# Preparation of
# Hazard, Vulnerability & Risk Analysis atlas and report for the state of Himachal Pradesh

## Landslide Hazard Risk Assessment

Composite Final Draft Report

(T6)

Prepared for

Disaster Management Cell, Department of Revenue
Government of Himachal Pradesh, Shimla

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## VOLUME GUIDE

This series of reports present detailed technical and methodological documentation of the study entitled “Preparation of Hazard, Vulnerability & Risk Analysis Atlas and Report for the State of Himachal Pradesh” for DM Cell, Revenue Department, Himachal Pradesh.

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### Hazard Risk

This volume contains Technical papers on hazard risk assessment due to natural and man-made hazards within Himachal Pradesh as presented below.

1. Avalanche Hazard Risk
2. Climate Change & Flood Hazard Risk
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4. Earthquake Hazard Risk
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# Hazard Risk

# Landslide Hazard Risk Assessment

## Composite Final Draft Report

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# Abbreviations

| | |
|---|---|
| GIS | Geographical Information Systems |
| DEM | Digital Elevation Model |
| SOI | Survey of India |
| GSI | Geological Survey of India |
| BRO | Border Roads Organization |
| BMTPC | Building Materials and Technology Promotion Council |
| LULC | Land use Land cover |
| MCA | Multi-Criteria Analysis |
| LHZ | Landslide Hazard Zonation |
| DST | Department of Science & Technology |
| GLC | Global Land Cover |
| SDMA | State Disaster Management Authority |

# Executive Summary

Landslides are one of the key hazard in the mountain regions particularly in the state of HP which cause damage to infrastructure i.e. roads, railways, bridges, dams, bio-engineering structures, and houses but also lead to loss of life, livelihood and environment. Hence it essential to develop a Landslide Hazard Zonation (LHZ) delineating the areas at risk to reduce potential disaster. Landslide inventory is an essential part and forms the basic information for any landslide zoning such as susceptibility, risk and hazard zonings. It involves the location, classification, volume, and travel distance, state of activity and date of occurrence of land sliding in that area. In addition, physiographic characteristics such as slope, aspect, relative relief, geology, drainage, rainfall pattern and land use land cover are key deciding factors for slope failure.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER sensor) data of 30m resolution from Terra satellite was used to derive baseline information on physiographic parameters such as slope, aspect, relative relief and drainage density. Classified geology and Soil profile was derived from the Geological Survey of India (GSI), maps. Land use/land cover was acquired from Global Land Cover 2000 and population grid for the year 2010 and 2015 from the Center for International Earth Science Information Network (CIESIN). Classified rainfall layer was formed using data from Indian Meteorology Department (IMD) and Indian Institute of Tropical Meteorology (IITM).

The inventory of past landslides was synthesized using the data from Geological survey of India, Building Materials and Technology Promotion Council (BMPTC) and TARU database. The weighted average method (based on methodology recommended by BMPTC, expert knowledge and analytical hierarchical process) was used to determine degree of hazard risk associated with landslides. The landslide hazard probability values thus obtained from three different approaches were classified into Unlikely/Restricted/water bodies, Low, Moderate and High.

According to the Landslide Hazard Zonation Atlas of India published by BMPTC more than 8% of the entire area of the state is under High Hazard Risk zone but according to revised methodology using expert knowledge (EK) and AHP indicate that around 3.20% and 5.65% area respectively under High Landslide Hazard Risk. It was observed that as per the Experts Knowledge and AHP approach majority of the total area of Himachal Pradesh is under Medium Landslide Hazard risk zone. Number of past landslide locations obtained from Geological survey of India (GSI), TARU and BMPTC fall on the High Hazard zone obtained from three different approaches applied to form Landslide hazard risk map for the State. Given the hazard zonation, much of the roads (total length of ~1628 Kms) in Himachal are seasonal and get closed during winters and monsoons due to heavy snowfall, landslides and washouts. Visual interpretation and GIS analysis indicate that most of the built-up area comes under the high risk zone. On further analysis it was found that around 10 Mega Hydropower projects of Himachal Pradesh are under maximum threat of Landslide followed by large hydropower projects which fall under medium landslide hazard risk.

# Chapter 1: Introduction

## 1.1 Geography

Located on the western corner of Himalaya, Himachal Pradesh extends between 30' 22' 40" North to 33' 12' 40" North latitude and 75' 45' 55" East to 79' 04' 20" East longitude. The state is divided into twelve districts and has 49 cities and towns. Mainly the region falls under the hilly terrain with altitude ranging from 350 meters to 7000 meters above sea level. The altitude increases from west to east and from south to north. The Himachal Pradesh region can be categorized into the following Geographical Divisions such as the Shivaliks or the outer Himalayas, the central zone or the lesser Himalaya and the northern zone or the great Himalayan and Zaskar. Followed by the Chief Rivers of the state that have a significant contribution towards the Natural prosperity of the state includes Chenab, Beas, Ravi, Yamuna, Sutlej and Spiti.

## 1.2 Geology

It has deeply dissected topography complex geological structure and a rich temperate flora in the sub-tropical latitudes. Physiographic ally, the State can be divided in to five zones-viz. (i) Wet Sub-temperate zone,(ii) humid sub temperate zone, (iii) dry temperate-alpine high lands, (iv) humid sub-tropical zone, and(v) sub-humid sub-tropical zone. Wet sub-temperate zone comprises Palampur and Dharamshala of Kangra district, Jogindernagar area of Mandi district and Dalhousie area of Chamba district, humid sub-temperate zone comprises the district of Kullu, Shimla, parts of Mandi, Solan, Chamba, Kangra and Sirmaur,

Dry temperate Alpine High lands include major parts of Lahaul-Spiti, Pnagi and Kinnaur, humid sub-tropical zone consists of Bilaspur, Bhattiyat valley of District Chamba, Nalagarh area of District Solan, Dehragopipur and Nurpur areas of district Kangra and sub-humid tropical zone comprises of District Una, Paonta-Sahib area of District Sirmaour, and Indora area of District Kangra.

The complex physiography, demography and developmental activities around this mountain environment are exposed to hazards such as heavy snowfall, floods, landslides, land subsidence, removal of vegetation and soil erosion. According to one estimate about 58.36 % of the land is subjected to intense soil erosion and majority of which is located in the Himalayas. An estimation of the sedimentation rate of the major river systems of the area depicts the seriousness of the erosion.

Hilly areas of Himachal Pradesh is vulnerable to landslides due to geological meteorological and anthropogenic factors. Several devastating landslides have occurred in Himachal Pradesh over the past decade. The hydro-meteorological conditions and fragile structural fabric of geological strata of Himachal Pradesh increase the possibility of landslides. Anthropogenic factors such as removal of vegetation cover, overloading of slopes by derbies also contribute to a great extent. Development activities like construction of roads, tunnels and excavation for hydro projects have further accentuated the problem. Loss of life, damage to buildings, soil erosion, and loss of tree cover, damage to bridges, communication lines and hydropower infrastructure are some of the impacts the landslide and slips tend to cause.

## 1.3 Previous Research

Landslides in mountainous terrain often occur during or after heavy rainfall, resulting in the loss of life and damage to the natural and /or built environment (Fuchu and Chack, 2002). Earthquakes, heavy rainfall, volcanic eruptions, etc. may act as triggering mechanisms to initiate a landslide (Kessarkar et al., 2011).

Geological Survey of India issues alerts and warnings to all designated authorities and agencies of the Central Government and State Governments/ district Administration for landslides in the following categories.

- **Category IV:** Landslides of small dimensions that occur away from habitations and do not affect either humans or their possessions.
- **Category III:** Landslides which are fairly large and affect infrastructural installations like strategic and important highways and roads, rail routes and other civil installations like various appurtenant structures of hydroelectric and irrigation projects
- **Category II:** The landslides that may occur on the fringes of inhabited areas and result in limited loss of life and property.
- **Category I:** Landslides of large dimensions that is located over or in close vicinity of inhabited areas like urban settlements or fairly large rural settlements. Activity on these slides can result in loss of human lives, dwellings on large scale. (Standard Operating Procedures for Responding to Disasters, Department of Revenue, Disaster Management Cell, H.P, 2012).

Advances in Geographical Information Systems (GIS) technology and the mathematical/statistical tools for modeling and simulation, have led to the growing application of quantitative techniques in many areas of the earth sciences thus have widened the application of satellite imageries and other spatial data to map the Landslide affected, prone area and to map the Risk zone under the prone disaster for the area (Carrara & Pike, 2008).

In the past, several research / academic institutions and government agencies have carried out landslides hazard zonation and susceptibility mapping. These landslides models were validated using ground truth surveys only which were not the reliable method. GIS is a useful tool for the construction of landslide prediction model and for application in regional planning, hazard mitigation, and sediments yield estimation (Lee et al., 2008). Landslide hazard zonation has been carried out in western Himalayan district of Kullu in Himachal Pradesh using remote sensing and GIS. Satellite imageries of LANDSAT ETM+, IRS P6, ASTER along with Survey of India (SOI) topographical sheets formed the basis for deriving baseline information on various parameters like slope, aspect, relative relief, drainage density, geology/lithology and land use/land cover. The weighted parametric approach was applied to determine degree of susceptibility to landslides. The landslide probability values thus obtained were classified into no risk, very low to moderate, high, and very high to severe landslide hazard risk zones. (Chauhan et. al., 2011).

Similar research was conducted for development of a landslide model by using multi-criteria decision analysis in GIS and remote sensing techniques for landslide hazard zonation of Giri river watershed in Yamuna basin. (Pareta et. al. 2012). This study was an attempt towards development of a landslide model by using multi-criteria decision analysis in GIS and remote sensing techniques for landslide hazard zonation.WorldView-02-MS and ResourceSAT-2 LISS- 4-Mx satellite imageries, SOI topographical maps, and field data were used as inputs to the study. These data layers represent the soil, land use, geological, topographical, and hydrological conditions of the terrain. A numerical rating scheme for the factors was developed for spatial data analysis in a GIS. The resulting landslide hazard zonation map delineated the area into different zones of four relative HZ-classes: very high, high, moderate, and low. The LHZ-map was corroborated by correlating the landslide frequencies of different classes.

In India, landslide data are collected by Geological Survey of India (GSI) and Border Roads Organization (BRO) at national level; State Department of Geology & Mines (DGM) at the State Level in few States, District Administration at the district level. In addition to these agencies, some academic, research and corporate sector organization are also involved in Landslide data collection and compilation.

Recent notable contributions among them are the Atlas on Landslides published by National Remote Sensing Agency, Department of Space in the year 2003. The atlas consists of landslide hazard and management maps for the pilgrimage routes of Himachal Pradesh and Uttarakhand Himalaya in the scale of 1:25,000. The maps have been validated using major, actual landslide data and it was found that most of these landslides occurred in the high and very-high risk zones identified in the atlas.

Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Development & Poverty Alleviation, New Delhi has also published an Atlas on Landslides in India in the year 2004, jointly with Centre for Disaster Mitigation & Management (CDMM), Anna University, Chennai. The Atlas presents Geographical Information System (GIS) based landslide inventory map and landslide hazard zonation maps of India at the scale of 1:6 million (BMTPC, 2004).

Geological Survey of India (GSI) has come up with a Landslide hazard map of India in early 90’s, demarcating the severity of Landslide hazard in different parts of the country and also published an Inventory of Landslides in the year 2005. GSI has developed a format and circulated it to States & other national agencies like BRO, CPWD etc. for reporting landslide incidences for input towards updating inventory. Incidences (1139) of landslides are available in this inventory report from Northwestern Himalaya, Eastern Himalaya & Northeastern states (GSI, 2005).

