Geoinformation Science and Earth Observation for municipal risk management;
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. The methods for risk assessment that are applied depend on the availability of existing data within the study area, and range from simple loss estimations based on historic information to more complex methods based on modeling. 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. Also local communities are involved in the collection of vulnerability information, and in the evaluation of social vulnerability and capacity. 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. The city of Naga in the Philippines has been selected for flood risk management, and the cities of Lalitpur in Nepal and Dehradun in India for seismic risk management. The project is carried out by research staff, PhD and Msc researchers of various disciplines at ITC, in collaboration with other partners (such as ADPC) and linked to external research and capacity building projects. In this paper an overview is given of the work done in Lalitpur.

1. Introduction

1.1 Increased urban vulnerability to disasters

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 out of a total of 2.2 billion newcomers, 2.1 billion will be urban citizens, and 2.0 are expected to be born in cities in developing countries (Source: USAID, 2001).

To quote the UN General Secretary Kofi Anan:

> *"We have entered the urban millennium. At their best, cities are engines of growth and incubators of civilization. They are crossroads of ideas, places of great intellectual ferment and innovation... cities can also be places of exploitation, disease, violent crime, unemployment, and extreme poverty...we must do more to make our cities safe and livable places for all"*

(Source: UN Press Release SG/SM/7479)

Apart from the above-mentioned problems, many of the cities in both developing as well as in developed countries are located in areas that are endangered by natural disasters, such as earthquakes, flooding, cyclones/hurricanes, landslides, volcanic eruptions, subsidence etc. Natural disasters are extreme events within the earth's system (lithosphere, hydrosphere, biosphere or atmosphere) which differ substantially from the mean, resulting in death or injury to humans, and damage or loss of 'goods', such as buildings, communication systems, agricultural land, forest, and natural environment (Alexander, 1993). Almost every day there is a disaster reported in the news. The number of reported disasters is showing an exponential increase, as are the losses and the number of casualties and people affected (Source: EM-DAT, 2004; MunichRe, 2004). As compared to the decade of the 1960's the number of large disastrous events (especially those of hydrometeorological origin) has increased with a factor 2.2 in the last decade, and the damage has increased with a factor of 6.7 (Source: MunichRe, 2004). The relative increase in disaster losses is larger than the relative increase in population, and is caused by other factors than pure population growth. An additional factor is related to climate change, leading to increased coastal flooding due to sea-level rise, increased windstorm activity outside the tropics, more frequent heat waves, and intensification of El Nino and La Nina phenomena (Source: IPCC 2001; IFRC, 2003)

Apart from the intensification of hazard, the increase in disaster losses is caused by an increase in vulnerability of especially urban societies. There are nowadays already about 450 cities in the world with a population of over 1 million people. Many cities expand dramatically, often in an unplanned manner and confronted with lack of space. This leads on the one hand to a densification of cities and an increase in population density, and on the other hand to the occupation of unsuitable land in more hazardous conditions (e.g. steep hillslopes or active floodplains), often by the poorest. About 50 percent of the large cities in the word is located either along active earthquake zones or tropical cyclone tracks. Also in developed countries the development of highly sensitive technologies can lead to a growing susceptibility of modern industrial societies to breakdowns in their infrastructure due to natural and man-induced disasters. However, cities in developing countries suffer most from natural disasters. 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 (Source: Kreimer et al. 2003).

1.2 Need for urban disaster management

Local authorities 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. It is not acceptable anymore to have a response-oriented attitude, and concentrate only on the organization of disaster relief. Disaster prevention and preparedness are equally important component of a proper disaster management, in order to reduce the urban vulnerability.

To quote the UN General-Secretary again:

"More effective prevention strategies would save not only tens of billions of dollars, but save tens of thousands of lives. Funds currently spent on intervention and relief could be devoted to enhancing equitable and sustainable development instead, which would further reduce the risk for war and disaster. Building a culture of prevention is not easy. While the costs of prevention have to be paid in the present, its benefits lie in a distant future. Moreover, the benefits are not tangible; they are the disasters that did NOT happen. "

(Source: UN, 1999)

Disaster management can be separated in several pre- and post-disaster phases (See table 1). Pre-disaster phases are risk identification, in which various types of risk are assessed in order to be able to carry out appropriate mitigation measures to reduce the risk, transferring of risk using financial means and all aspects leading to a better preparedness to predict and cope with the occurrence of hazardous events. Post disaster phases consist of disaster relief, rehabilitation and reconstruction.

Pre-disaster phases				**Post-disaster phases**	
Risk Identification	**Mitigation**	**Risk Transfer**	**Preparedness**	**Emergency response**	**Rehabilitation and Reconstruction**
Hazard Assessment	Physical structural mitigation works	Insurance/ reinsurance of public infrastructure and private assets	Early warning systems. Communication systems	Humanitarian assistance / rescue	Rehabilitation/reconstruction of damaged critical infrastructure
Vulnerability assessment	Land-use planning and building codes	Financial market instruments	Monitoring and forecasting	Clean-up, temporary repairs and restoration of services	Macroeconomic and budget management
Risk Assessment	Economic incentives	Privatization of public services with safety regulations	Shelter facilities Emergency planning	Damage assessment	Revitalization of affected sectors
GIS mapping and scenario building	Education, training and awareness	Calamity funds (national or local level)	Contingency planning (utility companies / public services)	Mobilization of recovery resources	Incorporation of disaster mitigation components in reconstruction

Table 1: Key elements of disaster management (source: IDB, 2000)

Unfortunately, until recently most of the emphasis has been on the post-disaster phases, and most disaster management organizations in developing countries have been established only for this purpose. 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. For example, the programme on Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters (RADIUS, 2000) has had a major impact in creating awareness among local authorities in many earthquake threatened cities regarding the seismic risk and methods for vulnerability reduction. More recently, also in the field of earthquake vulnerability reduction, the Earthquakes and Megacities Initiative (EMI, 2002) is an international initiative dedicated to the promotion and implementation of earthquake preparedness, mitigation and recovery of large urban areas (i.e. megacities). In Australia, the Cities and Critical Infrastructure Project (Cities Project, 2004) undertakes research for the mitigation of the risks posed by a range of geo-hazards to Australian urban communities. Activities undertaken in several regions, such as in Asia (Asian Urban Disaster Mitigation Programme), and Central America and the Caribbean (UNESCO-RAPCA, 2004), have demonstrated the usefulness of capacity building for urban disaster reduction.

