RS / GIS For Hazard Mapping & Vulnerability Assessment, Earthquake Disaster Management, Kathmandu, Nepal

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Background

This paper is part of the study conducted at Geoinformatics Centre of AIT, Bangkok for the Mini Project 2005-06. Two departments, namely, the Survey Department and the Department of Urban Development & Building Construction participated in the Mini-project. The study topic chosen was a joint decision of the two departments and reflects the current concern about disaster at the national and international level.

The Himalayas were formed due to the collision of the Indian plate with the Eurasian plate. The stress continues to build and is occasionally released through earthquakes. The earliest recorded earthquake in Kathmandu was in June 7, 1255 AD where one-third of the then population was killed including the King Abhaya Malla himself. Some assume the magnitude to be more than 8.0 in the Richter scale, taking into account of the extent of the damage. Another earthquake in 1934 AD, also known as the Great Bihar-Nepal earthquake was of magnitude of 8.4.

This paper aims to create hazard maps for a scenario earthquake of M=6.0, 7.0 & 8.0 for historical epicentres in the Kathmandu valley. This paper further performs assessments for vulnerability of buildings and population. This can aid in planning for mitigation and preparedness. Considerable part of the work has been done in RS/GIS environment and the results would be useful to planners who are looking for specific details for disaster preparedness. Finally risk assessment of a small part of the study area was done.

Objectives

The primary objective of the study is to assess the seismic hazard, vulnerability and risk for the Kathmandu valley, using Remote Sensing and GIS tools. To achieve this goal, the following secondary objectives are set forth.

- Preparation of seismic hazard maps
- Preparation of vulnerability maps
- Risk assessment of buildings

Methodology

The peak ground acceleration (PGA) was calculated using the Joyner – Boore (1981) attenuation formula adapted to local conditions, using a scenario earthquake of M=6.0, 7.0 & 8.0 and historical epicentres in Kathmandu. PGA amplification in soil was computed using soil amplification factors from engineering geological map. The liquefaction probability maps, lateral displacement maps and intensity hazard maps are prepared using the PGA maps. Using satellite imageries, land use classification was done to delineate settlement areas. Using other ancillary data, these are then grouped into public, residential, commercial or multipurpose housing types. Field verification of a sample area was done to collect training samples. From these residential types and population data, daytime and night-time population were calculated. From this population, intensity maps and building vulnerability curves, buildings and human vulnerability were calculated for each earthquake scenario. The prevailing depreciated building costs obtained from government agencies for calculating value of a house, risks assessment for the buildings in a small area was done.

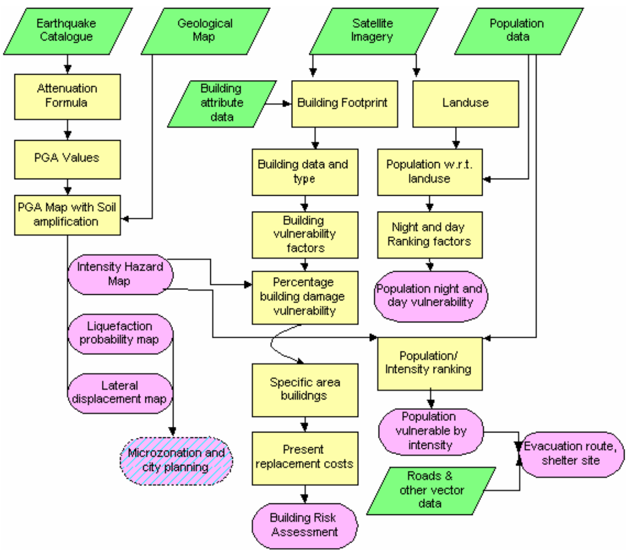

Figure 1: Methodology for the study

Study area

The study area, Kathmandu valley, comprises of three districts, Kathmandu, Lalitpur and Bhaktapur. Within these three districts are the municipalities of Kathmandu, Lalitpur, Bhaktapur, Thimi, Kirtipur and also other semi-urban and rural areas. The north and south of the study area is covered with forest and hills. The flat land in the middle of the valley is densely inhabited and is believed to be the bed of a pre-historic lake. Due to socio-economic and other factors, the growth rate has been immense, particularly in the past decade and a half. Thus, the population in the valley has become extremely vulnerable to multi-hazards and earthquakes in particular.

