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The use of Geoinformation for multi-hazard risk assessment in urban areas.

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ABSTRACT:

1 INTRODUCTION

There is more and more evidence that our climate is changing, leading to more floods, more droughts, sea level rise, more extreme weather events and tens of millions of people directly affected (Munich Re., 2000). Almost daily, we are confronted in the media with tragic consequences of the negligence of urban risk management, resulting in disasters that might have been prevented, especially in developing countries, where levels of risks are higher due to higher levels of vulnerability.

The larger risk in cities in developing countries is due to a number of factors, such as increased vulnerability of low level neighborhoods, both in terms of its buildings and its inhabitants, lack of resources for proper planning, lack of spatial information in order to make the right decisions. Even if such spatial information is available, it may be dispersed through different local authorities, without an operational procedure for sharing this information.

In order to be able to effectively take measures on risk reduction local authorities must be supplied with reliable, up-to-date, and interpreted information on the nature and geographical distribution of hazard and risk, and the possible risk scenarios. Risk assessment is considered as the central and most important aspect within disaster management. Risk is defined as “the expected number of lives lost, people injured or economic losses due to potentially damaging phenomena within a given period of time” (WMO, 1999). It is based on three components: probability (of the hazardous events and their magnitude), vulnerability of the elements at risk (expected degree of loss) and the replacement value of the elements at risk. Risk information, when presented spatially and for all threats, is needed by national and local authorities to take decisions on how to reduce the risk for particular areas, either by reducing the hazard probability (e.g. structural measures like dikes) or by reducing the vulnerability (e.g. restrictive zoning, building codes). Risk information also forms the basis for a proper emergency response planning.

While natural disaster mitigation receives recognition as a major area of concern in the developed countries, it is yet to receive the same status in the developing world. Studies into land-use planning in all its perspectives, including natural disaster mitigation and risk information, have not yet been fully taken up by the academia in developing countries. The reason may well be the inadequate involvement of key players of urban planning offices to integrate risk based mitigation tools in the process of urban planning to reduce the impact of natural disasters.

2. EXAMPLES OF LOSS ESTIMATION METHODS

Methodologies for data handling and quantification of risks have for a large part still to be developed. For the largest part the expertise is available within specialized organizations (mostly within re-insurance companies which do not publish their methods due to commercial reasons: e.g. MRQuake, MRStorm and MRFlood from Munich Reinsurance (Munich Re., 2000).

On an international non-commercial level, only a limited number of methods exist. The secretariat of the International Decade for Natural Disaster Reduction (IDNDR 1990-2000), United Nations, Geneva, launched the RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters) initiative in 1996. It aimed to promote worldwide activities for reduction of seismic disasters in urban areas, particularly in developing countries, by carrying out studies in 9 case-study cities. Based on the experiences of these case studies, practical tools for earthquake damage estimation projects were developed. A comparative study to understand urban seismic risk in the world was also conducted. More than 70 cities participated in the study to exchange information (Radius, 2001).

Whereas the RADIUS methodology is still very general, a much more elaborated methodology has been developed in the United States, called HAZUS. HAZUS is a nationally applicable standardized methodology implemented through PC-based Geographic Information Systems for estimating potential losses from earthquakes, floods, and wind. HAZUS is being developed by the Federal Emergency Management Agency (FEMA) under a Cooperative Agreement with the National Institute of Building Sciences (NIBS). HAZUS now has the capability to estimate earthquake losses, and flood and wind models are under development (HAZUS, 2001). HAZUS is a very advanced methodology, which requires large amounts of data, and is not very feasible to implement in most cities in developing countries within a reasonable time frame.

In Australia, the Cities Project is a program of applied research and technique development designed to analyze and assess the risks posed by a range of geohazards to urban communities (AGSO, 2001).

However, in most developing countries, there is a generally a lack of data to carry out such types of loss estimation studies. There is a need for methods that provide reliable estimates without extreme data requirements.

3. RESEARCH PROJECT: STRENGTHENING LOCAL AUTHORITIES IN RISK MANAGAMENT.

In order to develop a method for the use of geoinformation for urban risk assessment and management, the International Institute for Geo-information Science and Earth Observation (ITC) has recently started a research project entitled SLARIM (Strengthening local authorities in risk management).

