In Collaboration with the Earth Observatory Singapore

Uttarakhand Disaster Recovery Project

Disaster Risk Assessment of Uttarakhand

State Level Assessment

Volume 3A

Project Implementation Unit TA & CEDRM

January 2018

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Lump Sum for

DISASTER RISK ASSESSMENT OF UTTARAKHAND

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And

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Uttarakhand Disaster Recovery Project

Disaster Risk Assessment of Uttarakhand

State Level Assessment

Prepared for	Project Implementation Unit TA & CBDRM
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CONTENTS

3.1 Baseline Exposure Profile

This section will summarise the state of Uttarakhand as a whole, in terms of the baseline social (human) and economic which could potentially be exposed to the hazards under consideration. Uttarakhand's location is shown in the inset map to the right, relative to India's other states and international neighbours.

To illustrate the spatial distribution of this baseline exposure as a whole, a series of maps are presented in the following sections, grouping exposure into five portfolios: population (Volume 3.1.1), residential buildings (Volume 3.1.2), critical buildings (Volume 3.1.3), transportation infrastructure (Volume 3.1.4), power infrastructure (Volume 3.1.5), and agricultural/economic sectors (Volume 3.1.6).

As an initial summary, the figures below summarise pertinent demographic properties of the state of Uttarakhand. All figures are derived from the 2011 Census, noting that 2017 projections for population and number of households are based on the observed growth rates between the 2001 and 2011 Censuses.

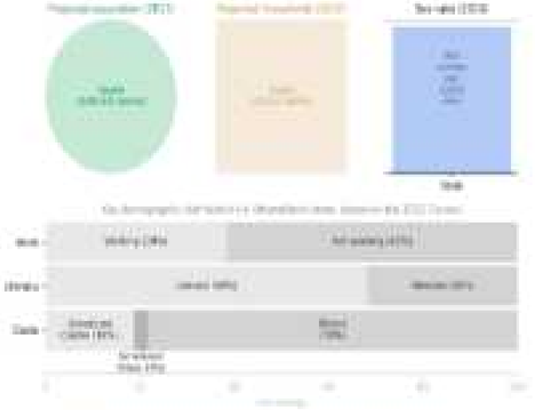
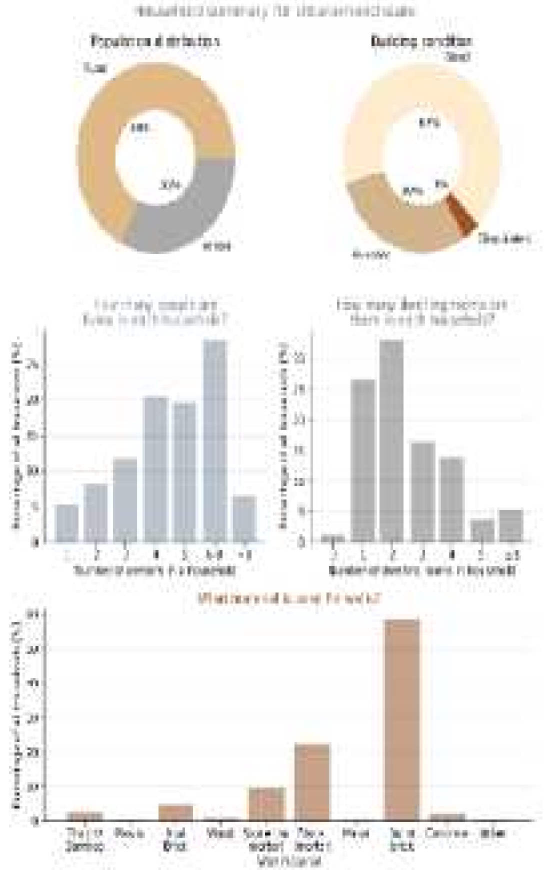
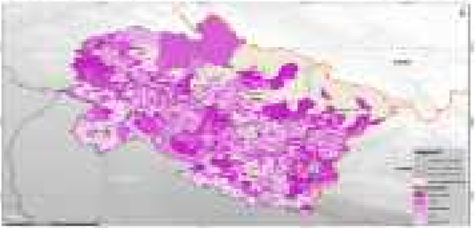


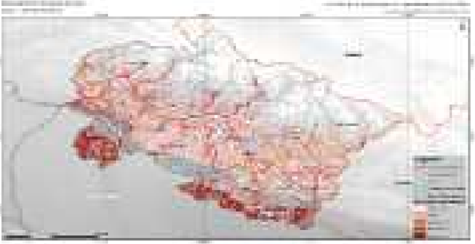
Figure 3.1: Baseline demographic statistics extracted from the 2011 Census for Uttarakhand

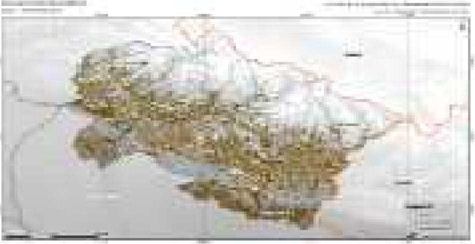
On the following page, a selection of baseline household statistics from the 2011 Census are visualised for the state in Figure 3.2, providing insight into the condition and use of its buildings, the most common building materials (for walls), and the general distribution of the population.

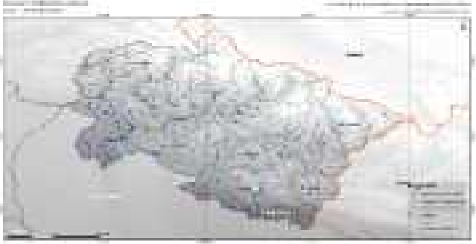


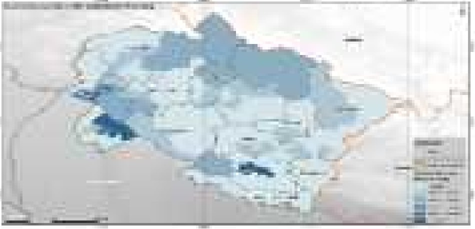
Population distribution
Building condition











3.2 Multi-hazard Assessment – Earthquakes & Fluvial Floods

Loss Profile

This section provides a summary of the average annual economic losses and the potential fatalities resulting from the probabilistic assessment of Earthquake and Fluvial Flood risk. Following the summary, the estimates and losses are presented in greater detail for each hazard.

Figure 3.14 shows the breakdown of the combined Economic AAL, in terms of the hazard type (inner ring) and portfolio (outer ring). It is clear that at the State level, losses due to earthquakes are far more significant than those due to fluvial floods, over the long term.

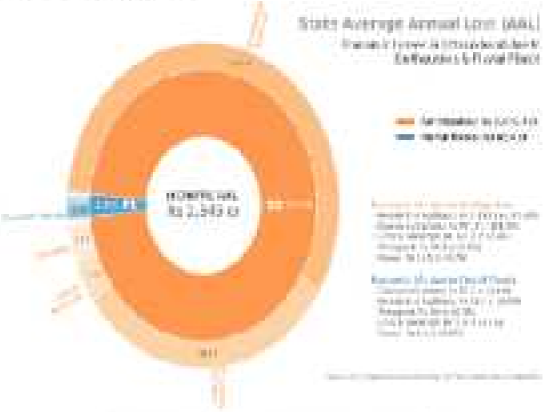
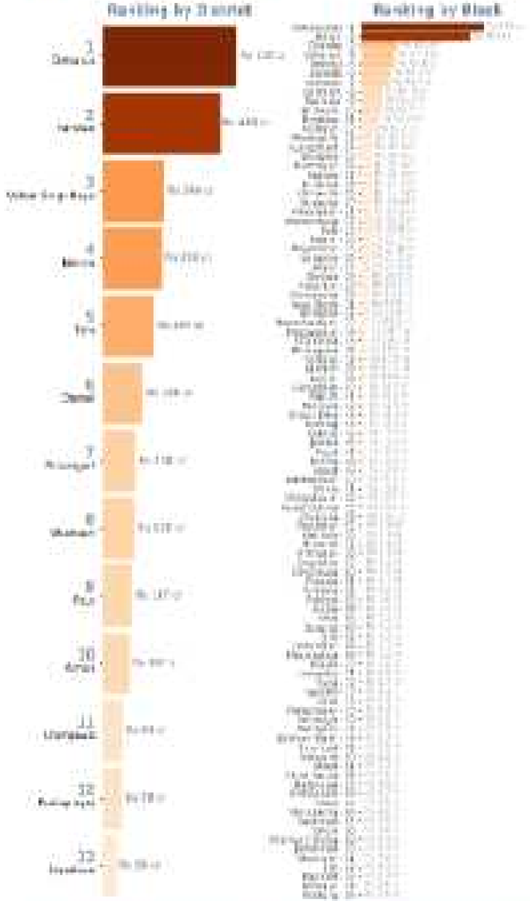


Figure 3.14: Breakdown of total annual average loss, by hazard and portfolio

Figure 3.15 presents a ranking of all Districts and Blocks within the State, in terms of their total Average Annual Loss (AAL), including losses due to both earthquakes and fluvial floods.


