# Multihazard Mapping of Banepa and Panauti Municipalities

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## Abstract

*A combination of rough topography, steep slopes, active tectonic and seismic process and intense impact of monsoon rain has made the fragile environment of Nepal vulnerable to a variety of natural hazards. Most frequent hazards are floods, landslides, epidemics, fires, earthquake and other hydro-meteorological disasters, causing heavy loss of human lives as well as economic loss including housing and infrastructures (MDRIP, 2009). Hence, hazard assessments are the need of the hour. They help district and regional decision makers, policy makers and development agencies prepare disaster risk reduction plans. The chosen study area was Banepa and Panauti municipality. Separate hazard assessments have been performed for four hazards, namely, earthquake, flood, landslide and industrial hazards.*

*Earthquake hazard zone maps have been made following the Probabilistic Seismic Hazard Assessment (PSHA) approach for 500 year return period to produce seismic intensity distribution maps in the form of Modified Mercalli Intensity (MMI) maps using Trifunac and Brady formula. Flood inundation maps have been made using HEC-RAS and HEC-GeoRAS extension for ArcGIS for return periods of 2, 10 and 500 of Chandeswori and Punyamata rivers. Landslide hazard susceptibility map has been made using the Stability Index Mapping (SINMAP) extension for ArcGIS that uses an infinite-slope equation* accurate *for debris flows. Industrial hazard maps that depict the vicinity that falls within various ranges of danger in the event of different industrial hazards like fire, Vapor Cloud Explosion (VCE) and Boiling Liquid Expanding Vapor Explosion (BLEVE) have been prepared as well. Finally, a composite multi hazard map has been prepared by combining all the four hazards.*

**Keywords:** earthquake, flood, landslide, industry, hazard assessment, composite multi-hazard

## 1. Introduction

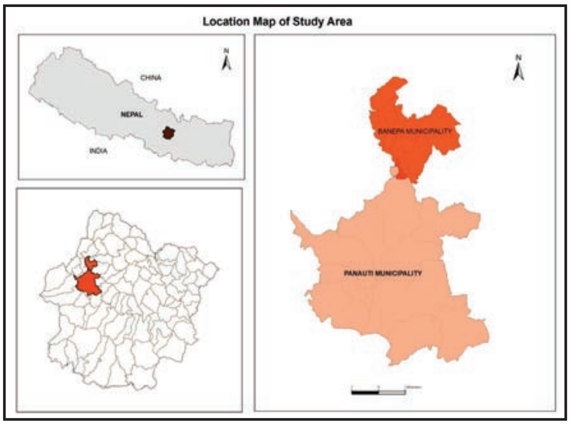
Nepal is prone to various geological and hydro-meteorological hazards owing to its diverse geographical coverage that includes rough topography, steep slopes and active tectonic and seismic processes.

The impact of multiple hazards has aggravated in recent years due to catalytic factors like climate change, rapid urbanization, and continual urban growth rates that result in high physical exposure and lack of preparedness both at national and local levels. In Nepalese context, mainstreaming disaster risk reduction efforts in municipal governance and development plans stills occupies low priority against other development plans. Further, the location of most urban cities in risk prone areas with loose networks of migrant populations increases the risk factor.

Multi hazard maps serve as guidelines to prepare effective disaster mitigation plans at local and national levels by depicting the intensity and probability of hazards in a given geographical location. Multi-hazard maps of landslide, earthquake, flood and industrial hazards are first prepared to produce composite multi-hazard maps of Banepa and Panauti. The resultant maps can help to identify the most vulnerable sectors and assist stakeholders to adopt necessary measures to increase resilience of the residents.

## 2. Study Area

The study areas comprised of Banepa and Panauti municipalities of Kavrepalanchok district. The spatial extent of Banepa municipality is between 27°37'01" to 27°39'03" north latitude and 85°30'45" to 85°32'52" east longitude geographically; and the spatial extent of Panauti municipality is between 27°33.5’ to 27°37’ north latitude and 85°29’ to 85°33.5’ east longitude.



