Geo-Information for Urban Risk Assessment in Developing Countries: The SLARIM project

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Abstract

The aim of this paper is to present the first results of a research project entitled: Strengthening Local Authorities in Risk Management (SLARIM). The main objective of this project is to develop a methodology for spatial information systems for municipalities, which will allow local authorities to evaluate the risk of natural disasters in their municipality, in order to implement strategies for vulnerability reduction. The project concentrates on medium-sized cities in developing countries, which do not yet utilize Geographic Information Systems in their urban planning, and which are threatened by natural hazards (such as earthquakes, flooding, landslides and volcanoes). The methodology concentrates on the application of methods for hazard assessment, elements at risk mapping, vulnerability assessment, risk assessment, and the development of GIS-based risk scenarios for varying hazard scenarios and vulnerability reduction options, using structural and/or non-structural measures. In the development of elements at risk databases use is made of interpretation of high-resolution satellite imagery, combined with extensive field data collection, using mobile GIS. Although the methodology is primarily designed to assist municipalities in the decision-making regarding vulnerability reduction strategies, the resulting databases are designed in such a way that they can also be utilized for other municipal activities. Within the project a number of case study cities have been identified. Here results are presented on earthquake loss estimation for the city of Lalitpur in Nepal, for buildings and for population losses. Databases have been generated of the buildings of the city, and of the subsurface conditions. Soil response modeling was carried out and vulnerability curves are applied to estimate the losses for different earthquake scenarios.

1 Introduction

The fast-growing world population is concentrating more and more into urban areas. Nowadays, almost half of the world’s 6 billion inhabitants already live in cities, and in the next thirty years it is predicted that 90 percent of the expected 2.2 billion newcomers will be born in cities in developing countries (USAID, 2001). Many of these cities are located in areas that are endangered by natural disasters, such as earthquakes, flooding, cyclones/hurricanes, landslides, volcanic eruptions, subsidence etc. It is estimated that over 95 percent of all deaths caused by disasters occur in developing countries and losses due to natural disasters are 20 times greater (as a percent of GDP) in developing countries than in industrial countries (Kreimer et al. 2003).

Local authorities in cities are responsible for the proper management of the area under their jurisdiction, and the well being of the citizens, which includes an optimal protection against disasters. Unfortunately, until recently most of the emphasis has been on the post-disaster phases, and mostly was under the responsibility of national civil defense organizations. Recently, the emphasis is being changed to disaster mitigation, and especially to vulnerability reduction. Since the International Decade for Natural Disaster Reduction in the 1990’s many initiatives have been launched worldwide to assess and reduce urban vulnerability. Some example are the program on Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters (RADIUS, 2000), the Earthquakes and Megacities Initiative (EMI, 2002), and the Cities and Critical Infrastructure Project (Cities Project, 2004).

Due to the diversity and large volumes of data needed, and the complexity in the analysis procedures, quantitative risk assessment has only become feasible in the last two decades, due to the developments in the field of Geo-Information science. When dealing with GIS-based hazard assessment, elements at risk mapping, and vulnerability/risk analysis, experts from a wide range of disciplines, such as earth sciences, hydrology, information technology, urban planning, architecture, civil engineering, economy and social sciences need to be involved.

2 The SLARIM Project

In order to contribute to urban risk assessment in developing countries the International Institute for Geoinformation Science and Earth Observation (ITC) launched a research project with the acronym SLARIM, which stand for "Strengthening Local Authorities in Risk Management". The main objective of this research project is to develop generic methodologies for GIS-based risk assessment and decision support systems that can be beneficial for local authorities in medium-sized cities in developing countries. For local authorities being able to handle this tool properly implies a lot of attention in this research for user requirements, institutional issues and spatial data infrastructure, connected with the methodologies of hazard and risk assessment on the one hand and the relevant DSS based GIS applications in urban planning and management (what can local authorities actually do with this data) on the other hand. The ultimate objective of this project is to improve the safety of communities, and consequently make them more sustainable and prosperous.

The methodology for the use of GIS in urban risk assessment and management is developed on the basis of a number of case studies. After carefully evaluation and visits to potential case study cities, a number of case study cities have been selected. The willingness of local authorities to participate actively in this project has been considered as one of the main criteria, besides the availability of data, and the types and severity of the hazards in the urban areas. Three case study cities have been selected (See Figure 1): Dehradun (India), Naga (Philippines) and Lalitpur (Nepal). In the following sections an example of the results of a number of the components will be given, namely on seismic loss estimation in Lalitpur (Nepal).