1.3 Developments in Geoinformation science and earth observation

Geoinformation science and earth observation consist of a combination of tools and methods for the collection, storage and processing of geo-spatial data and for the dissemination and use of these data and of services based on these data. This implies the development and application of concepts for spatial data modeling, for information extraction from measuring on image data, and for the processing, analysis, dissemination, presentation and use of geo-spatial data. It also implies the development and implementation of concepts for the structuring, organization and management of geo-spatial production processes in an institutional setting.

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.

For the average hazard and risk scientist it is difficult to keep up with the rapid developments in the field of Geo-information Science and Earth Observation. The number of new sensors and platforms, and the amount of acronyms is overwhelming. Also the change of GIS software from one version to the next, in which the methods that had been developed earlier on do no longer function, because of changes in file structure or interface, can be frustrating to many professionals. Nevertheless, GIS has become an almost compulsory tool in hazard and risk assessment, and it is the challenge to keep on using it as a tool, and not as an objective in itself.
For disaster management, and particularly for hazard and risk assessment the following recent developments in the field of Geoinformation Science and Earth Observation are considered to be important:

- **DEM Generation**. As topography is one of the major factors in many types of hazard and risk analysis (e.g. for flooding, landslides, forest fires, volcanic eruptions etc), the generation of a digital representation of the surface elevation, called Digital Elevation Model (DEM), plays a major role. During the last 15 years there have been important changes both in terms of data availability, as well as in terms of software that can be used on normal desktop computers, without extensive skills in photogrammetry. Nowadays DEMs are available from various sources, such as:
    - Digitizing of conventional topomaps or photogrammetrical methods using aerial photos;
    - Nearly the entire world is now covered by a DEM with a spatial resolution of 30 meters (although outside US distributed at 90 meters) from the NASA Shuttle Radar Topography Mission (SRTM);
    - ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) which is one of 5 instruments on the Terra platform, launched in 1999, and which offers stereoscopic imagery, at very low costs;
    - SAR interferometry (InSAR) is gaining increasing importance as a technique for rapid and accurate topographic data collection. A number of spaceborne InSAR systems are operational, (ERS, ENVISAT, RADARSAT) or in the planning and implementation stages;
    - LiDAR is an acronym standing for Light Detection and Ranging, and is an airborne method using a pulse laser to measure the distance between the sensor and the surface of the Earth. Normally LiDAR point measurements will render so-called Digital Surface Models (DSM), which contains information on all objects of the Earth's surface, including buildings, trees etc. Through sophisticated algorithms, and final manual editing, the landscape elements are removed and a Digital Terrain Model is generated. The difference between a DSM and the Digital Terrain Model (DTM) can also provide very useful information, e.g on elements at risk (buildings etc.) or the forest canopy height.

- **Higher spatial resolution**. In the last decades the use of satellite data has become a normal input into hazard and risk assessment projects. Now there is a potential value for the application of multispectral and panchromatic data with up to 1-meter spatial resolution. LANDSAT data has remained quite popular and also higher resolution imagery, such as SPOT and IRS-1C has been used for change detection and hazard mapping. Nowadays the emphasis is on the use of very high-resolution imagery, such as IKONOS or Quickbird;

- **Higher spectral resolution**. Hyperspectral remote sensing, or imaging spectroscopy, consists of acquiring images in many (>100) narrow, contiguous spectral bands, from which a continuous spectrum is obtained for each pixel, instead of only broad information in a few wide spectral bands. Hyperspectral images enable detailed spectral identification of minerals, rocks, soils and vegetation types at the surface. Spectra from airborne systems such as the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) and Hyperspectral Mapper (HyMap) have been used to successfully map soiltypes and swelling clays. Airborne hyperspectral data are available for limited parts of the world. Spaceborne imaging spectrometers are available, such as the ASTER and MODIS on board the NASA's Terra, and the MERIS on ESA's ENVISAT. The spatial resolution of these is still rather general, with the exception of ASTER.

- **Mobile GIS**. Several methods for digital field data collection have been developed, such as MapLT, PocketGIS, and the ArcPad software from ESRI, which is the most convenient one when working with ArcGIS. The input application can be made on a desktop PC and loaded into a palmtop. The software works with vector data (shape files) and raster data (JPEG, MrSID). The software runs on laptops, tablet pen computers, palm top computers which operate in a Windows CE environment and personal data assistants (PDA) operating in Palm OS. The system is integrated with a GPS system. Elements at risk inventories can be carried out at various levels of detail, depending on the requirement of the study. In urban and rural areas the detail of inventory will also differ. Normally such an inventory is time consuming and expensive. Furthermore, such an inventory is not only made for risk analysis, but can be used in more development planning processes and can also be related to cadastral information systems (Montoya, 2002).

1.4 Risk assessment

As can be observed in table 1, the analysis of risk forms the basis for many of the other phases of disaster management. Risk is defined as the "expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular damaging phenomena for a given area and reference period" (Varnes, 1984). When dealing with physical losses, (specific) risk can be quantified as the product of vulnerability, cost or amount of the elements at risk and the probability of occurrence of the event with a given magnitude/intensity. When we look at the total risk, the hazard is multiplied with the expected losses for all different types of elements at risk (= vulnerability * amount), and this is done for all hazard types. Schematically, this can be represented by the following formula:

$$\textbf{Risk} = \Sigma\, (H * \Sigma(V * A))$$

Where:
H = Hazard expressed as probability of occurrence within a reference period (e.g., year)
V = Physical vulnerability of a particular type of element at risk (from 0 to 1)
A = Amount or cost of the particular elements at risk (e.g., number of buildings, cost of buildings, number of people, etc.). Theoretically, the formula would result in a so-called risk curve, containing the relation between all events with different probabilities, and the corresponding losses, which forms the basis for the phases of risk reduction, risk transfer and preparedness planning.