Department of Science & Technology (DST) has published an Atlas on Landslide Hazard Zonation along Satluj River Valley in the year 2006 based on the work done through DST Sponsored Landslide Hazard Zonation Mapping Projects (1992 -1998).The Atlas also includes the works done on landslides at Wadia Institute of Himalayan Geology. DST has also supported a “Coordinated National Programme on Landslide Hazard Mitigation (CNPLHM)” since 1991-92. Under this programme, various integrated and interdisciplinary investigation have been carried out in the scale of 1:50,000 and 1:10,000, 1:1000-2000. A Mission Mode Project on Landslide Hazard Mitigation focusing in Uttarakhand State has been launched in the year 1999. DST recently published landslide hazard zonation maps for entire India (2012).

Border Roads Organization (BRO) is also compiling information on landslides incidences for the purpose of construction, maintenance and management of roads. The data remain confined to the official records as unpublished documents. Department of Geology and Mines in few States are also gathering information on the occurrence of landslides in their territories. Particularly the States like Sikkim, Andhra Pradesh, West Bengal, Tamil Nadu, Mizoram, Uttarakhand have been working on significant landslides in the respective territories. But very few publications on landslides databases are available to the public. Most of these data are lying in the official reports.

Central Building Research Institute (CBRI) is building landslides databases in parts of Uttarakhand, Himachal, Sikkim and Darjeeling Himalaya since late 1980s. CBRI has published landslide inventories and zonation maps of these sectors on 1:50,000 and 1:25,000 scales. Besides working on landslide inventory and zonation, the Institute has also undertaken some site specific studies and micro-zonation studies in Himalayan region.

Disaster Mitigation & Management Centre (DMMC), Dehradun is also involved in landslide data collection in Uttarakhand State. DMMC has compiled information on existing landslides in Rudraprayag District of Uttarakhand. The information is being collected using Differential Global Positioning System. Although the landslide hazard zonation maps (or susceptibility maps to be more accurate) are available in different scales yet very little application of these maps has been made for planning and implementation of developmental projects.

Various academic and research organizations have produced the landslide susceptibility maps / atlas merely as academic exercises and not being used in decision making process by the operational agencies. Risk maps considering infrastructure, population and other amenities is yet to developed. Similarly, there are a few cases of known landslide sites or unstable slopes where proactive preventive and mitigation measures have been undertaken after appropriate investigations and observations.

# Chapter 2: Data Availability

Digital maps of Himachal Pradesh with district boundaries were used for preparation of Flood hazard risk map and to perform Risk assessment. The table below gives the sources of the data are mentioned below:

| Layer Name | Sub-type | Source | Layer Type |
|---|---|---|---|
| **Base Layers** | Geological | GSI, HP State | Polygon |
| | Soil | GSI, HP State | Polygon |
| | Rainfall | IMD and IITM, 2009 | GRID |
| | Land use Land cover | GLC 2000 | Polygon |
| | Population density map | CIESIN: 2010 and 2015 | GRID |
| **Remote Sensing Data** | Slope | ASTER(30m) | GRID |
| **Geological Hazard** | Landslide | GSI, HP State, BMPTC, TARU | Point |

# Chapter 3: Methodology

The main objective of this study is to assess and map Landslide Hazard risks and Vulnerability of different elements, at district level across the State. This paper explains the methodology adopted in this exercise and presents Landslide Hazard risk and Vulnerability maps.

Landslide hazard of an area is determined by multiple factors. There are many techniques which have been applied to delineate the area into different landslide hazard zones. These techniques are broadly divided into direct and indirect method. Direct method includes Geomorphological mapping and Landslide distribution analysis whereas there are number of indirect ways for landslide Hazard zonation. Indirect method includes Index overlay, Fuzzy logic, Analytical Hierarchical process, multivariate technique, Deterministic modelling etc.

In 1974, one of the largest landslides was recorded in history in the Mantaro River valley in the Andes Mountains of Peru (Hutchinson & Kogan, 1975). To assess the relative landslide hazard was the objective of the method described in this study. Group combinations of the factors like bedrock, slope steepness, and hydrologic factors inventory of past landslides were considered in a way to define four levels of landslide hazard. The group was achieved by performing a combined factor analysis or matrix assessment (DeGraff & Romesburg, 1980).

In another case, a study was conducted in the valley of Garhwal Himalaya for landslide hazard zonation on GIS/Statistical based approach. For this exercise statistical landslide index method was used for hazard zonation. The method was based on statistical correlation of a Landslide map with different parameter maps. All the weighted maps were integrated to delineate the zones of landslide hazard. Slopes, deforestation, heavy precipitation and the road construction itself are found to be the main cause of slope instability in the Himachal, resulting into varieties of landslide movements. An attempt to create the Landslide Susceptibility or Hazard Zonation Map was done along with some predictive locations, remote sensing data and with the GIS layers mainly DEM, slope maps, and flow accumulation maps in small area of the Giri river valley in Sirmaur district of Himachal Pradesh in this study. (Parmar et. al, 2012)

No one method is accepted universally for effective assessment of landslide hazards. In recent years, several attempts have been made to apply different methods of LHZ and to compare results in order to find the best suited model. The advanced multivariate techniques are proved to be effective in spatial prediction of landslides with high degree of accuracy.

## 3.1 Limitations

The above method of Landslide hazard risk zonation have large number of limitations, derived largely from the lack of required data, time and resources. A Brief list of limitations are presented below:

- Non availability of data on dips and slips
- Layers used for Hazard mapping are of moderate resolution.
- Population density- Gridded population data of 2001 was interpolated by statistical methods by assuming 12.86% uniform growth in population density. However there exists variation between different population grids.
- Tectonic map as indicated in categories available in BMPTC Vulnerability atlas not available. So the influence value of 12% was distributed to other layers similar to North Eastern Himalayas.
- For Soil map, hazard classification rank was assigned on basis of depth only. However other factors like weathering, drainage, vegetation cover etc. have not been used for ranking soil based on hazard proneness.
- The results and the layers formed were not cross checked and verified on ground
- Lack of geomorphological map for the region prevents from detailed analysis in some areas.

## 3.2 Methods Proposed for the Study

For the present study three approaches of Multi Criteria Analysis technique were used for landslide hazard and vulnerability mapping. Classified LULC layer, classified geology layer, classified soil layer, classified rainfall layer and classified slope layer were used for overlay analysis. Weights indicating measures of influence of different layers were quantified by three means: 1) BMPTC vulnerability assessment method 2) experts knowledge and 3) analytical hierarchical process. These methods were chosen for the present study because it has been applied and tested for Hazard mapping at different regional level within India. The second contributing reason for selecting this method was on based on the availability of data. With time there are many irreversible changes occurring over the land use pattern and nature of climate. Due to such high degree of spatial dynamics and variability the influencing factors also changes therefore and thus making the results uncertain to a level.

In this study, remote sensing technology and Geographical Information System (GIS) was integrated with Multi criteria Analysis (MCA) to perform the Hazard risk mapping. The main focus of this method is to provide more flexible and more accurate decisions to the decision makers in order to evaluate the effective factors and prepare the hazard map. The factors considered were classified rainfall, classified slope layer, classified geology layer, land cover and classified soil layer (Yahaya, 2008).

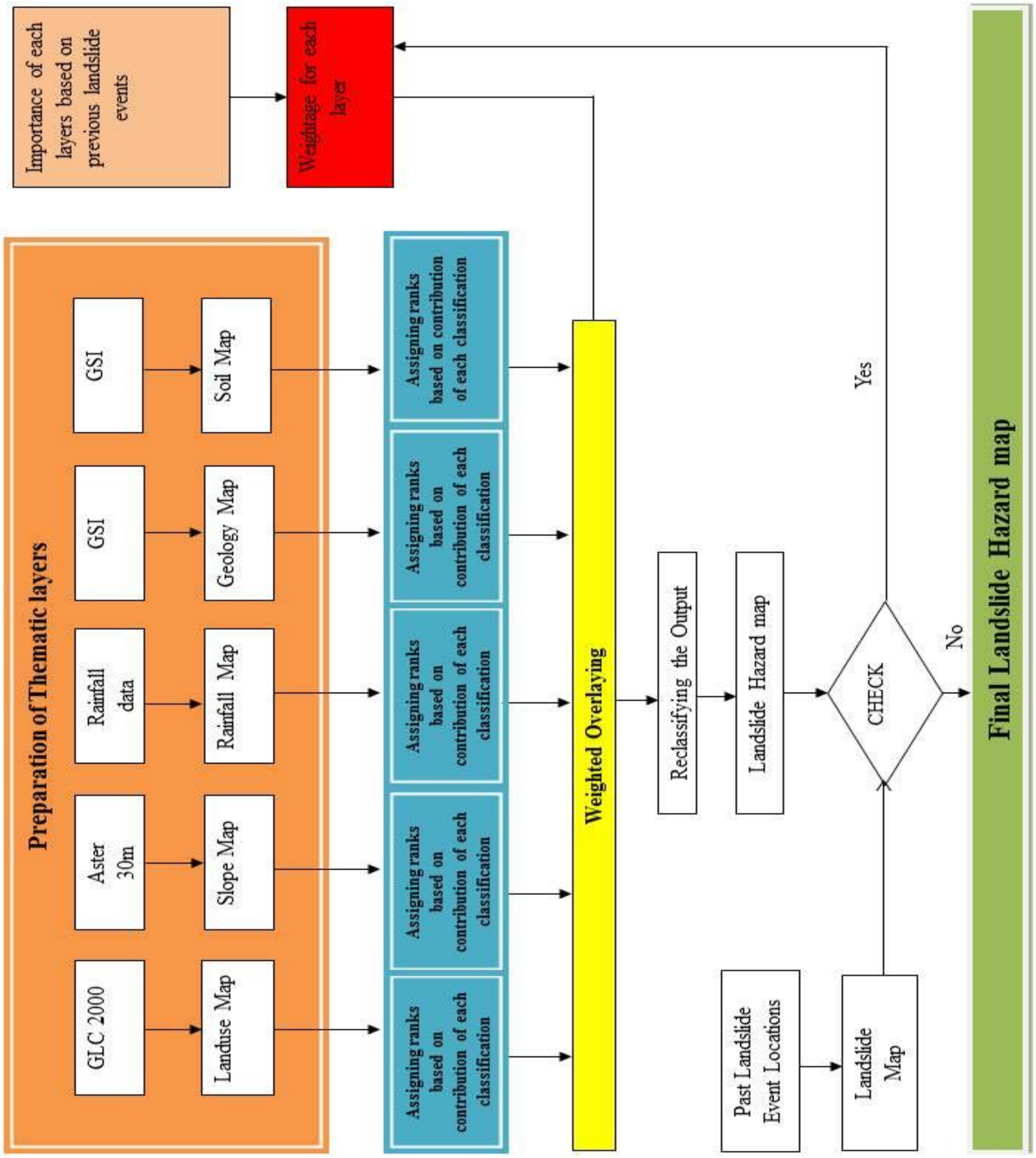
The scope of the present study is to generate a hazard risk map which delineates the area under the different levels of threat of landslides. There are several factors which contribute to the effect of landslide hazard in a given area.

The method and weights assigned to each layer has been explained below in detail.

### 3.2.1 Multi Criteria Analysis using guidelines of BMPTC atlas.

Weighted Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis (ESRI developer network). It overlays only the raster files (in form of ESRI GRID) using a common measurement scale and weights each according to its importance. Five thematic layers were used to run this model so as to obtain the Landslide Hazard Map.