3 Earthquake Loss Estimation in Lalitpur, Nepal.

3.1 Case Study City

The Lalitpur Sub-Metropolitan City is located in the Kathmandu valley, neighboring the capital of the Kingdom of Nepal, Kathmandu. Lalitpur has a population of 163,000, in 35,000 households, according to the 2001 census. The municipality is divided into 22 wards. Lalitpur is one of the oldest cities in Nepal, supposedly founded in 299 A.D., with one of its most important periods during the Malla dynasty from 1200 – 1768.

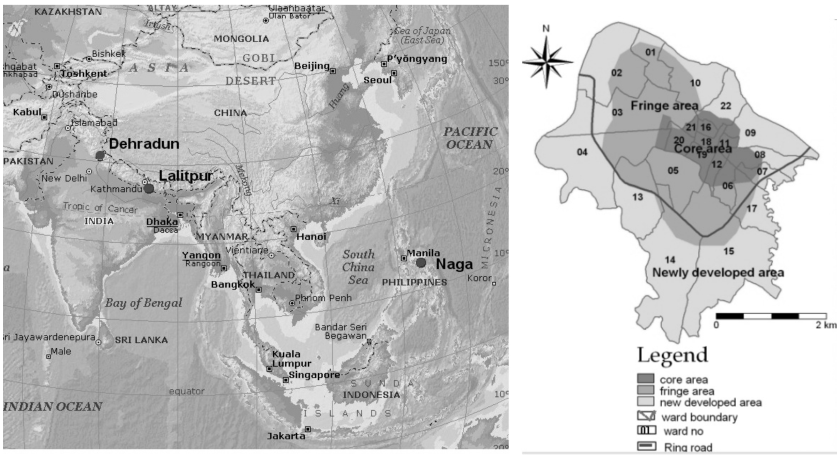


Fig. 1. Left: Location of the three case study cities for the SLARIM project. Right: Structure of Lalitpur

The old core area is famous for its cultural heritage, and has a very dense structure, with a majority of buildings with load-bearing masonry, with mud mortar and adobe. Many houses are built in a courtyard pattern, with very narrow streets. With the increase in population, and the vicinity of the capital, the city started to expand considerably, especially after the construction of the ring road in the 1980s. In the fringe area, which was developed between the core area and the ring road, the majority of buildings are masonry with brick in cement and RCC. In the last year, also rapid construction takes place in the areas, on the outer side of the ring road, where the majority consists of RCC buildings. Until recent, Lalitpur did not have a system for building permit issuing and evaluation. Lalitpur has suffered from damaging earthquakes in the past, such as in 1255, 1408, 1810, 1833, 1934, 1980 and 1988. In the earthquake of 1934, which had a magnitude of 8.4, it was estimated that about 19,000 buildings were heavily damaged within Kathmandu valley, causing the death of more than 3800 people (JICA, 2002).

Lalitpur is located on a former lake in the middle Himalayan mountain range, of which the surface materials are mainly consisting of alluvial terrace deposits on top of a thick sequence of lake sediments, with a thickness up to 400 meters (Fujii et al., 2001).

Various institutions have carried out studies on earthquake hazard and risk in Kathmandu Valley. After the earthquake in 1988, a first study was carried out by the Ministry of Housing and Physical Planning (MHPP), with technical assistance from the United Nations Development Program. In this project a regional scale seismic hazard map for Nepal was produced, and a National Building Code was established, which was unfortunately not implemented (UNDP, 1994). In 1998 this was followed by the Kathmandu Valley Earthquake Risk Management Project (KVERMP), which was implemented by the National Society for Earthquake Technology – Nepal (NSET), with support from the Asian Disaster Preparedness Centre (ADPC), which focused on awareness raising and capacity development at different levels of society, including school reinforcement, mason training, organization of an earthquake safety day, and development of an earthquake risk management plan together with local authorities (Dixit et al., 2002). The project was based on a simple earthquake loss estimation, estimation the losses if the 1934 would occur today. A more detailed study on earthquake loss estimation was made by the Japanese International Cooperation Agency (JICA, 2002). This study divided Kathmandu Valley into large grid cells of 500 by 500 meters, for which the number of damaged buildings were calculated using three scenario earthquakes.

