



GIS for Urban Disaster Management

Facing the Unexpected

Urban areas are particularly vulnerable not only because of the concentration of population, but also due to the interplay that exists between people, buildings, and technological systems.

■ LORENA MONTOYA and IAN MASSER

Natural disasters are the impact of a natural hazard upon a vulnerable community resulting in disruption, damage and casualties that cannot be relieved by the unaided capacity of locally-mobilised resources (United Nations Disaster Relief Coordinator 1991). In addition to their direct social and economic impact, natural disasters affect employment, the balance of trade, and foreign indebtedness for years after their occurrence, and funds intended for development are often diverted into costly relief efforts (Organization of American States, 1990). Unfortunately, as pointed out by Mitchell (1999), until very recently, disaster management and long term development tended to be seen as distinct entities instead of inextricably linked and part of the same ongoing process.

It has been estimated that per capita losses of the GNP in developing countries are 20 times greater than in the developed countries (Clarke and Munasinghe, 1994). The greater losses to natural disasters in the developing world highlight differences in terms of the weakness of the economies, the perception of people towards natural disasters and inadequate disaster management.

By concentrating into small areas, the bigger interplay between the

different urban elements that exists creates higher damage indices compared with the same elements widely spread in a rural environment. For this reason, more than ever before, the issues of planning and disaster management are high on urban agendas.

Methodological Issues

Disaster management should consist of an organised effort to mitigate against, prepare for, respond to, and recover from a disaster (Federal Emergency Management Agency, National Emergency Training Center *et al.*, 1998). *Mitigation* is two-fold: it aims to prevent losses from occurring in undeveloped land (prevention) and to lower the expected losses in existing buildings and other structures (reduction). Examples of mitigation mechanisms include land-use regulations, engineering works, building codes, and insurance programs. *Preparedness* consists of planning how to respond in case an emergency or disaster occurs and working to increase resources available to respond effectively. Preparedness activities include contingency planning, resource management, mutual aid and cooperative agreements with other jurisdictions and response agencies, public information, and the training of response personnel. *Response* refers activities that occur

during and immediately following a disaster. It is designed to provide emergency assistance to victims of the event and reduce the likelihood of secondary damage. Response activities include search and rescue, evacuation, emergency medical services, fire-fighting as well as reduction of the likelihood of secondary damage such as to the contents of damaged buildings. Recovery constitutes the final phase of the disaster management cycle and it continues until all systems return to normal or near normal. Recovery activities include temporary housing, restoration of basic services (i.e. water, electricity), food and clothing, debris clearance, psychological counselling, job assistance, and loans to restart small businesses.

To some extent, the task of scientists, geo-information technicians and urban planners relates to the gathering of data, its processing and presentation to allow a series of successive questions to be answered. It therefore involves an understanding of the processes that lead to the disaster, both in terms of the phenomenon itself, and its impact on a community and to the production of relevant information to assist decision-makers.

The first question in this sequence is: *what is the risk?* In other words, what would be the expected in terms of human, property and production losses if the hazard scenario or scenarios presented by earth and atmospheric scientists would take place? Box 1 presents a set of definitions of the key elements of risk assessment, (such assessment involves complex multi-disciplinary work). In terms of the specific methodologies for the determination of damage losses, there are many organisations that have carried out such disaster loss modelling work. Unfortunately, the access tends to be highly restricted as these methodologies and related software have a high commercial value in the insurance and real-estate markets.

When such risk has been determined, planners need to decide whether *is it within acceptable limits*. The United Nations Disaster Relief Co-ordinator (United Nations Disaster Relief Co-ordinator 1984) considers risk to be unacceptable when a community undergoes severe damage and incurs such losses to its members and physical appurtenances that the social structure is disrupted and the fulfilment of all or some of the essential functions of the society is prevented.

