# Urban multi-hazard risk analysis using GIS and Remote Sensing: A case study from Kohima Town, Nagaland, India.

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**Abstract:** Many cities develop without any proper urban development planning, let alone that within these development plans natural hazards, such as landslides or earthquakes, and the risk they pose to the city and its inhabitants, are taken into account. Therefore a study on multi-hazard risks in urban areas is of prime importance to be able to implement vulnerability reduction measures, and involve risks as an integral component of development planning. This study gives an example of such as multi-hazard risk assessment, carried out for a rapidly developing city with very limited availability of existing data: the town of Kohima, capital of the state of Nagaland in North eastern India. Building footprints, which serve as the basis for the multi-hazard risk assessment, were generated from remote sensing images. The characteristics of the elements at risk, such as building structure, material, condition of buildings, socio-economic aspects, population information, etc. were collected through extensive field surveys with the help of the digital footprint map. Along with the data collected from remote sensing data, field mapping and historical data, individual hazards were analyzed in GIS environment using vector operations, and all the individual hazard maps were integrated to prepare a multi-hazard map. The number of households in each building was calculated to derive the population at risk to different individual hazards. Individual buildings with both single and multi-hazard were identified and population at risk was calculated. A comparison of the existing situation in the study area with that of the standards prescribed at the national level was made. The situation in the study area is falling short of the norms and efforts should be made by both local authorities as well as local communities to reduce the high level of vulnerability.

**Keywords**: multi-hazard risk assessment, urban, earthquake, landslide , fire;

## 1) Introduction

More than half of the fast-growing world population is living in urban areas, and this is only expected to grow more in the coming decades (USAID, 2001). Most of the urban centres in the world are exposed to natural hazards, such as tropical storms, flooding and subsidence if they are located in coastal regions, or earthquakes and landslides if they are located in seismically active or mountainous regions. Apart from these natural hazards, cities are also confronted with anthropogenic hazards, such as accidents, pollution, explosions and fire. Urban centres also have a varying degree of vulnerability, depending on the level of development, the coping capacity and the level of level to which effective risk reduction strategies have been implemented. The basis for such risk reduction measures is an assessment of the hazards, elements at risk, and their vulnerability of these to the hazard types, resulting in a risk assessment (Ingleton, 1999). In most urban areas, the demand of land for expansion is getting higher than the availability of suitable land, leading to haphazard urban sprawl and the deliberate locating the settlements on areas highly vulnerable to natural hazards. Many cities develop without any proper urban development planning, let alone that within these development plans natural hazards, such as landslides or earthquakes, and the risk they pose to the city and its inhabitants, are taken into account. Therefore a study on multi-hazard risks in urban areas is of prime importance to be able to implement vulnerability reduction measures, and involve risks as an integral component of development planning. In order to do this, detailed spatial information should be available on the extend of the hazards, in the form of a series of hazard footprints, which indicate the expected process (e.g. fire, ground shaking, ground movement) and the intensity according to certain hazard scenarios. Also detailed spatial information should be available on the building footprints in the area, their landuse and construction characteristics as well as on the population, infrastructure and essential facilities (Montoya, 2002). Such data could be derived from existing cadastral and census information. However, in many cities such data is not available, and will have to be collected using Remote Sensing, combined with extensive field mapping (Van Westen, et al., 2002). This study gives an example of such as multi-hazard risk assessment, carried out for a rapidly developing city with very limited availability of existing data.

## 2) Study area

Kohima, the capital of the East Indian state of Nagaland, is an example of such as rapidly developing city, located in a hilly environment in a seismically active region. Kohima is located between 9404'12.14" E to 9408'56.68"E Latitude and 25037'26.35" N to 25045'2.72" N Longitude, at an altitude between 800 to 1500 meters above mean sea level (see figure 1). Kohima is a hill town constructed on the top of a series of hills with most of the buildings constructed on steep slopes. The roads are narrow, leaving no further scope for widening due to its topographic setting. There is only one main road connecting the northern and southern parts of the town. Every year the town suffers from landslide problems, especially during the later part of the rainy season, from July to September. Buildings are damaged and landslides block the few roads that connect Kohima with the other parts of the country regularly. Nagaland, like all other North-eastern states of India lies in the seismic zone V (fifth), liable to seismic intensity IX on the Modified Mercalli Intensity Scale (Revenue Deficit Department, 2004). This is the most severe seismic zone and is referred to as the Very High Damage Risk Zone. The region experienced 18 large earthquakes ($M \geq 7$) during the last hundred years including the earthquakes of Shillong (1897, $M \geq 7$) and Assam-Tibet border (1950, $M=8.7$) (Tiwari, 2004). According to the USGS, there were three earthquakes that had its epicentres near Kohima. One is at 20 km towards the eastern parts of Kohima in Phek district with a magnitude of 4.5. The second is about 41 km towards the south with a magnitude of 5.7, and the third is about 58 kilometres from to the east with a magnitude of 5.4. However, there was no casualty and loss to property reported (Tiwari, 2004).