**Figure 1: Flowchart for Hazard Mapping**



Source: Modified from BMPTC, 2004

The influence and rank provided to each layer depends on the expert knowledge gained through literature or experience in the field (as given in BMPTC Vulnerability Atlas). All the thematic layers assigned influence values and were reclassified into major classes and influence ranks were assigned based on landslide susceptibility. The Table 1 depicts the influence and rank assigned while running the weighted overlay model in ArcGIS.

**Table 1: Five Thematic Layers with Their Influence and Scale Value for Different Classes (As per the values used in BMPTC Vulnerability Atlas)**

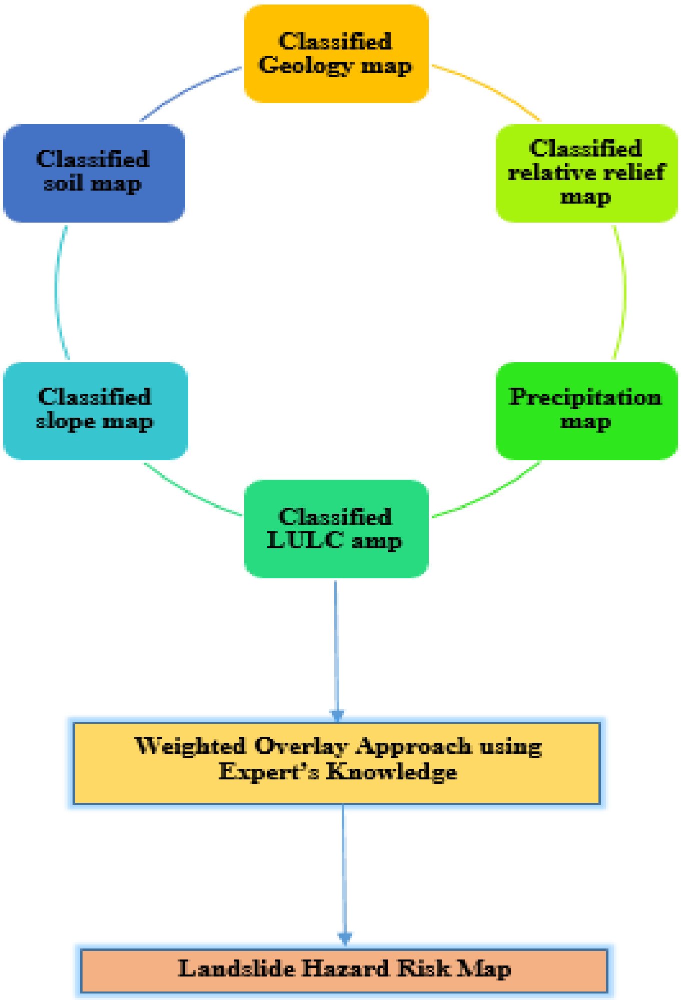
| Layer / Class | % Influence | Scale/ Rank (in 5 Points Scale) |
|---|---|---|
| I. Classified Land cover | 25 | |
| 1. Forest | | 1 |
| 2. Glacier | | 1 |
| 3. Forest plantation | | 2 |
| 4. Scrub and grass | | 3 |
| 5. Forest degraded | | 3 |
| 6. Cold desert | | 4 |
| 7. Unproductive | | 4 |
| 8. Agriculture | | 5 |
| 9. Settlement | | 5 |
| II. Classified rainfall layer (in mm) | 8 | |
| 1. 800-1000 | | 3 |
| 2. 1000-1200 | | 4 |
| 3. 1200-1400 | | 4 |
| 4. 1400-1600 | | 4 |
| 5. 1600-2000 | | 4 |
| 6. 2000-2400 | | 4 |
| 7. 2400-2800 | | 4 |
| 8. 2800-3200 | | 5 |
| IV. Classified Soil layer | 17 | |
| 1. Deep | | 1 |
| 2. Medium deep | | 2 |
| 3. Medium deep to deep | | 3 |
| 4. Mountain and valley glaciers | | 3 |
| 5. Rock outcrops | | 4 |
| 6. Rocky cliffs | | 4 |
| 7. Valley glaciers | | 4 |
| 8. Shallow | | 5 |
| Classified Geology layer | 22 | |
| Mesoproterozoic-Neoproterozoic, Quaternary. | | 1 |
| Paleaezoic, Unknown age, Neoproterozoic(upper), Neoproterozoic, Triassic-Jurassic | | 2 |
| Proterozoic (undiff), Ordovician-Devonoan, Permian, Triassic, Neoproterozoic (lower) | | 3 |
| Carboniferous-Permian, Meo-Pliocene, Mesoproterozoic, Cambrian, Plio-Pliestocene, Palaeocene-Eocene, Jurassic, Cretaceous, Eocene-Miocene | | 4 |
| Classified Slope (in degree) | 25 | |
| • < 1 | | 1 |
| • 1-4 | | 1 |
| • 4-8 | | 1 |

| Layer / Class | % Influence | Scale/ Rank (in 5 Points Scale) |
|---|---|---|
| • > 8-17 | | 2 |
| • >17-37 | | 3 |
| • > 37-87 | | 4 |
| • >87 | | 5 |

### 3.2.2 Multi Criteria Analysis using Expert Knowledge

Weighted Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis (ESRI developer network,). It overlays only the raster files (in form of ESRI GRID) using a common measurement scale and weights each according to its importance. In the present study this technique was used to generate Landslide Hazard map and to perform Risk assessment for the Himachal Pradesh. Six thematic layers were used to run this model so as to obtain the Landslide Hazard Map. The Six thematic layers used were (1) Classified land cover layer, (2) Soil (3) precipitation, (4) geological profile layer (based on bearing capacity), (5) Classified slope layer and (6) Classified relative relief.

**Figure 2: Flowchart for Hazard Mapping**



These six layers were ranged and scaled depending upon the influence or relation they have in context to Landslides (Chandel, et. al., 2011). The scale provided to each layer depends on the expert knowledge gained through literature or experience in the field. All the thematic layers were reclassified into 5 major classes by using the ranks given to each class. The layers used for this analysis were classified LULC layer, classified soil layer, Precipitation layer, classified slope layer and geology. Earlier the geology layer was classified on the bases of the ages of the rock type but in the revised methodology geology layer is classified on the bases of the bearing capacity[1].

In general terms, bearing capacity of the soil determines the maximum load the soil can take up with getting displaced. So less the bearing capacity less it can hold the pressure of landslides and therefore will get eroded easily. A bearing capacity failure results in very large downward movements of the structure, typically 0.5 Feet to over 10 Feet in magnitude.

In the revised methodology relative relief layer was considered for analysis. Relative relief is difference between summit level, the highest altitude for a given area, and base level, lowest altitude for a given area. Relative relief can be used as an index of the relative velocity of vertical tectonic movements. Relative relief is applied to study reveal active tectonic structures, to recognize palaeo-surfaces, to estimate seismic activity, and to study the interaction between endo- and exogenic processes of orogenesis. The layer was classified into 5 classes based on their standard deviation In the classified LULC layer field of settlement was removed and instead field of water body was added which was later marked as restricted.

The Table 2 defines the range and scale given to each factor while running the weighted overlay model. In this method six layers were used: classified LULC layer, classified soil layer, classified geology layer, classified relative relief layer, classified rainfall layer and classified slope layer. Classified geology layer, classified soil layer, classified LULC and classified slope layer was given the same percentage influence value i.e. 20% whereas on the other classified relative relief layer and classified rainfall layer were given same percentage influence value i.e. 10%. The scale value for each layer was determined on the basis of previous studies and experts knowledge. The geology layer was classified on the bases of the bearing capacity.

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[1] Bearing capacity - It is the ability of soil to safely carry the pressure placed on the soil from any engineered structure without undergoing a shear failure with accompanying large settlements.

**Table 2: Expert Knowledge: Influence and Scale Value for Each Layer**

| Name of the Layer | % Influence | Scale (1 by 5) |
|---|---|---|
| Classified Land cover | 20 | |
| • Glacier | | 1 |
| • Forest | | 1 |
| • Forest plantation | | 2 |
| • Forest degraded | | 3 |
| • Scrub and grass | | 3 |
| • Cold desert | | 4 |
| • Unproductive | | 4 |
| • Agriculture | | 5 |
| • Water body | | Restricted |
| Classified rainfall layer (in mm) | 10 | |
| • 800-1000 | | 3 |
| • >1000-1200 | | 4 |
| • >1200-1400 | | 4 |
| • >1400-1600 | | 4 |
| • >1600-2000 | | 4 |
| • >2000-2400 | | 4 |
| • >2400-2800 | | 4 |
| • >2800-3200 | | 5 |
| Classified Soil layer | 20 | |
| • Deep | | 1 |
| • Medium deep | | 2 |
| • Medium deep to deep | | 3 |
| • Mountain and valley glaciers | | 3 |
| • Rock outcrops | | 4 |
| • Rocky cliffs | | 4 |
| • Valley glaciers | | 4 |
| • Shallow | | 5 |
| Classified Geology layer (Based on Bearing Capacity) | 20 | |
| • High | | 1 |
| • High to very High | | 1 |
| • Moderately high | | 2 |
| • Medium to high | | 3 |
| • Low to medium | | 4 |
| • Variable | | 5 |

| Name of the Layer | % Influence | Scale (1 by 5) |
|---|---|---|
| Classified Slope (in °) | | |
| - 0-1 | 20 | 1 |
| - >1-4 | | 1 |
| - >4-8 | | 1 |
| - >8-17 | | 2 |
| - >17-37 | | 3 |
| - >37-87 | | 4 |
| - >87 | | 5 |
| Classified Relative relief (in %) | | |
| - 0-10.77 | 10 | 1 |
| - >10.77-28.16 | | 2 |
| - >28.16-45.54 | | 3 |
| - >45.54-62.93 | | 4 |
| - >62.93-65 | | 5 |

### 3.2.3 Multi Criteria Analysis using Analytical Hierarchical Process (AHP).

In this study, the analytical hierarchy process (AHP) was also employed to produce Landslide Hazard risk map. The AHP is a theory of measurement for dealing with quantifiable and intangible criteria that has been applied to numerous areas, such as decision theory and conflict resolution (Dasnanda & Intarawichian, 2010). For this approach, five layers were used - Classified LULC layer, classified soil layer, Precipitation layer, classified slope layer and classified geology layer.

The AHP method was used to define the factors that govern landslide occurrence and their influencing factors. Using this method each layer were further classified into sub-classes and then scaled depending upon the cross matrix formed using these five factors and in relation with the number of landslides falling in that each sub-class. Lastly these sub-classes were weighted based on their importance, and finally the layers prepared were analyzed to generate the final Hazard risk map.