In all of the previous studies, the basis of the loss estimation has always been at a rather general level. The spatial distribution of the earthquake losses is a very important basis for a proper earthquake vulnerability reduction and emergency planning at municipal level. Municipalities would need to have databases at individual building level, in order to be able to carry out proper control over building construction. This study used high-resolution satellite imagery, together with aerial photographs and field survey in the generation of a building database for seismic loss estimation in Lalitpur. An overview of the method is used is given in Figure 2.

3.2 Generation of the Dataset

The Lalitpur Sub-Metropolitan City Office did not yet have a GIS section, nor did they have GIS data on the building stock and other characteristics within their municipality. The Information Department of the neighboring Kathmandu Metropolitan Office, however, was able to provide a series of large-scale topographic maps at scale 1:2,000 in digital form, containing information on drainage, roads, contourlines (1 meter resolution) and building footprints, which was generated in the framework of a European project. These topomaps were in AutoCad format and were converted into a usable GIS database, consisting of separate layers for buildings, roads, contours and drainage.

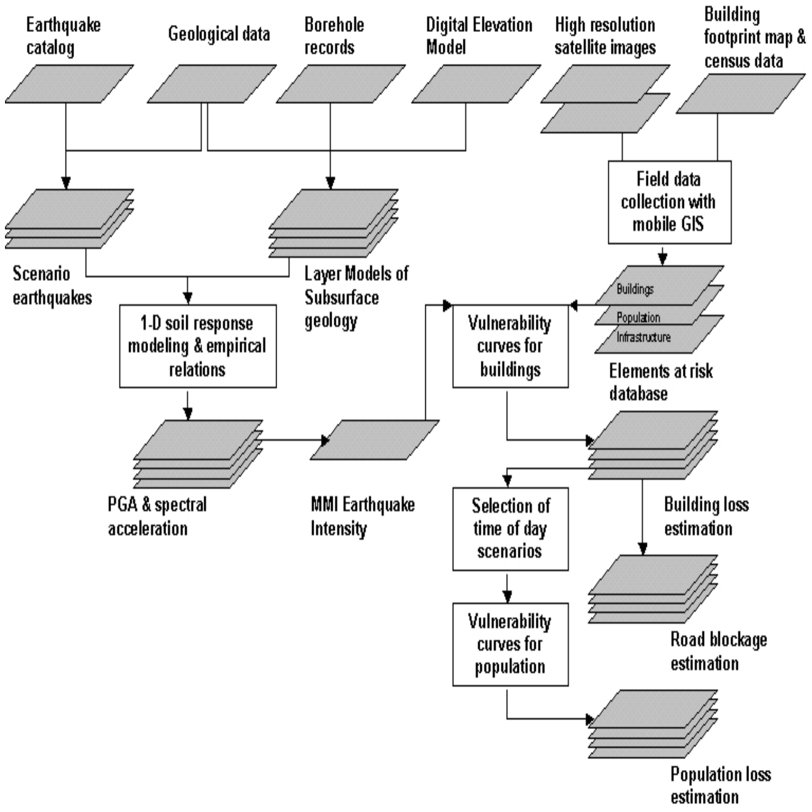


Fig. 2. Flowchart of the procedure for seismic loss estimation in Lalitpur, Nepal. See text for explanation

Especially the generation of building polygons from the segments in the building footprint layer proved to be very cumbersome.

The building footprint map was prepared based on aerial photos of 1981 and 1992 and was updated in 1998. All the buildings constructed after this year as observed in the available IKONOS image from 2001 were digitized on screen to create the building data set for the year 2001. As also a CORONA image was available from 1967, this image was used to delete those buildings that were not yet present in 1967, and generate a building footprint map for that year. In the old center of the city, where most of the buildings are attached to each other and form large complexes around courtyards, the existing building footprint maps did not make a separation between individual buildings, but rather displayed entire complexes of buildings as a single polygon. To calculate the number of buildings the building footprint area of these polygons was divided by the average plinth area of a building, which was taken as 45 m^2 based on samples. A total number of 26,873 buildings are estimated for the year 2001. These buildings were compared to the number of households from the census data (34,996).

The original digital building footprint maps did not contain any attribute information regarding the buildings within the city. Since a complete building survey would require too much time for field data collection, it was decided to use so-called homogeneous units as the basic mapping units within the city. In the field mobile GIS was used to characterize the buildings within each unit according to age (based on procedure outline earlier), occupancy class, land use type and building type, which was a combination of construction material and number of floors.