Ranking by District
Ranking by Block

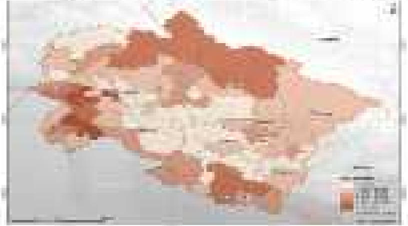
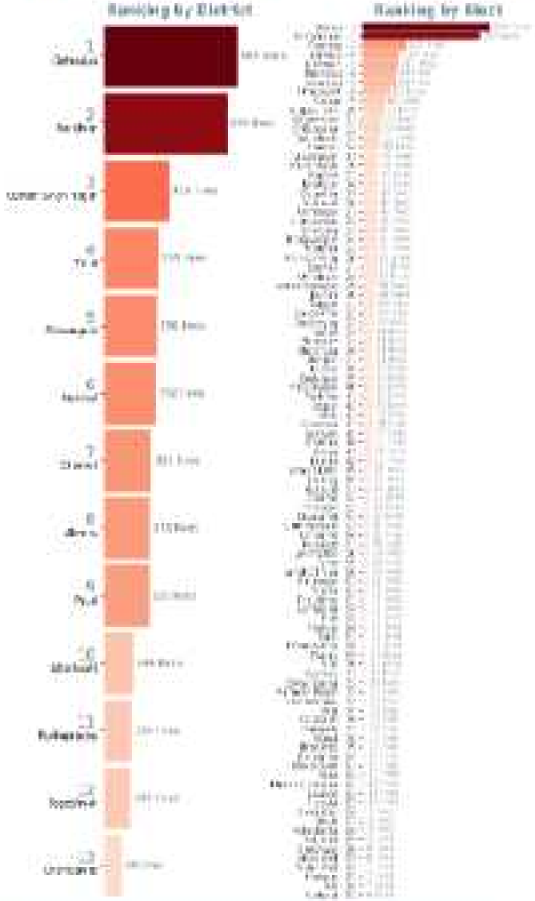


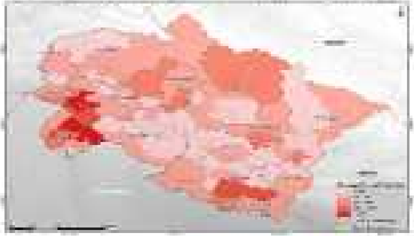
Figure 3.17 shows the breakdown of the combined Average Annual Fatalities (rounded), in terms of the hazard type (inner ring) and the sensitivity of the affected population (outer ring).

Figure 3.17 Breakdown of estimated loss of life by hazard, location and sensitive type

Figure 3.18 presents a ranking of all Districts and Blocks within the State, in terms of their total combined Average Annual Loss (AAL) of life, as a result of both earthquakes and flash floods.



Ranking by District
Ranking by Block



3.3 Earthquakes

Hazard Profile

Seismicity along the Himalayan arc is a consequence of the ongoing continent-to-continent collision between the Indian and Eurasian plates, with the state of Uttarakhand exposed to earthquakes along the Himalayan Thrust zone.

At the time of writing, 50 historical earthquakes with epicentres within the state boundaries had so far been recorded. Table 3.1 summarises the largest and the most recent of these, while the map in section 3.3.1 presents all historical earthquake events which have been recorded in the state of Uttarakhand.

Table 3.1: Summary of the largest and most recent earthquake events recorded in the state

Historical earthquake event	Date	Magnitude
Largest earthquake recorded	1803	8.0
Most recent earthquake recorded	06.12.2011	4.7

Based on the probabilistic seismic hazard assessment carried out for Uttarakhand (see Volume 1, Chapter 3 for a full description of the methodology), maps of the predicted seismic intensity in terms of Peak Ground Acceleration have been generated for the whole state, for nine different return periods. The ranges of PGA values estimated for all of these return periods are summarised in Figure 3.20, while the following sections (Sections 3.3.2 - 3.3.5) present the maps for four of the return periods (10, 100, 475 and 5,000 years).

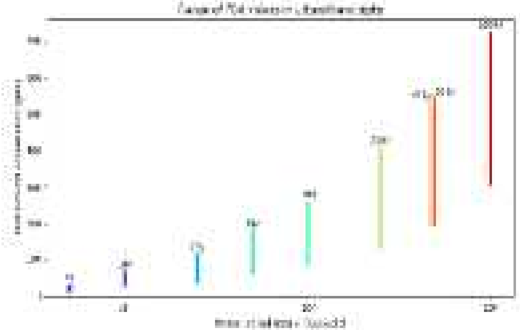
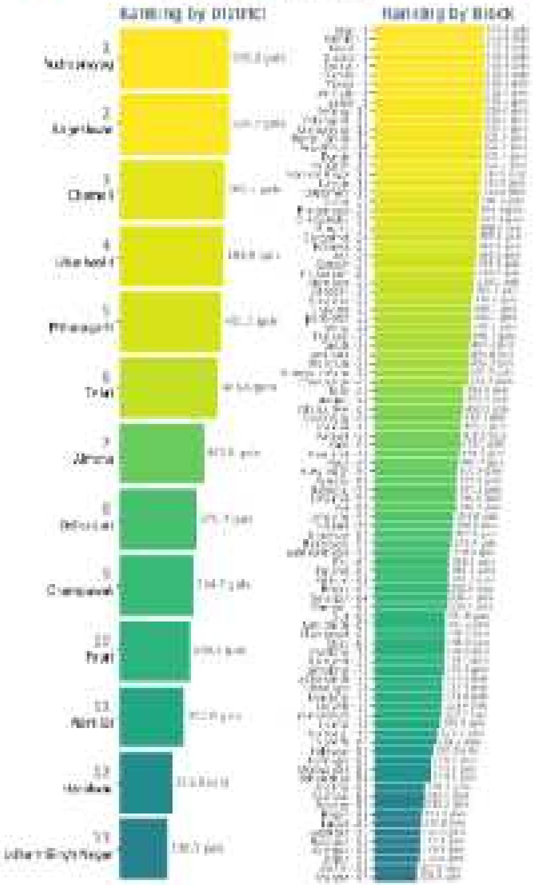


Figure 3.20: Ranges of estimated PGA values (cm/s²) in Uttarakhand, for all return periods

For each district and each block in the state, the median PGA values (for the 475 year return period) were used to develop ranking tables. These are presented in Figure 3.21 (following page), with the district ranking on the left and blocks on the right.


Ranking by District
Ranking by Block

These PGA values were also converted into intensity classes in the Modified Mercalli Intensity scale, based on the equation developed by [illegible] et al. ([illegible]) for the Indian region. The distribution of these intensity classes across the state is presented in Figure 3.22 for all return periods investigated, on the basis of eight classes ranging from 'Very Low' to 'Extreme' intensities. For example, the plot shows that for the 5 year return period, approximately [illegible] of the state is in the 'Low' class, with the remaining [illegible] in the 'Moderate' intensity class.

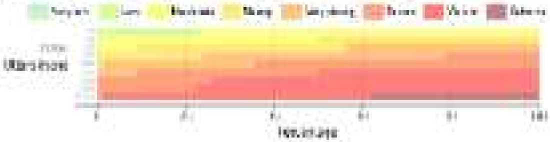
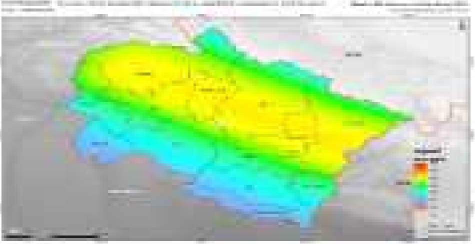
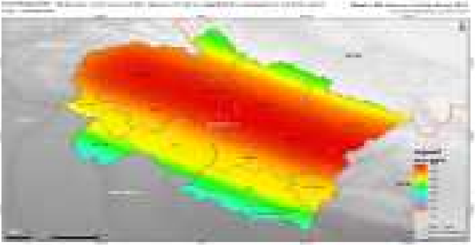


Figure 3.22: Seismic intensity class distribution in the state of Uttarakhand





Hazard

3.3 Earthquakes

Exposure Profile

This section presents a summary of the state's exposure to seismic hazards. Rather than estimating losses, the exposure assessment only looks at the extent to which people and economic assets are exposed to different hazard intensities, providing a useful preliminary indication of impact (which isn't subject to the uncertainties associated with economic valuation and vulnerability functions).

For this purpose, estimated PGA values for the 100 year return period earthquake hazard map were classified into [illegible] intensity classes, using a conversion to the Modified Mercalli Intensity (MMI) classes previously proposed for the Indian context[1]. These intensity classes are based on observed effects, with lower classes defined by how earthquakes are felt by people and higher classes by observed structural damage, and provide an intuitive way to describe seismic intensity.

As shown in Table 3.2, the earthquake hazard intensities estimated across the state with a 100 year return period cover three MMI classes: Moderate, Strong and Very Strong. In order to be able to visualise and assess exposure in more detail, each of these classes has been split into five equally-spaced subclasses (such that the Moderate class is made up of subclasses M1 - M5 and so on). As can be seen from the table, the full intensity of the 100 year return period hazard across the state ranges from a low of M5 (the highest Moderate subclass) up to a high of VS3 (the middle Very Strong subclass). All subsequent maps and plots illustrating exposure to hazards will use this classification system.

Table 3.2: Summary of MMI classifications used for assessing the state's exposure to the 100 year RP earthquake hazard

MMI Class	PGA Range	Description	Subclass	100yr RP
Moderate	[illegible] cm/s²	Felt by nearly everyone, many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.	M1	
			M2	
			M3	
			M4	
			M5	
Strong	[illegible] cm/s²	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.	S1	
			S2	
			S3	
			S4	
			S5	
Very Strong	[illegible] cm/s²	Damage 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; some chimneys broken.	VS1	
			VS2	
			VS3	
			VS4	
			VS5	

[1] [illegible]

Figure 3.29 visualises the exposure of all portfolios considered, in terms of the percentage of each population group or economic asset exposed to "limited" (Moderate/Strong) as opposed to "significant" (Very Strong) earthquake intensities with reference to the 100 year return period earthquake intensities. In the sections which follow, each portfolio will be considered separately, showing the first intensities to which they are each likely to be exposed to in each area based on the 100 year return period intensities.