On the basis of matrix-based pair-wise comparison each layer was ranked on the scale of 1-5depending upon the intensity of historical landslides. The final risk map was classified into three major classes i.e. Low, Medium and High risk areas. The Table 3 presented below highlights the influencing factor and scale used for each class and sub class:

**Table 3: Analytical Hierarchical Process: Influence and Scale Value for Each Layer**

| Name of the Layer | Influence factor | Scale (1 by 5) |
|---|---|---|
| Classified Land cover | 0.16 | |
| • Glacier | | 1 |
| • Forest | | 1 |
| • Forest plantation | | 2 |
| • Forest degraded | | 3 |
| • Scrub and grass | | 3 |
| • Cold desert | | 4 |
| • Unproductive | | 4 |
| • Agriculture | | 5 |
| • Water body | | Restricted |
| Classified rainfall layer(in mm) | 0.29 | |
| • 800-1000 | | 3 |
| • >1000-2800 | | 4 |
| • >2800-3200 | | 5 |
| Classified Soil layer | 0.17 | |
| • Deep | | 1 |
| • Medium deep | | 2 |
| • Medium deep to deep | | 3 |
| • Mountain and valley glaciers | | 3 |
| • Rock outcrops | | 4 |
| • Rocky cliffs | | 4 |
| • Valley glaciers | | 4 |
| • Shallow | | 5 |
| Classified Geology layer (Based on Bearing Capacity) | 0.15 | |
| • High | | 1 |
| • High to very High | | 1 |
| • Moderately high | | 2 |
| • Medium to high | | 3 |
| • Low to medium | | 4 |
| • Variable | | 5 |
| Classified Slope (in °) | 0.23 | |
| • 0-1 | | 1 |
| • >1-4 | | 1 |
| • >4-8 | | 1 |
| • >8-17 | | 2 |
| • >17-37 | | 3 |
| • >37-87 | | 4 |
| • >87 | | 5 |

# Chapter 4: Landslide Risk Assessment

Landslide Risk analysis usually consider the potential damage due to landslides in any area. Vulnerable factors includes population, infrastructure, agriculture, critical facilities and so on. Major roadways, location of hydropower projects and settlement area were the elements taken into consideration to analyze the risk associated with them. Simple overlay, thematic mapping, multi-criteria selection and visual interpretation techniques were also used to understand the risk associated with each element under different Hazard risk.

For Risk assessment the results obtained from AHP approach was used with different elements such as location of hydropower projects, major roadways, villages and major towns to analyze the risk associated with these elements.

## 4.1 Results and Analysis

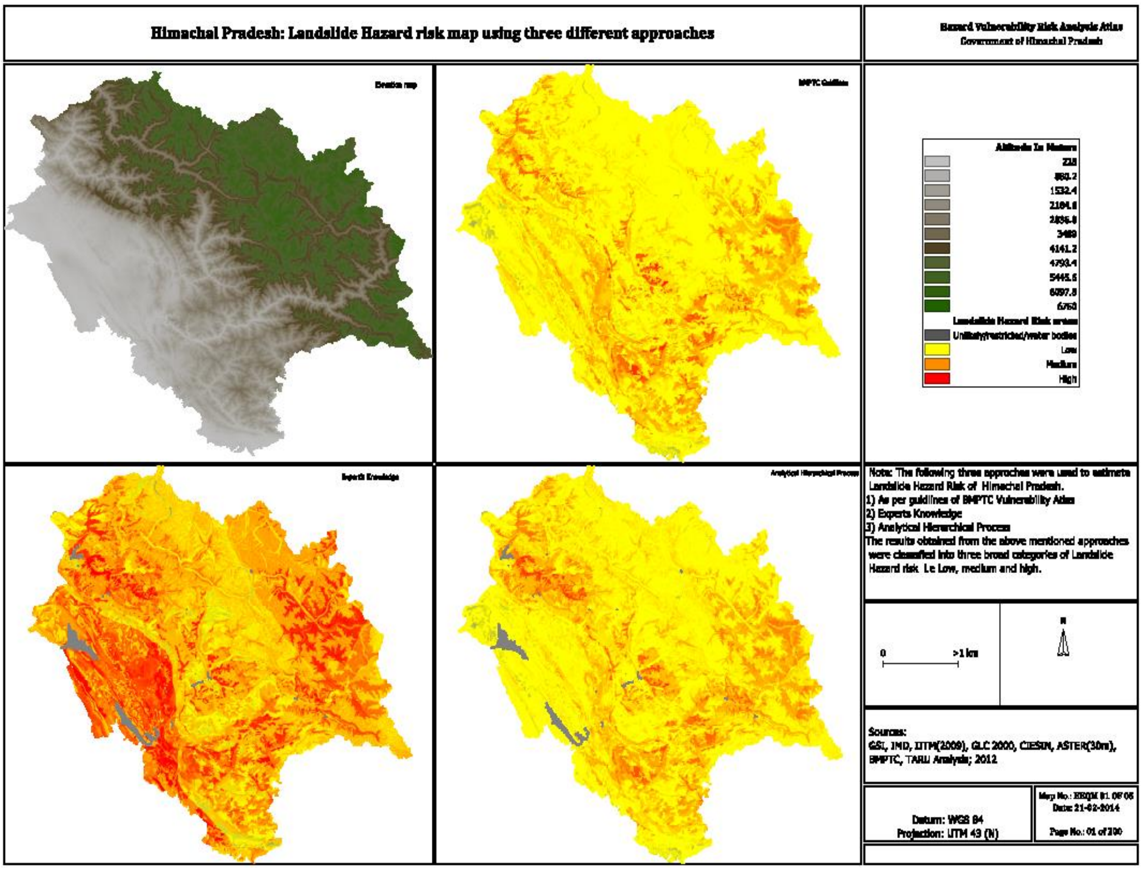
### 4.1.1 Landslide Hazard Map using Multi Criteria analysis (As per the Methodology adopted in BMPTC Vulnerability atlas, Expert's Knowledge and AHP)

As we know weighted overlay is a technique which combines all the raster's files using common measurement scale and weights according to the influence the raster has on the particular event. For this revised methodology six thematic layers were generated- Classified slope layer, classified land use land cover layer, soil profile, precipitation pattern and geological profile of the Himachal Pradesh. Weighted overlay is the technique which is purely dependent on the percentage influence and the importance that particular layer has on the event.

The weights given to each layer is dependent on the approach adopted in the particular case. In case of Landslides we know that topographic, land use pattern and geological profile of the area plays major role in triggering or suppressing the damage caused by this natural disaster. In this model slope, geology and land use pattern layer was given the maximum influencing factor followed precipitation, relative relief and soil layer. Most of the area under the state of Himachal Pradesh is under threat of Landslides. It is the topographical profile of the state and the extreme climatic conditions which makes it susceptible to Landslides.

Hazard risk map of the state depicts that the area of the state falling under the three categories of hazard proneness viz. low, medium and high hazard. Most of the area under the state of Himachal Pradesh is under high hazard. The following Figure no. shows the result obtained from three different methodologies that is as per the methodology adopted in BMPTC vulnerability analysis, as per Expert's knowledge and as per Analytical Hierarchical Process.

## Figure 3: Landslide Hazard Risk Zone Map



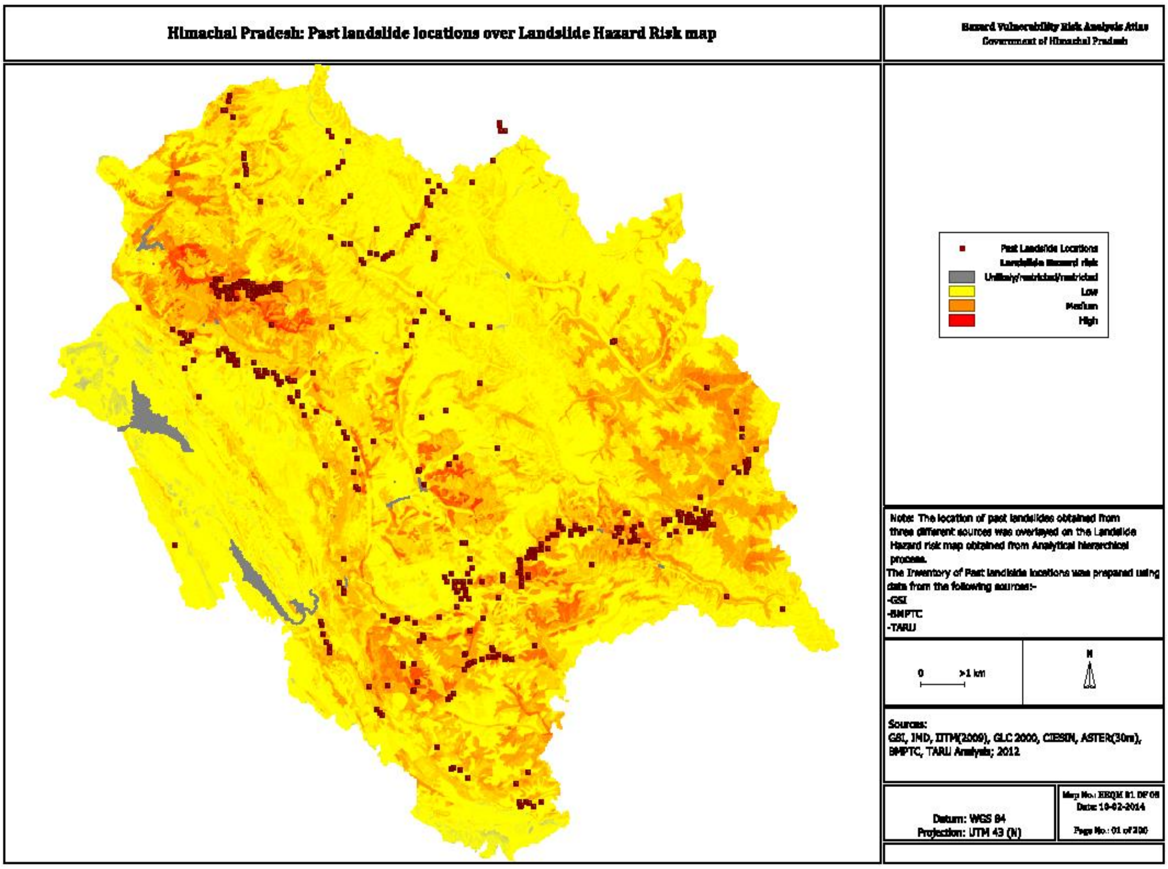
Note: The following three approches were used to estimate Landslide Hazard Risk of Himachal Pradesh.
1) As per guidlines of BMPTC Vulnerability Atlas
2) Experts Knowledge
3) Analytical Hierarchical Process
The results obtained from the above mentioned approaches were classified into three broad categories of Landslide Hazard risk. I.e Low, medium and high.

Sources:
GSI, IMD, IITM(2009), GLC 2000, CIESIN, ASTER(30m), BMPTC, TARU Analysis; 2012

Source: TARU Analysis, 2012.

An inventory of past landslides that have occurred in Himachal Pradesh was made using the data obtained from Geological survey of India, BMPTC and TARU. All the past landslide locations were marked on the map. On overlaying the layer of the past landslides over the landslide hazard risk map prepared from AHP approach it was found that almost landslide points fall in the Zone of high hazard. The following Figure 8 shows the past landslide points falling under different landslide hazard zones.