Population data were available from the latest population census in Nepal, which was held in 2001, published by the Central Bureau of Statistics (CBS) of Nepal. Information was only available at Ward level, according to age and gender. In order to calculate the population distribution per homogeneous unit, which was taken as the basic unit for the loss calculation, wardwise population figures had to be distributed over the various units within the ward. This was done by calculating the percentage of floor space in residential buildings within each homogeneous unit as percentage of the total floor space of residential buildings in the ward. The average population density within different types of buildings (residential, commercial, institutional etc.) was estimated based on 196 detailed samples of buildings carried out by a local NGO, the National Society for Earthquake Technology (NSET) and the Lalitpur Sub-Metropolitan City Office. Based on these samples estimations were made of the population amounts present in different types of buildings during different periods of the day.

3.3 Soil Response Modeling

In order to be able to analyze the seismic hazard in Lalitpur and its surroundings a sub-surface database was generated for the entire Kathmandu valley. A geological database was made for storing the information for 185 deep boreholes, with depths ranging from 35 to 575 meters, of which 36 boreholes actually reached to the bedrock, and 328 shallow boreholes with depths less than 30 meters. Only the shallow borehole records contained both lithological and geotechnical information.

All boreholes were divided into main stratigraphical units, for which the depth was determined and used in GIS for subsequent layer modeling. The horizontal and vertical distribution of the valley fill within the Kathmandu valley is very complex, mainly consisting of intercalations of fluvial and lacustrine deposits. In order to generate layer models for such a heterogeneous environment, a certain degree of generalization had to be accepted. In this case, all sediments of the basin were divided into four layers: Holocene alluvial and anthropogenic deposits, lacustrine deposits formed between 2,500,000 to 29,000 years B.P. (Yoshida and Igarashi, 1984), alluvial deposits below the lacustrine sediments, and the underlying bedrock (See Figure 3). The depth of each of the layer boundaries, including the surface elevation was used in GIS and Digital Elevation Models of each of these surfaces were obtained through point interpolation.

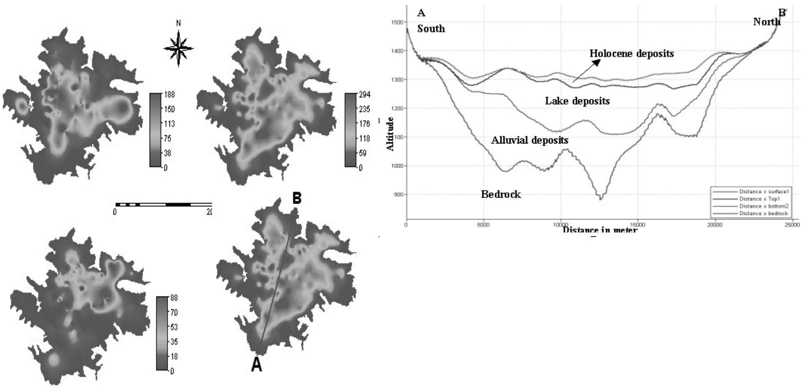


Fig. 3. Left: Thickness maps of the three main material types in the Kathmandu valley. Right: Cross section based on the layer thickness maps

The GIS layer models were used for one-dimensional calculations of the ground response, with the help of SHAKE2000, which is derived from the original SHAKE software, used widely for soil response analysis since 1971 (Ordonez, 2002). For each material type, average values for shear wave velocity, and unit weight, were used, and 5% damping was selected. Unfortunately no strong motion records are available for Kathmandu valley, so comparable records were used from other locations. Three earthquake scenarios were selected in line with the ones used in the study by JICA (2002): one comparable in magnitude and epicentral distance to the 1934 earthquake (called Mid Nepal earthquake), one located North of Kathmandu valley (North Bagmati earthquake) and a local earthquake in the valley itself. The analysis was carried out by sampling the depths of the GIS layers at regular intervals. Each of the sampling points was transformed into a soil profile, which was entered in the SHAKE2000 program, and which was analyzed using the above mentioned scenario earthquakes. The results were calculated as Peak Ground Acceleration (PGA) as well as spectral acceleration for frequencies of 5, 3 2 and 1 Hz. These values were later linked back to the sampling points and maps were obtained through point interpolation.