## 3. Materials Used

Datasets used for the project included socio-economic data, Quickbird images at 0.6m spatial resolution, geological map, 20m DEM, topographic map with 20m contour interval, building inventory and land cover data along with Seismic Hazard Map of Nepal prepared by Department of Mines and Geology, 2002.

## 4. Methodology

The general framework (Figure 1) adopted to prepare multihazard maps can be listed as:

- Preparation of earthquake hazard maps in form of PGA and MMI maps using PSHA approach.
- Flood depth and inundation maps for 2, 10 and 500 year return periods using HEC-RAS and HEC-GeoRAS extension of ArcGIS.
- Generation of landslide hazard susceptibility map from SINMAP analysis and a GIS based spatial multi-criteria evaluation technique.
- Vector analysis to depict hazard indices for fire hazards, Vapor Cloud Explosion (VCE) and Boiling Liquid Expanding Vapor Explosion (BLEVE).
- Perform weighted sum to derive the final composite hazard maps that depicted the multi-hazard region.

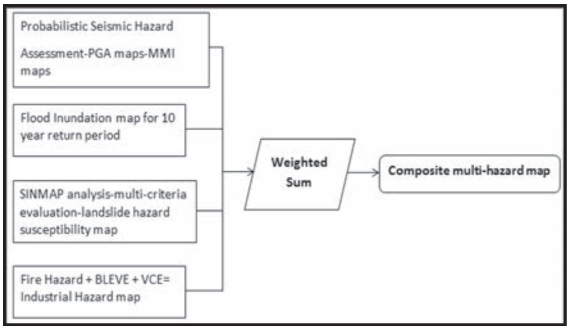


*Figure 1: Overall method of multi-hazard mapping*

Among the different faults identified by The National Building Code Implementation Project (1993), the (Main Central Thrust) MCT 3.3 fault with potential 7.6 Richter scale was chosen for earthquake hazard mapping since it is the closest active fault that can generate the worst scenario earthquake for the study area.

PSHA approach was chosen to describe earthquake hazard in terms of the level of ground shaking that has a 10% chance of being exceeded in 50 years corresponding to a return period of 475 years.

First, the regional seismicity model is prepared based on an arbitrary scenario earthquake that occurs as a local earthquake. Next, attenuation model is created that represents the isoseismic contours at bedrock level and was generated using R.R.Youngs et.al, 1997 analysis followed by the site response model that describes how local geology affect the ground shaking experienced during an earthquake. The subsurface amplification values derived are used along with the attenuation model to produce surface Peak Ground Acceleration (PGA) maps. The PGA maps were modified to MMI maps using Trifunac and Brady 1975 relationship. The MMI maps are more intuitive and provide qualitative measure for earthquake intensity.

Flood hazard assessment consists of hydrologic/hydraulic analysis; topographical analysis followed by feature creation from satellite image; steady flow simulation and further processing to delineate flood inundation and flood depth maps. Field discharge measurement and cross section survey were followed by TIN preparation from contours to obtain base layer; layers of river centerline, banks, flowpaths and cross-section were created by digitizing existing topographic data with simultaneous referral to satellite images, using RAS Geometry of HEC-GeoRAS extension in

ArcGIS 9.3. Land-use map was used to extract the Manning's n value based on Manning's Roughness coefficient. Then, flow frequency analysis was computed from WECS/DHM (Water and Energy Commission Secretariat/Department of Hydrology and Meteorology) formula.

These preprocessed data were used as input for one dimensional Steady Flow Analysis in HEC-RAS which was run using the peak discharge value corresponding to the return periods flood event. The simulated HEC-RAS model was then visualized in ArcGIS environment through its HEC-GeoRAS extension using RAS mapping where: HEC-RAS export was used to define Flood Inundation extent followed by water surface generation. Finally, flood inundation and flood depth maps for 2, 10 and 500 year return periods were produced.