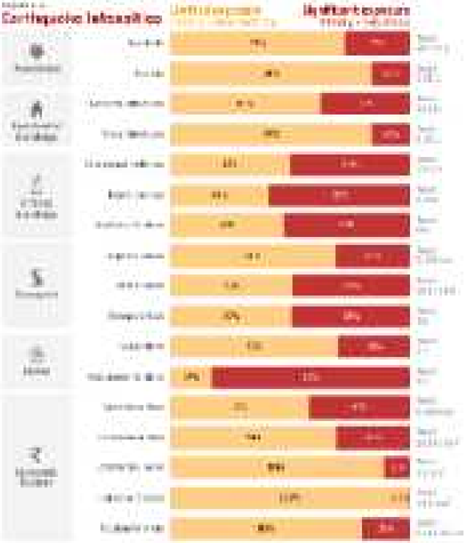
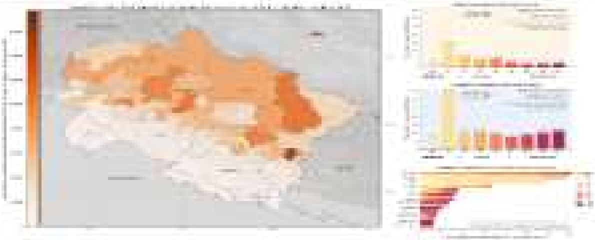
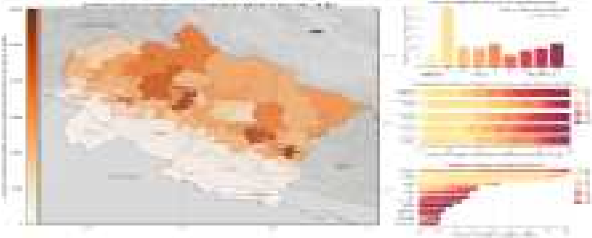
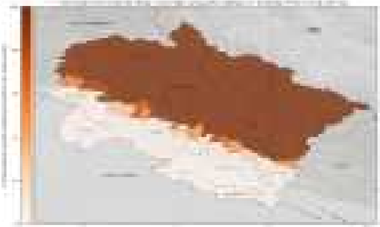
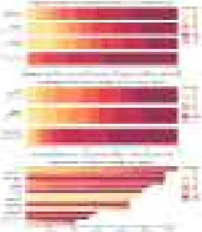


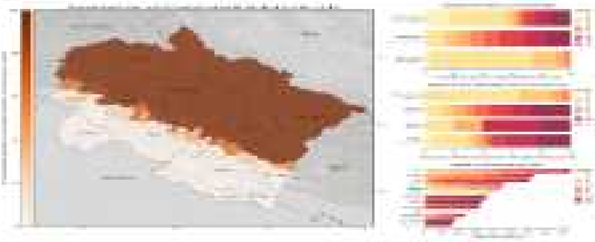
Figure 3.29 Visual summary of the State's overall exposure to earthquake intensities for the 100 year return period

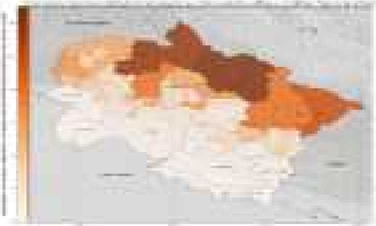


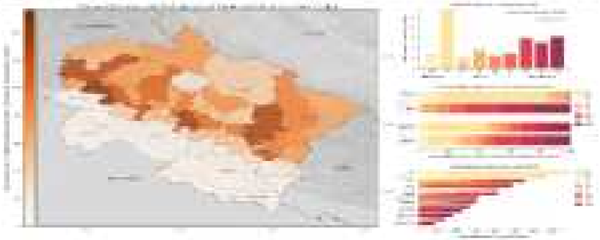


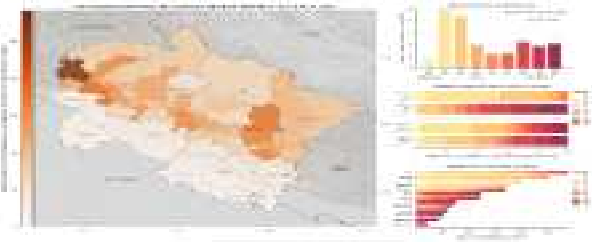


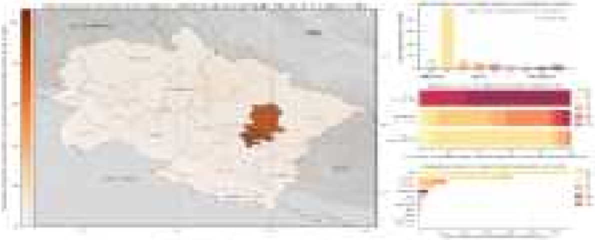


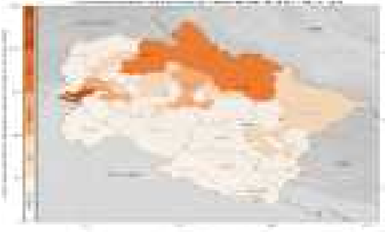












3.3 Earthquakes

Loss Profile

The Average Annual Loss (AAL) of economic value in the State due to earthquakes is approximately Rs 2,460 crores. Figure [illegible] shows how the total is distributed between the various portfolios and their individual components.

Figure [illegible]: Distribution of Economic AAL due to earthquakes by portfolio and subportfolio

In Figure [illegible], the total AAL of economic value in each district is displayed, as well as the distribution of each district's total AAL by portfolio.

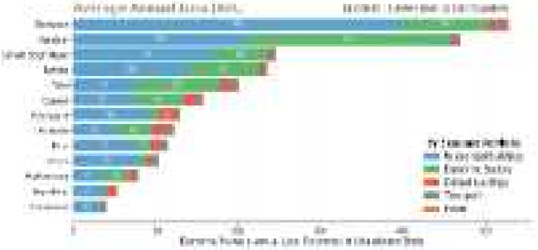


Figure [illegible]: Distribution of Economic AAL due to earthquakes by portfolio and district

The economic losses presented above include both direct losses (those incurred at the time of the disaster, in terms of damaged assets that have to be repaired or replaced) and indirect losses (the loss of likely future income due to the disruption of revenue streams such as industrial production or tourism activities).

In the case of the latter, assumptions must be made as to the maximum period over which revenue streams may be impacted by a given disaster (with actual losses scaled proportionally according to the calculated damage percentage). Table 3.3 summarises these assumptions for each economic portfolio/sub-portfolio included in the risk assessment, as well as providing a general overview of the direct and indirect losses considered. It is noted that cascading indirect losses (such as industrial losses due to disruption of power infrastructure) are not within the scope of the current assessment and therefore not accounted for in the loss estimates.

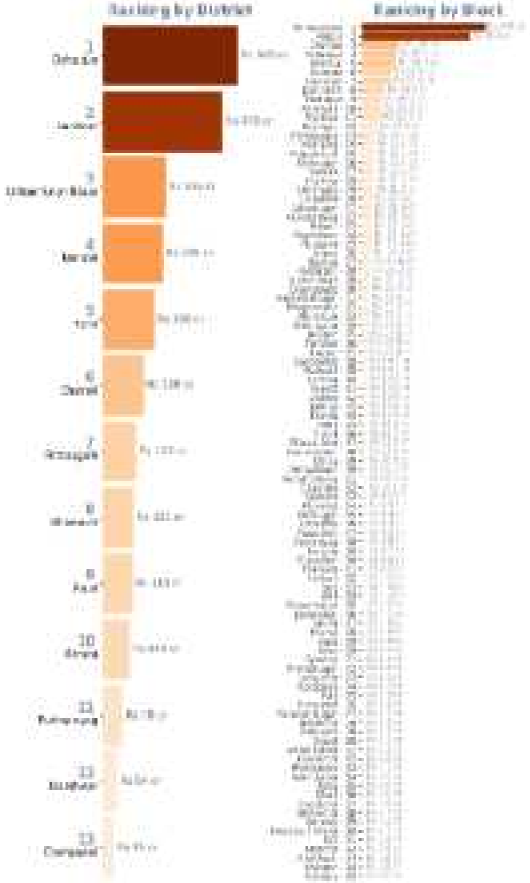
Table 3.3 Overview of direct and indirect losses accounted for, including maximum disruption period for indirect losses

Portfolio	Sub-portfolio	Direct losses	Indirect losses	Max. disruption
Residential Buildings	Pucca	Replacement cost	None	N/A
	Kutcha			
Critical Buildings	Health, Schools, Government	Replacement cost	None	N/A
Transport Infrastructure	Road, Rail, Air	Replacement cost	None	N/A
Power Infrastructure	Power substations	Replacement cost	None	N/A
	Hydropower stations	Replacement cost	Loss of electricity revenue	1 year
Economic Sectors	Agriculture, Horticulture	Replacement cost (capital investment)	Loss of future yields	1 year
	Industry	Replacement cost (capital investment)	Loss of future production revenue	1 year
	Commerce	None	Loss of manufacturing & services revenue	1 year
	Mining	None	Loss of production revenue	1 year
	Tourism	None	Loss of tourism revenue	3 years [illegible] 3 years [illegible] 1 year [illegible]

Figure 3-41 illustrates the distribution of direct and indirect losses within the state's overall economic AAL due to earthquakes.

Figure 3-41 Distribution between direct and indirect losses in the state's economic AAL due to earthquakes

Figure 3-42 presents the ranking of all districts and blocks within the state, in terms of their total Average Annual Loss (AAL) of economic assets, as a result of both direct and indirect losses caused by earthquakes.


Ranking by District
Ranking by Block

Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure 3.43 presents the overall PML curve for all economic assets modelled in the study.

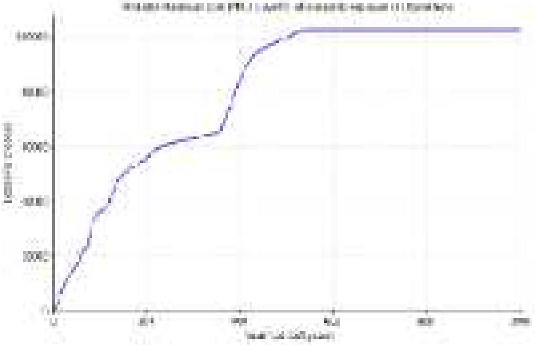


Figure 3.43: Probable Maximum Loss (PML) curve for all economic assets in [illegible]

Figure 3.44 presents individual PML curves for each of the mapped economic portfolios in the study.