The population of Kohima, according to the Census of India in 2001 was 78,584. Being the capital town of the state, the population is growing at a fast rate of about 6% per year. The population has increased from 51,418 in 1991 to 78,584 in 2001. The growth of Kohima town did not follow the guidelines prescribed by the Master Plan of 1974, prepared by the Urban Development Department. As a consequent of this rapid population increase, the problem of scarcity of land led to haphazard growth and settlement on hazard prone areas. Infrastructures and facilities are not allocated judiciously due to natural constraints. For instance, there is only one fire service station in the town, which is located on the extreme south where there is availability of water. This unfavourable location of the fire station hinders an appropriate fire-fighting service in the north of the town, as it takes too much time to reach during a major fire incident. There is only one government owned hospital and only a few private nursing homes, which not only serve the town, but also are suppose to give service to the surrounding villages. As Kohima town has a rather difficult access route, it always had difficult to transport construction materials for Reinforced Concrete Cement (RCC) buildings from other areas. As the region has always been rich in forest resources, most of the old buildings are made of wood. Therefore, the buildings can be ignited by fire easily, and once they catch fire, it can spread very fast since the buildings are constructed very close to each other.

In Kohima, there is no separate administrative department dealing with Disaster Management, and the disaster management tasks of other organizations are not well defined. The Relief Branch of the Home department is assigned with the task of natural calamity relief, only. However, other than receiving applications of natural calamity reports and disbursing relief to the affected persons, there is no initiative for disaster mitigation by the Relief Branch. Recently, the Home department has initiated the preparation of a disaster management plan for the state under a UNDP funded project, which may be considered as a stepping-stone for disaster management in the state. However, it is felt that it might not be able to address problems at local or settlement level and specific hazard that are pertinent in a hazard prone state like Nagaland. There are departments such as the Urban Development Department, Public Works Department, Irrigation and Flood Control, Waste Land Development Department, etc., that take up issues pertaining to natural hazards. But there is no adequate coordination among these departments. Initiated by the Urban Development Department, a building Bye-law has been prepared and has become official legislature in 2001. However, there are problems to successfully implement the building Bye-law. Because of the fact that land cannot change owner (the Non-Transferability of Land laid down in the constitution of India, Article 371), the government agency cannot impose strict rules on the land owned by the private parties. This is a major hindrance for the government agencies to fully implement the development programmes.

## 3) Methodology

The main objectives of the study is to develop a method for multi-hazard risk assessment in urban areas with limited access to spatial data, using Remote Sensing and (mobile) GIS and to test it in the town of Kohima. Therefore an analysis was made of landslide, earthquake and fire hazards in three wards of Kohima town (New Market, Midland, Hospital Colony wards), based on historical analysis, a mapping survey and a questionnaire survey combined with elements at risk inventory to derive a multi-hazard risk map, which can be used as base map for reallocation of facilities and infrastructure, formulation of plans for future expansion and emergency planning. Kohima town is characterised by an extreme scarcity of data. Since this area is politically instable, the access to topographic data and aerial photographs for this region is restricted. Other thematic data is also often lacking. For instance, the Geology Department of the Nagaland University, Kohima does not have a geological map and the Directorate of Soil and Water Conservation could not produce a soil map of the city. Data should either be collected using Earth Observation satellite images, by extensive field surveys, or by a combination of both. In addition, data from the Indian satellites are not freely available for this region. Unfortunately, the study area lies between two scenes of IRS data that sometimes it could not capture the study area by either of the scenes. A flowchart of the methodology which was used is shown in Fig. 2.