In order to obtain quantitative risk maps the first essential requirement is to carry out a quantitative hazard assessment. Most hazard maps still are of a qualitative nature and do not express the probability of occurrence of potentially damaging phenomena with a certain magnitude within a given period of time. In many developing countries qualitative hazard mapping is the only possibility, due to the scarcity of input data for quantitative analysis, or the absence of historical records (e.g. rainfall, discharges, earthquake catalogs). There is an important role for data collection using remote sensing and the design of databases for hazard assessment, as well as the use of various types of modeling techniques depending on the available data and the scale of analysis. Emphasis is now given to the development of quantitative hazard maps, derived by earth-scientists, based on probabilistic or deterministic modeling.

Elements at risk refer to the population, buildings, civil engineering works, economic activities, public services, utilities and infrastructure, etc., that are at risk in a given area. Each of these elements at risk has its own characteristics, which can be spatial (related to the location in relation to the hazard), temporal (such as the population, which will differ in time at a certain location) and thematic characteristics (such as the material type of buildings, or the age distribution of the population).

The next step in the analysis of risk is the quantification of vulnerability, which is achieved by making an inventory of the elements at risk and an assessment of the degree of damage that may result from the occurrence of a potentially damaging phenomenon. Emphasis is given to techniques for rapid inventory of elements at risk in densely populated areas (urban and rural), using high-resolution images, and the generation of elements at risk databases, which should be designed for multi-purposes, on the basis of cadastral databases. One other aspect is the modeling of vulnerability, using vulnerability curves in a GIS.

1.5 Loss estimation models

Risk analysis, assessment and management require a large amount of information. Relatively large volumes of multi-disciplinary and technical information have to be collected, processed, analyzed, and eventually communicated to a broad range of users under quite different conditions, ranging from planning and regulatory activities to emergency management. Modern information technology provides some of the tools to support these activities, leading to the development of risk information systems that can be used for both analyzing risk and evaluating the consequences of decisions that have to be taken to mitigate or reduce risk at both short term (emergency planning) and long term (development planning).

The spatial information of hazard and vulnerability is used in a GIS-based model for quantitative risk analysis, including the losses due to different hazards with different return periods and magnitudes. Methodologies for data handling and quantification of risks have been developed mainly in the United States over the last two decades. Within the reported methods, a basic subdivision can be made between the commercial and non-commercial ones.

Commercial catastrophe modeling techniques have been developed for earthquakes, floods, tropical cyclones, windstorms, and subsidence. They have been developed by dedicated companies or by the (re-)insurance companies, such as MRQuake, MRStorm and MRFlood (MunichRe), RiskLink (RSM), EQEHAZARD (EQECAT), CATMAP or CLASIC (AIR), CATEX (CATEX), EPEDAT(Early Post-Earthquake Damage Assessment Tool, ImageCat) and REDARS (Risks from Earthquake Damage to Roadway Systems) etc. Although most of these models have been developed in the United States, they are applied worldwide, depending on data availability. The models as well as the data are not freely available.

Non-commercial loss estimation models are those for which the software is freely available, and for which the manuals can be downloaded from the Internet. In Canada, the Natural Hazards Electronic Map and Assessment Tools Information System (NHEMATIS) has been developed by Emergency Preparedness Canada. The primary purpose of NHEMATIS is to "provide emergency planners with a tool that supports the definition and execution of elaborate models which will assist in predicting/estimating the potential impact of a natural hazard/disaster in a defined area of interest." (Source: Brun et al., 1997.) A example of a freely available method for loss estimation for building damage to Hurricanes is presented by OAS (Source: OAS, 1996)

The major achievement in loss estimation software, which is publicly available, is the HAZUS software, an interactive software released by the Federal Emergency Management Agency (FEMA, 2004) and National Institute for Building Sciences (NIBS) since 1997. Where the first version of HAZUS was only dealing with earthquake loss estimation, the recent HAZUS-MH is a multi-hazard loss estimation system, dealing with earthquakes (ground shaking, and earthquake induced hazards such as liquefaction, landslides, fires, floods, debris etc.) windstorms (hurricanes) and floods (coastal and riverine flooding). HAZUS-MH is made for ARCGIS and full datasets on the level of census tract can be obtained for the entire United States. Due to the complexity and large quantity of the input data, it has proven to be rather difficult to apply the HAZUS methodology in other parts of the world, where less accurate data is available. They have to be adapted for use at different levels of details, and different applications (e.g. nation-wide, provincial or municipal scale). At the municipal scale, whereas large cities often are able to attract the resources and capacity to set-up such a risk management information system, medium-size cities most often lack these possibilities.

2. The SLARIM project

2.1 Objectives of the SLARIM project

In 2002 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 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.

Risk management is a typically multi-disciplinary endeavor, requiring many types of data with spatial and temporal attributes that should be made available to local authorities in the right format for decision-making. For ITC, in order to acquire the necessary expertise it is crucial that experts from different disciplines work closely together, and in combination with relevant partners. The ultimate objective of this project is to improve the safety of communities, and consequently make them more sustainable and prosperous.

2.2 Case study cities

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. The following cities have been selected (See figure 1):

- **Naga city, Philippines**

The city of Naga is a medium sized city on the island of Luzon in the Philippines. It is located in an area that is frequently hit by typhoons that cause severe inundations of the city and the surrounding agricultural lands. Several types of floods affect the area, sometimes in combination: a) riverine floods from the Bicol, the main river in the area, b) flash-floods from the torrent Naga, and c) storm surges from the sea. In close collaboration with the municipality of Naga, a research program was initiated to investigate to what extend hydrodynamic modeling can be used as an instrument to assess the flood hazard situation in terms of inundation probability and to make a risk assessment based on the flood hazard and the elements at risk. Naga city is expanding very fast and the same trend will continue in the future since Naga is the centre for commercial, educational and industrial sectors in the Bicol region. The annual estimated growth rate of household population within the city limits for next ten years is over 1.6% and current estimated population is over 144,000.