When the risk is not acceptable, urban planners are faced with the need to know *how can risk be reduced?* Choosing the right strategy; however, can be difficult since there are many available options. The three-dimensional matrix in Figure 1 allows an insight into the range of options: levels of government (who will implement the strategy?),

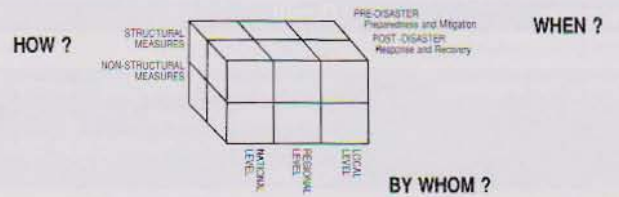


Figure 1: Range of Implementation Strategies (Montoya, 2002)

management phase (when will the strategy be implemented?) and implementation measure (how will it be implemented?). In establishing possible implementation measures such as educational campaigns, another question must be answered: *what or who do people blame for disasters?* The degree of perceived risk varies greatly between individuals of the same age and sex according to education, location, occupation and lifestyle.

If the risk is not within "tolerable limits", *what are the costs of the various prevention and mitigation measures?* In the light of the scarce economic resources that developing countries possess, the cost of structural measures to prevent or mitigate disasters must be carefully investigated through cost-benefit analyses. One of the difficulties in such an analysis relates to the trade-off between life safety and construction costs, as putting a price tag on the life of human beings is a difficult ethical issue.

Geographic Information Systems in Disaster Management

Bridging gaps in disaster management does not only involve advances in technical aspects but also in the more pragmatic aspects of knowledge transfer in a manner that enables the final user, (the decision-making community), to understand and use it... "the right information, in the right format, in time to make the right decision" (Global Disaster Information Network, 2002).

Unfortunately, in developing countries, weak disaster management is partly rooted in the lack of integrative (i.e. risk scenario) information products. Tucker *et al* (1994) illustrate the problem clearly by indicating that the 1988 Spitak earthquake in Armenia (former USSR) and the 1989 Loma Prieta earthquake in California were of similar size and affected comparably-sized populations. However, the Armenian event killed 25,000 people while the Californian earthquake killed 63. In this case the difference in the casualty figures does not result from the hazard but from vulnerability of the buildings.

In summary, for ensuring successful urban disaster management, four different types of information must be made available to decision makers:

1. Self "coping" capacity refers to the degree to which the different income groups can either cover the economic losses themselves or through disaster insurance.
2. Hazard assessment and risk assessment of likely scenarios (i.e. property damage, human casualties) summed up as annual losses (or in any other interval required by decision-makers) for each type of natural phenomena.
3. Triggering effects of natural phenomena.
4. Mitigation options (types and costs).

All four types of information requirements necessary for disaster mitigation planning have a geographic component. The greatest advantage of geographic information systems (GIS) for disaster management is their speed. Following the input of basic data, GIS systems facilitate the rapid generation of the various information products that are necessary for decision-makers during emergency situations. During the response and recovery phases, GIS is a very

Key Definitions

- Natural hazard (H)** determination involves the estimation of the probability of occurrence (within a specific period of time in a given area) of a potentially damaging natural phenomenon.
- Vulnerability (V)** determination involves the estimation of the degree of loss to a given element at risk or a set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage).
- The elements at risk (E)** include the population, the buildings, the civil engineering works, economic activities, public services, utilities and infrastructure, etc., at risk at a given area.
- Specific risk (Rs)** determination involves the estimation of the expected degree of loss due to a particular natural phenomenon and as a function of both natural hazard and vulnerability ($R_s=H*V$).
- Risk (Rt)** determination involves the estimation of the expected damage or loss of property and human lives and disruption of economic activity due to a particular natural phenomenon ($R_t=E*Rs$).