Due to the presence of eleven reliable landslides inventory in the study area, a deterministic method by using SINMAP model was used to prepare landslide susceptibility map where weights selected for multi criteria analysis are based on the report of (MHRA, 2011) and expert opinion. Semi-quantitative indicators have been used with resulting landslide susceptibility expressed in a scale from 0 – 10 for better representation of spatial variability. Only the final susceptibility was classified into qualitative classes of very low, low, moderate, high, and very high.

Eight indicators have been input to generate landslide hazard susceptibility maps. Three indicators were obtained from the SINMAP analysis and rests are obtained from secondary data. A spatial multi-criteria evaluation technique has been implemented in GIS system. Each indicator was processed, analyzed and standardized according to its contribution to hazard and percentage of existing landslide lies on different indicators. The indicators were weighted using comparison and rank-ordering weighing methods, and weights were combined to obtain the final landslide susceptibility maps. Eight thematic layers comprising from six conditioning factors and two triggering factors were created. The thematic layers were ranked into several classes from safe condition to the most prone condition for landslide hazard. Those layers are then combined with different values of weighting.

Different probabilistic mathematical calculations were performed for fire hazard map. At first, buffer zones of 25, 50, 75 and 100m were classified. The effects of thermal radiation on these zones were determined using mathematical formula. This produced different hazard intensity zones.

VCE and BLEVE were determined only for selected depots. Mathematical equations estimated the effective distances for VCE and BLEVE to be 120 and 80m respectively. Following parameters were considered for assessing the impacts of fire hazard:

- Availability of fire brigade
- Fire spreading environment
- Fire fighting mechanisms

Then, the different degrees of hazard zone were determined and the building inventory data were overlaid to determine very high, high, medium and low vulnerability zones.

The produced hazard maps were used to prepare composite multi hazard map (Figure 2). For this, individual hazard maps were given values 1, 2, 3 according to their output ranges for flood, landslide, industries and 2.5, 2.75, 3 for earthquake hazard maps. Weighted sum was done to derive the final composite hazard maps that depicted the multi-hazard region under three hazard regions, low, medium and high.

## 5. Results

The PGA distribution map for MCT 3.3 local earthquake scenario reveals that the municipal region would experience PGA range of 179 - 269 gal (i.e. 0.18g-0.27g). For Banepa, the core municipal areas would experience PGA of 230 - 260 gal (Figure 2a). The core part of Panauti would experience PGA range of 230 -260 primarily due to its alluvial soil composition which amplify earthquake waves. The outskirts would face less PGA since the geological composition of residual and colluvial soils comparatively minify ground motion than alluvial soils.