- **Lalitpur Sub-Metropolitan City, Nepal**

The Lalitpur Sub-Metropolitan City is located in the Kathmandu valley, on the Southern side of 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. 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. Lalitpur, like its neighbouring cities of Kathmandu and Bhaktapur in the Kathmandu valley, are threatened by earthquakes. The last major earthquake took place in 1934, and less damaging earthquakes were reported in 1960 and 1988.

- **Dehradun, India.**

Dehradun is located in the eastern part of Doon valley, at the foot of the Himalayas, in the northern state of Uttaranchal, in India. Dehradun has a total population of about 600,000 living in 45 wards. Due to its pleasant location at the foot of the Himalayas, the city is well known for its many school and colleges and the headquarters of many National Institutes and Organizations. The city has recently become the capital of the state of Uttaranchal and is experiencing a rapid increase in population. Dehradun is located near the main active thrustzones in the Himalayas, such as the Main Boundary Thrust (MBT) and Main Central Thrust (MCT). The city is located within one of the highest seismic hazard zones of the country, but has not experienced a major earthquake in recent times. The last two earthquakes that caused serious damage on the countryside, namely the Uttarkashi (1991) and Chamoli (1999) earthquakes, did not cause major damage in the city.

Figure 1: Location of case study cities for the SLARIM project.

The plan is to extend the number of case study cities, depending on research partners and countries of origin of MSc and PhD researchers.

2.3 Structure of the research project

The SLARIM research project is consisting of a number of components, which are divided along a number of work packages. The following components can be distinguished:

- **Users need assessment and organizational setting**, which investigates the requirements of local authorities with respect to information and decisions regarding natural disasters. The research will develop a methodology for the evolutionary design of a spatial decision support system for risk management that is based on a continuous monitoring of actor needs, organizational learning processes, and subsequent performance at risk management.
- **Flood hazard and risk assessment** research that focuses on the development of the science, models and techniques to develop a quantitative approach to the analysis and assessment of flood risk. It evaluates the applicability of various hydrological and hydraulic models in developing countries with limited amount of data. The research also intends to compare the result of the modeling approach with participatory mapping using a community-based vulnerability and capacity assessment approach. The research also deals with the comparison of vulnerability curves for different elements at risk and different countries.

- **Earthquake Hazard and risk assessment** research, which focuses on the development of the science, models and techniques to analyze and assess the risks posed by earthquakes, in developing countries that have limited amounts of data. Existing approaches such as RADIUS or HAZUS are evaluated and adapted to the local conditions regarding data availability and types of elements at risk.
- **Landslide hazard and risk assessment**, which evaluates the types of GIS-based models for landslide susceptibility and hazard assessment can be used at different scales, and depending on the available input data. The research also concentrates on defining practical methods for landslide vulnerability assessment, and the combination of hazard and vulnerability into landslide risk maps, both using qualitative as well as quantitative methods.
- **Volcanic hazard and risk assessment**, which evaluates the various approaches for modeling different volcanic processes, such as lava flows, pyroclastic flows, lahars, ashfall etc. both using conventional methods as well as using GIS-based models. Another important element is the quantification of vulnerability of elements at risk in volcanic hazard zones.
- **Elements at risk mapping** focuses on the use of remote sensing data for the generation of elements at risk maps and the characterization of the elements at risk using mobile GIS. High-resolution images play an important role in the generation of building footprint maps, in combination with LiDAR data if available. One other aspect of this component is to define the most appropriate basic unit for risk assessment (e.g. individual building, homogeneous unit, census tract, ward etc.) and techniques for sampling.
- **Geographic information systems and data bases**, which focuses on the development of techniques and decision support tools using GIS to integrate, manipulate and display a wide range of risk-related information.
- **Use of Earth Observation data for disaster management**, which focuses on the use of remote sensing for base data collection for hazard and risk assessment, and damage assessment.

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. Example: Earthquake loss estimation in Lalitpur, Nepal.

3.1 Introduction

Lalitpur is located on a relatively flat area, which used to be a former lake in the middle Himalayan mountain range, of which the surface materials are mainly consisting of alluvial terrace deposits, belonging to the Chapagaon Formation of mainly Holocene Age (Fujii et al., 2001). The terrace deposits are on top of a thick sequence of lake sediments, belonging to the Kalimati Formation, with an average thickness of 200 meters and a maximum thickness of about 400 meters.

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). Several areas in Lalitpur have also experienced liquefaction phenomena during the 1934 earthquake (UNDP, 1994).

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 (UNDP). In this project a regional scale seismic hazard map for Nepal was produced, and a National Building Code was established (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). The aims of this project were to develop capacities and create awareness in earthquake vulnerability reduction 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 KVERMP was based on a simple loss estimation, which assumed that if the same earthquake as in 1934 would occur today, the losses would be catastrophic. A more detailed study on earthquake loss estimation was made recently by experts of 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.

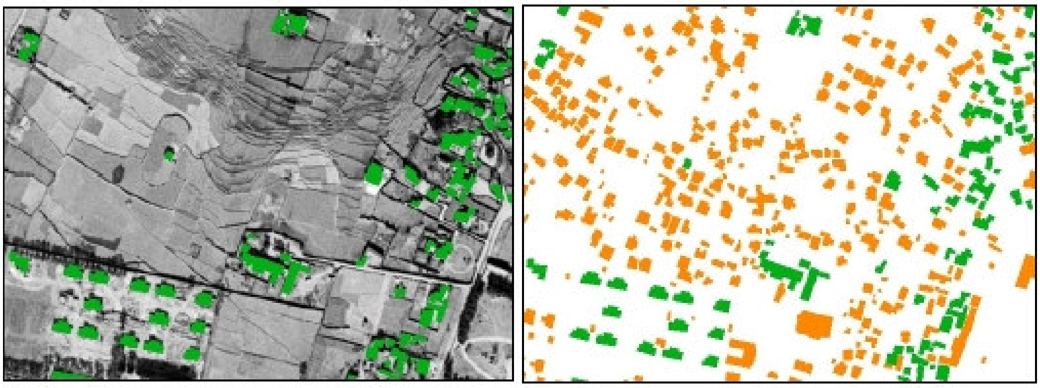
In all of the previous studies, the basis of the loss estimation has always been at a rather general level. The spatial distribution of the earthquake losses is a very important basis for a proper earthquake vulnerability reduction and emergency planning at municipal level. Municipalities would need 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.