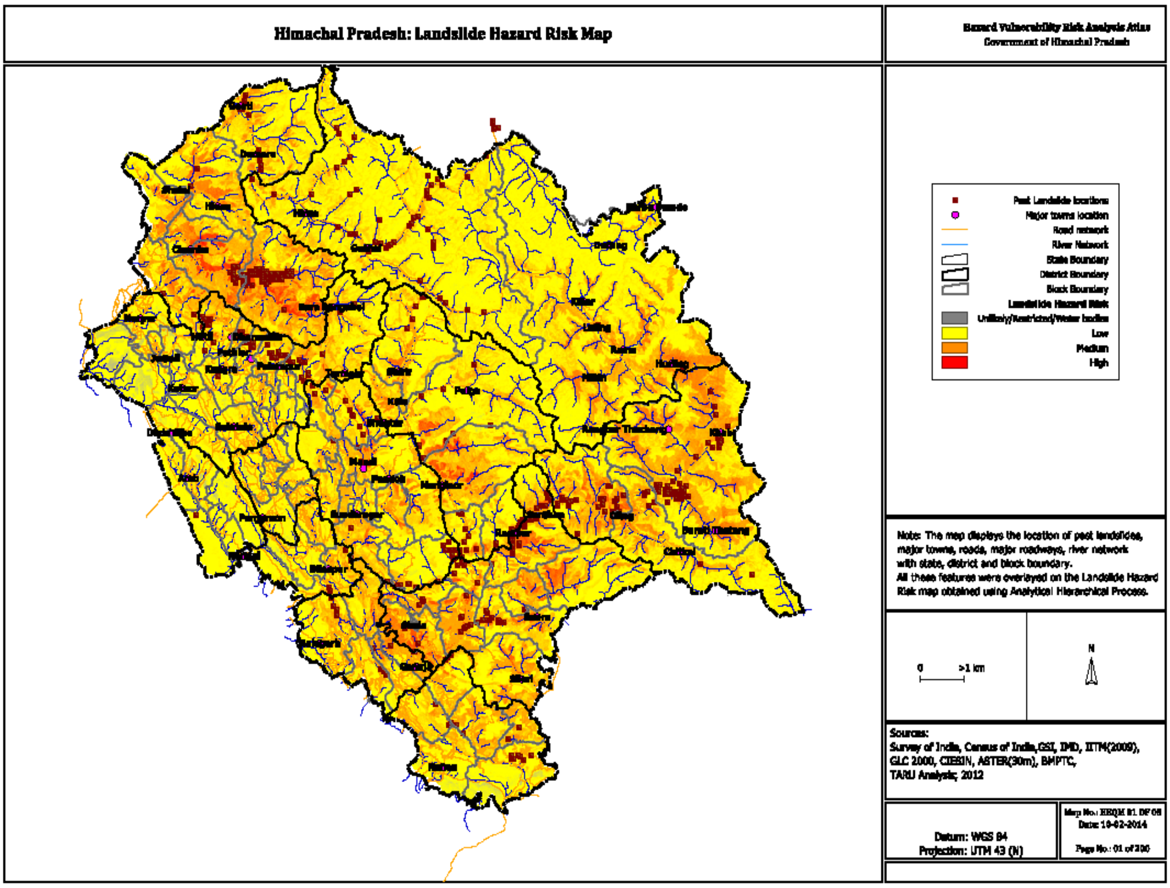
## Figure 4: Past Landslide Locations



Source: GSI (2005), BMPTC, TARU Analysis (2012)

The Figure no. 4 shows the location of major towns, major roadways, river network and past landslide locations with state, district and block boundary over the landslide Hazard risk map obtained from Analytical Hierarchical Process.

## Figure 5: Landslide Hazard Risk Map



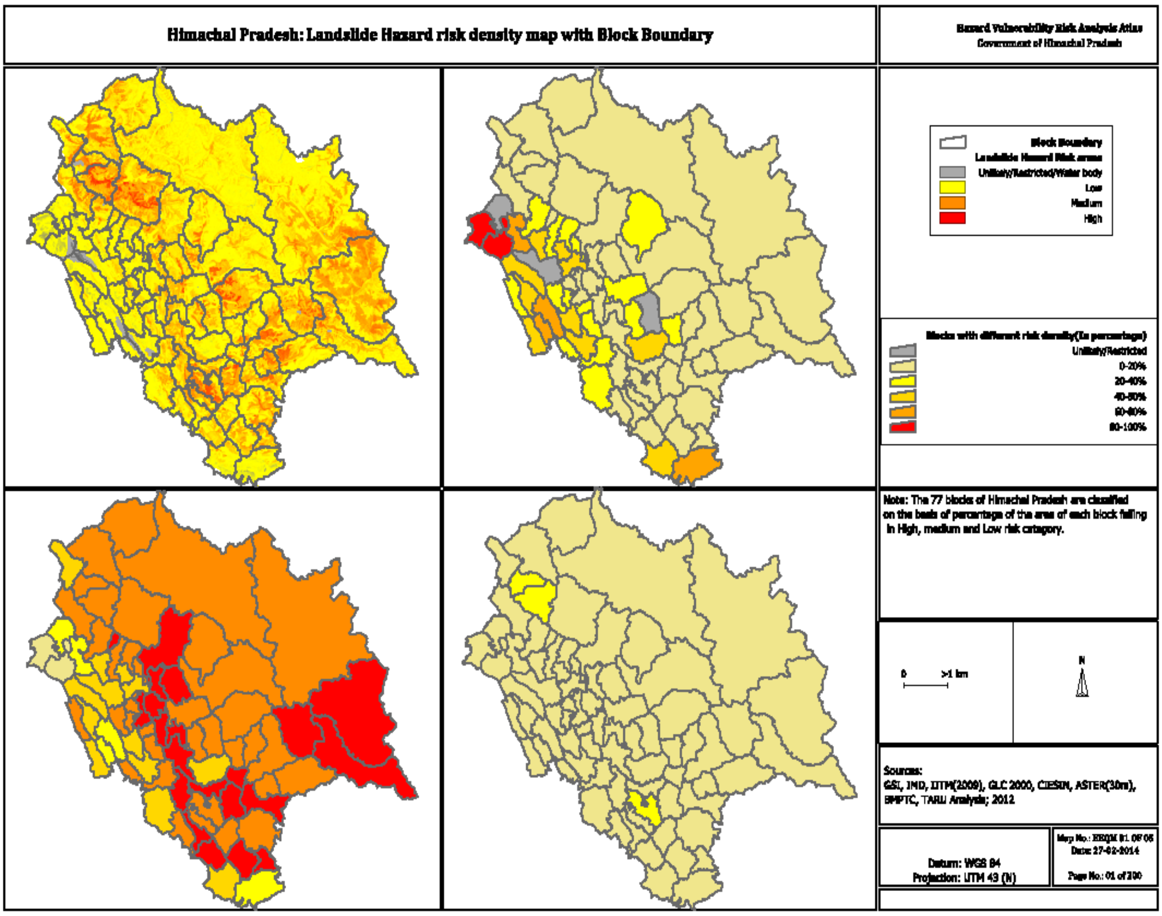
Note: The map displays the location of past landslides, major towns, roads, major roadways, river network with state, district and block boundary.
All these features were overlayed on the Landslide Hazard Risk map obtained using Analytical Hierarchical Process.

Sources:
Survey of India, Census of India,GSI, IMD, IITM(2009),
GLC 2000, CIESIN, ASTER(30m), BMPTC,
TARU Analysis; 2012

*Source:* TARU Analysis, 2012

The Figure 6 shows the percentage of High, medium and low risk area in 77 block of Himachal Pradesh. The area of each block was divided into three broad categories i.e. high, medium and low. Percentage of the area was classified in five classes ranging from 0 to 100 %.

# Figure 6: Landslide Risk Area



# Chapter 5: Elements at Risk

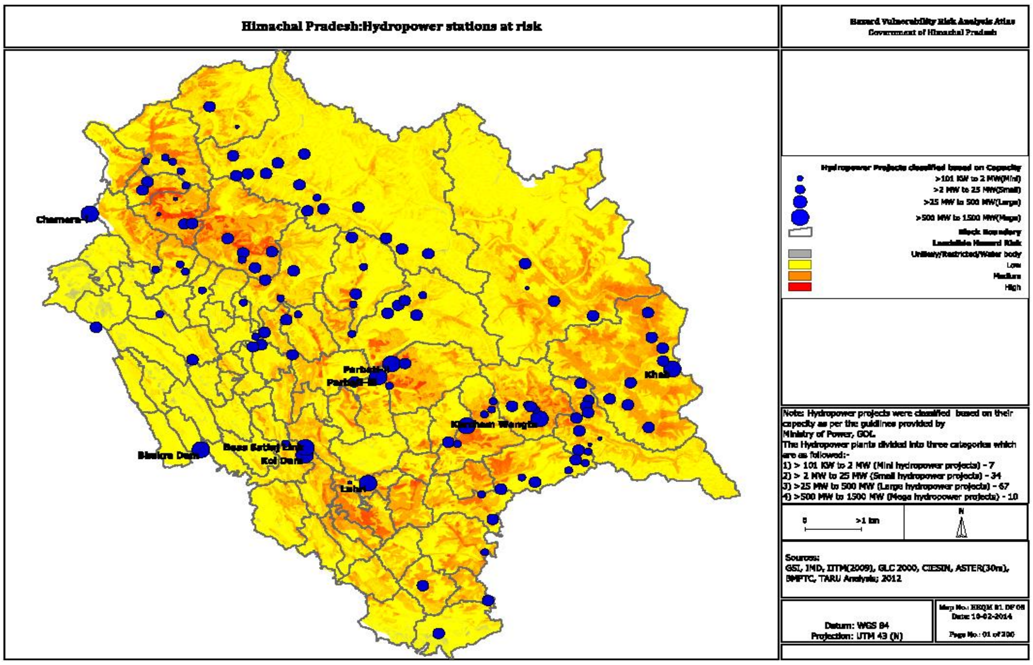
Landslide Risk analysis usually considers range of variables to estimate the risk associated with the disaster. In the present study location of major towns, villages, major roadways, location of hydropower projects were considered to assess the risk associated with each of these elements if a landslide occurs in the area. The data obtained from these elements were overlaid on the Landslide Hazard risk map obtained from Analytical Hierarchical process used to analyze the risk associated with them.

## 5.1 Hydropower stations at risk

In state of Himachal Pradesh is extremely rich in its hydel resources. There are around 118 Hydropower station which include Mini, small, large and Mega hydropower stations. The capacity of these hydropower stations varies from 101 KW to 1500 MW. On analysis it was found that a huge number of hydropower stations i.e. 67 are under threat of landslide Hazard risk followed by small hydropower stations and then Mini hydropower stations.

On the other hand it was found that 10 Mega hydropower stations are in the medium and high risk landslide area. The hydropower stations such as Karcham wangtu, Nathpa jhakri and Bhakra Dam have major role in meeting the growing need of the power for industries, agriculture and rural electrification but are under maximum threat so immediate major steps should be taken to eradicate the risk associated with these major hydropower stations. The following Figure shows the location of major hydropower stations over the landslide Hazard risk map.