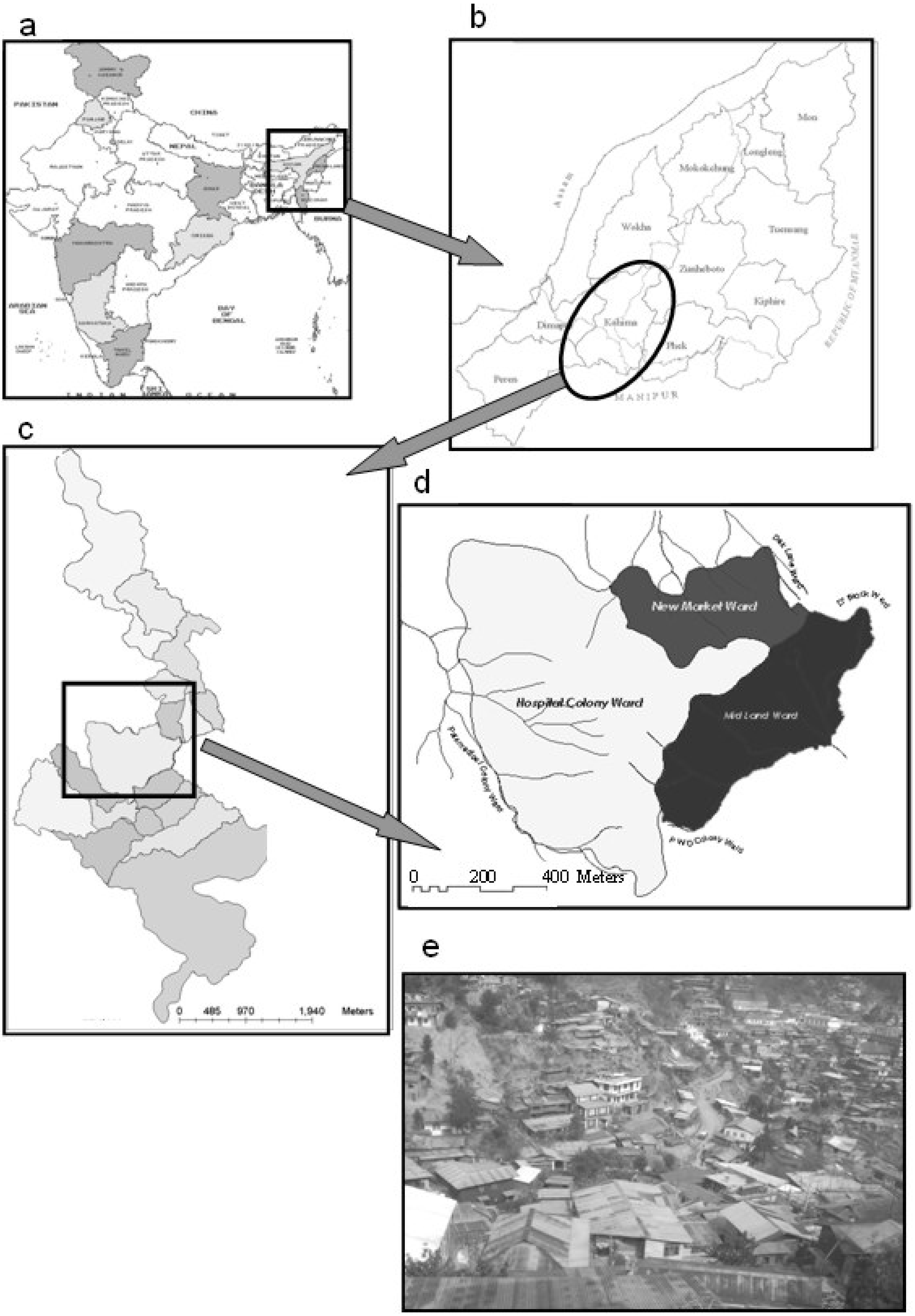

**Fig. 1: Location of the study area. a: Map of India with the location of the state of Nagaland; b: Map of Nagaland with the location of Kohima town; c: Map of Kohima town with the location of the study area; d: the three wards that have been selected as study area: Hospital Colony Ward, New Market Ward and Mid Land Ward; e: densely populated hillslope in Kohima .**