3.2 Generation of base 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. In the neighbouring municipality of Kathmandu, the situation was quite different. The Information Department of Kathmandu Metropolitan Office was managing a large database, which was generated in the framework of a European project. This database contained 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. These topomaps were in AutoCad format and also covered the urban area of Lalitpur. With some difficulties this data set was converted into a usable GIS database, consisting of separate layers for buildings, roads, contours and drainage. 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. An example of the various building footprint maps for a part of the city is shown in figure 2.

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. In order to be able to analyze the vulnerability of buildings, transportation networks and population, information should be available on the important characteristics in relation to seismic vulnerability. 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. Homogeneous units are groups of buildings with more or less similar characteristics that can be delineated from high-resolution satellite imagery, and that can be described in the field. The boundaries of the units were mostly taken along streets and roads. Before going in the field, the homogeneous unit map was made based on image interpretation, and the map was combined with the building footprint map in order to calculate the percentage built-up area and the number of buildings per unit (see figure 3). In the field mobile GIS was used to characterize the buildings within each unit according to age (based on procedure outline earlier), occupancy class, landuse type and building type, which was a combination of construction material and number of floors.



Buildings in 1967

Buildings in 1998

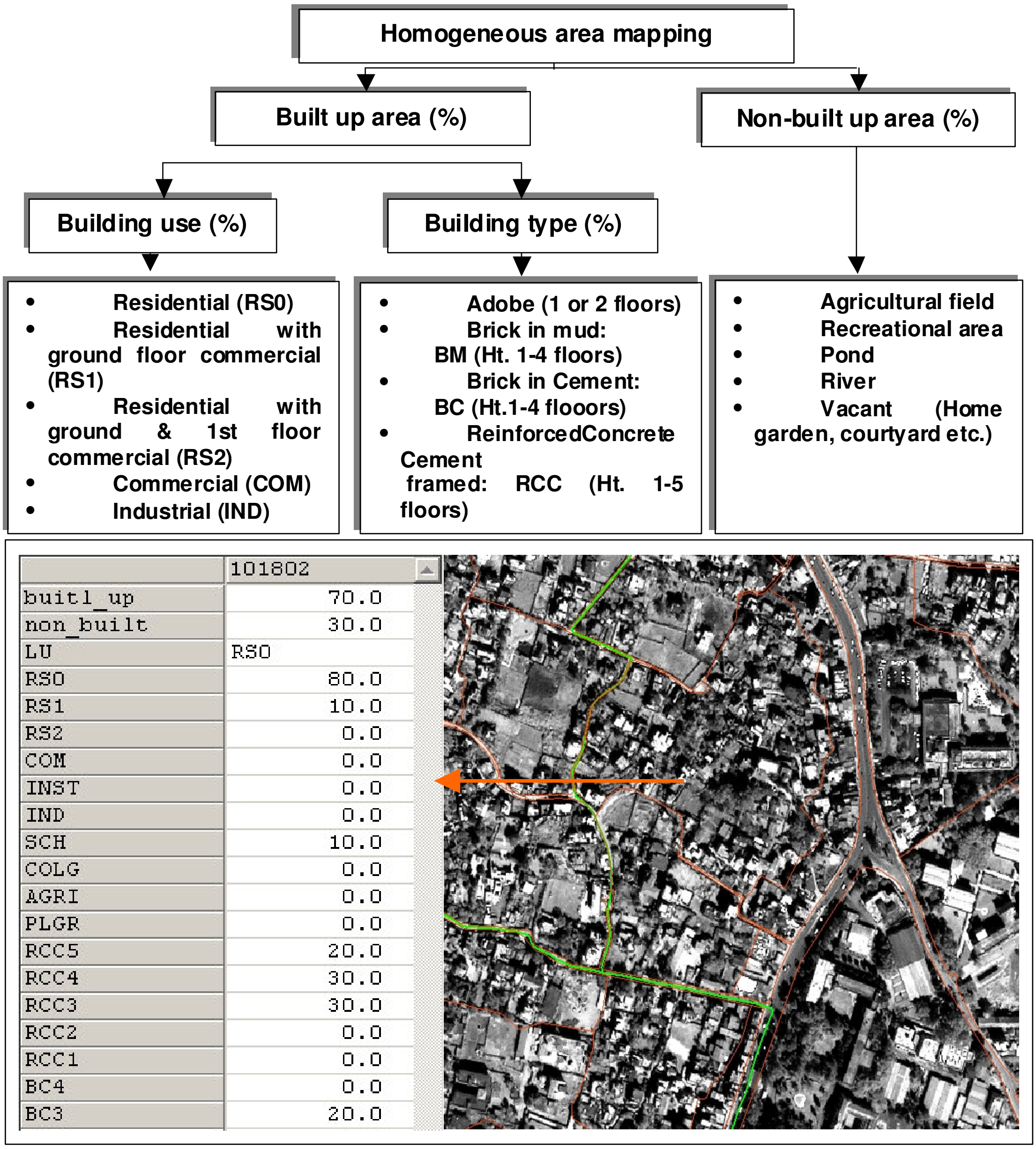
Additional buildings (1998-2001)

Total buildings in 2001

Figure 2: Illustration of the use of multi-temporal imagery for the generation of building footprint maps for different periods for a part of the city of Lalitpur.

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 floorspace in residential buildings within each homogeneous unit as percentage of the total floorspace of residential buildings in the ward. Floorspace of residential buildings per homogeneous unit was calculated by multiplying the number of floors of residential buildings with the footprint area. 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.

Infrastructure data was collected from various institutions and by mapping the road network in Lalitpur, using Mobile GIS and a set of characteristics describing factors used in determining the vulnerability of the roads during an earthquake, such as width of the road, traffic intensity, type of road surface, and distance to buildings.