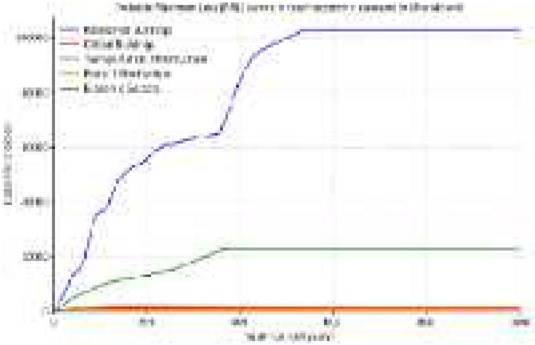


Figure 3.44: Probable Maximum Loss (PML) curves for each [illegible]

As for human losses, the Average Annual Loss (AAL) in the State due to earthquakes is estimated to be 3,000 lives. Figure 3.45 summarises the distribution of this loss, in terms of the residency of those killed (state residents or tourists), the time of the earthquake (more people are inside buildings at night and therefore more exposed), and the structural quality of the building they were in at the time (in terms of Kutcha/Pucca structural types).

Figure 3.45: Average Annual Loss (AAL) of human lives, by residency, time of earthquake and building quality

Figure 3.46 summarises the AAL of human lives in each of the State's districts, as well as the distribution of each district's AAL in terms of the residency of those affected (state residents or tourists).

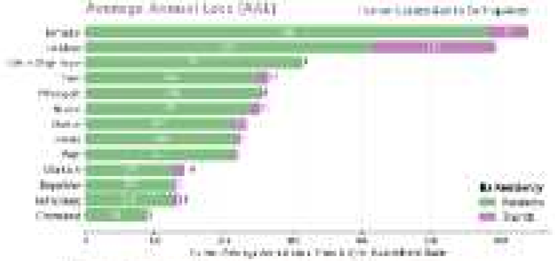
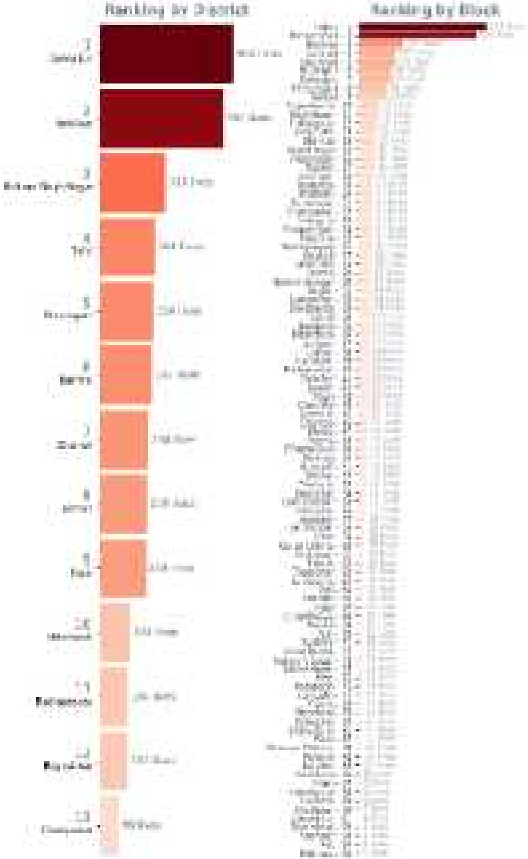


Figure 3.46: Average Annual Loss (AAL) of human lives, by district and residency (residents/tourists)

Figure 3.47 presents the ranking of all Districts and Blocks within the State, in terms of their total Average Annual Loss (AAL) of human life, as a result of earthquake hazards.


Ranking by District
Ranking by Block

[illegible]

Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure 3-45 presents the overall PML curve for all people (residents and tourists) in the state.

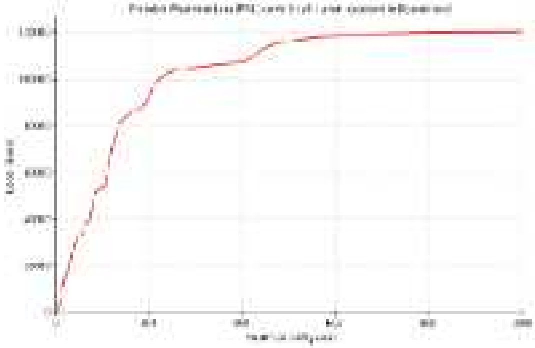


Figure 3-45: Probable Maximum Loss (PML) curve for all human population in Uttarakhand due to earthquakes

Figure 3-46 presents individual PML curves exploring the impact of earthquake timing on likely fatalities, given very different spatial distributions of population at different times of day.

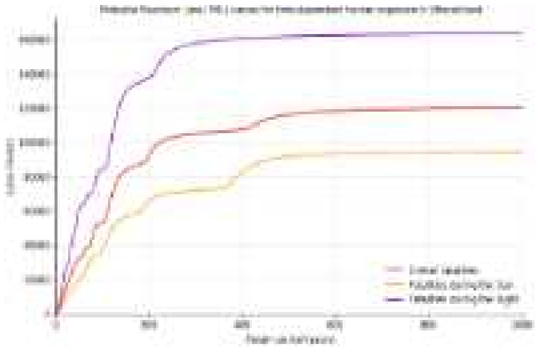


Figure 3-46: Probable Maximum Loss (PML) curve(s) for all human population in Uttarakhand due to earthquakes at different times of the day, based on modelled differences in the spatial distribution of the exposed population

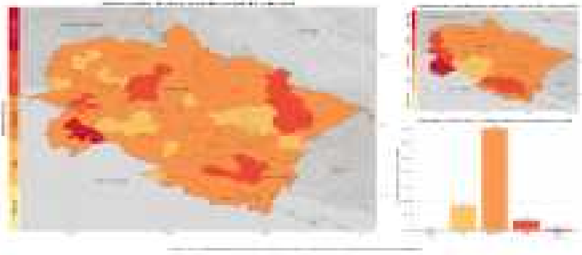
The human AAL calculated so far provides an estimate of the likely loss of life directly attributable to earthquakes (primarily resulting from the collapse of buildings during or immediately following the earthquake). However, there are likely to be longer-term mortality impacts too, depending on the extent to which the affected area's capacity to respond to the disaster has been compromised. This will depend on factors such as:

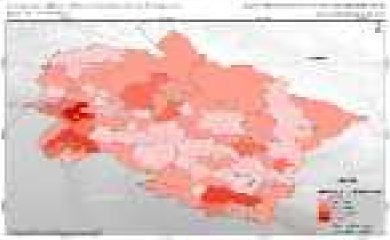
- Size of displaced population to be housed in temporary camps (where disease outbreaks more likely)
- Capacity of local health facilities (those still functional post-disaster)
- Capacity of other government facilities to support response/recovery efforts
- Transport connectivity within the affected area (particularly road and air transport)
- Pre-existing socio-economic vulnerability of population in affected area
- Fraction of affected population made up of tourists (less local knowledge and thus more vulnerable)

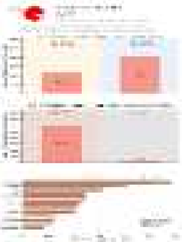
While detailed modelling to quantify this risk is not possible, a qualitative assessment has been performed, in order to evaluate the likely significance of mortality in the state overall and also in terms of the individual factors listed above, as a result of the scoring and index estimated.

It should be clearly noted that this is a relative assessment only (each District is compared to all other Districts in the State, and likewise for Blocks) rather than being assessed against an external standard or reference. Thus it can be stated with some confidence that one District is at a higher mortality risk than another, but the actual level of that risk remains unknown.

A map showing the overall earthquake secondary mortality risk score estimated for each Block (left) and each District (lower right) in Uttarakhand is presented in Figure 3.59, along with a histogram of the class distribution for blocks (lower right). Further details for each District and Block are available in the corresponding Atlas volume.







Probable Maximum Loss (PML) curves [illegible] for a range of different return periods. Figure [illegible] presents the PML curve for [illegible]

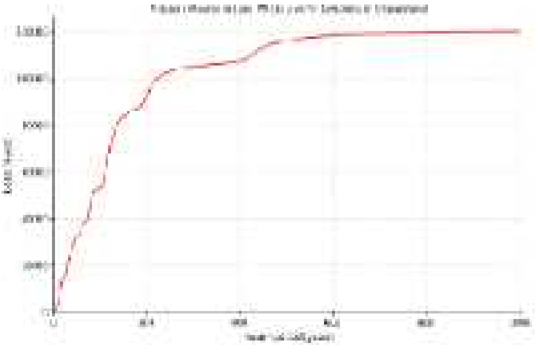
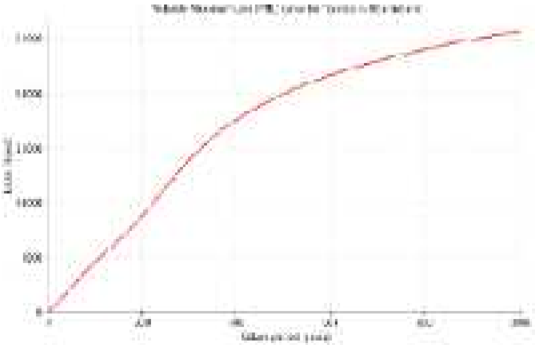
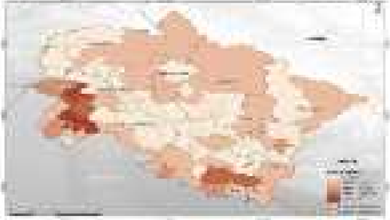


Figure [illegible] Probable Maximum Loss (PML) curve [illegible]

Probable Maximum Loss (PML) [illegible] Figure [illegible] PML curve [illegible]



[illegible]



Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure [illegible] presents the PML curve for residential buildings in the [illegible].