An analysis of liquefaction potential was made using both qualitative and quantitative methods. In the qualitative analysis the methods of Iwasaki et. al (1982) and Juang and Elton (1991) were used and the quantitative analysis was carried out using simplified methods developed by Iwasaki et al. (1984) and Seed and Idriss (1971). The qualitative methods are based on weights, assigned to a number of factors such as Depth to water table, Grain size distribution, Burial depth, Capping layers, Age of deposition and Liquefiable layer thickness. Following this method, the analysis was carried out for 69 boreholes located at 40 different sites, resulting in 35 boreholes where liquefaction is likely to occur at a particular depth. The final liquefaction susceptibility map was prepared by combining the point information of the boreholes with geomorphological units in a GIS.

3.4 Loss Estimation

For analyzing seismic vulnerability, the buildings in Kathmandu valley have been divided into a number of classes (See table 1). The vulnerability curves used in the GIS analysis were derived by NSET-Nepal and JICA (JICA, 2002). For each MMI class and building type, minimum and maximum values are given of the percentage of buildings that would be heavily damaged (collapsed or un-repairable) or partly damaged (repairable, and available for temporary evacuation).

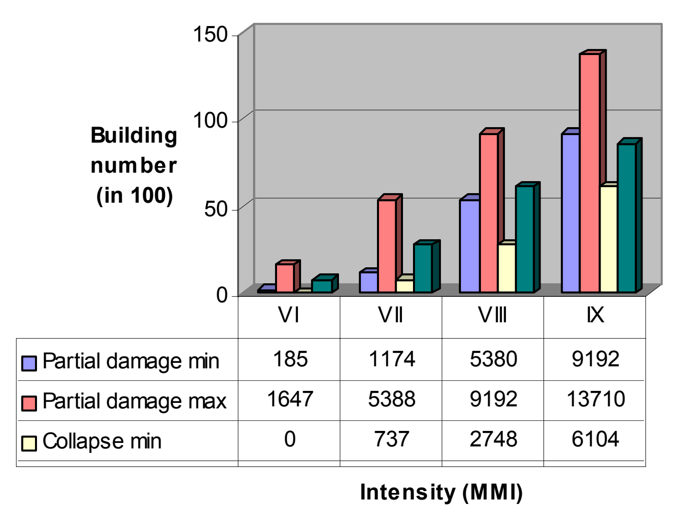
The earthquake intensity maps were used in combination with the building map and the vulnerability relations indicated in table 1 to calculate the range of completely and partially damaged buildings for each earthquake intensity. In figure 4 some of the results are given. This figure gives the total number of vulnerable buildings in different damage grades and in the four earthquake-intensities used ranging from VI to IX. For example, if an earthquake of intensity IX would occur a number of buildings ranging from 9,192 to 13,710 might be partially damaged and 6,104 to 8,583 might collapse in Lalitpur.

Building type	**MMI**	**VI**	**VII**	**VIII**	**IX**
	PGA (% g)	**5-10**	**10-20**	**20-35**	**>35**
Adobe + Fieldstone Masonry Buildings	Total Collapse	2-10	10-35	35-55	55-72
	Partial Damage	5-15	15-35	30	30
Brick in Mud (BM)	Total Collapse	0-6	6-21	21-41	>41
	Partial Damage	3-8	8-25	25-28	<28
Brick in Mud (BMW) and Brick in Cement (BC)	Total Collapse	0-1	1-5	5-18	>18
	Partial Damage	0-11	1-31	31-45	<45
R. C. Framed (≥4 storied)	Total Collapse	0-2	2-8	8-19	19-35
	Partial Damage	0-4	4-16	16-38	38-65
R. C. Framed (≤3 storied)	Total Collapse	0-2	2-7	7-15	15-30
	Partial damage	0-4	4-14	14-30	30-60

Table 1. Damage matrixes for different types of buildings in Kathmandu (The values represent percentages of buildings with the same material type. Source: NSET Nepal)

In a next step specific damage estimations were made for three earthquake scenarios mentioned before. For each of these scenarios the ranges of partially and heavily damaged buildings have been estimated, with and without the effect of liquefaction. In order to take into account the liquefaction effect, the intensities in areas with high liquefaction susceptibility have been increased with 1 on the MMI scale. For the Mid Nepal and Local Earthquakes the amount of partially damaged building ranges from 5,380 to 9,192 and heavily damaged buildings from 2,748 to 6,104. If liquefaction is also included the estimations for partly damaged buildings rise to the range 5,804 – 9,779 and for heavily damaged buildings between 3,034 and 6,412.