Source: United Nations Disaster Relief Co-ordinator, 1991

Disciplines	Output
Earth & atmospheric scientists	Hazard scenarios
Construction engineers	Buildings and infrastructure inventory Vulnerability scenarios ? Direct physical specific risk loss scenarios
Economists	Indirect economic specific risk scenarios
Human geographers	Population density scenarios Direct human specific risk scenarios
Insurers/re-insurers	Insurance coverage
Urban planners	Risk scenarios ? Development & re-development scenarios
Emergency planners	Real-time display of progress in the response and recovery activities

Table 1: Disciplines Involved and Outputs Developed

valuable tool as it enables real-time display of disaster events. Examples of useful applications include the tracking of progress in the assessment of damage, the clearing of rubble and the rehabilitation of basic services (primarily water, electricity and transport).

Using GIS, the different groups involved in geo-information production can generate a wide range of valuable information for disaster management. Table 1 illustrates the products that can be developed by the various disciplines involved.

GIS is a useful and efficient tool that integrates data from many different sources to carry out a complex chain of dataset integration in a speedy and methodical manner. Since natural disasters do not respect administrative or political boundaries, the establishment of disaster information networks could lead to a considerable improvement in disaster management. Setting up successful disaster data/information infrastructure networks is one of the greatest challenges faced by the geo-information community.

The Case of Cartago

The city of Cartago in Costa Rica was selected as case study due to its high susceptibility to hazards as it represents a typical example of a city with very limited geographic data and information products. The city is medium-sized (150,000 inhabitants) and is located downstream from rivers originating near the Irazú volcano's crater and it has therefore been washed away by lahars (mudflows of volcanic origin) several times throughout its history. On the path of one of these rivers lies the San Blas landslide, considered the biggest landslide in Central America in terms of volume. Two active seismic faults, located a few hundred metres from built-up areas, have been responsible for earthquakes which devastated the city in 1841 and 1910. This city therefore requires not only an appropriate disaster management plan but one which should be of a multi-hazard nature, as a volcanic eruption can trigger a lahar or an earthquake can trigger a landslide. The city is very diverse in terms of the building materials and drastic changes in population densities that occur throughout the day due to its condition as "dormitory city" since many of its inhabitants work in San José and commute on a daily basis.

Information Products

To illustrate the possible scope of GIS application to disaster management, a few relevant earthquake-mitigation information products generated using GIS are presented.

The identification of essential facilities is particularly important since they must remain fully operational during a catastrophic event. Using

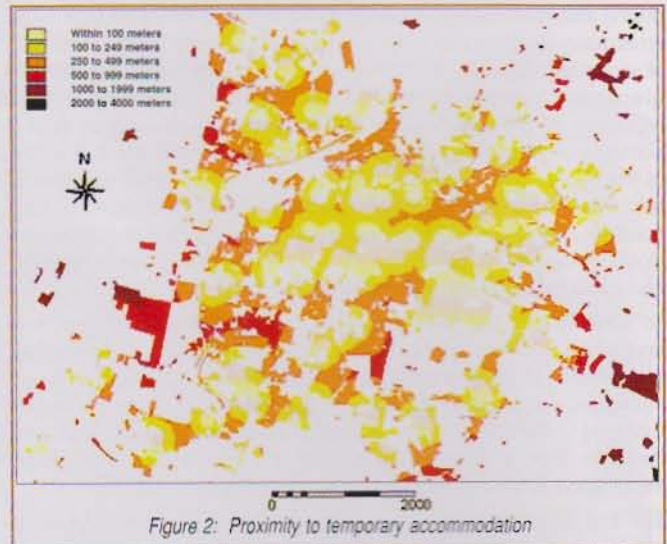


Figure 2: Proximity to temporary accommodation

a detailed land-use map as input, a simple reclassification of pixels can be applied to group essential facilities into those which are key for rescue and relief ("first order"), those which could provide temporary accommodation ("second order") and all other remaining uses into another class.

A simple buffer operation was then applied to the pixels classified as "essential facilities - second order" to assess the proximity to potential temporary accommodation (Figure 2). This allows emergency planners to identify "un-serviced areas" where tent camps might need to be set up.