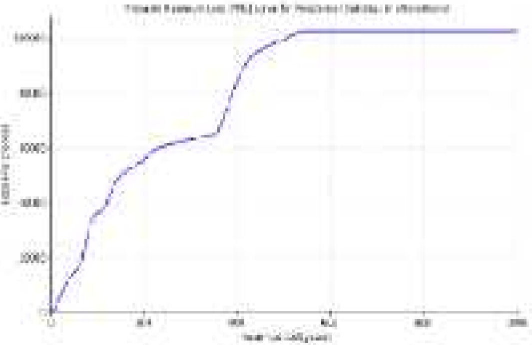
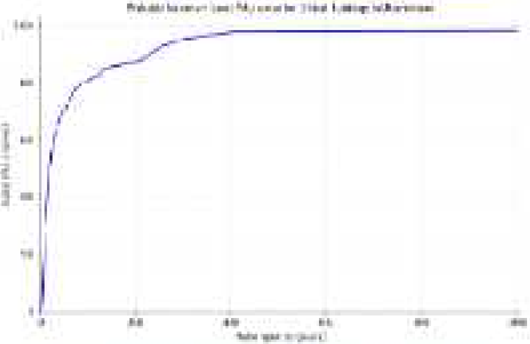


Figure [illegible] Probable Maximum Loss (PML) curve for residential buildings in [illegible]

Probable Maximum Loss (PML) curves [illegible] PML curve [illegible]



[illegible]

Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure [illegible] presents the PML curve for [illegible] in the 2050.

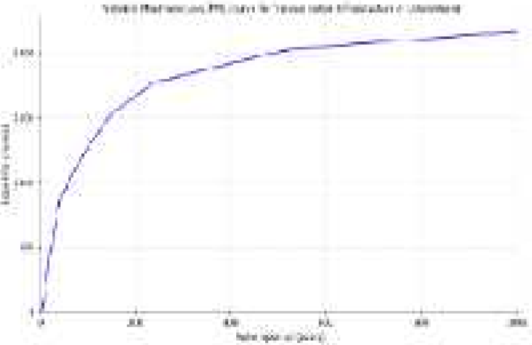
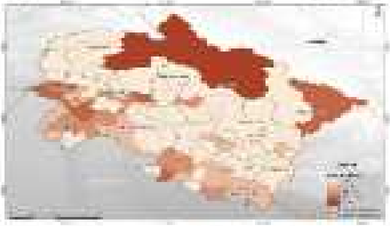
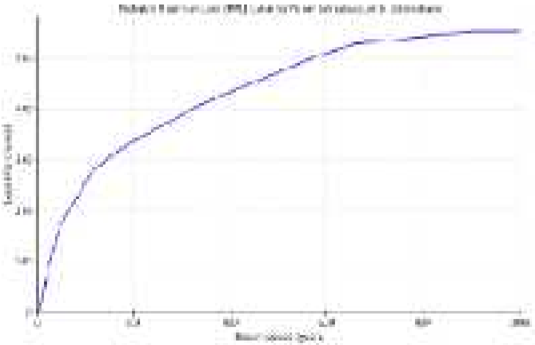


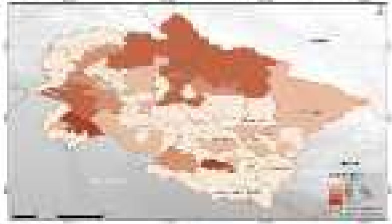
Figure [illegible]: Probable Maximum Loss (PML) curve for [illegible]



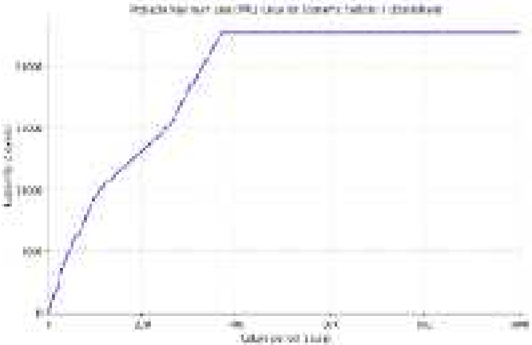
Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure [illegible] presents the PML curve for [illegible] infrastructure in the [illegible].



[illegible]

Probable Maximum Loss (PML) is [illegible] that the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure [illegible] presents the PML curve for economic sectors in Chhattisgarh State, encompassing agriculture (irrigation tanks only), industry, commercial, mining and tourism [illegible].



[illegible]

3.4 Floods

Hazard Profile (Fluvial & Flash Floods)

Assessing flood hazards for Uttarakhand required two modelling approaches in order to capture the different types of flood that may pose a threat to people and property in the state. Fluvial (river) floods were modelled using basin-scale coupled 1D models (hydrological and hydrodynamic), based on long-term time series of daily rainfall data. Flash floods and ponding due to short-duration, localised rainfall events were modelled using a 2D model, based on the design rainfall events. Further details regarding the fluvial flood and flash flood modelling approaches are presented in Volume 1, Chapter 3.

In the following sections, Volume 3.4.1 presents a map showing which of these approaches was used for different parts of the state. The main river network (modelled using the long-term fluvial flood model) is indicated by the green and red lines; the different colours show the level of uncertainty in simulated results along that stretch, which is mainly a function of the underlying DEM quality. The remainder of the state was covered by the short-term localised model, capturing overland and gully flows, as well as rainfall-induced ponding. The map also shows digitised building clusters, as a simple indication of exposure, as well as glacial lakes which have been assessed to pose a threat related to Glacial Lake Outburst Floods (GLOFs).

In Volume 3.4.2, a map of flood depths which have a 100 year return period is presented, combining outputs from the two modelling approaches described above, in order to ensure the fullest possible coverage of the entire state. Over any 50 year period, a flood of this magnitude (or greater) has a 40% chance of occurring at least once. It is estimated that such a flood event would result in approximately [illegible]% of the state being inundated to a depth of [illegible] or greater. This is illustrated in the plot below, breaking it down into six different inundation depth classes.

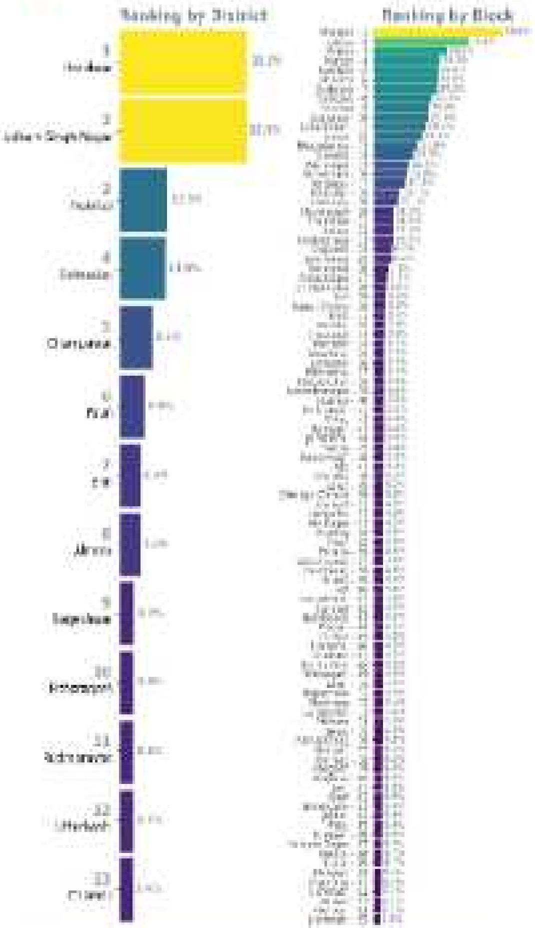
Figure 3.4.1: Proportion of state in different inundation depth classes (based on a 100 year return period)

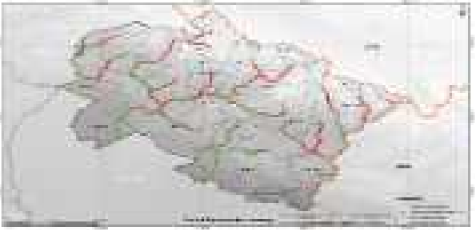
Based on the same analysis, the following page presents a ranking of all districts (left) and blocks (right) in the state of Uttarakhand, in terms of the percentage of their area expected to be inundated to a depth of [illegible] or higher during the 100 year return period flood.

As well as inundation depths, flow velocities are significant in evaluating the overall flood hazard, particularly in terms of the risk to people and buildings during flash flood events. The map in Volume 3.4.3 presents the flash flood hazard zones defined for Uttarakhand, based on both depth and flow velocity, following a widely used approach to hazard ratings developed by HR Wallingford et al. (2006).

The plot below summarises the proportion (by area) of Uttarakhand in each hazard zone, as a quick visual summary of its flash flood hazard profile.

Figure 3.4.2: Proportion of state in different flash flood hazard zones (based on a 100 year return period)


Ranking by District
Ranking by Block



3.4 Floods

Exposure Profile (Fluvial & Flash Floods)

This section presents a summary of the state's exposure to flood hazards, in terms of both fluvial/pluvial flood depths and flash floods hazards (which are based on flow velocity as well as depth). Rather than estimating losses, the exposure assessment only looks at the extent to which people and economic assets are exposed to different hazard intensities, providing a useful preliminary indication of impact (which isn't subject to the uncertainties associated with economic valuation and vulnerability functions).

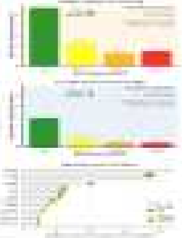
Figure 3.73 visualizes the exposure of all portfolios to fluvial/pluvial flood depths, in terms of the percentages of each population group or economic asset exposed to "limited" depths (<0.3m) as opposed to "significant" depths (≥0.3m), with reference to 100-year return period flood depths.