Data used

Vector data

Contour - (Survey Department, 1998), Administrative boundary, (Survey Department, 1998), Land use, (Kathmandu Valley Town Development Committee, 2001), Building polygons

Satellite images

Aster (Aug 24, 2005) Spatial Resolution 15 m., IKONOS (Dec 18, 2000) Spatial Resolution 4 m.

Hard Copy Maps

Topographic Map, 1995 (Survey Department, 1:25,000), Engineering & Geological Map, 1998 (Department of Mines and Geology, 1:50,000)

Other data

Population data, Census, 2001 (Central Bureau of Statistics), Earthquake catalogue 1255-2001 (Department of Mines and Geology)

Field Survey

The field survey was conducted in Chakupat area of Lalitpur district taking 55 GPS waypoints. Building types and attributes, for instance, the density of the buildings in the area, the number of stories, building material type, usage (residential, commercial, heritage etc.) were examined during the field survey. Landuse types were examined for evacuation or shelter purposes especially open space or school's football field etc.

The observed buildings varied by not only the construction materials but also by usage i.e. schools, residential, commercial and multipurpose use. Most of the buildings in the survey area are quite narrow and low in height. The average height of the buildings is approximately 3 stories and 3 meters at each floor. Buildings are remarkably congested and yet, new constructions are still going on.

Results and discussion

Hazard Maps

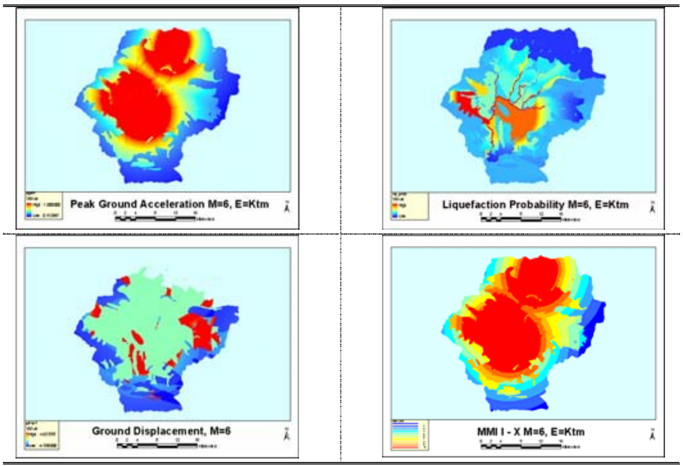

Table 1: Maps derived for M=6.0 and epicenter in Kathmandu

Peak ground acceleration maps were prepared using the Joyner Boore 1981 attenuation formula

Log PGA = 0.249 * M – Log (ÖD) – 0.00255 * (ÖD) – 0.8 (M=Magnitude, D=Epicentre distance).

Liquefaction probability maps and Ground Displacement maps were prepared using conditional probability from PGA maps as set out by the Hazard US (HAZUS) manual of Federal Emergency Management Agency (FEMA). The intensity hazard maps were prepared using the Trifunac & Brady 1975 formula.

Peak ground acceleration maps were prepared considering earthquakes of magnitude 6, 7 and 8 in Richter scale for epicentres in Kathmandu using historical earthquake catalogue. This was used to prepare (1) Liquefaction probability maps, (2) Lateral displacement maps and (3) Intensity hazard maps. The Intensity hazard map was reclassified from MMI I to XII as Low: MMI d" 5, Medium: 6 d" MMI d" 7 and High: 8 d" MMI. For magnitude 6, 7 & 8 with epicentre in Kathmandu the percentage of hazardous areas are shown in Table 2:

Magnitude	Intensity	Hazard Area (%)
M=6	Low (0 - 5)	31
	Medium (6 - 7)	14
	High (8 - 12)	55
M=7	Low (0 - 5)	15
	Medium (6 - 7)	9
	High (8 - 12)	76
M=8	Low (0 - 5)	15
	Medium (6 - 7)	9
	High (8 - 12)	76

Table 2: Percentage of hazard area

For an earthquake of magnitude M=6, 55% of the whole Kathmandu valley is under high hazard area and will experience considerable damage. The value reaches 76% for M=7 and 8. Thus, for an earthquake with epicentre in Kathmandu, the extent of damage expected for a magnitude of M=7 is as high as for M=8. So precautionary measures taken for M=7 will be sufficient for M=8 as well. However, since much of the valley is under hazardous areas, immediate steps must be taken for mitigation and preparedness.