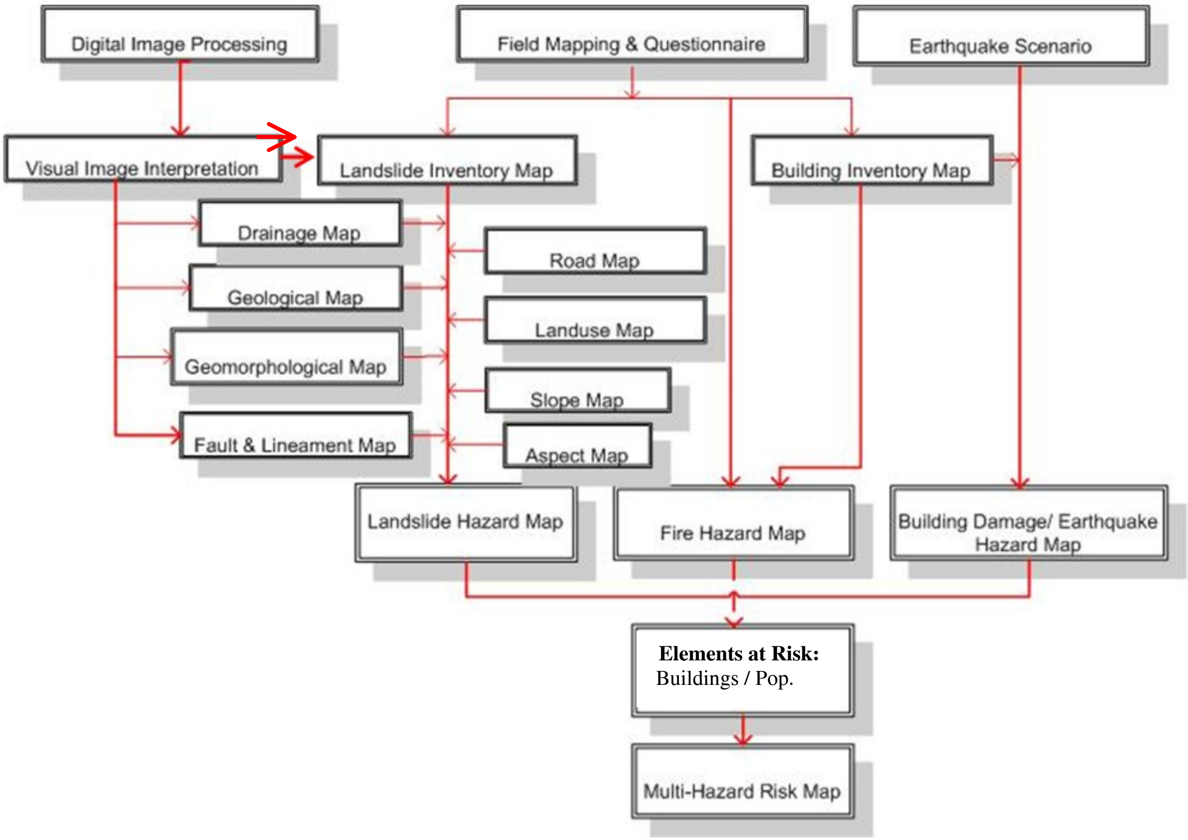

**Fig. 2: Generalized flowchart of the method followed for multi-hazard risk assessment in the city of Kohima**

### 3.1) Building inventory

Fortunately a geo-referenced building footprint map was made available in digital format by the Urban Development Department, of the Government of Nagaland. The footprints of the buildings had been extracted from aerial photographs that were taken by the National Remote Sensing Agency (NRSA) on 29th December 2001. With the upcoming municipal election in the city, in December 2004, the Government of Nagaland had re-demarcated the ward boundaries of Kohima town in 2003. This re-demarcation of boundaries has reshaped the whole of Kohima town and also the study area. The boundaries of the wards were redrawn. The geo-referenced line features were converted to polygons and processed to arrive at the individual building plots. The ward maps with buildings, roads and drainage information were printed at a scale of 1:1,000 in order to be used as a base map for subsequent field survey. Each building block on the footprint map was given a unique identification number in order to use as reference number to identify the individual buildings in the field. Since the digital map is geo-referenced by NRSA using differential GPS (Global Positioning System), the new buildings that have come up after December 2001 were marked tentatively with co-ordinates from the GPS. In order to separate houses from other small buildings, such as sheds and stables, a threshold of 15 square meters was used with an ArcGIS spatial query, and subsequent field checks. The buildings that are not inhabited were identified during the field survey and excluded. After the collection of the buildings attributes, it was found that there are 2105 inhabited and 124 uninhabited buildings in the study area. Analysis was performed on all the 2229 building blocks. A survey format was prepared and physical verification with the help of Mobile GPS with a Pocket PC was carried out for all buildings. The following types of information were collected:

- Building structure type (load bearing, Reinforced Concrete/Frame Structure) ,
- Wall material (wood, bamboo, adobe, masonry, concrete)
- Roof material (Corrugated Galvanized Iron Sheet, concrete, wood)
- Floor material (mud, cement, wood)
- Number of stories,
- Presence of landslide indicators (cracks on the walls, cracks on drainage, cracks on footpaths, etc.)

- Urban land use (residential, commercial, industrial, institutional, recreational, with second level description of the actual use, e.g. primary school, workshop, tea shop etc).

The economic and demographic data was collected through a random household survey, and an approximate sample of about 5% of the total buildings in the study area was physically surveyed. The household survey was conducted during the day time, so the majority of the respondents were housewives. No formal recording was done in the presence of the respondents. This has the advantage of not raising the curiosity of the respondents, which may prevent them from answering certain questions. Latter, the information collected was recorded in the proper format in the GIS. The household survey considered the following aspects: number of household members, age of household members, and occupation of the household head, estimated income, and fuel type used for cooking, etc. For instance, the reason for collecting the information on fuel-wood used for cooking is to see whether the material is a cause of fire hazard. Likewise, information on the size of the household and age composition is important; because this will help to know how the household will respond to a disaster. The economic aspects of the survey are collected to assess the economic status of the people living that particular area. The existence of community based organizations such as women organizations, youth organizations, clubs, etc., and their activities were also asked.