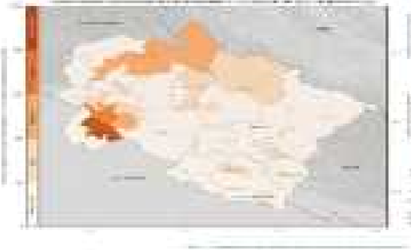
Figure 3.73: Visual summary of the State's current exposure to flood depths with a 100-year return period

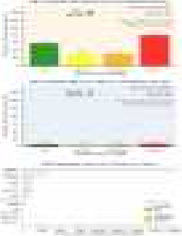
Figure 3.74 visualises the exposure of all portfolios to flash flood hazard zones, in terms of the percentages of each exposure group or economic asset exposed to 'limited' hazards (only the 'Low' zone) as opposed to 'significant' hazards (all zones higher than Low), with reference to 100 year return period flood depths and flow velocities. As described in the Hazard Profile section of this Volume, flash flood hazard zones were defined based on both maximum flood depths and flow velocities, following a widely used approach developed by HR Wallingford et al. (2017).

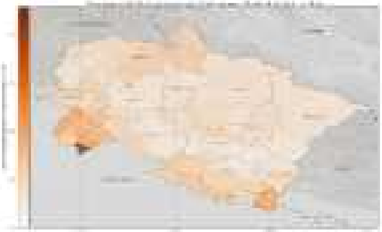
Figure 3.75: Visual summary of the District's overall exposure to flash flood hazard zones with a 100 year return period.

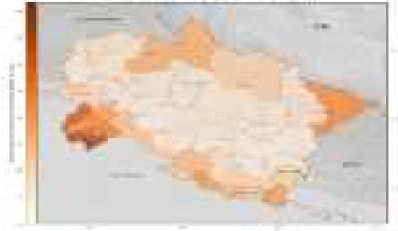
In the sections which follow, each portfolio will be considered separately, showing its exposure to floods in terms of both flood depth ranges and flash flood hazard zones for each case based on the 100 year return period flood depths and flow velocities.

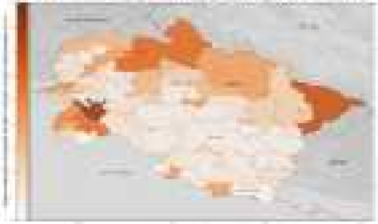


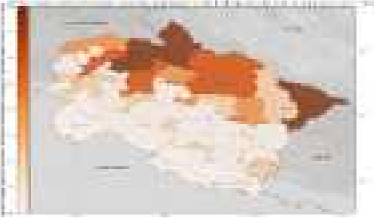


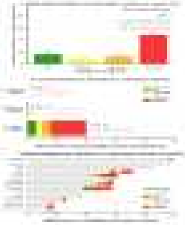


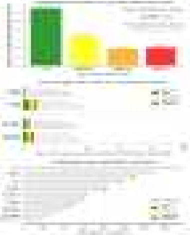



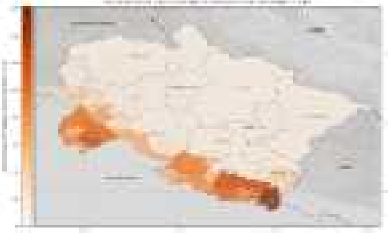


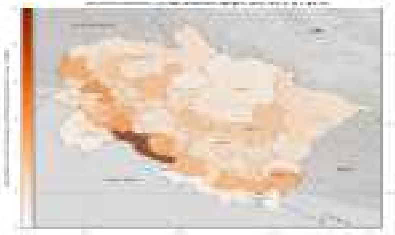


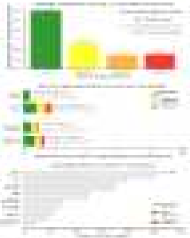


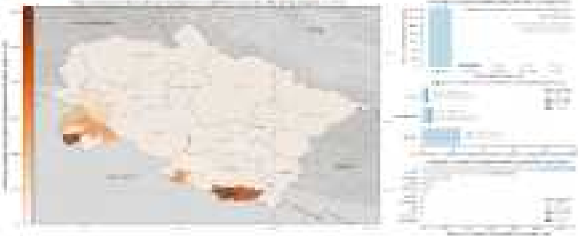


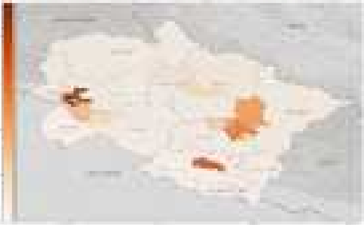


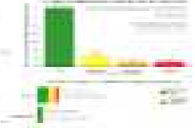


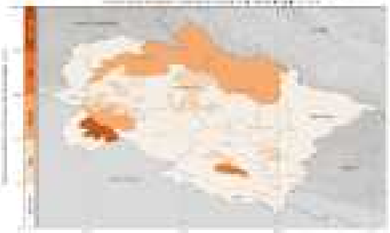


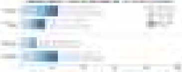


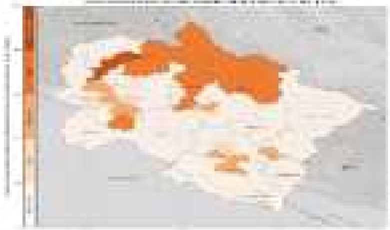


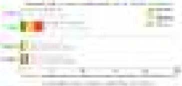













3.4 Floods

Loss Profile (Fluvial Floods Only)

The Average Annual Loss (AAL) of economic value in the State due to fluvial floods is approximately Rs [illegible] crores. Figure 3.[illegible] shows how this loss is distributed between the various portfolios and their individual components. Note that buildings and goods have been assumed to be protected from higher frequency events (up to the 100-year event in urban areas and the 25-year event in rural areas), based on observations made during field trips around the state. This does not apply to agriculture, horticulture, roads or railways, which are considered unprotected.

Figure 3.[illegible] Distribution of economic AAL due to fluvial floods, by portfolio and subportfolio

In Figure 3.[illegible], the total AAL of economic value due to fluvial floods in each district of the state is displayed, as well as the distribution of each district's total AAL by portfolio.

Figure 3.[illegible] Distribution of economic AAL due to fluvial floods, by portfolio and district

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Replacement cost	None	[illegible]
	[illegible]			
[illegible]	[illegible]	Replacement cost	None	[illegible]
[illegible]	[illegible]	Replacement cost	None	[illegible]
[illegible]	[illegible]	Replacement cost	None	[illegible]
	[illegible]	Replacement cost	Loss of [illegible] revenue	1 year
[illegible]	[illegible]	Replacement cost [illegible]	[illegible]	1 year
	[illegible]	Replacement cost [illegible]	[illegible]	1 year
	[illegible]	None	[illegible]	1 year
	Mining	None	Loss of [illegible] revenue	1 year
	[illegible]	None	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]


Ranking by District


Ranking by Block

Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure [illegible] presents the overall PML curve for all economic assets mapped in the state, for two sets of assumptions: standard protection (built exposure protected up to the 20-year event in villages and the 100-year event in towns) and no protection at all. The reality is likely to be somewhere in between.

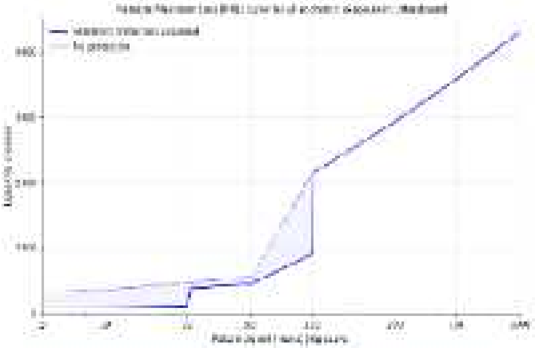


Figure [illegible]: Probable Maximum Loss (PML) curve for all economic assets in [illegible]

Figure [illegible] presents individual PML curves (based on the standard protection assumption described above) for each of the mapped economic portfolios in the state.

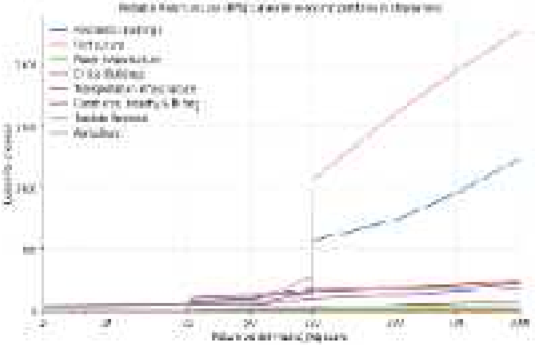


Figure [illegible]: Probable Maximum Loss (PML) curves for each economic portfolio in [illegible]

As for human losses, the Average Annual Loss (AAL) in the State due to fluvial floods is estimated to be [illegible] lives. Figure [illegible] summarises the distribution of this risk, in terms of the residency of those killed (local residents or tourists), the time of the flood event, and the land use [illegible].

