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GIS APPLICATIONS FOR NATURAL HAZARDS MANAGEMENT IN LATIN AMERICA AND THE CARIBBEAN

ABSTRACT: Geographic information systems (GIS) have been used successfully in Latin America and the Caribbean to assist development planners in natural hazards assessments. Individual and multiple hazards analysis have been combined with information on natural resources, population, and infrastructure using PC-based GIS technology to assess vulnerability of sectoral development projects as well as to support emergency preparedness and response activities. Applications have been at the national, regional, and local levels. The design of databases, selection of GIS software and computer hardware, and introduction of spatial analysis into integrated development planning and emergency planning processes have been carried out in accordance with counterpart agency skill and experience levels. Participants in technical assistance, training, and technology transfer activities have been drawn from the development planning, emergency preparedness, and engineering/natural science research communities.

BACKGROUND

In 1983, the Organization of American States, through its Department of Regional Development (OAS/DRD), and with the support of the United States Agency for International Assistance, Office of Foreign Disaster Assistance (USAID/OFDA), initiated the Natural Hazard Risk Assessment and Disaster Mitigation Pilot Project in Latin America and the Caribbean Basin (NHP). The fundamental objective of the NHP is to reduce vulnerability to natural disasters by incorporating natural hazard risk assessment and mitigation measures into integrated regional development planning. From the

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outset, this initiative has lead to the development and testing of applied information generation methodologies and systems. Emphasis has been placed on using available information and threshold levels of GIS application through on-going and proposed planning studies in the region.

INTRODUCTION

Traditionally, disaster management in Latin America and the Caribbean has concentrated on reacting to the damage caused by natural hazards. Reducing the vulnerability of production facilities, infrastructure, and human settlements is frequently ignored. While disaster prevention is widely recognized as the most efficient and effective means of reducing damage and loss of life, mitigation measures have been difficult to implement. Mitigation ought to be part of investment activities, and the development planning process must include natural hazard analysis and the introduction of mitigation measures if significant reduction of damage is to be achieved.

An increasing number of planning agencies throughout the region are attempting to undertake this approach. Efforts have been directed at preventing loss of life and property through short-range disaster prevention activities in areas already identified as hazardous and through medium to long-range disaster mitigation areas hitherto unclassified as to risk. While the expertise and baseline data in the form of maps, documents, and statistics needed may exist for these activities, there is often a lack of a systematic approach and the technical institutional means for execution. Manual approaches were once used for this purpose, but the volume of information needed for natural hazards management, particularly in the context of integrated development planning, makes it compelling to use computerized techniques.

At its inception, NHP identified as an important area for experimentation the use of Geographic Information Systems (GIS) and computer aided natural hazards risk assessment and mapping. In 1985, three pilot studies were conducted using a main-frame computer program for Saint Lucia, Honduras, and Paraguay, and replicated in 1986 with a personal computer (PC) in two of the three countries. In all cases, the use of GIS provided direct information inputs into the respective on-going OAS/DRD technical cooperation activities.

Five years of experience and close to 200 maps covering a broad variety of geographical settings, natural resource endowment, population density, and natural hazards in more than 20 countries in Latin America and the Caribbean has given the NHP valuable insights as to how, where, and when to use this technology for hazards management. This paper describes some applications of GIS as a major support tool for natural hazard assessment and natural hazard information management within the context of integrated development planning.

GIS FOR HAZARDS MANAGEMENT IN LATIN AMERICA

The contention that GIS can be beneficial for planners in Latin America and the Caribbean is based on a number of facts. First, GIS is a powerful tool that can be surprisingly cheap; very expensive equipment and highly specialized technicians can be avoided by proper selection of the system and its applications. Second, the main constraint to the use of GIS in planning agencies is commonly not the lack of funds, but the lack of trained personnel; if training is included as a component of any project, this constraint can be overcome. Third, GIS can multiply the productivity of a technician and reduce costs. And, fourth, use of GIS can give higher quality results than manual techniques, regardless of the costs involved. It can facilitate decision making and improve coordination among agencies when efficiency is at a premium.

Natural hazard mitigation can best be implemented through development planning studies. GIS plays a crucial role in this process, serving as a tool to collect, organize, and analyze data, and as the means of providing the information needed. In general, there are four types of information that can be assembled in a GIS for hazards management: natural hazards, natural resources, population, and infrastructure. The availability and scale of the data will be determined by the level of application pursued (national, regional or local), and/or by the type of application to be executed: natural hazard assessments, vulnerability assessments, disaster preparedness and response, and post-disaster relief and reconstruction activities.

Natural hazards information denotes the presence and effect of natural phenomena, and should include location, severity, frequency, and probability of occurrence of a hazardous event. Other descriptive data are optimal. In Latin America and the Caribbean, however, planners will most likely find only their locational component (location of active volcanoes, potential flood areas, fault lines, etc.). More specific data on natural events (i.e. disaster records), scientific research (papers, articles, newsletters, etc.), and hazards mapping (floodplains, erosion patterns) covering other components can often be obtained from sectoral agencies, natural hazard research and monitoring centers, and, increasingly, integrated development planning studies.