**Figure 7: Location of Hydropower Stations**



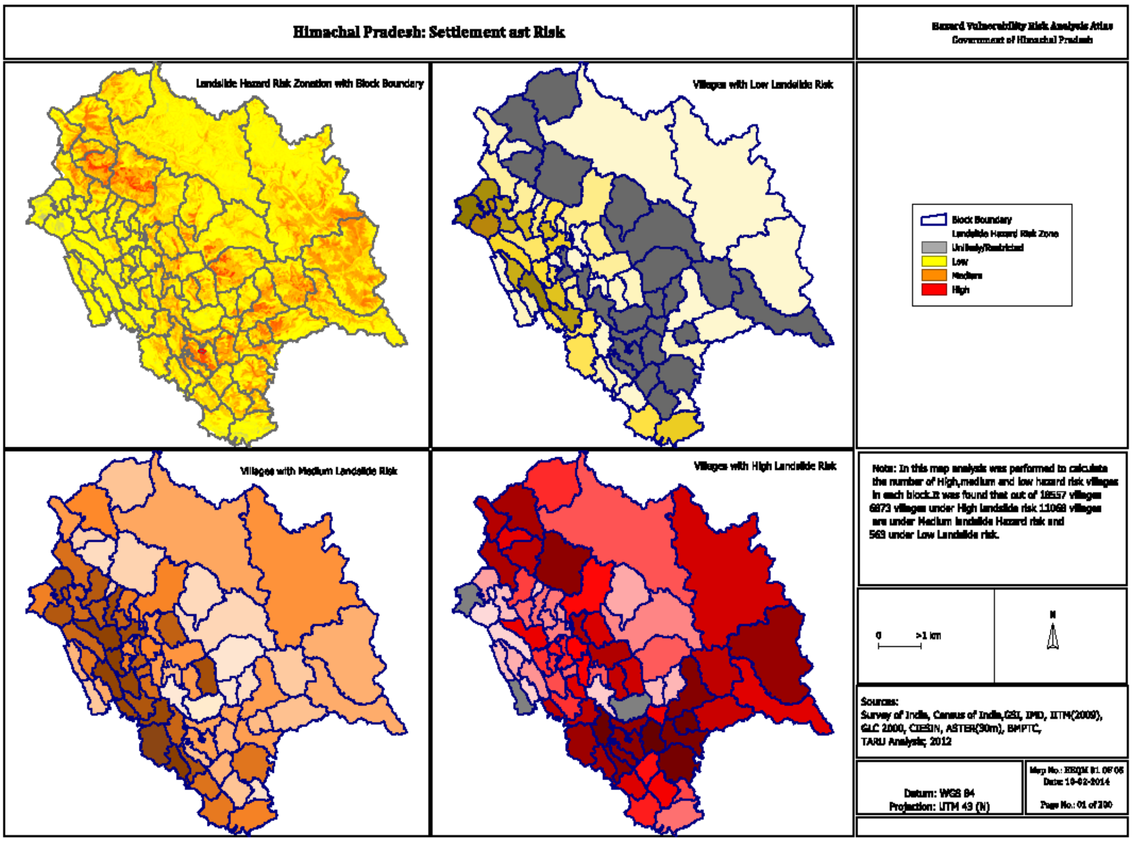
Note: Hydropower projects were classified based on their capacity as per the guidlines provided by Ministry of Power, GOI.
The Hydropower plants divided into three categories which are as followed:-
1) > 101 KW to 2 MW (Mini hydropower projects) - 7
2) > 2 MW to 25 MW (Small hydropower projects) - 34
3) >25 MW to 500 MW (Large hydropower projects) - 67
4) >500 MW to 1500 MW (Mega hydropower projects) - 10

Source: TARU Analysis, 2012

## 5.2 Settlements at Risk

The total built up area of the Himachal Pradesh is 866.14 sq. km. On the basis of visual and GIS interpretation it was found that mostly the built-up area comes under the high risk area. Population is the most vulnerable class which is most affected by the disaster. In total there are 77 blocks in Himachal Pradesh having over 18,577 villages scattered all over the state. On performing spatial analysis all the villages were classified on the basis of the Hazard risk associated with them. On further analysis number of high, medium and low risk villages falling in a particular block were calculated. The number of villages with different risk factor in each block is provided in the Annexure (2).

**Figure 8: Distribution of Villages with Different Vulnerability in Each Block**



Note: In this map analysis was performed to calculate the number of High,medium and low hazard risk villages in each block.It was found that out of 18557 villages 6873 villages under High landslide risk 11068 villages are under Medium landslide Hazard risk and 563 under Low Landslide risk.

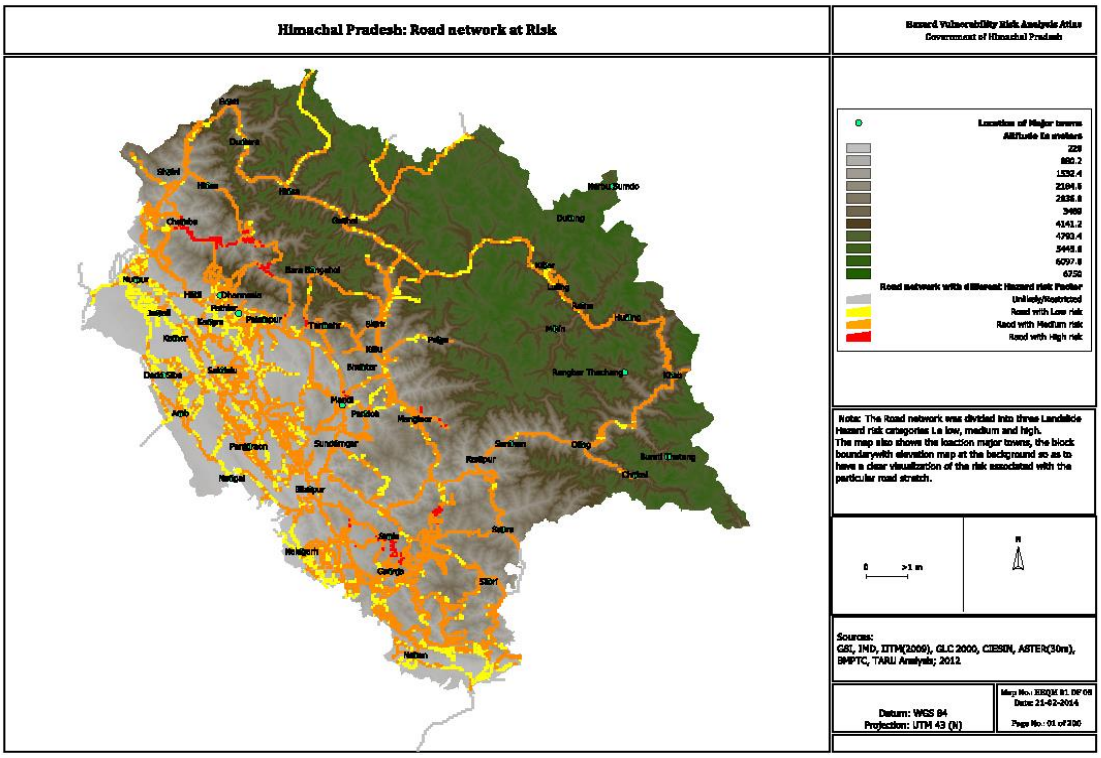
Sources:
Survey of India, Census of India,GSI, IMD, IITM(2009),
GLC 2000, CIESIN, ASTER(30m), BMPTC,
TARU Analysis; 2012

Source: TARU Analysis, 2012.

## 5.3 Roadways at Risk

Eight national highways (NH) pass through the state with a total length of 1628.377 Kms of National Highway. Out of the total stretch on Different National Highway 993.29 sq. km. in high vulnerable zone, 516.46km fall in Moderate risk zone and 10.96 sq. Km in Extreme vulnerable zone. In addition to the National Highways, the state also has a large mesh of highways and village roads comprising of 2178.988 kms of total stretch. Out of the total stretch of the State highway major portion falls in High vulnerable zone that is 1111.552 kms. The remaining stretch of 873.24 km falls in moderate vulnerable zone. Most tourist spots in Himachal Pradesh such as Shimla, Manali, Dharamsala etc. are well connected by roads. Some of the roads in Himachal are seasonal and get closed during winters and monsoons due to heavy snowfall, landslides and washouts which in turn affect the economy of the state as Tourism is yet another important factor that plays major role in growth of economy of the state.

## Figure 9: Map Showing Major Roadways under Different Vulnerable Zone



Note: The Road network was divided into three Landslide Hazard risk categories i.e low, medium and high.
The map also shows the loaction major towns, the block boundarywith elevation map at the background so as to have a clear visualization of the risk associated with the particular road stretch.

Sources:
GSI, IMD, IITM(2009), GLC 2000, CIESIN, ASTER(30m), BMPTC, TARU Analysis; 2012

Source: TARU Analysis, 2013

# Chapter 6: Comparison between the Results

Comparison between the results obtained from the methodology adopted in BMPTC vulnerability atlas, Expert Knowledge and AHP.

According to the Landslide Hazard Zonation Atlas of India published by BMPTC and Centre of Disaster Mitigation and Management, Anna University in 2005, more than 30% of the entire area of the state is under Extremer to Very High Hazard zone but according to revised methodology only 9.50% of the total state area is under very high to extreme zone. According to revised methodology negligible area is under the unlikely zone of the landslide hazard. Similarly the Vulnerability map obtained from revised methodology shows that very less area in high and extreme vulnerable zone whereas the according to the BMPTC rule around 40% and 32% area of Himachal Pradesh was under High and very high vulnerable zone respectively. The following table shows the comparative analysis of the data used, method and results.

**Table 4: Comparative Analysis of The Data Used, Method And Results**

| Method adopted in BMPTC Vulnerability atlas. | Experts Knowledge | Analytical Hierarchical Process |
|---|---|---|
| For Hazard Mapping | | |
| Layers/ data used | | |
| Classified LULC<br>Classified geology (on basis of age)<br>Classified soil layer<br>Classified slope<br>Precipitation layer | Classified LULC<br>(Excluded settlement :Water body as restricted class)<br>Classified geology layer (on basis of bearing capacity)<br>Classified soil layer<br>Classified slope<br>Precipitation layer<br>Relative relief | Classified LULC<br>Classified geology(on basis of age)<br>Classified soil layer<br>Classified slope<br>Precipitation layer |
| Scale | | |
| 0-5 | 0-5 | 0-5 |
| Influence (in %) | | |
| Classified LULC - 25<br>Classified geology- 22<br>Classified soil layer - 17<br>Classified slope - 28<br>Precipitation layer - 8 | Classified LULC - 20<br>Classified geology layer - 20<br>Classified soil layer - 20<br>Classified slope - 20<br>Precipitation layer - 10<br>Relative relief - 10 | Classified LULC – 0.16<br>Classified geology – 0.15<br>Classified soil layer - 0.17<br>Classified slope – 0.23<br>Precipitation layer – 0.29 |
| For Vulnerability Mapping | | |

| **Method adopted in BMPTC Vulnerability atlas.** | **Experts Knowledge** | **Analytical Hierarchical Process** |
|---|---|---|
| No vulnerability analysis is performed by BMPTC so no set criteria for vulnerability mapping. However BMPTC had used settlement as a class in LULC for hazard mapping. After obtaining the Vulnerability map – Layer of major towns, Road network etc was overlaid for further analysis | No vulnerability analysis is performed by BMPTC so no set criteria for vulnerability mapping. | Hazard map and gridded population data was used for vulnerability mapping. Equal weight ages given After obtaining the Vulnerability map – Layer of major towns, Road network etc was overlaid for further analysis |
| Comparison Of The Results | | |
| Landslide hazard zonation | | |
| In terms of Area ( in sq.Km &percentage) | | |
| Low - 29328.48 52.52 | Low - 2235.52 4.00 | Low- 10991.74 19.60 |
| Medium–20414.49 36.55 | Medium- 50756.45 90.90 | Medium-40854.85 73.16 |
| High – 4538.88 8.12 | High – 1784.29 3.19 | High – 3156.05 5.65 |

## 6.1 Selection of the approach

As per the results it was found that 3156.05 sq. km of the area is under high risk zone as per AHP approach, 1784.30 sq. Km as per Expert’s Knowledge and 4538.88 sq. Km as per the guidelines adopted in BMPTC Vulnerability atlas. On comparison it was found that the results obtained from the Analytical Hierarchical Process approach are more correlated to the past landslides since that information was incorporated within the analysis.

# Chapter 7: Implications and Risk

Hazard and Vulnerability mapping are the most vital steps to be conducted so as to tackle the adverse effects of the natural disaster. This exercise was carried out to delineate the areas under different hazard zones and further analyze the vulnerability to landslides in state of Himachal Pradesh. Comparison of both the results obtained from methodology as adopted in BMPTC Vulnerability atlas with incidences of past landslides recorded by GSI indicates that Hamirpur, Bilaspur and Una although falling under high to very high hazard area hardly having any incidences of landslides in the past. Similar results are observed in the case of revised methodology as well.