In Cartago, a ban on the construction of mud-brick buildings was issued in 1840 and another one was issued on un-reinforced masonry buildings in 1910. Since these bans have been observed and enforced, it can therefore be concluded that these building types can only be found within the "1945 or earlier" class. A historical map of urban development with an associated table (Figure 3a and 3b) was therefore

Year	Adobe	Brick	Artl	Stucco	Stl	Stc	Staxr	Wood	St+15	St10
1945 or earlier	30	33	0	3	0	5	4	20	0	5
1946 to 1974	5	0	20	2	20	20	0	12	0	10
1975 to 1999	0	0	0	0	40	10	0	0	0	20
1992 to 2000	0	0	0	0	0	10	0	0	0	75

Figure 3a: Attribute table containing the building type percentage values per development period

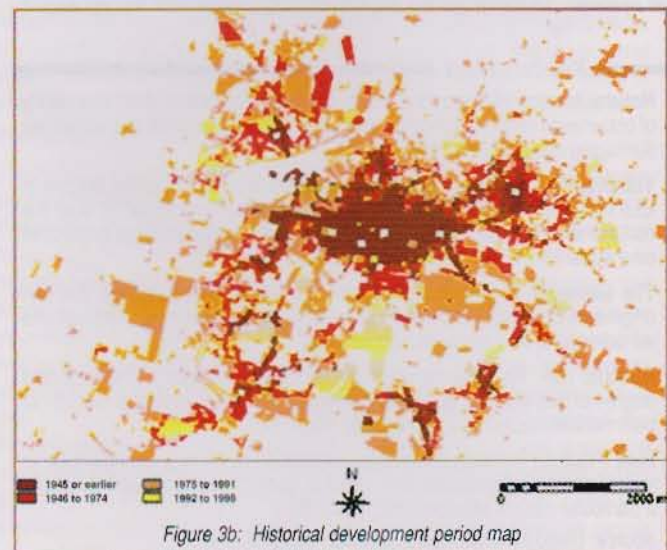


Figure 3b: Historical development period map

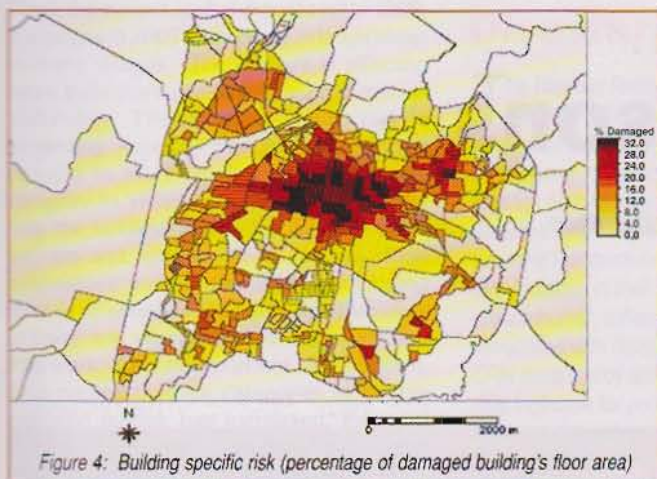


Figure 4: Building specific risk (percentage of damaged building's floor area)

used to identify the areas with highly vulnerable buildings. Such an identification is important for disaster managers as it allows them to concentrate their efforts in a particular area rather than conducting city-wide studies.

Table calculations and overlaying procedures such as the 'crossing' of maps enabled the generation of a final building damage map which has been aggregated to the census tract level in order to conduct further data integration (Figure 4). This map highlights the areas where more economic damage is expected and permits the prioritisation of further damage reduction studies. Aggregation is not only important from the point of view of linking up with lower resolution datasets but it is also an important tool to avoid the representation of individual area objects. By this technique it is possible to keep the uncertainties related to data accuracy and precision under control.

The risk scenarios were annualized to identify the most damaging one. Finally, a cost-benefit analysis was carried out for two implementation measures (Table 2). This constitutes a mitigation analysis of a reduction nature. In terms of a mitigation analysis of a prevention nature, the environmentally constraint areas were identified. Individual data layers were created for each of the hazards (fault rupture, river flood and lahar) as well as for nature protected areas. The fault rupture and river flood maps were produced using buffering techniques as regulations and recommendations indicate that no development should occur at given distance from these features. All four maps were overlaid to produce one single map.

