed, amended and distributed.	DM Plans developed within 6 months of the drafted HIPTR, followed by annual reviews.
As part of the TDMP increase public awareness and understanding, support & participation through the development of a city, Division or Block wide sales and marketing strategy and campaign focused on building awareness and a "need to know" desire focused on key participants in the Tourism Sector.	Community awareness, preparedness and response capability is predicated on risk awareness and right response behavior. This process needs to be fast tracked for all tourist.	A well informed tourism sector capable of planning for and responding to disasters at a level that will significantly diminish probable loss of life and assets	A public awareness campaign designed and sponsored within 12 months

7.8.3.2 Planning and Preparation

Recommendation	Drivers	Outcomes	KPIs
Establish an integrated Hazard Emergency Warning System and awareness education for all tourists on arrival	The warning or alarm elements of a EWS needs to be simple in its approach so is easily understood and awareness is not compromised through complexity.	A readily understood EWS notification system integrated to include all hazards and an indication of level of response needed.	EWS established within 12 months, awareness training and education material created and distribution begun as soon as W|EWS activated
Develop a TDM Evacuation Plan (CDMEP), including escape routes and identification of safe buildings, and ensure it is widely distributed and understood.	The TDMEP not only needs to be part of mainstream processes of the city but tailored to the site characteristics associated with the tourism type. Signage (international/Multilanguage) and other awareness programmes to be developed	A well prepared and tested TDMEP that is regularly reviewed, amended and distributed.	Development of the DMP within 12 months followed by regular annual reviews.
Emergency response testing (closing the gap)	Experience elsewhere shows that education and awareness does not guarantee the right responses nor in a timely manner. Response testing with tourists is not normally possible in terms of a training exercise but can be checked through questioners assess understanding and to improve awareness. Not that such questionnaires can be used to also gain valuable feedback data on tourism processes.	An effective awareness programme tested against regular measures of understanding and response	Annual survey reports based on awareness and response testing
Develop damage assessment competency as part of the HIPTR process	As with all DMPs an understanding the damage the sector has suffered as a result of a disaster is fundamental to planning for future recovery and mitigation. In this case	Competent assessors able to undertake evaluations with respect to infrastructure, socio-economic conditions,	Annual assessments as part of the overall TDM plan and assessment review

Recommendation	Drivers	Outcomes	KPIs
	socio economic data are critical as is the need to present a realistic picture of the level of damage and functionality to tourist.	supply chain functionality.	
Seek out mechanisms to introduce both microfinance and micro-insurance opportunities relating to the tourism supply chain as a way to build resilience in the sector	Both micro-finance and micro-insurance takes a lot of efforts to put in place – need to bring aboard authorities, re-insurers, local insurers and banks with their distribution channels – this take time and effort but both have been shown to make a positive contribution in disasters situations an improving livelihoods so building resilience as a result of readily available funding to help people and businesses get back on their feet	A reduced dependency on post event State funding for compensation, and more effective financial management by individuals and businesses.	A Micr0-financing and a separate micro-insurance scheme evaluation completed in 12 months
Develop local warden skills in tourist guides or comparable staff such as hotels, medical and police force.	Language and cultural differences can vary amongst all tourists. Such traits are exacerbated under stress. As a result there is a need for designated wardens trained suitable communications and cultural behaviors understanding during emergency evacuation and response situations	A well recognised and trained Warden task force capably of bridging both language and cultural gaps under emergency situations	Evaluation of effectiveness under annual DM training programmes
Development of an international and national language and cultural aid database	All countries are tied to international tourism with respect to their own citizens as a result of their proactive use of travel advisors, and aid in time of crises. Understanding how to take advantage of both and to seek support in times of crises is an important resources for the management of the tourism sector and its perception in the market.	A resources database and communications process relating to foreign country tourists facilitating access to interpreter skills and travel advisory content.	An annual review of a database accessible through the TDM process

7.8.3.3 Response

Recommendation	Drivers	Outcomes	KPIs
Develop local warden skills in tourist guides or comparable staff such as hotels, medical and police force.	Language and cultural differences can vary amongst all tourists. Such traits are exacerbated under stress. As a result, there is a need for designated wardens trained suitable communications and cultural behaviors understanding during emergency evacuation and response situations	A well recognised and trained Warden task force capably of bridging both language and cultural gaps under emergency situations	Evaluation of effectiveness under annual DM training programes
Development of an international and national language and cultural aid database	All countries are tied to international tourism with respect to their own citizens as a result of their proactive use of travel advisors, and aid in time	A resources database and communications process relating to foreign country tourists	An annual review of a database accessible through the TDM process

Recommendation	Drivers	Outcomes	KPIs
	of crises. Understanding how to take advantage of both and to seek support in times of crises is an important resource for the management of the tourism sector and its perception in the market.	facilitating access to interpreter skills and travel advisory content.	

7.8.3.4 Recovery

Recommendation	Drivers	Outcomes	KPIs
Undertake tourism Sector damage assessment as part of the DM response process	An understanding of the damage the sector has suffered is fundamental to planning for future recovery and mitigation. Including the need to present a realistic picture of the level of damage and functionality to tourism within the market in order to minimize losses.	Competent assessment of the status and actions needed with respect to infrastructure, socio-economic conditions, supply chain functionality.	An immediate assessments as part of the overall DM response and recovery process with the first 6 months
Establish a Sector recovery plan including a media plan to inform national and international perceptions.	A sector recovery plan serves 2 functions. One is to ensure that the hardships associated post even recovery are minimized and the sector reestablishes it functionality as a soon as possible. The second it to advise the market of the real status of the sector as opposed to what is frequently reported in the media and in travel advisory's.	A well planned recovery minimizing socioeconomic losses and human hardship. A well-informed national and intentional market as to the unfolding realities.	Number of returning tourist and the reestablishment of the supply chain on an initial 6 and then 12 monthly basis.

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8 REFERENCES

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