### 3.2 Landslide inventory and hazard assessment

Three methods were used for landslide mapping: interpretation of satellite imageries, walk-over survey, and analysis of historical data. Two data sets were tested for landslide inventory mapping from EO data: a merged IRS LISS III - PAN image and an ASTER image (see fig. 3). Unfortunately, high resolution imagery was not available and the aerial photographs that were used for generating the building footprint map were restricted. Due to the poor spatial resolution of the satellite data and high density of the buildings in the study area, it was very difficult to identify landslides from both sets of available images. Due to the scarcity of land in the town, residents continue to build on instable slopes and on old landslides zones that may get re-activated in the coming year. The Figure 2.2 shows the LISS III PAN merged image and ASTER image of the study area. The resolution of the LISS III PAN merged data with a spatial resolution of 5.8 meters is too small for the small landslides to be seen. However geological features such as lineament, fault and geomorphologic information were extracted from satellite data.

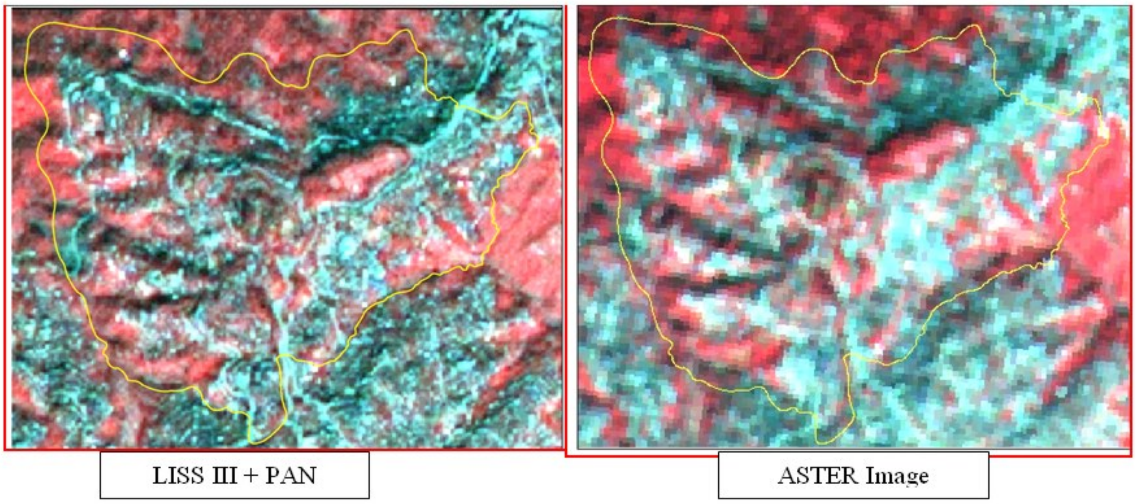

**Fig. 3: Image used for landslide inventory mapping. Left: LISS-3 Pan merged data; Right: ASTER image**

An anaglyph stereo-pair generated from the Aster data was also used for Geomorphologic mapping and identification of the regional lithological pattern. The landslide areas were mapped through a walkover survey, by observing the displacement on the ground, damage to buildings and facilities, within the study area. The presence and the patterns of cracks on building walls, retaining walls, drainage channels, concrete footpaths, roads, etc. were mapped to record the location of instable zones. Wherever there was a recognizable landslide, mobile GIS (Palmtop with ArcPad and GPS) was used to draw polygons indicating the extent of the instable area, and at the same time, the landslide area was plotted on the base map of the study area at a scale of 1:1,000. Mass movements were categorized into: old landslide and active (sinking/subsidence and creeping). During the field study elderly people were consulted to obtain information on the historical dates of damaging events, such as landslides, fires and earthquakes. This involved interviewing of local residents and also old people that are living in the study area and outside the study area, but who know the area well. Various types of methods exist for landslide hazard assessment, which can be classified into): landslide inventory analysis, heuristic methods, statistical methods and deterministic methods (Soeters and Van Westen, 1996). The method adopted for landslide hazard in this study is a bivariate statistical method, namely the Information Value method (Yin and Yan, 1988), and the following parameter maps were used in the statistical analysis: landuse, geology, geomorphology, slope steepness, slope direction, distance to faults and lineaments, drainage density, and distance to roads. The resulting hazard map is shown in fig. 4.