Vulnerability assessment

Vulnerability assessment was done for buildings. Five building types namely 1) Stone-Adobe, 2) Brick with mud mortar, 3) Brick with cement mortar, 4) RCC with 3 or less stories and 5) RCC with 4 or more stories were considered and their vulnerability was assessed from fragility curves prepared by JICA, from intensities VI to >IX.

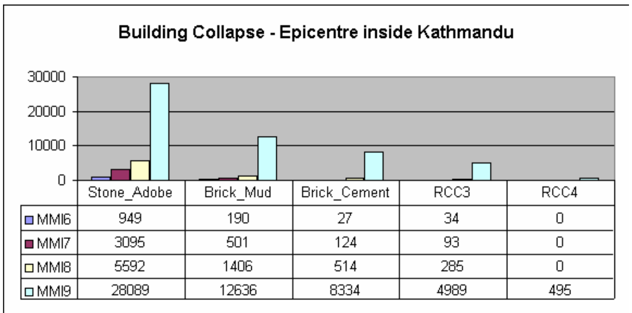

Figure 2: Building collapse for each building type per intensity

Figure 2 indicates that the population living in Stone_Adobe buildings are highly vulnerable to an earthquake in Kathmandu. Nearly all Stone_Adobe buildings will be collapsed at an intensity of MMI IX. There is an urgent need to fortify these buildings to prevent from immediate collapse to minimize casualties of people living in these buildings. Brick_Mud, Brick_Cement and even reinforced cement concrete buildings of 3 or less stories (RCC3) buildings are vulnerable to an earthquake of intensity MMI IX or more. The last earthquake of magnitude 8.4 was in 1934. From historical records in Table 3, we see that the approximate recurrence interval for an earthquake of magnitude 7.5-8 Richter scale is 40 years, so an earthquake of this magnitude would be highly devastating for Kathmandu, so building reinforcement should be undertaken without delay. New buildings should be built with earthquake resistant technology.

Richter Magnitude	No. Of Events	Approximate Recurrence Interval (Year)
5-6	41	2
6-7	17	5
7-7.5	10	8
7.5-8	2	40
>8	1	81

Table 3: Magnitude-Frequency Data on Earthquakes in Nepal and the Surrounding Region (1911-1991)

Source: http://www.geohaz.org/contents/projects/kathmandu.html

Risk assessment

Risk assessment was done on the Chakupat area of Lalitpur district, the field study area where high-resolution satellite image was available. The average height and building type was RCC3. The prevailing rates of construction and depreciated rates used by government agencies were used to calculate value of a house. The damage percentage was calculated using the fragility curves for RCC3 type for the 1493 buildings in the area.

Present construction cost rate (NRs./sq.ft.)	1,000
Depreciated cost rate (NRs./sq.ft.)	750
Total number of buildings	1,493
Total built area (sq.ft.)	6,617,321
Total present cost (NRs.)	6,617,321,000
Total depreciated cost (NRs.)	4,962,990,750
Average building cost (NRs.)	3,324,175
Number of collapsed buildings	448
Damage costs (NRs.)	1,489,230,400
Remarks: US$1 = NRs. 70	US$ 21,274,720

Table 4: Risk Assessment

Table 4 shows that for the buildings alone, without taking into account the valuables and commodities inside a house or other collateral damage to infrastructure, the estimated damage amounts to US$ 21 million. This can be extended to other similar areas for an estimate of expected damage costs using high-resolution satellite imagery.

Conclusion

Remote sensing and GIS was extensively used in the study for earthquake vulnerability and risk assessment in Kathmandu valley. Extraction of building information from IKONOS image was relatively easy but the image covered only a small part of the study area. High-resolution stereo satellite images could be used not only to generate precise DEM but also to extract information like building footprints, building area, building height and building density etc. With the use of high-resolution images the risk assessment could be extended to the whole study area easily, which is currently limited to approximately 10 hectares only. Better landuse maps can be prepared from high-resolution images to incorporate landuse patterns for vulnerability assessments and also for seismic microzonation. The hazard maps and vulnerability maps helped to estimate population and building vulnerability, potential losses and areas at risk. The results obtained can be useful for strategy formulation for mitigation and planning, creating awareness about earthquake disaster and as guidelines for future urban planning and zoning.

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