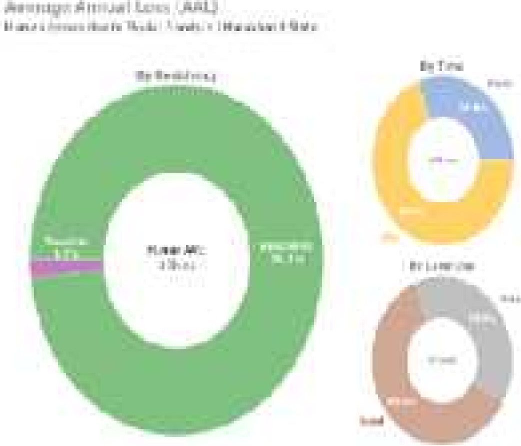
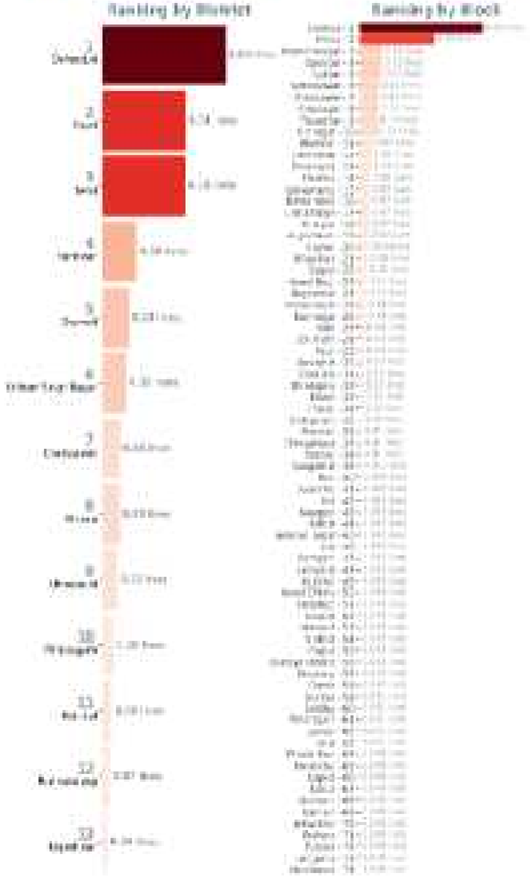


Figure [illegible] Average Annual Loss (AAL) of human lives by residency, time of flood event and land use type

Figure [illegible] summarises the AAL of human lives in each of the affected districts, as well as the distribution of each district's AAL in terms of the residency of those affected (local residents or tourists).

Figure [illegible] Average Annual Loss (AAL) of human lives, by district and residency [illegible]

Figure [illegible] presents the ranking of all Districts and Blocks within the State, in terms of their total Average Annual Loss (AAL) of human lives, as a result of fluvial floods. Note that only those blocks impacted by the major rivers modelled for this study are shown here.


Ranking by District
Ranking by Block

Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure 5.104 presents the overall PML curve for all people (residents and tourists) in the atoll, for two sets of assumptions: standard protection (assets protected up to the 25 year event in villages and the 100 year event in towns) and no protection at all. The reality is likely to lie somewhere in between.

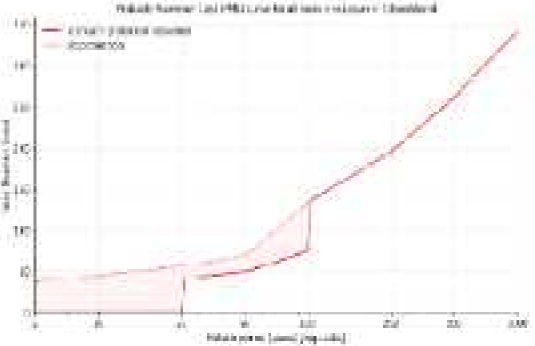


Figure 5.104: Probable Maximum Loss (PML) curve for human life for [illegible] for the floods

Figure 5.105 presents individual PML curves (based on the standard protection assumption described above) for each of the mapped human groups in the atoll (residents and tourists).

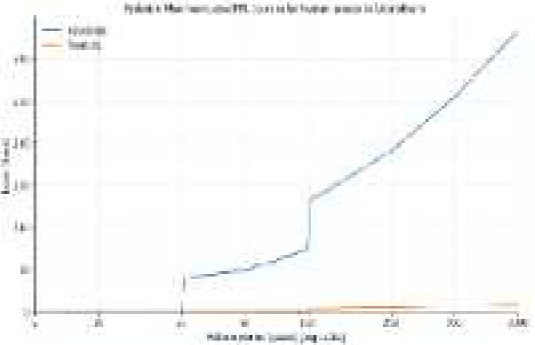


Figure 5.105: Probable Maximum Loss (PML) curves for each human group in [illegible] for the floods

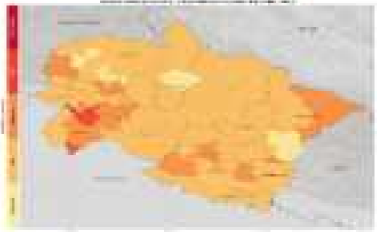
The human AAL discussed so far provides an estimate of the likely loss of life directly attributable to fluvial floods (primarily resulting from drowning and the impact of flood-borne debris). However, there are likely to be longer-term mortality impacts too, depending on the extent to which the affected area's capacity to respond to the disaster has been compromised. This will depend on factors such as:

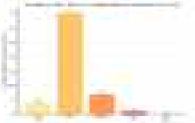
- Size of displaced population to be housed in temporary camps (where disease outbreaks more likely)
- Likelihood of significant standing water near population (increased risk of vector-borne diseases)
- Capacity of local health facilities (those still functional post-disaster)
- Capacity of other government facilities to support response/recovery efforts
- Transport connectivity within the affected area (particularly road and air transport)
- Pre-existing socio-economic vulnerability of population in affected area
- Fraction of affected population made up of tourists (poor local knowledge and thus more vulnerable)
- Risk of vector- and water-borne disease transmission due to stagnant water after a flood

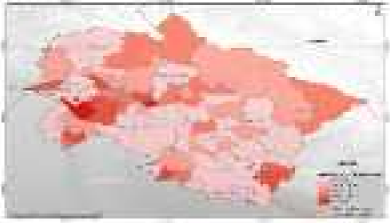
While detailed modelling to quantify this risk is not possible, a qualitative assessment has been performed, in order to evaluate the likely significance of mortality in the state overall and also in terms of the individual factors listed (above) due to fluvial floods.

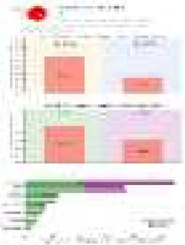
It should be clearly noted that this is a **relative** assessment only: each District is compared to all other Districts in the State, and likewise for Blocks, rather than being assessed against an external standard or reference. Thus it can be stated with some confidence that one District is at a higher mortality risk than another, but the actual level of that risk remains unknown.

A map showing the overall fluvial flood-dependent morbidity risk class estimated for each Block (left) and each District (lower right) in Uttarakhand is presented in Figure 5.118, along with a histogram of the class distribution for blocks (upper right). Further details for each District and Block are available in the corresponding Atlas volume.

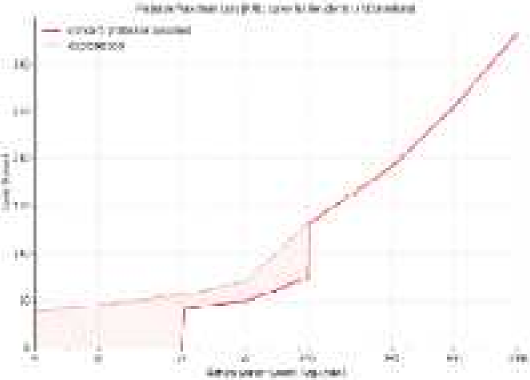




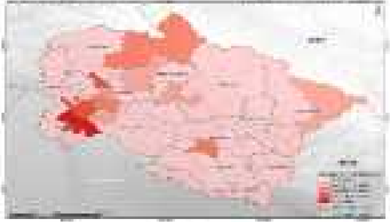




Probable Maximum Loss (PML) curves show the maximum losses that would reasonably be expected for [illegible] for a range of different return periods. Figure [illegible] provides the PML curve for human loss [illegible] for two sets of assumptions: standard protection [illegible] up to the 20 year event in villages and the 100 year event in towns and no protection at all. The reality is likely to be somewhere in between.



[illegible]



Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure 5.11[illegible] presents the PML curve for [illegible] in the area, for two sets of assumptions: standard protection (people protected up to the 20 year event in villages and the 100 year event in towns) and no protection at all. The reality is likely to be somewhere in between.

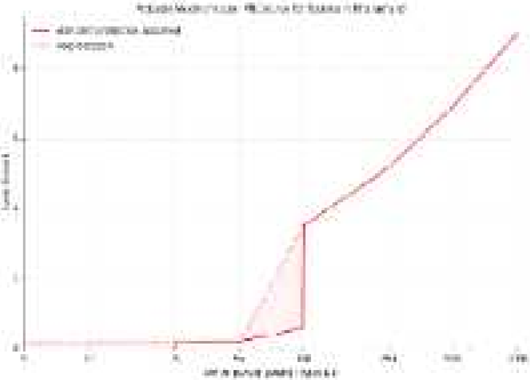
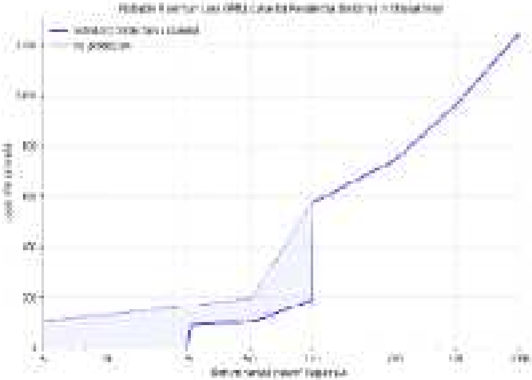
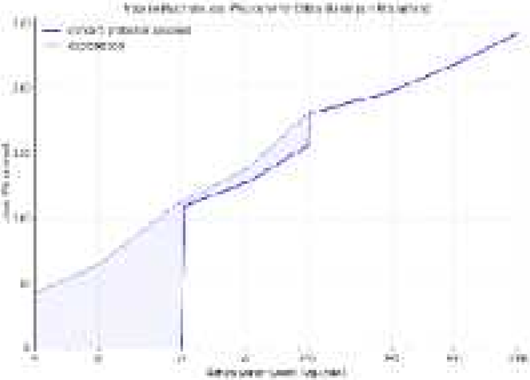


Figure 5.11[illegible]: Probable Maximum Loss (PML) curve for [illegible]





Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure 2.115 presents the PML curve for transportation infrastructure in the state. Note that only one version of the curve is presented for transportation infrastructure, based on the assumption of no protection given the wide spatial distribution of the exposed elements making up this portfolio.