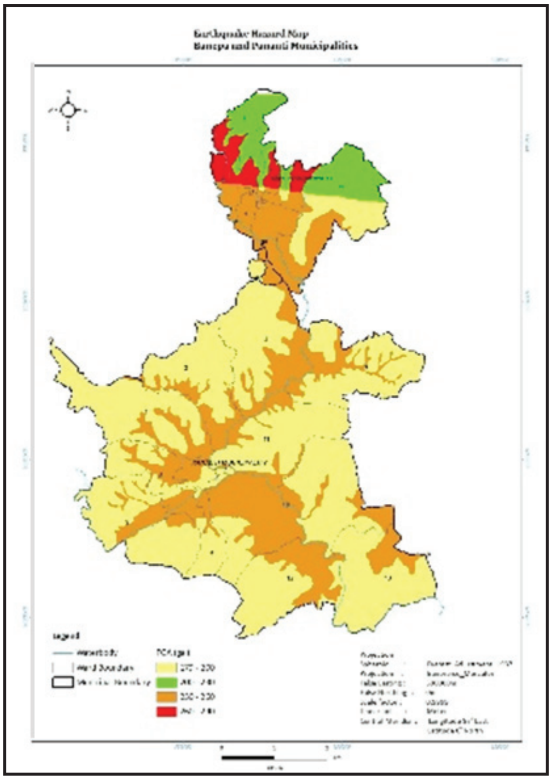


*Figure 2a: PGA map*

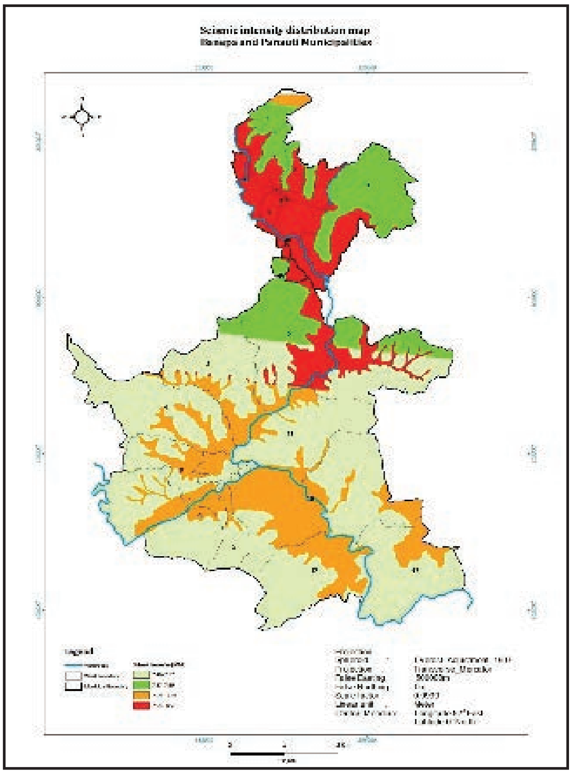


*Figure 2b: Trifunac and Brady MMI map*

The MMI maps reveal that the central and southern parts of Banepa fall within very high seismic hazard zone of 7.94 - 8.55 MMI. In contrast, only 165 hectares of Panauti fall under very high seismic zone but 2659 hectares cover the high hazard zone. Panauti is relatively less vulnerable with major region falling within the lowest range of 7.46 - 7.57.

Flood inundation maps (Figure 3a) for 10 year return period (RP) show that 50.17 hectares and 0.389 hectares land fall under significant flooding region in Banepa and Panauti respectively. Flood depth was categorized into slight, moderate and significant depth based on specifications prepared by HAZUS. 25 buildings in Banepa were located in significantly vulnerable region compared to none in Panauti. The results obtained from landslide susceptibility maps (Fig 4b) are ranked from 35-450, which defines the landslide susceptibility from safe (very low) to very susceptible (very high). These maps further classified into five zones shows 5.16% of total land area nearly 34.5 sq.km falls under very high, 9.60% fall under high and 23.77% fall under moderate hazard index respectively.