The International Institute for Geo-information Science and Earth Observation is an autonomous organization which primarily aims at international education, flanked by research and project services. Its activities relate to international knowledge exchange, focusing on capacity building and institutional development in countries that are economically and technologically less advanced. ITC's activities concentrate on "Geo-information Science and Earth Observation" whereby geo-spatial data collection is predominantly based on aerospace survey techniques. Two distinct geo-spatial issues determine ITC's focus: data modelling (including information extraction from imagery) and production processes. ITC's training

programmes offer some 40 different specialisation courses, most at professional master, MSc and PhD levels. In 50 years, ITC has trained approximately 15,000 scientists and other professionals from more than 150 countries, thus creating a worldwide network of alumni. ITC has a research programme with six themes, of which one deals with disaster management.
The SLARIM research project, with a duration of three years, has the overall objective to development a methodology for the implementation of risk assessment and spatial decision support systems for risk management by local authorities in flood and earthquake threatened urban areas in developing countries. Currently, many medium-size in developing countries, lack an information infrastructure for disaster management. Disaster management is often only present as a culture of disaster response, whereas the phases of disaster prevention and preparedness are mostly lacking.
Within the framework of disaster management, risk assessment forms the central component. Risk assessments are made so that strategies may be developed that will ultimately lead to the elimination, reduction, transfer or acceptance of the risks, and to ensure that the community is prepared to cope with a hazard impact.
A mature risk management culture will see the decisions made by the executive, administrative, public health, planning, environmental, engineering, fiscal, legal and emergency management elements, becoming more integrated, consistent and coordinated. Such an approach would also tend to widen the timeframe of local planning from the typical current two or four years period, restricted by electoral periods, to one 10, 20 or even 50 years. For a comprehensive risk management culture to flourish, it is necessary for it to be supported by a strong and effective information infrastructure. The decision support tools can be used to produce disaster-specific plans on which to base all aspects of the disaster management. They enable, for example, the development of disaster response and recovery plans for specific levels of risk, and use the scenarios on which they are based to run realistic exercises and training. Also in the recovery phase, GIS can be used to model the impact of a scenario event, and to forecast the requirements for short-term and long term shelter.
The project will follow a sequence of workpackages, dealing with analysis of the institutional setting, user needs assessment, evaluation of the spatial data infrastructure, hazard assessment, generation of databases of elements at risk, vulnerability assessment and risk assessment.
The main deliverable of this project will be a web-based training manual for the use of geoinformation in urban risk assessment and management. Apart from that the methodology will be developed in a number of case study cities, located in Latin America and Asia. We are currently in the process of selecting these case study cities by collecting city profiles and establishing contacts with local authorities.

4 FIRST TEST SITE RESULTS: TURRIALBA, COSTA RICA

The first of these case studies is the multi-hazard risk assessment of the city of Turrialba, located in the central part of Costa Rica. The city with a population of 33,000 people is located in an area, which is regularly affected by flooding, landslides and earthquakes. The city is also near the Turrialba volcano, which had its last eruption about 100 years ago (see figure 1)

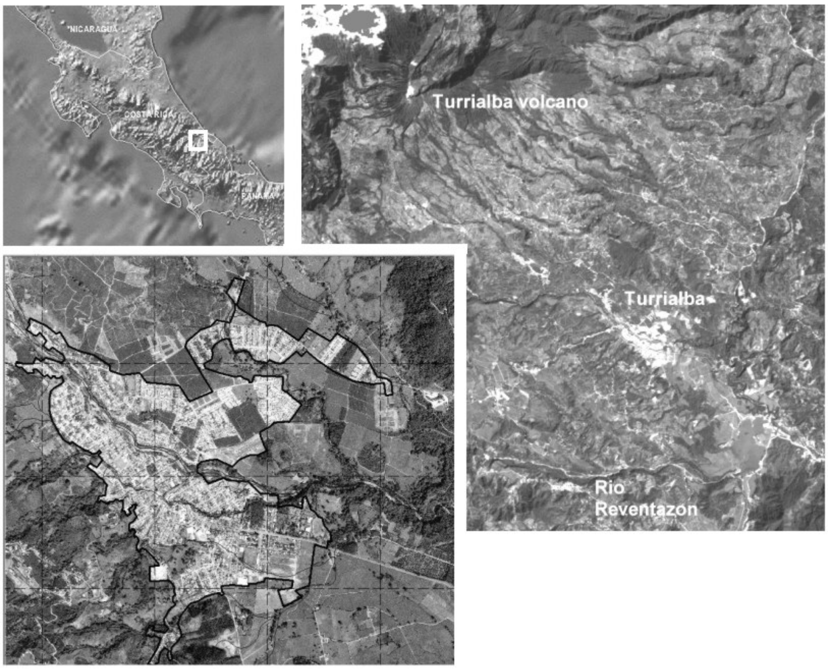

Figure 1: A: Location of the study area; B: Landsat TM image of the Turrialba region; C: Orthophoto of the city of Turrialba.