	101802
buitl_up	70.0
non_built	30.0
LU	RS0
RS0	80.0
RS1	10.0
RS2	0.0
COM	0.0
INST	0.0
IND	0.0
SCH	10.0
COLG	0.0
AGRI	0.0
PLGR	0.0
RCC5	20.0
RCC4	30.0
RCC3	30.0
RCC2	0.0
RCC1	0.0
BC4	0.0
BC3	20.0

Figure 3: Above: Schematic overview of homogeneous unit mapping approach. Below: example of the resulting database.

3.3 Seismic amplification and liquefaction potential

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 (see figure 4) 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 such as grain size distribution, Atterberg limits, N-values, moisture content, specific gravity, density, unit weight, angle of friction, direct shear and soil type (USCS).

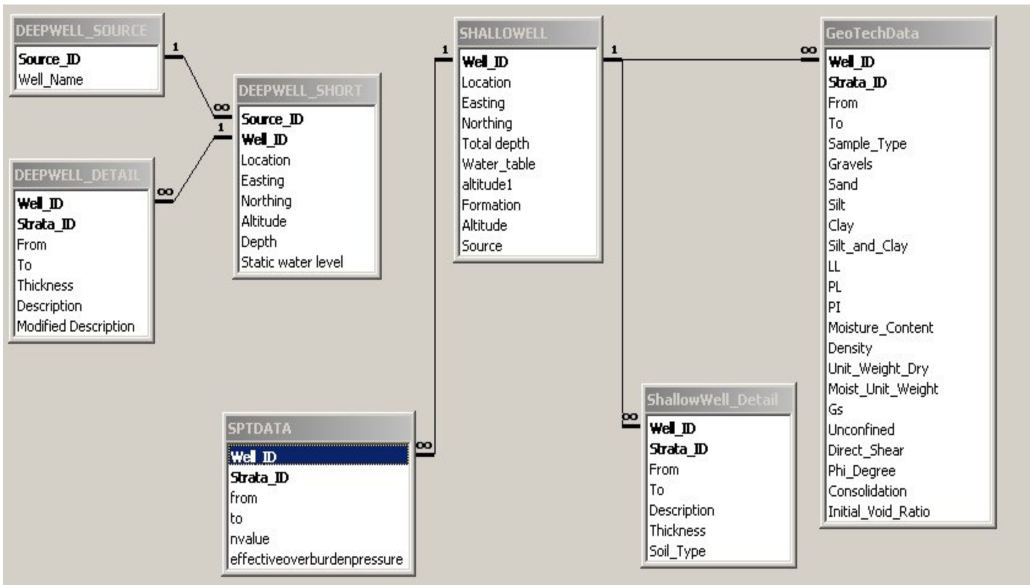
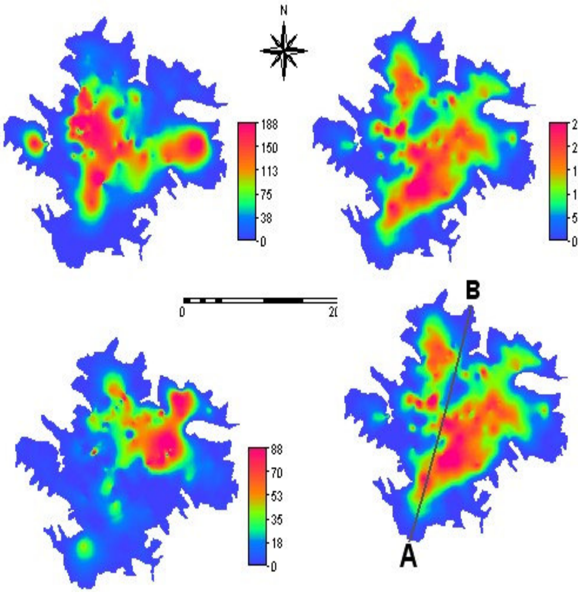


Figure 4: Structure of the geological database for Kathmandu valley.

The geological data were used in the geological software Rockworks in order to generate lithological cross sections and fence diagrams. Based on these 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, the entire sediments of the basin are 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. 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 was obtained through point interpolation. The results are shown in figure 5.



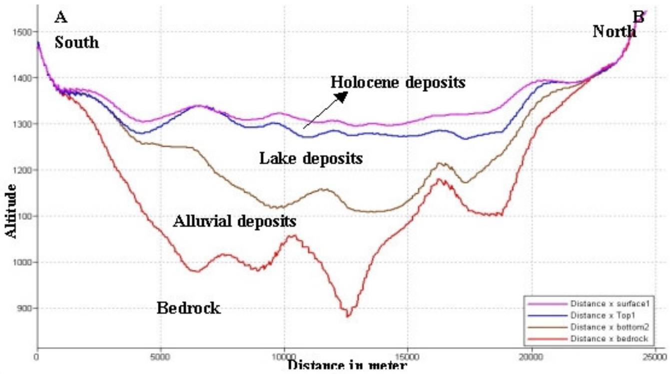


Figure 5: Left: Thickness maps of the three main material types in the Kathmandu valley. Right: Cross section based on the layer thickness maps.

The layer-modeling concept is used in this study in order to separate between the lake deposits and the non-lake deposits so that the thickness of the different layers of the sediments could be determined and hence could be applied for the estimation of ground amplification during an earthquake

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 soilprofile, 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 overview of the method is shown in figure 6.