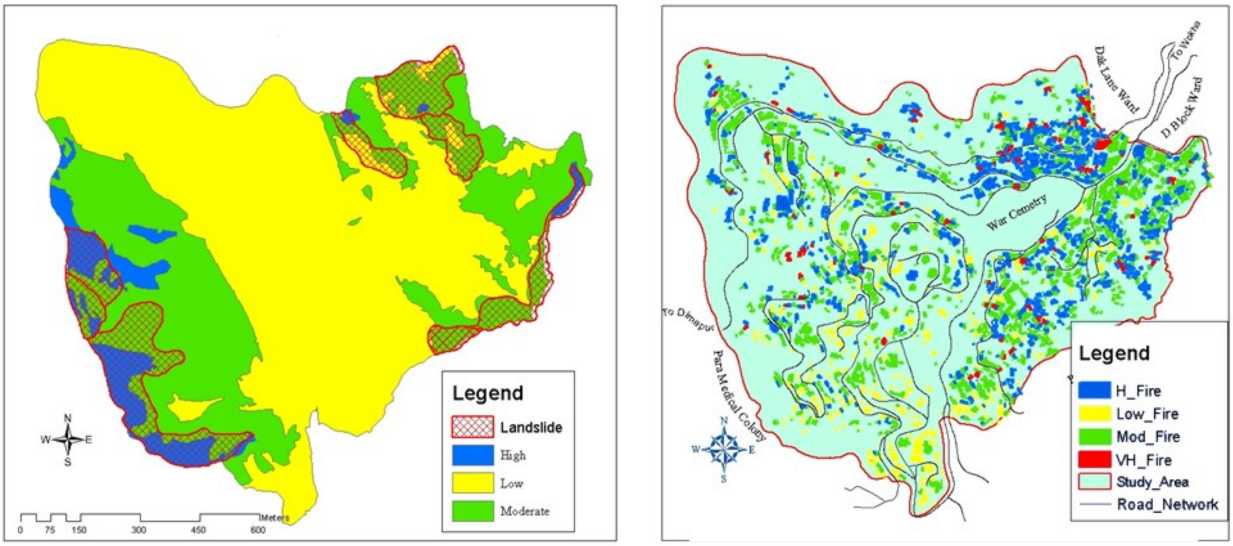

**Fig. 4: Left: Landslide susceptibility map; Right: Fire susceptibility map.**

### 3.3) Urban fire susceptibility map

In Kohima, many of the old buildings are made of wood with Corrugated Galvanized Iron Sheets (CGI) roofing. The material of the buildings includes timber, bamboo, GCI sheets and brick. The cause of accidental fire in the town is from LPG (Liquefied Petroleum Gas) accidents, candles, and fire-wood as fuel used for cooking. Fire takes place usually during March to May when the weather is dry and windy.

To prepare a fire hazard map for the study area a multi criteria evaluation was carried out including the following criteria: building typology, building material, space between buildings, distance from the road, distance from fire service stations, etc. were taken into consideration. Weight values ranging from 1 (low) to 10 (high) were assigned to the different criteria depending on the severity observed in the historic fire events. The building material type is assumed to be the most important parameter for the fire hazard assessment, and was given overall weight value of 10. The space between buildings was also considered important and was given a weight value of 6 because once a building is on fire it easily spreads to the neighbouring buildings if they are very close. Distance from the road was assigned a lower weight of 4 since the maximum distance of the buildings from the road is 200 meters which is still accessible using the existing technology of the fire brigade. Finally the distance from the single fire station in the city is given a relatively low weight of 2 because the service is said to be not very efficient as had been manifested by the local residents. Using ArcGIS SQL vector operations, fire hazard was calculated for the 2229 individual buildings, and was classified in four classes (see fig. 4). The results are summarized in Table 1.

**Table 1: Fire Hazard Classes**

| Fire Hazard Categories | | | |
|---|---|---|---|
| *Sl No* | *Category* | *No of Bldgs* | *Percentage (%)* |
| 1 | Very High Fire Hazard | 107 | 4.80 |
| 2 | High Fire Hazard | 783 | 35.13 |
| 3 | Moderate Hazard | 951 | 42.66 |
| 4 | Low Fire Hazard | 388 | 17.41 |
| Total | | 2229 | 100.00 |

### 3.4 Earthquake intensity map

Due to the lack of reliable lithological and geotechnical data, no attempt has been made to generate a map with soil- and topographic amplification for the city of Kohima. Instead three generic earthquake scenarios were assumed with earthquake intensities of VII, VIII and IX on the Modified Mercalli scale in order to assess the expected building damage. Vulnerability relations were used of seismic intensity versus expected damage to buildings, developed by A. S. Arya on the basis of damage data from the Kangra region of Himachal Pradesh were used (Arya, 1990). In consultation with the geologists and urban planners in the area, weights and ranking were assigned to a number of parameters: building structure, visible cracks in the buildings, number of floors, proximity to other buildings and roof materials. Building structure was given the highest ranking value (10), followed by the presence of cracks in the structure, which are an important sign of internal weakness (8). Since there is no PGA or spectral acceleration map available, the different response of the buildings with different heights to ground shaking could not be known. Therefore a direct relation between building height (number of floors) and seismic vulnerability is assumed, and a rank value of 6 was given to this factor. The proximity to other buildings is given a ranking value of 6, as pounding effects might occur if buildings are very close. Roof material is given the least weight of 2, because the dominant roof material is CGI which has less weight and is flexible, and most of the RCC buildings with RC roofs are recently constructed that can be considered less vulnerable to earthquakes. An example of the resulting map for earthquake intensity IX is shown in fig. 5.