In Costa Rica, disaster management is the responsibility of the National Emergency Commission (CNE). The commission also has regional and local bodies, which act with its coordination and support. The Local Emergency Commission is responsible for disaster management at a municipal and cantonal level. In order to assist the local emergency commission and the municipality, a pilot study was carried out in the development of a GIS –based system for risk assessment and management.

The work was based on a series of color aerial photographs with a scale of 1:40,000, which were scanned with high resolution and combined with a Digital Elevation Model and a series of ground-control points for the generation of an orthophoto-map. On the orthophoto all buildings within the city and its direct surroundings were digitized, as well as the land parcels, the roads and other infrastructures. This resulted in a digital parcel map, consisting of 7800 polygons. Each polygon was described in the field by a team of investigators, making use of checklists for the collection of data on hazard and vulnerability (see figure 2).

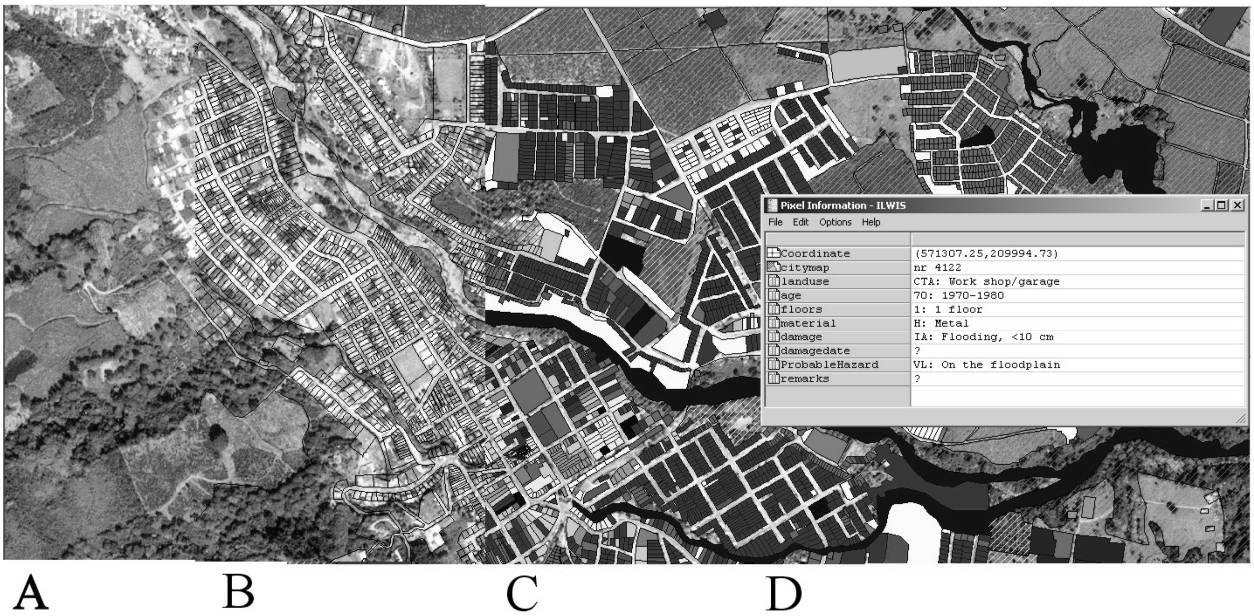

Figure 2: Different views of a portion of the large-scale database for the city of Turrialba. A: orthophoto, B: vector overlay of parcels, C: polygons displaying landuse type, D: reading information from the attribute database.

4.1 Historical analysis

Hydrologic studies have been carried out in the area with the use of HEC-1, (Rojas, 2000; Solis et al. 1993; Solis et al. 1994; Badilla Coto, 2002) and peak discharges for different return periods calculated for the main rivers in the study region. Unfortunately, no discharge data is available for the area in order to calibrate the results. The studies have also indicated a number of possible bottlenecks along the local streams (Gamboa and Colorado) and the main river (Turrialba). In this way it was established that the main Turrialba river has enough capacity for a 100-year return period discharge while the Gamboa stream and the Colorado river may overflow once every one or ten years respectively.