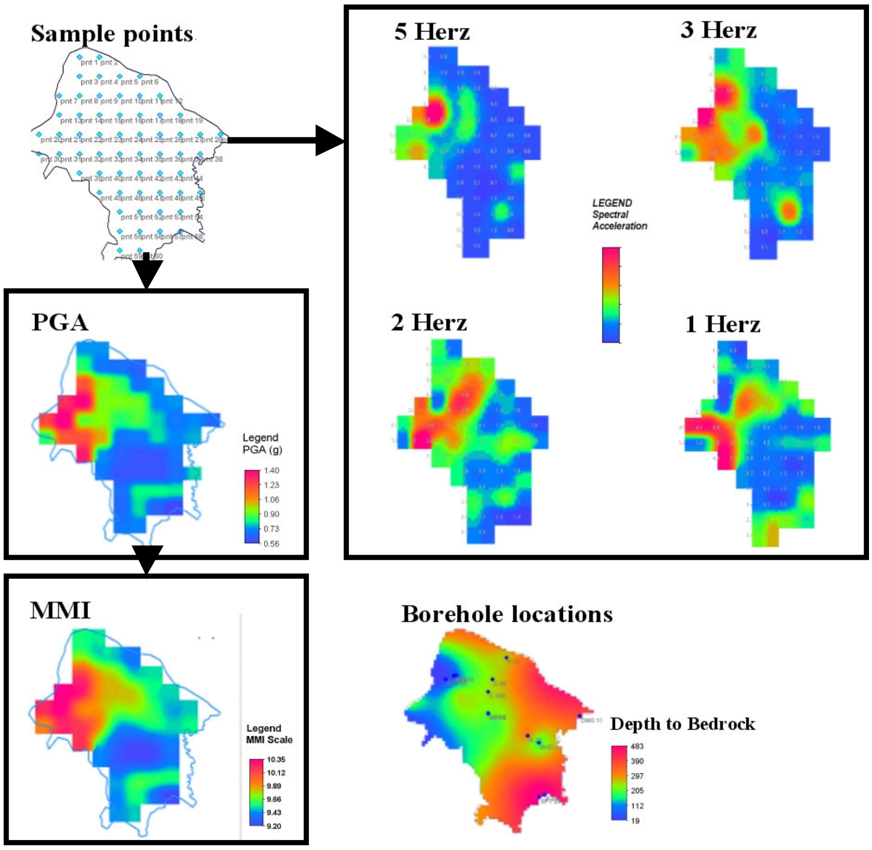


Figure 6: Schematic representation of the two methods used for soil response analysis. One resulting in PGA and MMI maps, and one resulting in spectral acceleration maps.

An analysis of liquefaction potential was made using both qualitative and quantitative methods. In the qualitative analysis the method of Iwasaki et. al (1982) and Juang, and Elton method (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. For the Seed and Idriss method (1971) the calculation was made for an earthquake of Ms = 7.5, and PGA value of 0.1g. 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 Building loss estimation

For analyzing seismic vulnerability, the buildings in Kathmandu valley have been divided into a number of classes indicated in figure 3 and table 2. The vulnerability curves used in the GIS analysis were derived by NSET-Nepal and JICA considering the fragility curves prepared during an earlier building code project with some modification which again was based on the damage pattern observed in the 1988 earthquake in Nepal. 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 unrepairable) or partly damaged (repairable, and available for temporary evacuation). See table 2.

Table 2: Damage matrixes for different types of buildings in Kathmandu (The values represent percentage of buildings with the same material type. Source: NSET Nepal)

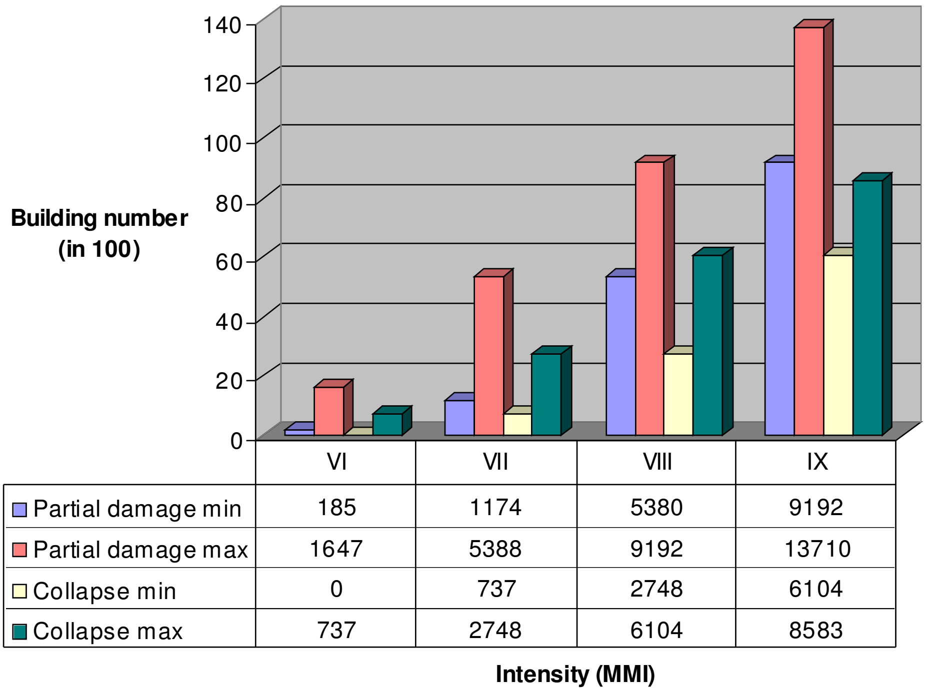
Building type	**MMI**	**VI**	**VII**	**VIII**	**IX**
	PGA (% g)	**5-10**	**10-20**	**20-35**	**>35**
Adobe+Fieldstone Masonry Buildings	Total Collapse	2-10	10-35	35-55	55-72
	Partial Damage	5-15	15-35	30	30
Brick in Mud (BM)	Total Collapse	0-6	6-21	21-41	>41
	Partial Damage	3-8	8-25	25-28	<28
Brick in 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

The following four types of columns for each type of the intensity (from VI to IX) were created in GIS in order to calculate the number of vulnerable buildings in the homogeneous unit.

- Partial damage min (Minimum probable number of buildings having partial damage)
- Partial damage max (Maximum probable number of buildings having partial damage)
- Collapse min (Minimum probable number of buildings having total damage)
- Collapse max (maximum probable number of buildings having total damage)

In figure 7 the results of the building vulnerability analysis in Lalitpur area are given. This table 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 occurred in the entire Lalitpur Sub-Metropolitan area, a number of buildings ranging from 9,192 to 13,710 will get partially damaged and 6,104 to 8,583 will collapse and in total, 15,296 to 22,293 buildings will be partially or completely damaged.

In a next step specific damage estimations were made for three earthquake scenarios that have been defined in an earlier study (JICA, 2002), namely a large earthquake comparable to the 1934 event (Mid Nepal Earthquake), a moderate earthquake occurring north of Kathmandu (North Bagmati Earthquake) and a local earthquake caused by an active fault within the valley itself. 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.