The number of casualties was estimated at homogeneous unit level for the three different earthquake scenarios mentioned earlier. The data used for this calculation were the population distribution for different periods of the day and within different occupancy classes, the building loss estimation discussed in the previous section and vulnerability and casualty ratios with respect to building damage. These casualty ratios were derived from the HAZUS methodology, which uses the widely accepted ATC-13 vulnerability curves (FEMA, 2004) and which make a separation into fours severity classes (See table 2). With these relations, the number of casualties was estimated for the three different earthquake scenarios, and for both a daytime and nighttime scenario, with a different distribution of population over the various occupancy classes. Preliminary results are shown in Figure 5 for the Mid Nepal Earthquake scenario.



	VI	VII	VIII	IX
🟦 Partial damage min	185	1174	5380	9192
🟥 Partial damage max	1647	5388	9192	13710
☐ Collapse min	0	737	2748	6104

Fig. 4. Building loss estimations for different earthquake intensities in Lalitpur

Building damage level	**Injury level (in %)**			
	Severity 1 Slight injuries	**Severity 2** Injuries requiring medical attention	**Severity 3** Hospitalization required	**Severity 4** Instant death
Partial damage	1	0.1	0.001	0.001
Complete damage	40	20	5	10

Table 2. Various injury levels according to building damage. Modified from HAZUS

Normally, nighttime scenarios are expected to result in higher casualty numbers. The deviation in this case might be related to the inaccuracy of the population input data, as original data was only available at ward level, and also in the distribution of population over the city in different periods of the day.

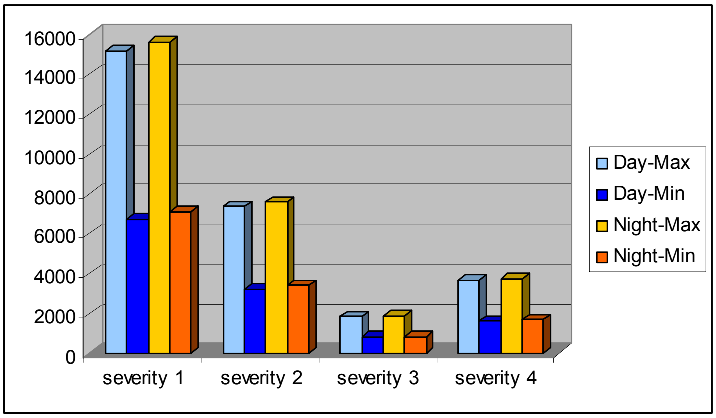


Fig. 5. Casualty estimation for the Mid Nepal Earthquake scenario in Lalitpur

Clearly more detailed information for this should be collected. It might also be caused by the fact that many of the buildings where people are during the daytime, such as schools, shops etc. are equally vulnerable, or sometime more vulnerable than the residential buildings.

4 Conclusions

The results from the earthquake loss estimation for Lalitpur Sub-Metropolitan City in Nepal illustrates the urgent need to support local authorities in developing countries with methods to collect and manage information used for risk assessment in order to be able to implement strategies for vulnerability reduction and disaster preparedness. The collection of basic data is of prime importance, and should be carried out by staff from the municipality in collaboration with local institutions and the local communities. The data collected thus far was mostly in the framework of rather short MSc fielddata collection campaigns, and should be further verified and extended. In the initial period of the project contacts with the Lalitpur Sub-Metropolitan City Office (LSMCO) have been established, and the results of the research was shared with their staff in a workshop. Also a user needs assessment was carried out, leading to the installation of a GIS center within LSMCO and basic GIS training of 12 of their staff. With LSMC a number of phases have been outlined, starting with the collection of base data and the development of a municipal database, leading to the integrated use of this data for various urban planning and management activities, including disaster prevention and preparedness. One of the priority areas for the application of the municipal GIS in the framework of vulnerability reduction is the development of a building permit issuing and control system, that takes into account seismic vulnerability as one of the factors. Some other high priority GIS applications outlined by the LSMCO are the set-up of a proper addressing system for the city, which can be linked to geographic positioning using GPS, and urban heritage management. In a later phase LSMCO plans to apply it to other aspects such as solid waste management, infrastructure management, revenue management, etc. What has become clear in the case study with the Lalitpur Sub-Metropolitan City so far is that specific GIS based Decision Support Systems for Disaster Management at municipal level can only be implemented if a municipality has experience with GIS and has developed a municipal database. Even then, such a system would be less useful for disaster prevention, as vulnerability reduction measures should be an integrated part of all common municipal activities, than for disaster preparedness.

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