Historical flood data available dates back to 1737, (GarcÍa, 1990; Zuñiga and Arce, 1990; Aparicio, 1999, Cardona et al. 2000; Badilla Coto, 2002). The most important flood events reported in the city are from the following dates: September 1737, October 1891, December 1908, November 1923, November 1928, November 1933, November, 1936, December 1949, February 1966, December 1970, September 1983, December 1987, May 1990, August 1991, February 1996, and May 2002. The flood events of 1996 and 2002 were studied in detail. The event from 1996 was related to the flooding of the Colorado river, which overflowed in a number of critical points, covering most of the city center. The flood event from 2002 was related to the main Turrialba river, causing severe lateral erosion which destroyed most of the protective dikes along the city leaving the city center exposed to severe flood hazard from the main river. Also a series of houses and bridges were destroyed.

Since no discharge data was available the historical data has been used in combination with precipitation records in order to find out possible return periods. In this way it was established that the 1996 represents an event with a return period of 50 years. For this flood event a map was prepared based on the point information of flood depths reported during the field questionnaire survey.

4.2 Hazard assessment

In the study three types of hazards were analyzed: seismic, flooding and landslide hazard. A database of earthquakes records in digital format is available as part of the main seismic information. Historic and recent regional earthquake information has been processed (Climent et al 1994, Schmidt et al 1997, Laporte et al. 1994). The historic seismicity of Turrialba indicates that 9 seismic events within the range of 5.0-7.5 and depths of around 15 km have occurred within a 50 km distance to the area. Probabilistic methods were used in order to obtain the respective values of PGA (peak ground acceleration) of rocks for different return periods, based on the work by Laporte et al. (1994) and Climent (1997).

Soil amplification was estimated by means of a soil type map with a table with amplification values for each soil type for the return periods 25, 50, 100, and 200 years. Topographic amplification has been based on the location and distance from the scarps in the study area. Certain weights have been given to different distances from the scarps (Urban Lamadrid, 2002). These weights were multiplied with PGA maps with soil amplification for all the return periods resulting in new PGA maps with amplification for soils and topography. To convert the PGA values to the Modified Mercalli Intensity, the relation from Trifunac and Brady (1975), was applied. The analysis resulted in four MMI maps for return periods 25, 50,100 and 200 years.

Flood hazard maps were made related to two different phenomena: lateral erosion hazard and inundation depth. As indicated before flood depth maps were made using historical information from field questionnaires. The resulting point file was converted into a raster map in GIS using contour interpolation and point interpolation. The resulting flood depth maps, for return periods of 25, 50 and 75 years, were classified into a number of classes.

In order to determine the hazard for lateral erosion, distance was calculated from the river channel of the Turrialba and Colorado Rivers. The distance classes were converted to hazard zones, based on historical information, and areas which were likely to be affected by lateral erosion with return periods of 25, 50 and 75 years were indicated.

Also a hazard map was generated for a hypothetical maximum flood event, which might be related to an eruption of the nearby Turrialba volcano, caused by a very large lahar (volcanic debris flow) event that might hypothetically take place. Although information on return periods for such an event were not available (only the knowledge that approximately 15.000 years ago the entire area was devastated by a large debris avalanche) a hypothetical return period of 5000 years was assumed for such an event, which would lead to total destruction of all elements at risk in the area.

Landslide hazard was determined based on the historical landslide inventory and a number of factor maps, using a statistical approach (Cheyo, 2002) (see figure 3).