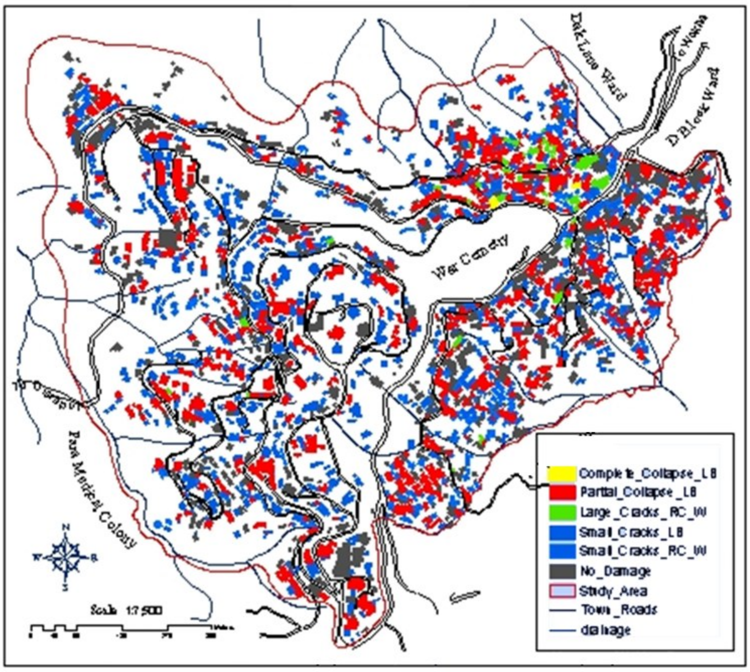

**Fig. 5: Estimated distribution of earthquake damage in case of an earthquake with local intensity of IX.**

## 4.) Multi-hazard loss estimation

After deriving the individual hazards, they were combined into a Multi-Hazard Map. For this the worst situation the highest hazard category was taken into account. Several matrices were made for the various combinations of hazards and weights were assigned to each combination. The combination of the hazards was done using an ArcGIS spatial query operation. The output map was then classified into three categories: high hazard (14-20), moderate hazard (7-13) and low hazard (0-6). The results are given in the Table 2.

**Table 2: Combination of Hazards**

| Sl No | Code | Multi-Hazards | No. of Buildings |
|---|---|---|---|
| 1 | ELF | Earthquake, Landslide & Fire | 187 |
| 2 | EL | Earthquake & Landslide | 127 |
| 3 | EF | Earthquake & Fire | 246 |
| 4 | LF | Landslide & Fire | 187 |
| 5 | E | Earthquake | 157 |
| 6 | L | Landslide | 433 |
| 7 | F | Fire | 252 |
| 8 | NIL | No Hazard | 622 |

There are 187 buildings that are confronted with the three hazards, i.e., earthquake, landslide and fire (EFL). The combination of earthquake and fire hazards (EF) has the maximum number of buildings (246). The combination of earthquake and fire are inter-related, in the sense that, an earthquake can cause fire, but this may not be true in the other way round. There are 187 buildings that are having the combination of both landside and fire hazards (LF), and 127 buildings that have a combination of earthquake and landslide hazards. There are many buildings that are prone one single hazard only. For instance, there are 433 buildings that are under high landslide susceptible zone, followed by 252 buildings in high fire zone, and 157 building in high earthquake zone. The spatial distribution of the combination of hazards is shown in fig. 6.