	VI	VII	VIII	IX
🟦 Partial damage min	185	1174	5380	9192
🟥 Partial damage max	1647	5388	9192	13710
🟨 Collapse min	0	737	2748	6104
🟩 Collapse max	737	2748	6104	8583

Figure 7: Total number of damaged buildings in different damage grades in four earthquake intensities.

3.5 Population loss estimation

The number of human 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. In this study, the term casualty refers to human injury, from slight injury to highest fatality, which is instant death. The four stages of severity for casualty, which are defined by HAZUS, were also adopted here. The relation between building damage state and injury levels is given in table 3.

Table 3: Various injury levels according to building damage. Modified from HAZUS.

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

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 8 and Figure 9 for the Mid Nepal Earthquake scenario. From figure 8 it can be observed that the differences between daytime and nighttime scenarios were smaller than expected. 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. 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.

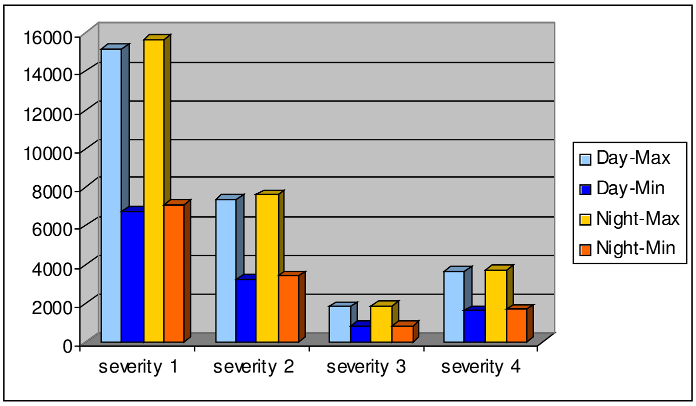


Figure 8: Casualty estimation for the Mid Nepal Earthquake scenario in Lalitpur.

4. Conclusions

The example from Lalitpur Sub-Metropolitan City in Nepal illustrates the direction of the SLARIM research project, in supporting local authorities with methods to collect and manage information used for risk estimation, analysis, assessment and finally management. 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 presentation 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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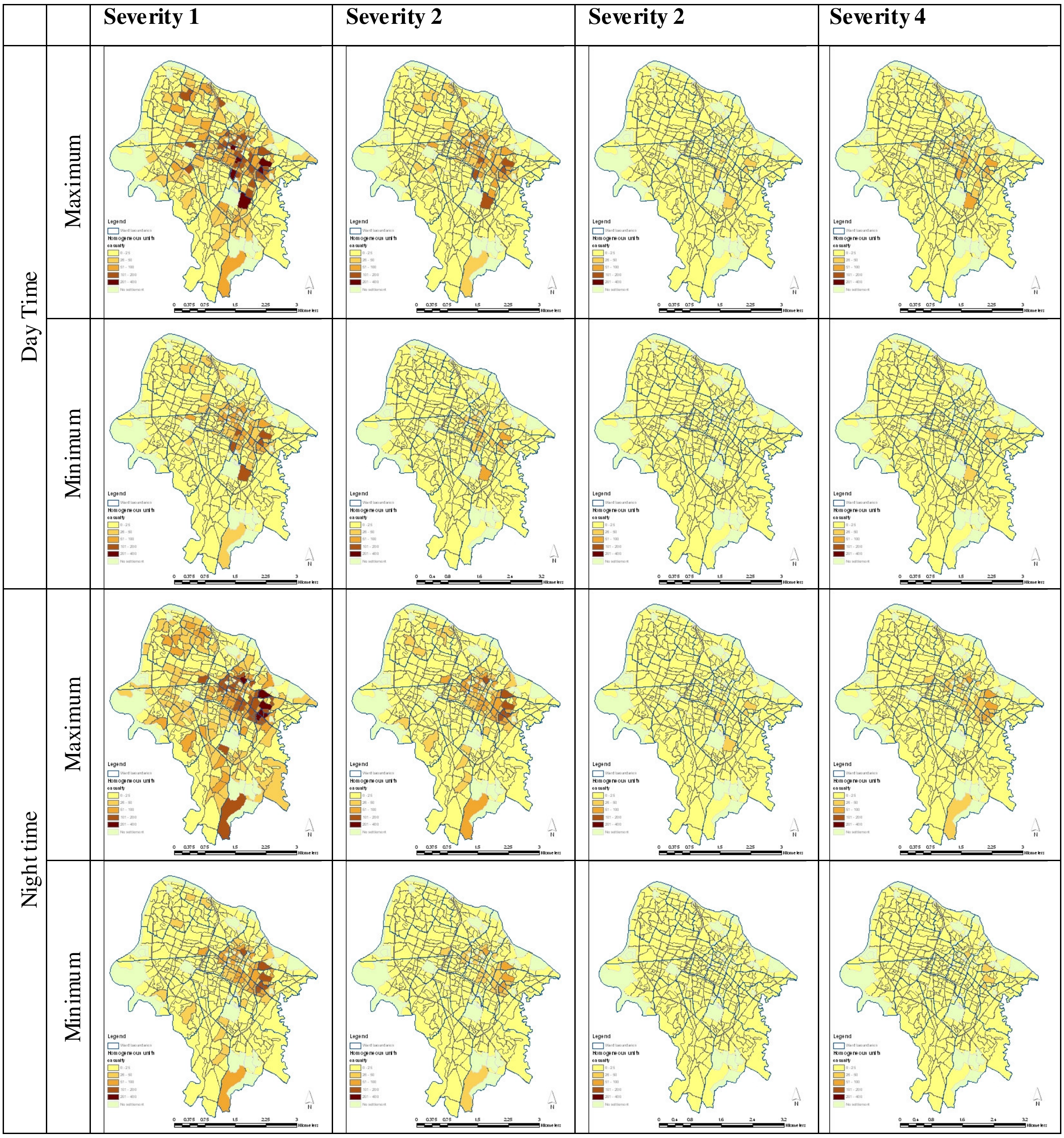

Figure 9: Various casualty levels for the Mid Nepal earthquake scenario.

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