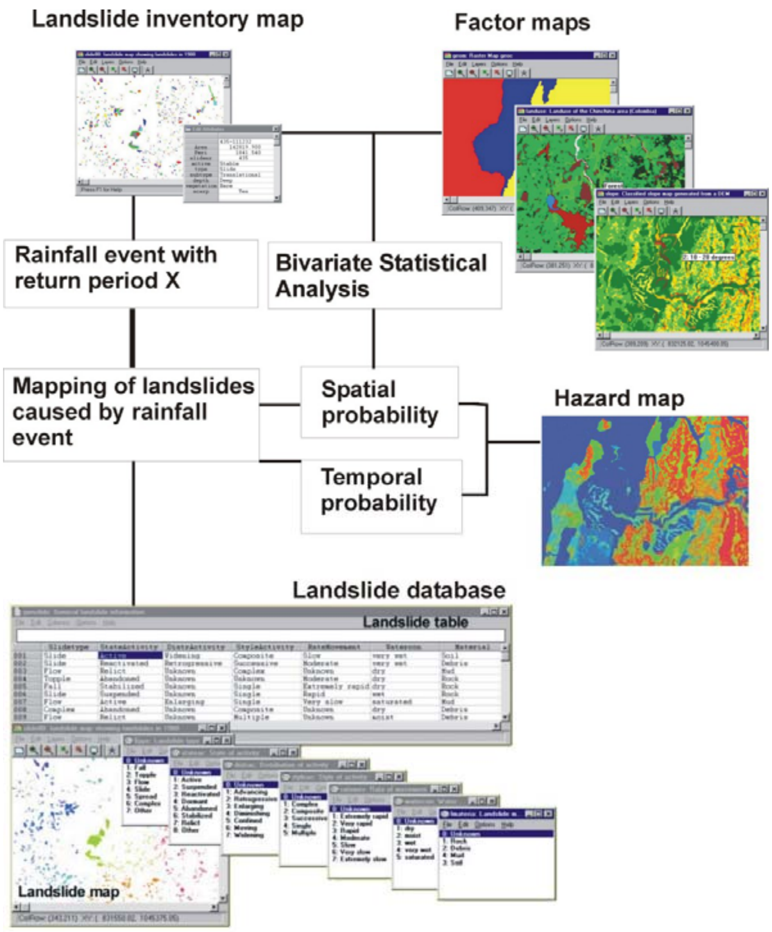

Figure 3: Combination of bivariate statistical analysis with rainfall threshold assessment allows to obtain both spatial as well as temporal probability.

4.3 Vulnerability assessment

In this study vulnerability assessment was only carried out for the buildings and the contents of buildings, and basically only looking at direct tangible losses. The basic method used was the application of damage-state curves, also called loss functions or vulnerability curves (Smith, 1994). The cadastral database of the city was used, in combination with the various hazard maps for different return periods to generate vulnerability maps for the city.

Damage due to flooding depends on several factors, such as water-depth, duration of flooding, flow velocity, sediment concentration and pollution. The study only focused on damage related to water-depth, and to velocity in the case of lateral erosion. Generally flooding time is not very important, since most events are related to flashfloods with limited duration. The method used in this study for flood vulnerability assessment can be considered as a GIS-based hybrid between the actual flood damage approach and the existing database approach. This is because the vulnerability assessment is based on a detailed database of elements at risk and on field data collection related to the 1996 flood reported damages. Depending on the building type and the number of floors a degree of loss (ranging from 0 to 1) was assigned to each category of elements at risk, in relation with the different floodwater depth classes used. Separate values were assigned for the expected losses related to the contents of buildings (refer to table 3). In the case of lateral erosion vulnerability was assumed to be 1 (complete destruction) both for the building as well as for the contents.

For the determination of seismic vulnerability, the MMI maps were used in combination with

vulnerability functions for different types of constructions adapted from Sauter and Shah (1978), who elaborated functions for Costa Rica as a whole. Vulnerability assessment of population for seismic events was made according to the Radius method, based on the building vulnerability and the type of building (residential, school, office etc.) assuming two different scenarios: during daytime and nighttime.
For the landslide vulnerability the size of the potential landslide area determined whether the vulnerability was 0, 0.5 or 1.
All vulnerability data was used in GIS to generate vulnerability maps for each type of hazard and return period.

4.4 Cost estimation
In order to determine the cost of the elements at risk, differentiation was made between the costs of the constructions and the costs of the contents of the buildings. The costs of the buildings were determined using information from real estate agents and architects in the area. A cost per square meter was entered in the attribute table linked to the cadastral map, and the cost per parcel was obtained by multiplication with the area of the parcel, and the number of floors. A correction factor was applied related to the percentage of the plot, which was actually built-up area, and also a depreciation factor was applied related to the age of the buildings.
An estimation of the cost of the contents of buildings was made based on a number of sample investigations for different building types and socioeconomic classes within the city.
Based on the cost information three raster maps were generated: one representing the building costs, one representing the construction costs, and one for the total costs.