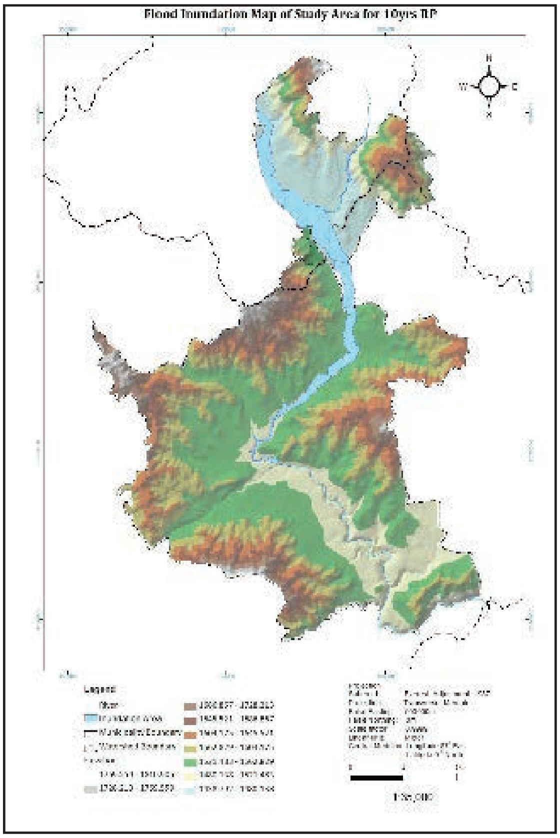


*Figure 3a: Flood inundation map for 10 yr RP*

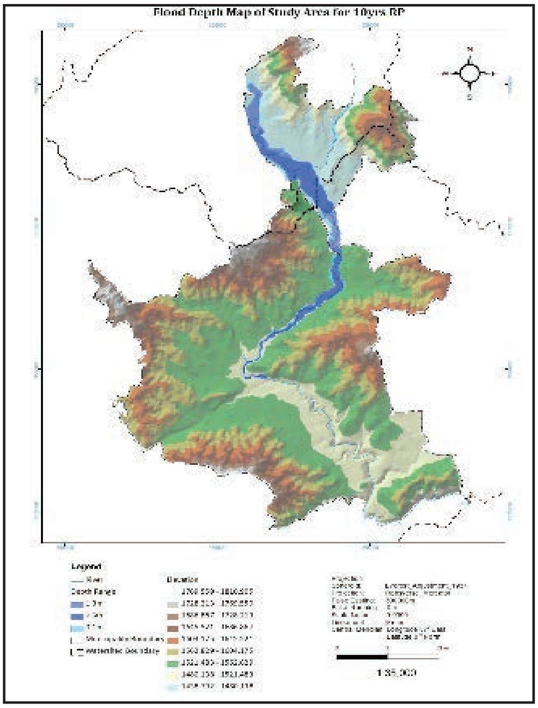


*Figure 3b: flood depth map for 10 yr RP*

For industrial hazards, the chance for a fire accident is quite low due to less storage of inflammable materials and most buildings being RCC/RBC type. However, lack of abundant fire extinguishers/ brigades could even amplify a small fire.