Past landslide location map was prepared using GSI Atlas No. 71. Most of the past landslides were along the roads/highways and along the pilgrimage routes as observed in NRSC Atlas. This clearly indicates that the slides are triggered mainly due to anthropogenic factors. This results calls for taking immediate measures to check the unplanned development along the high hazard areas. Road cuttings and other development activities should be carried keeping in consideration of the hazard profile to reduce present and emerging risk due to landslides. Such hazard zoning and vulnerability assessments may use as an integral part of the disaster management plans and also development plans to provide guidance to government and regulatory authorities for better land use and physical planning process in hazard prone areas.

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# Annexure

## Annexure 1: Himachal Pradesh: Location of Past Landslides

| No. | Latitude | Longitude | No. | Latitude | Longitude | No. | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|
| 1 | 31°37'12" | 78°06'15" | 121 | 77°38'40" | 31°22'05" | 242 | 32°28'5" | 76°26'53" |
| 2 | 31°37'00" | 78°06'22" | 123 | 31°23'05" | 77°38'40" | 243 | 32°27'28" | 76°27'22" |
| 3 | 31°33'55" | 78°03'45" | 124 | 31°24'00" | 77°40'15" | 244 | 32°26'40" | 76°22'50" |
| 4 | 31°34'00" | 78°04'10" | 125 | 31°24'50" | 77°39'55" | 245 | 32°26'40" | 76°22'50" |
| 5 | 31°33'55" | 78°04'40" | 126 | 31°24'00" | 77°38'40" | 246 | 32°27'05" | 76°28'00" |
| 6 | 31°33'45" | 78°04'20" | 127 | 31°24'56" | 77°38'35" | 247 | 32°27'42" | 76°27'50" |
| 7 | 31°32'45" | 78°03'55" | 128 | 3I°24'55" | 77°38'00" | 248 | 32°28'00" | 76°27'35" |
| 8 | 31°32'07" | 78°02'55" | 129 | 31°24'35" | 77°33'30" | 249 | 32°28'00" | 76°28'00" |
| 9 | 31°31'12" | 78°04'45" | 130 | 31°23'35" | 77°33'30" | 250 | 32°27'53" | 76°28'30" |
| 10 | 31°30'55" | 78°07'40" | 131 | 31°26'28" | 77°38'10" | 251 | 32°27'20" | 76°28'30" |
| 11 | 31°31'00" | 78°08'13" | 132 | 31°26'38" | 77°57'15" | 252 | 32°27'18" | 76°29'30" |
| 12 | 31°30'55" | 78°07'30" | 133 | 31°27'32" | 77°38'38" | 253 | 32°27'27" | 76°28'15" |
| 13 | 31°31'00" | 78°07'36" | 134 | 31°28'35" | 77°40'52" | 254 | 32°27'00" | 76°28'29" |
| 14 | 31°30'55" | 78'07'40" | 135 | 31°28'45" | 77°40'50" | 255 | 32°26'43" | 76°28'20" |
| 15 | 3I°31'I5" | 78°08'40" | 136 | 31°29'23" | 77°41'22" | 256 | 32°26'25" | 76°28'20" |
| 16 | 31°31'20" | 78°08'13" | 137 | 31°29'30" | 77°41'20" | 257 | 32°26'12" | 76°29'30" |
| 17 | 31°31'30" | 78°08'32" | 138 | 31°29'25" | 77°40'47" | 258 | 32°26'00" | 76°29'57" |
| 18 | 31°31'30" | 78°08'32" | 139 | 31°29'25" | 77°40'53" | 259 | 32°25'18" | 76°29'37" |
| 19 | 31°32'10" | 78°08'07" | 140 | 31°29'32" | 77°41'10" | 260 | 32°25'33" | 76°29'03" |
| 20 | 31°32'22" | 78°08'07" | 141 | 31°29'45" | 77°41'25" | 261 | 32°26'08" | 76°28'25" |
| 21 | 31°32'22" | 76°08'07" | 142 | 31°29'35" | 77°40'45" | 262 | 32°26'00" | 76°28'10" |
| 22 | 31°33'25" | 78°07'50" | 143 | 31°29'00" | 77°41'32" | 263 | 32°26'25" | 76°33'04" |
| 23 | 31°34'03" | 78°08'12" | 144 | 31°29'07" | 77°41'42" | 264 | 32°26'15" | 76°32'50" |

| No. | Latitude | Longitude | No. | Latitude | Longitude | No. | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|
| 24 | 31°35'05" | 78°09'55" | 145 | 31°28'25" | 77°42'07" | 265 | 32°26'35" | 76°31'52" |
| 25 | 31°31'00" | 78°09'00" | 146 | 31°28'48" | 77°42'10" | 266 | 32°26'30" | 76°30'25" |
| 26 | 31°32'15" | 78°17'20" | 147 | 31°29'43" | 77°42'07" | 267 | 32°27'08" | 76°30'20" |
| 27 | 31°32'50" | 78°19'20" | 148 | 31°29'38" | 77°42'15" | 268 | 32°27'00" | 76°31'08" |
| 28 | 31°33'00" | 78°18'55" | 149 | 31°29'50" | 77°42'22" | 269 | 32°27'20" | 76°30'45" |
| 29 | 31°35'00" | 78°16'10" | 150 | 31°28'07" | 77°40'27" | 270 | 32°27'32" | 76°32'00" |
| 30 | 31°35'15" | 78°16'10" | 151 | 31°30'15" | 77°45'20" | 271 | 32°27'30" | 76°31'50" |
| 31 | 31°35'15" | 78°17'10" | 152 | 31°33'00" | 77°47'00" | 272 | 32°27'28" | 76°32'30" |
| 32 | 31°36'35" | 78°19'30" | 153 | 31°32'17" | 77°45'50" | 273 | 32°27'00" | 76°33'19" |
| 33 | 31°36'42" | 78°19'40" | 154 | 31°32'20" | 77°45'35" | 274 | 32°27'22" | 76°34'00" |
| 34 | 31°36'55" | 78°20'00" | 155 | 31°32'12" | 77°45'30" | 275 | 32°27'18" | 76°34'49" |
| 35 | 3I°36'20" | 78°20'35" | 156 | 31°33'07" | 77°47'32" | 276 | 32°27'40" | 76°35'58" |
| 36 | 31°36'08" | 78°20'10" | 157 | 31°33'00" | 77°48'15" | 277 | 32°28'18" | 76°35'20" |
| 37 | 31°35'30" | 78°20'I5" | 158 | 31°34'50" | 77°48'30" | 278 | 32°28'21" | 76°36'32" |
| 38 | 31°35'30" | 78°22'00" | 159 | 31°34'25" | 77°49'50" | 279 | 32°27'50" | 76°36'45" |
| 39 | 31°35'22" | 78°22'O7" | 160 | 31°34'45" | 77°49'10" | 280 | 32°27'27" | 76°36'28" |
| 40 | 31°35'00" | 78°22'20" | 161 | 31°33'25" | 77°51'50" | 281 | 32°27'18" | 76°36'04" |
| 41 | 31°35'00" | 78°22'50" | 162 | 31°33'15" | 77°51'37" | 282 | 32°27'00" | 76°35'29" |
| 42 | 31°35'22" | 78°22'35" | 163 | 31°36'15" | 77°48'50" | 283 | 32°26'53" | 76°35'07" |
| 43 | 31°35'35" | 78°22'25" | 164 | 31°33'55" | 77°57'00" | 284 | 32°26'48" | 76°36'28" |
| 44 | 31°36'00" | 78°22'28" | 165 | 31°34'05" | 77°53'00" | 285 | 32°26'48" | 76°36'28" |
| 45 | 31°36'45" | 78°22'52" | 166 | 31°34'40" | 77°52'55" | 286 | 32°26'52" | 76°33'45" |
| 46 | 31°35'50" | 78°23'18" | 167 | 31°34'05" | 77°53'22" | 287 | 32°26'30" | 76°33'18" |
| 47 | 31°35'50" | 78°23'18" | 168 | 31°34'05" | 77°54'10" | 288 | 32°27'00" | 76°36'50" |
| 48 | 3I°35'12" | 78°23'40" | 169 | 31°33'15" | 77°54'50" | 289 | 32°13'30" | 76°20'30" |
| 49 | 31°35'05" | 78°24'10" | 170 | 31°33'20" | 77°54'37" | 290 | 32°13'20" | 76°20'30" |
| 50 | 31"35'05" | 78°24'20" | 171 | 32°48'00" | 76°08'00" | 291 | 32°13'15" | 76°20'15" |
| 51 | 31°35'05" | 78°24'25" | 172 | 32°48'00" | 76°08'00" | 292 | 32°13'50" | 76°22'20" |
| 52 | 31°35'00" | 78°24'55" | 173 | 32°17'55" | 76°10'30" | 293 | 32°14'15" | 76°22'20" |

| No. | Latitude | Longitude | No. | Latitude | Longitude | No. | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|
| 53 | 31°35'00" | 78°25'00" | 174 | 32°18'40" | 76°08'22" | 294 | 32°14'10" | 76°21'45" |
| 54 | 31°35'00" | 78°25'05" | 175 | 32°18'40" | 76°08'22" | 295 | 32°14'10" | 76°21'50" |
| 55 | 31°35'00" | 78°25'17" | 176 | 32°15'40" | 76°11'00" | 296 | 32°14'15" | 76°21'45" |
| 56 | 31°35'20" | 78°25'17" | 177 | 32°17'50" | 76°10'55" | 297 | 32°14'15" | 76°21'50" |
| 57 | 31°34'55" | 78°26'73" | 178 | 32°16'20" | 76°12'08" | 298 | 32°12'15" | 76°22'45" |
| 58 | 31°34'55" | 78°26'50" | 179 | 32°16'20" | 76°12'45" | 299 | 32°13'00" | 76°23'22" |
| 59 | 31°35'00" | 78°26'55" | 180 | 32°17'30" | 76°11'08" | 300 | 32°12'00" | 76°23'00" |
| 60 | 31°35'42" | 78°27'35" | 181 | 32°15'50" | 76°10'50" | 301 | 32°12'15" | 76°22'40" |
| 61 | 31°35'20" | 78°26'42" | 182 | 32°17'25" | 76°13'00" | 302 | 32°12'20" | 76°23'00" |
| 62 | 31°35'22" | 78°25'35" | 183 | 32°11'55" | 76°13'52" | 303 | 32°12'30" | 76°24'12" |
| 63 | 31°35'22" | 78°22'35" | 184 | 32°11'57" | 76°13"57" | 304 | 32°12'30" | 76°24'18" |
| 64 | 31°35'22" | 78°22'35" | 185 | 32°10'00" | 76°11'15" | 305 | 32°13'00" | 76°23 '55" |
| 65 | 31°35'22" | 78°22'35" | 186 | 32°29'40" | 76°20'10" | 306 | 32°11'45" | 76°25'15" |
| 66 | 31°36'15" | 78°27'00" | 187 | 32°29'25" | 76°21'00" | 307 | 32°11'45" | 76°24'50" |
| 67 | 31°36'15" | 78°27'18" | 188 | 32°29'25" | 76°19'57" | 308 | 32°11'45" | 76°24'00" |
| 68 | 31°36'23" | 78°22'35" | 189 | 32°27'43" | 76°20'00" | 309 | 32°11'45" | 76°24'15" |
| 69 | 31°35'22" | 78°22'35" | 190 | 32°27*50": | 76°20'00" | 310 | 32°11'5" | 76°24'50" |
| 70 | 31°36'35" | 78°28'10" | 191 | 32°27'00" | 76°20'45" | 311 | 32°10'30" | 76°25'00" |
| 71 | 31°36'30" | 78°28'15" | 192 | 32°27'00" | 76°20'45" | 312 | 32°11'40" | 76°29'30" |
| 72 | 31°37'22" | 78°26'15" | 193 | 32°27'23" | 76°22'08" | 313 | 32°04'25" | 76°15'15" |
| 73 | 31°37'47" | 78°24'50" | 194 | 32°27'25" | 76°23'00" | 314 | 32°08'45" | 76°32'45" |
| 74 | 31°33'07" | 78°22'35" | 195 | 32°27'20" | 76°23'30" | 315 | 32°07'50" | 76°38'40" |
| 75 | 31°33'33" | 78°25'05" | 196 | 32°27'38" | 76°22'55" | 316 | 32°08'08" | 76°31'40" |
| 76 | 31°33'40" | 78°25'10" | 197 | 32°26'37" | 76°20'30" | 317 | 32°09'15" | 76°32'50" |
| 77 | 31°33'20" | 78°26'15" | 198 | 32°26'13" | 76°20'00" | 318 | 32°08'45" | 76°34'30" |
| 78 | 31°33'45" | 78°27'00" | 199 | 32°26'3" | 76°20'20" | 319 | 32°07'00" | 76°35'47" |
| 79 | 31°33'52" | 78°26'50" | 200 | 32°26'45" | 76°20'58" | 320 | 32°06'45" | 76°36'15" |
| 81 | 31°34'12" | 78°26'30" | 202 | 32°25'00" | 76°22'40" | 321 | 32°07'05" | 76°39'12" |
| 82 | 31°34'17" | 78°27'10" | 203 | 32°25'10" | 76°23'00" | 322 | 32°09'45" | 76°32'30" |