4.5 Risk assessment
Risk means the expected degree of loss due to potentially damaging phenomena within a given time. In this case there are many different potentially damaging phenomena with different return periods. Therefore risk was determined by first calculating specific risk for each hazard type, through the generation of annual risk curves. Specific risk results from multiplying the annual probability factor, vulnerability and cost or indirectly multiplying annual probability with expected damage. Specific risk maps were generated for each type of hazard and each return period by multiplication of the potential damage maps and the annual exceedence probability. First damage maps were generated by multiplication between vulnerability maps and cost maps. For flood risk, damage maps were generated for three return periods (25, 50 and 75 years) from the various vulnerability maps multiplied by the cost map of the contents only, because it was assumed that the flooding will normally have little influence on the building itself. This is due to the fact that the floods have generally a small duration, and flood velocities are normally not very high. For the maximum flood damage map the vulnerability was considered to be 1 (total destruction). For the lateral erosion damage map also a vulnerability of 1 was assumed, since both buildings and their contents would be lost due to collapse in the event of undercutting. Specific risk maps for seismic hazard were made for the four return periods mentioned earlier (25, 50, 100 and 200 years), each using its own vulnerability map. Estimation of specific risk for landslides was one of the most difficult tasks, since both the probability, magnitude of the landslide, and therefore the vulnerability are very difficult to predict. Here an expert judgment was made and three vulnerability classes were used: 0, 0.5 and 1.
The resulting specific risk maps gave information on the total amount of damage expected annually due to a certain type of hazard with a certain return period. This damage was

aggregated for the entire city and plotted in a graph of probability versus potential damage, though which a curve was fitted. The area below the graph represents the total damage for the specific type of hazard. Out of these a total risk curve was derived for the combination of the various hazard types, which represents the annual expected losses to buildings and contents of buildings for the various types of natural hazards in the city of Turrialba. The estimation of annual losses for each hazard type and each return period represents a very important "standardization process" which allows to put hazards into perspective and prioritize accordingly. The data generated can also be used to display a total risk map.

4.6 Limitations

It is important to stress here that the work presented here was aiming primarily on the development of a methodology for GIS-based risk assessment in urban areas, with relatively little basic information available. In such cases the analysis relies heavily on historical information, and expert judgment, also regarding the relationship between magnitude and return period of the different events. Also, due to the limited time for field data collection, a number of assumptions and simplifications had to be made. In the flood hazard assessment, more emphasis should be placed on the other effects of flooding than the water depth only, such as duration of flooding, flow velocity and pollution. Also the evaluation of lateral erosion has to be based not only on the distance of the river channel, but also on the geomorphological situation and the meandering pattern of the river. In the case of seismic hazard assessment, more information should be obtained on the three dimensional configuration of the soil layers, and their geotechnical properties, and earthquake spectra should be used instead of single PGA values. In the vulnerability assessment, more emphasis should be paid to infrastructure, lifelines, critical facilities and population, and also indirect damage should be taken into account. Also more accurate cost information should be obtained, requiring the help of local economic experts and architects. As a whole the data collection could be significantly improved if was carried out over a longer time period by local experts.

Due to these limitations, the resulting risk values are only indicative, and should not be taken as absolute values for individual buildings. But they do serve to indicate the relative importance of each type of hazard, and the degree of impact it is likely to have.

5. SUSTAINABLE CAPACITY BUILDING ON URBAN DISASTER MITIGATION IN ASIA USING IT&C LEARNING TOOLS

As an addition to the SLARIM project a proposal has been written for the Asia IT&C programme of the European Commission. The project will take place with three partners from Thailand (Asian Disaster Preparedness Center, ADPC), The Netherlands (International Institute for Geoinformation Science and Earth Observation, ITC, and France (Institut Geographique Nacional, IGN). Within the project collaboration is planned with universities and training institutes in seven Asian countries, being India, Sri Lanka, the Philippines, Indonesia, Vietnam, Nepal, Thailand. These universities and training institutes are all partners in the existing Asian Urban Disaster Mitigation Program (AUDMP), coordinated by ADPC in Bangkok, Thailand.

The project aims to build capacity on modern disaster mitigation tools, as part of the existing Asian Urban Disaster Mitigation Program (AUDMP), targeted at reducing disaster vulnerability of urban regions in Asia. It will do so by providing support to the institutionalization of academic courses on disaster mitigation in existing urban planning curricula at university level, thus provide Asia with young urban planners knowledgeable of modern disaster mitigation tools. To support knowledge sharing cost-effectively, an Internet-based platform for E-learning will be developed. Target group exists of lecturers of urban planning departments of universities in the AUDMP network. The project period is 12 months, and is planned to start in April 2003.

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