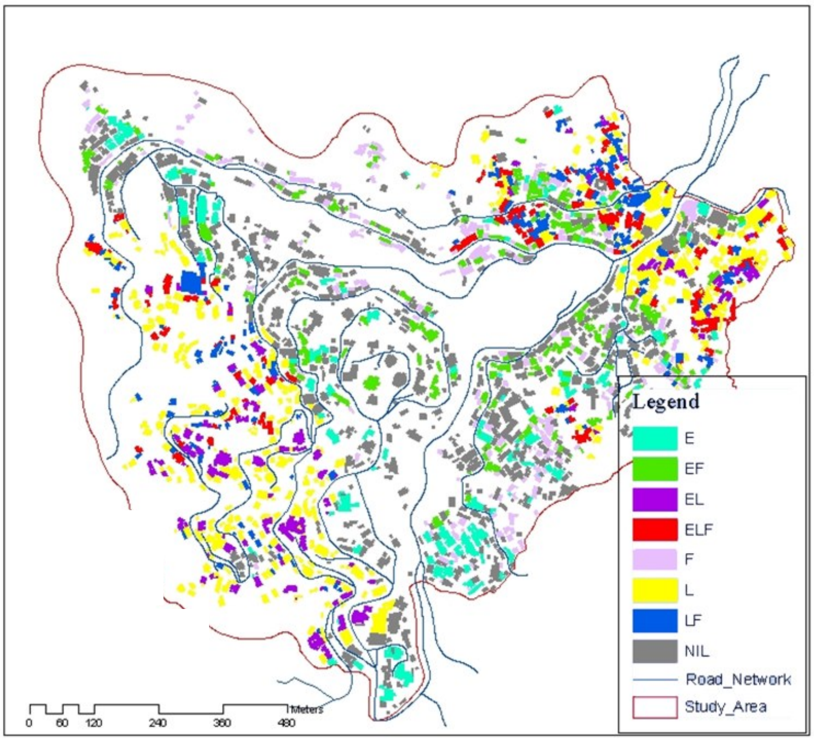

**Fig. 6: Multi-Hazard combination (see table 2 for explanation of the codes)**

The population was calculated based on the information collected from the field and the building footprint map. The number of households in each building was multiplied with the average family size in the three wards of the study area to estimate the population at risk. The population per building ranges from 0 to 32 for the residential buildings. For the other buildings such as schools an estimate was made per building of the maximum number of inhabitants.
A summary of buildings and population at risk from the different combinations of hazards is given in table 3 for the three different wards in the study area. Among the three wards in the study area, New Market Ward has the highest number of buildings belonging to all the three hazards (EFL) with 69 buildings. This number is about 17.21% of the total buildings in the ward. New Market ward is also having 78 buildings with the hazard combination of landslide and fire, which constitute about 19.45% of the buildings in the ward. Hospital Colony ward and Midland ward have 57 buildings and 61 buildings in the three multi-hazards, which is about 7.7% and 5.91% of the total buildings in the wards respectively. Among the wards, New Market is most vulnerable wards to fire hazard with 61 buildings, which is about 15.21% of the building in the ward. Hospital Colony ward has the highest number of buildings that is prone to Landslides with 253 buildings, which is about 34.19% of the total buildings in the ward belonging to high landslide hazard. In case of landslide, among the three wards, Hospital colony has the highest percentage (8.78%) of buildings in high earthquake hazard.

## 5) Conclusions

In the face of lack of available data on elements at risk and hazard types, an approach was adopted which was based on detailed field surveys and historical data collection as the main source of information for the study. Information on historical data related to three types of hazards namely earthquakes, landslides and urban fire was collected by interviewing with the local residents and the elderly people in the study area. The population density in the study area is higher than the standard prescribed by under Urban Development Plan Formulation and Implementation (ITPL, 1996). The average density of population in the study area is 124 persons per hectare whereas a maximum is given in the standard of 60-90 pph. Midland Colony Ward and New Market Ward have a density of 184 and 167 persons per hectares respectively. This figure is almost double the standard norms prescribed by UDPFI Guidelines. Hospital Colony Ward has a population density of 91 pp/ha, which is close to the standards prescribed in UDPFI.

Kohima is a hilly town which is threatened by both natural as well as anthropogenic hazards. The government agencies that deal with spatial planning are frequently confronted with hazardous events, which deplete the scarce financial resources. Given the limited financial resources, it is sometimes difficult to correctly understand what are the critical problems that need immediate attention. This study therefore, tries to understand how to address some of the hazards that are widespread in Kohima town such as landslides, earthquakes, and urban fires and develops a methodology that can be adopted for other towns that have similar problems using Remote Sensing data and Geographic Information System (GIS) techniques.

**Table 3: Ward-wise distribution of Buildings and population with Multi-Hazard Risk**

| Buildings in different wards with Multi-Hazard | | | | |
|---|---|---|---|---|
| *Wards* | *Multi-Haz* | *No of Bldgs* | *% of the ward Bldgs* | *Popn at risk* |
| New Market Ward | ELF | 69 | 17.21 | 306 |
| | EL | 9 | 2.24 | 68 |
| | EF | 72 | 17.96 | 356 |
| | FL | 78 | 19.45 | 423 |
| Midland Ward | ELF | 61 | 8.24 | 279 |
| | EL | 23 | 3.11 | 144 |
| | EF | 113 | 15.27 | 504 |
| | FL | 33 | 4.46 | 203 |
| Hospital Colony Ward | ELF | 57 | 5.91 | 203 |
| | EL | 95 | 9.85 | 387 |
| | EF | 79 | 8.20 | 333 |
| | FL | 76 | 7.88 | 414 |
| Total | | 765 | | 3620 |

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