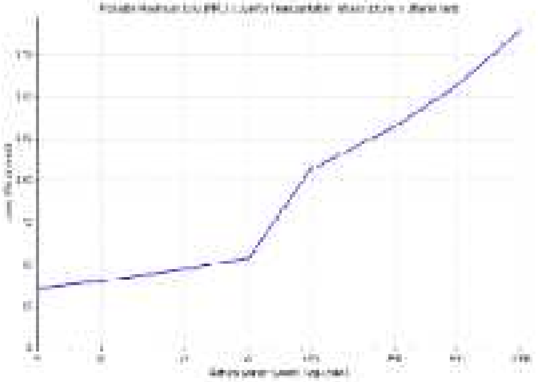
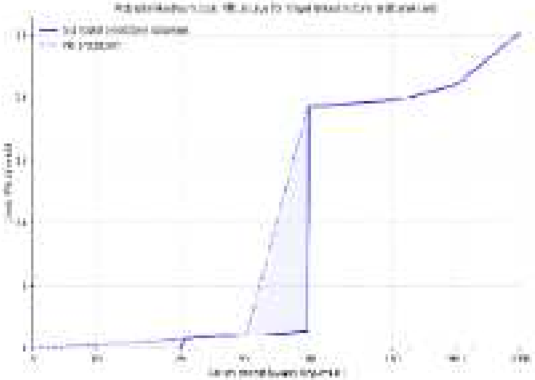
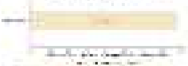


Figure 2.115: Probable Maximum Loss (PML) curve for transportation infrastructure due to fluvial flood





Probable Maximum Loss (PML) curves [illegible] assets, for a range of different return periods. Figure 3.[illegible] presents the PML curve for [illegible] that only one variation of the curve is presented for [illegible] based on the assumption of no protection [illegible]

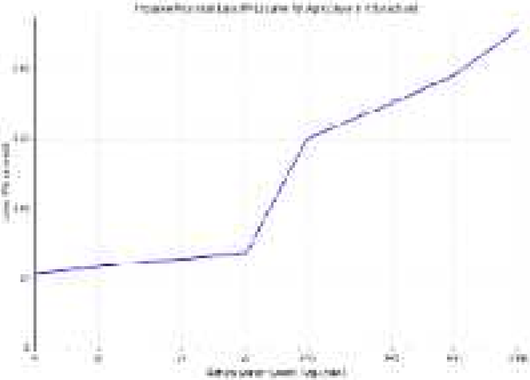
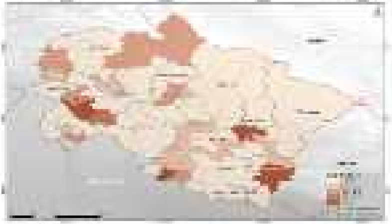


Figure 3.[illegible]: Probable Maximum Loss (PML) curve for [illegible]



Probable Maximum Loss (PML) curves show the maximum losses [illegible] for a range of different return periods. Figure [illegible] presents the PML curve for [illegible] [illegible] Based on the assumption of no protection [illegible]

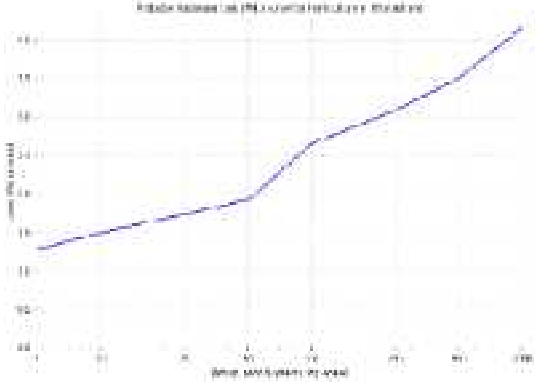
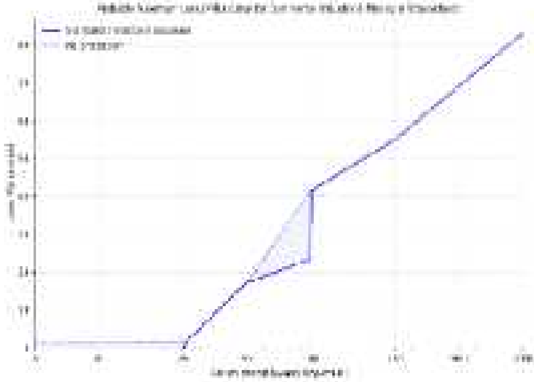


Figure [illegible] Probable Maximum Loss (PML) curve [illegible]

Probable Maximum Loss (PML) [illegible] for commercial and industry in the state, [illegible] up to the 25 year event in villages and the 100 year event in towns [illegible] no protection at all. The reality is likely to be somewhere in between.



Probable Maximum Loss (PML) curves show the maximum losses that could reasonably be expected for exposed assets, for a range of different return periods. Figure 3.126 presents the PML curve for tourism revenue in the state, for two sets of assumptions: standard protection (built exposure protected up to the 25 year event in villages and the 100 year event in towns) and no protection at all. The reality is likely to be somewhere in between.

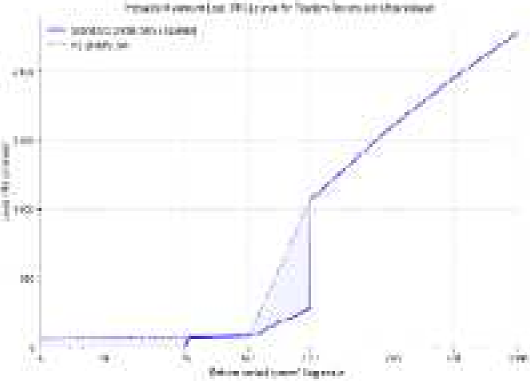


Figure 3.126: Probable Maximum Loss (PML) curve for tourism revenue in Uttarakhand due to fluvial floods

3.5 Landslides

Hazard Profile

Landslide susceptibility modelling has been executed using a series of district-level Maxent models (with the exception of Udham Singh Nagar district, where no historical landslides have yet been recorded and which could therefore not be modelled). Further details of the modelling methodology are provided in Volume 1, Chapter 3.

In each of the district-level landslide susceptibility sections, a brief summary of the district's Maxent model is presented, giving a useful insight into which of the many input datasets proved to make the largest contributions to the model in that particular district. All of these are summarised in Figure 3.127, showing clearly the significant impact that road cuttings have, as well as topographical properties such as slope and aspect.

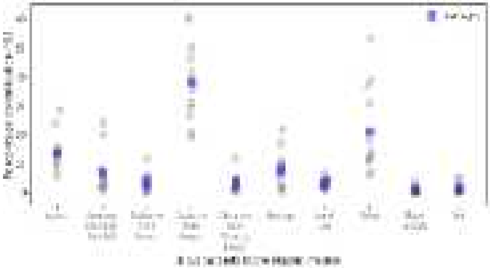


Figure 3.127: Distribution of each input dataset's contribution to the final models, for the 12 district models run

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, the average train and test scores were [illegible] and [illegible], respectively, indicating a significantly superior performance over random prediction.

The results of these Maxent landslide models were reclassified into five categories, ranging from 'None' to 'Very High', in terms of landslide susceptibility. In the case of Udham Singh Nagar (for which a Maxent model could not be established) it was assumed that the district fell entirely in the 'None' category, given that no landslides have ever been reported there. Figure 3.128 shows the distribution of these classes (by area) across the entire state.

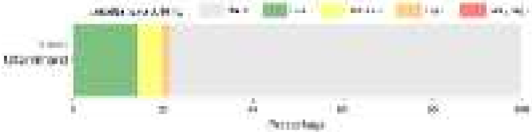
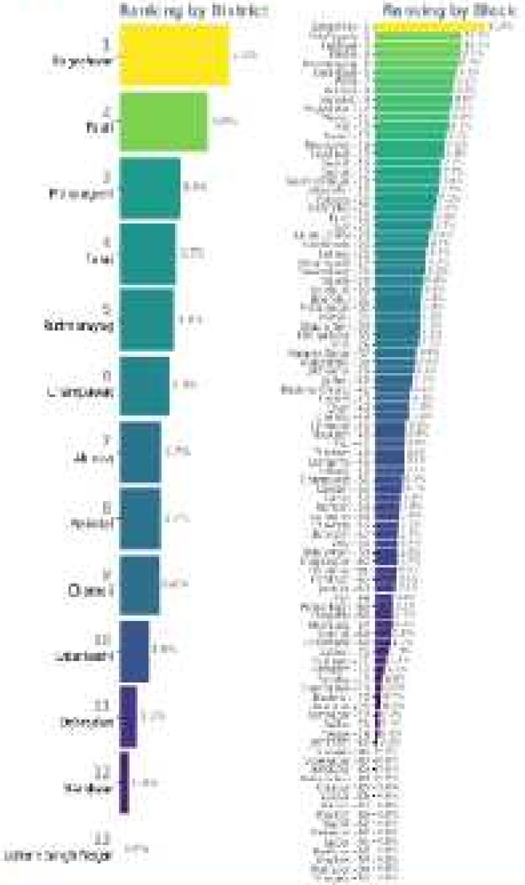
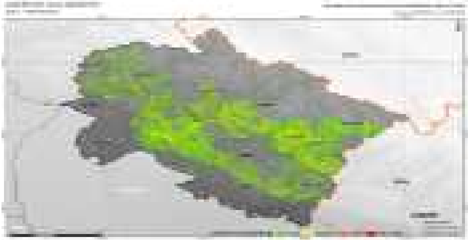


Figure 3.128: Proportion of area in the five landslide susceptibility classes

For each district and block, these distributions were also used to calculate a weighted average of the proportions covered by different classes (with higher susceptibility classes weighted more heavily). These weighted averages were used to rank all districts and blocks in the state, the results of which are shown in Figure 3.129.


Ranking by District
Ranking by Block



3.3 Landslides

Exposure Profile

[illegible]

[illegible]

[illegible]

[illegible]