| No. | Latitude | Longitude | No. | Latitude | Longitude | No. | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|
| 83 | 31°34'15" | 78°27'25" | 204 | 32°25'10" | 76°23'17" | 323 | 32°08'15" | 76°35'25" |
| 86 | 31°40'00" | 78°26'00" | 207 | 32°26'19" | 76°23'45" | 324 | 32°07'30" | 76°35'19" |
| 87 | 31°46'00" | 78°35'00" | 208 | 32°26'55" | 76°24'10" | 325 | 32°06'55" | 76°39'07" |
| 88 | 31°47'30" | 78°38'00" | 209 | 32°27'05" | 76°24'10" | 326 | 32°08'12" | 76°30'40" |
| 89 | 31°52'30" | 78°37'00" | 210 | 32°27'33" | 76°23'50" | 327 | 32°07'10" | 76°39'30" |
| 90 | 31°54'30" | 78°37'00" | 211 | 32°27'20" | 76°23'45" | 328 | 32°08'25" | 76°31'30" |
| 91 | 31°58'00" | 78°36'00" | 212 | 32°26'55" | 76°23'55" | 329 | 32°04'50" | 76°41'05" |
| 92 | 31°43'00" | 78°31'00" | 213 | 32°26'45" | 76°23'15" | 330 | 32°09'00" | 76°30'25" |
| 93 | 31°18'30" | 78°32'00" | 214 | 32°27'05" | 76°23'10" | 331 | 32°09'00" | 76°30'26" |
| 94 | 31°15'20" | 78°46'20" | 215 | 32°27'00" | 76°22'30" | 332 | 32°09'28" | 76°30'45" |
| 95 | 31°06'00" | 77°07'00" | 216 | 32°27'5" | 76°22'12" | 333 | 32°09'00" | 76°30'52" |
| 96 | 31°06'00" | 77°09'57" | 217 | 32°26'22" | 76°23'22" | 334 | 32°08'40" | 76°31'00" |
| 97 | 31°15'30" | 77°28'00" | 218 | 32°25'53" | 76°23'27" | 335 | 32°07'35" | 76°35'30" |
| 98 | 31°18'12" | 77°21'45" | 219 | 32°25'33" | 76°23'27" | 336 | 32°07'00" | 76°36'30" |
| 99 | 31°20'05" | 77°22'55" | 220 | 32°27'33" | 76°24'00" | 337 | 32°07'05" | 76°39'05" |
| 100 | 31°20'07" | 77°23'45" | 221 | 32°27'47" | 76°24'45" | 338 | 32°07'00" | 76°39'55" |
| 101 | 31°19'52" | 77°24'45" | 222 | 32°28'07" | 76°24'52" | 339 | 32°07'00" | 76°40'00" |
| 102 | 31°23'10" | 77°28'30" | 223 | 32°28'15" | 76°25'00" | 340 | 32°07'05" | 76°40'20" |
| 103 | 31"23'30" | 77°28'10" | 224 | 32°28'20" | 76°26'05" | 341 | 32°03'47" | 76°38'58" |
| 104 | 31°23'35" | 77°25'25" | 225 | 32°28'16" | 76°26'45" | 342 | 32°03'00" | 76°39'53" |
| 105 | 31°26'20" | 77°26'00" | 226 | 32°28'42" | 76°26'42" | 343 | 32°01'30" | 76°41'45" |
| 106 | 31°27'55" | 77°25'00" | 227 | 32°28'00" | 76°29'15" | 344 | 32°00'08" | 76°42'25" |
| 107 | 31°25'00" | 77°24'35" | 228 | 32°28'2" | 76°29'12" | 345 | 32°09'15" | 76°45'00" |
| 108 | 31°23'15" | 77°23'35" | 229 | 32°28'02" | 76°29'12" | 346 | 32°04'00" | 76°40'40" |
| 109 | 31°22'00" | 77°23'35" | 230 | 32°28'02" | 76°29'11" | 347 | 32°9'30": | 76°30'03" |
| 110 | 31°23'30" | 77°22'25" | 231 | 32°28'12" | 76°28'45" | 348 | 32°33'00" | 76°58'00" |
| 111 | 31°22'00" | 77°20'50" | 232 | 32°28'40" | 76°28'10" | 349 | 32°32'30" | 76°58'43" |
| 112 | 31°23'40" | 77°20'50" | 233 | 32°28'40" | 76°27'22" | 350 | 31°53'50" | 77°00'30" |
| 113 | 31°25'00" | 77°20'37" | 234 | 32°28'37" | 76°26'50" | 351 | 30°35'00" | 77°40'00" |

| No. | Latitude | Longitude | No. | Latitude | Longitude | No. | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|
| 114 | 31°24'40" | 77°18'37" | 235 | 32°28'30" | 76°27'12" | | | |
| 115 | 31°23'10" | 77°19'10" | 236 | 32°28'00" | 76"26'00" | | | |
| 116 | 31°30'15" | 77°41'15" | 237 | 32°27'40" | 76°25'52" | | | |
| 117 | 31°30'15" | 77°42'40" | 238 | 32°27'52" | 76°25'55" | | | |
| 118 | 31°30'15" | 77°43'35" | 239 | 32°27'50" | 76°25'20" | | | |
| 119 | 31°31'30" | 77°43'55" | 240 | 32°27'45" | 76°24'58" | | | |
| 120 | 31°20'05" | 77°32'30" | 241 | 32°27'25" | 76°24'52" | | | |

Source: GSI Inventory of Landslides of Northwest Himalaya, 2005

## Annexure 2: Number of Villages in Each Block With Different Risk Factor

| Block Name | No. of villages in Different Hazard Risk Zone | | |
|---|---|---|---|
| | High | Medium | Low |
| Amb | 9 | 163 | 25 |
| Ani | 8 | 12 | 0 |
| Baijnath | 54 | 141 | 5 |
| Balh | 30 | 87 | 1 |
| Bamsan | 45 | 226 | 0 |
| Bangana | 14 | 295 | 48 |
| Banjar | 31 | 11 | 0 |
| Basantpur | 201 | 108 | 0 |
| Bharmour | 215 | 32 | 0 |
| Bhatiyat | 163 | 171 | 4 |
| Bhawarna | 23 | 147 | 11 |
| Bhoraj | 29 | 185 | 5 |
| Bijhari | 35 | 290 | 18 |
| Bilaspur | 148 | 288 | 10 |
| Chamba | 84 | 42 | 1 |
| Chauntra | 163 | 119 | 1 |
| Chirgaon | 114 | 57 | 1 |
| Chopal | 252 | 164 | 0 |
| Dehra | 83 | 323 | 9 |
| Dharampur | 236 | 538 | 4 |
| Dharamshala | 6 | 40 | 1 |
| Drang | 96 | 215 | 5 |
| Fatehpur | 2 | 239 | 70 |
| Gagret | 7 | 88 | 1 |
| Ghumarwin | 94 | 178 | 5 |
| Gohar | 124 | 111 | 2 |
| Gopalpur | 66 | 114 | 0 |
| Hamirpur | 40 | 148 | 10 |
| Haroli | 0 | 53 | 2 |
| Indora | 0 | 144 | 65 |
| Jhandutta | 43 | 243 | 32 |
| Jubbal | 250 | 111 | 2 |
| Kalpa | 94 | 95 | 0 |

| **Block Name** | **No. of villages in Different Hazard Risk Zone** | | |
|---|---|---|---|
| | High | Medium | Low |
| Kandhagat | 206 | 62 | 0 |
| Kangra | 25 | 234 | 19 |
| Kullu | 20 | 29 | 0 |
| Kumarsain | 72 | 109 | 0 |
| Kunihar | 301 | 209 | 1 |
| Karsog | 0 | 2 | 0 |
| Lahul | 32 | 103 | 1 |
| Lambagaon | 21 | 267 | 17 |
| Mashobra | 415 | 111 | 0 |
| Mehla | 157 | 18 | 0 |
| Nadaun | 43 | 400 | 13 |
| Naggar | 10 | 28 | 0 |
| Nagrota Bagwan | 24 | 273 | 7 |
| Nagrota Surian | 7 | 182 | 30 |
| Nahan | 46 | 149 | 11 |
| Nalagarh | 186 | 468 | 10 |
| Nichar | 144 | 47 | 0 |
| Nirmand | 8 | 18 | 0 |
| Nurpur | 12 | 257 | 35 |
| Pacchad | 95 | 167 | 1 |
| Panchrukhi | 13 | 132 | 4 |
| Pangi | 44 | 54 | 0 |
| Paonta sahib | 24 | 143 | 17 |
| Pooh | 189 | 91 | 1 |
| Pragpur | 3 | 202 | 16 |
| Rait | 39 | 236 | 4 |
| Rajgarh | 51 | 89 | 0 |
| Rampur | 215 | 111 | 1 |
| Rohru | 257 | 74 | 0 |
| Sadar | 152 | 123 | 4 |
| Saluni | 150 | 114 | 2 |
| Sangrah | 67 | 54 | 0 |
| Seraj | 113 | 266 | 266 |
| Shillai | 36 | 13 | 1 |

| **Block Name** | **No. of villages in Different Hazard Risk Zone** | | |
|---|---|---|---|
| | High | Medium | Low |
| Solan | 219 | 255 | 2 |
| Spiti | 100 | 127 | 1 |
| Sujanpur | 48 | 129 | 1 |
| Sulah | 18 | 214 | 19 |
| Sundernagar | 5 | 3 | 0 |
| Theog | 329 | 88 | 0 |
| Tissa | 166 | 134 | 0 |
| Una | 3 | 98 | 2 |

Source: TARU Analysis, 2014

TARU

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