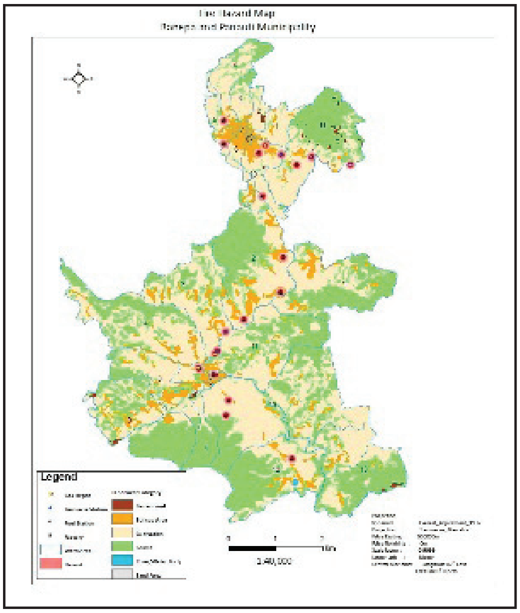


*Figure 4a: Industrial hazard map*

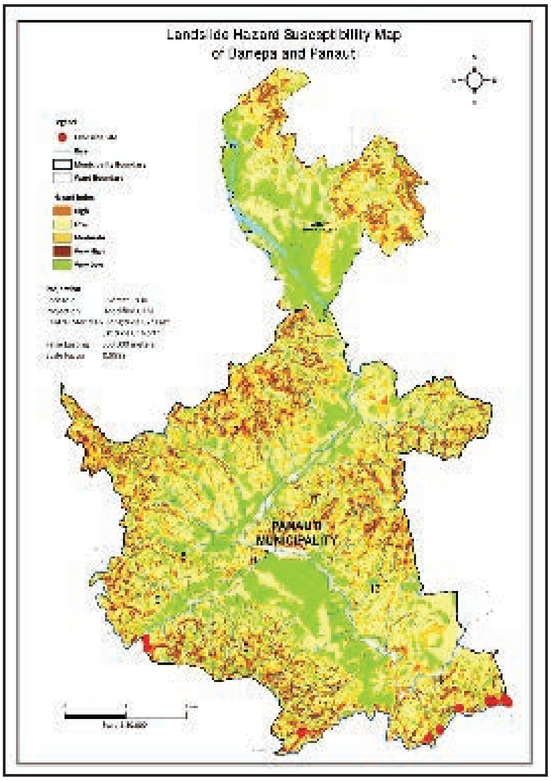


*Figure 4b: landslide hazard susceptibility map*

Probabilistic industrial hazard maps showing different hazard indices for fire hazards, VCE and BLEVE were prepared based on rapid assessment field survey done to summarize the status of industrial hazards and preparedness level. Fire hazards maps (Fig 4a) show very-high, high, medium, and low zones on the basis of heat achieved within selected buffer distances of 25, 50, 75 and 100m respectively.

## 6. Conclusion

Four hazard assessments were performed to produce hazard maps of three geological hazards namely earthquake, landslide, flood and one technological hazard- industrial hazard. The results include PGA distribution maps, MMI maps, landslide susceptibility maps, flood inundation, flood depth maps and industrial hazard maps showing the zones of different intensity or probability of certain hazard. The hazard maps have been used as a basis to calculate exposure statistics to predict the vulnerability scenario. This scenario has been used to study the vulnerability assessment.

The results of the research project suitably indicate that Panauti is more vulnerable to industrial and landslide hazards compared to Banepa. However, comparatively Panauti is less vulnerable to earthquake and flood hazards than Banepa. The hazard assessment performed could be used to formulate land use plans, disaster risk reduction plans in order to bolster our own adaptive capacity.

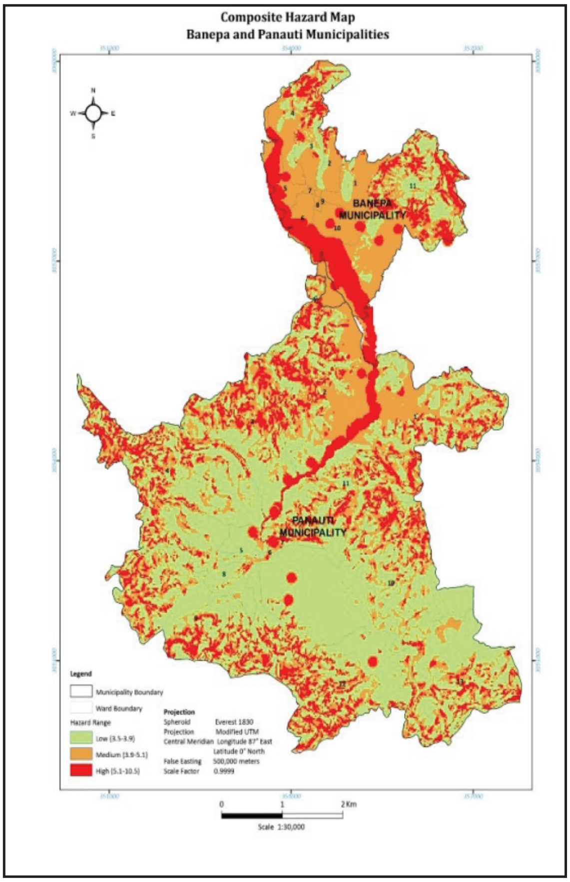


***Figure 5: Composite Hazard Map of Banepa and Panauti Municipalities.***

## 7. Recommendation

- Due to constant change of geospatial features over time, regular map updating and field validation are necessary to maintain validity, accuracy and reliability of the hazard maps.
- Landslide inventories need to be increased for accurate landslide hazard assessment and risk estimation
- More shear wave velocity measurements must be done to build a database of the site average shear-wave velocities that can be used to verify, calibrate and possibly improve the original earthquake hazard maps.
- Liquefaction potential should also be considered to fortify earthquake hazard maps.
- Field cross-section measurement is recommended for better results in flood hazard assessment.
- Effect of wind direction and river presence could also be considered to enhance industrial hazard assessment.

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