Return Period	Millions of US \$				Reduction Factor (1. Highest, 0. Lowest)	
	Unmodified	Scenario A	Scenario B	Scenario A	Scenario B	
1	0.95	0.00	0.95	1.00	0.00	
11	9.94	1.25	3.76	0.87	0.62	
29	9.39	5.68	8.52	0.40	0.09	
64	8.07	5.30	7.46	0.34	0.08	
137	5.55	3.75	5.16	0.33	0.07	
227	4.46	3.09	4.16	0.31	0.07	
363	3.36	2.37	3.14	0.30	0.07	
617	2.34	1.67	2.19	0.29	0.06	
1007	1.67	1.20	1.56	0.28	0.06	

Table 2: Cost-benefit analysis of reduction measures

Final Remarks

The role of GIS in disaster management should focus on the integration of information from many diverse sources to produce interactive products for decision-makers rather than being used as a tool for mapping and visualizing raw data. The illustrations in the previous section have demonstrated the need for data integration. In cases when there is no attempt to integrate datasets, the implications of the information are not immediately visible, causing confusion and in the worst cases, the formulation of inadequate strategies. It may also be argued that the lack of integrative products hampers the transparency and accountability of the decision-making process.

Note

This is based on Ph.D. research carried out at the International Institute for Geo-Information Science and Earth Observation (ITC) and the University of Utrecht (UU) ■

References

Clarke, C. L. and M. Munasinghe (1994). Economic Aspects of Disasters and Sustainable Development: An Introduction. World Conference on Natural Disaster Reduction, Yokohama.

Federal Emergency Management Agency, National Emergency Training Center, et al. (1998). Introduction to Mitigation Independent Study Course. Maryland, Federal Emergency Management Agency: 121.

Global Disaster Information Network (2002). International Global Disaster Information Network, Global Disaster Information Network., 2002.

Mitchell, J. (1999). Protecting Development. Development at Risk? Natural Disasters and the Third World. J. Twigg. London: 14-19.

Montoya, L. (2002). Urban Disaster Management: A Case Study of Earthquake Risk in Cartago, Costa Rica. PhD Thesis, University of Utrecht, (ITC, Enschede, Publication Series No. 96).

Organization of American States (1990). Disasters, Planning and Development: Managing Natural Hazards to Reduce Loss. Washington, United States Agency for International Development.

Tucker, B., J. G. Trumbull, et al. (1994). Some Remarks Concerning Worldwide Urban Earthquake Hazard and Earthquake Hazard Mitigation. Issues in Urban Earthquake Risk. C. N. Hwang. Dordrecht, Kluwer Academic Publishers. 271: 1-10.

United Nations Disaster Relief Co-ordinator (1984). Preparedness Aspects. New York, United Nations.

United Nations Disaster Relief Co-ordinator (1991). Mitigating Natural Disasters: Phenomena, Effects and Options. A Manual for Policy Makers and Planners. New York, United Nations.



Prof. Ian Masser retired from the position of Professor of Urban Planning at ITC in September 2002 after four and a half years service. Prior to that he was Professor of Town and Regional Planning at the University of Sheffield for nearly 20 years. He currently holds the positions of Visiting Professor in the Faculty of Geographical sciences at the University of Utrecht and the Centre for Advanced Spatial Analysis at University College London. f.masser@ukonline.co.uk



Dr. Arq. Lorena Montoya is currently Lecturer and Researcher at Department of Urban and Regional Planning and Geo-Information Management, International Institute for Geo-Information Science and Earth Observation, The Netherlands. Her doctoral research was carried out jointly at the ITC and the University of Utrecht, and culminated in her PhD thesis in December 2002 entitled "Urban Disaster Management, A Case Study of Earthquake Risk in Cartago, Costa Rica". montoya@iuc.nl