Readily available information related to population and infrastructure is the basis for quantifying the impact natural events can have on existing and planned development activities. Large-scale data describing lifeline infrastructure and human settlements are critical elements for preparing vulnerability assessments, and for initiating disaster preparedness and response activities.

Information on natural ecosystems (e.g., slopes and slope stability, river flow capacity, vegetation cover, etc.) provides the basis for estimating the effect natural hazards can have on the goods and services these systems offer; such information also determines the factors or conditions that create, modify, accelerate, and/or retard the occurrence of a natural event.

Altogether, information on natural hazards, natural resources, population, and infrastructure serves as baseline data in the GIS for hazards management. The GIS can be used at the various levels of development planning. At a national level, it can provide a general familiarization with the study area, giving planners a reference to the overall hazard situation. GIS can be used in hazard assessments at the regional level for resource analysis and project identification. At the local level, planners can use a GIS to formulate investment projects and specific mitigation strategies for disaster prevention activities. The following sections demonstrate the versatility of GIS. In some instances, real OAS/DRD applications are included to further illustrate its potential use in hazards management.

Applications at a National Scale

At a national level, planners can use GIS to categorize land with regard to natural hazards. Examples of categories include: hazard-free areas apt for development activities, areas prone to severe natural hazards where development should be avoided, hazardous areas where development has already taken place and where mitigation measures are needed, and areas where further hazard evaluations are required. The presence of hazards will indicate the need for further qualitative and quantitative assessments for successive stages of development planning at greater detail.

A flood-hazard map for example at the national level, can give planners the location and extent of areas where heavy capital investments should be avoided and/or where less flood-susceptible activities should be implemented. Similarly, a seismic intensity map will indicate areas prone to severe shaking where activities less susceptible to earthquakes, tsunamis or volcanoes should be considered (recreation areas, agriculture, etc.).

In hazard-prone areas, GIS can be used to overlay hazard information with socio-economic or infrastructure data for a preliminary evaluation of the possible impacts of natural events. General hazards information, together with general information on population density, location of urban areas, port and airport location, road and electric network, provide the necessary elements for a preliminary quantitative assessment of people and infrastructure at risk.

OAS/DRD has used this approach for several countries in Latin America and the Caribbean. Synthesis information from such analysis include population and infrastructure in high seismic intensity areas, in zones at risk of a volcano eruption, and in areas susceptible to tsunami. It has been shown for example, that up to 670 km of paved roads in Ecuador lay within 30 km radius of active volcanoes, that all major airports in Guatemala are located in seismic intensity areas of VII or more, and that close to 300,000 people in Peru are living in tsunami-susceptible areas of 5m wave heights or more.

Synthesis maps prepared at this level can also be important for disaster preparedness and response actions. The identification of existing critical production facilities, infrastructure, and population in high risk areas, is the first step in the vulnerability assessment for disaster preparedness. This, together with the appraisal of the possible impact of natural events, can provide the necessary elements for the identification of structural and/or non-structural mitigation measures aimed at reducing vulnerability. These mitigation measures are usually incorporated as a component in integrated sectoral development projects, or as part of a national strategy to lessen vulnerability.

In 1989 for example, the Costa Rica Energy Directorate (DSE) requested OAS/DRD to assist in the analysis of the energy sector vulnerability to natural hazards. Application of GIS in the study indicated advantages in terms of technician's time and cost where pre-existing information was available. Maps and reports of the transport sector, the electric system, and petroleum derivatives system were combined in a GIS with information on earthquakes, volcanic eruptions, landslides, and floods to orient field investigations. The synthesis information showed the potential disruption of important segments of the main transmission lines by landslides, floods, and earthquakes, and pointed out critical areas where hazard reduction activities should be quickly implemented.

The process included the generation of a package of interrelated investment project ideas based on priority sector objectives vis a vis the economy and the population. These contained the necessary mitigation measures to reduce vulnerability of these critical elements within social and economic parameters acceptable to the country. Further elaboration of these projects will result in "bankable" proposals to be included in the sector's capital improvement program.

Similar GIS exercises are being undertaken in other OAS member states to assess the vulnerability of the agricultural, tourism, and transportation sectors. Country specific action plans are being complemented with training of local personnel, and policy-oriented workshops for sector administrative leaders.

Applications at a Regional Scale

At the regional scale, GIS can be used for a more detailed study of selected areas, and a more in-depth identification of development potential and hazard-related constraints. Study-area hazard assessments, together with up-scaled information on natural resources, population, and infrastructure can be combined in a GIS for a more extensive analysis relating natural hazards to planned or existing development activities. As with national scale exercises, the vulnerability of existing critical segments of production facilities, infrastructure, and human settlements can be identified by comparing them with hazards information. The identification of vulnerable elements in high-risk areas helps prioritize disaster mitigation and disaster preparedness activities in conjunction with development activities.

Typically, national scale information is complemented at the regional level with more comprehensive and detailed mapped and tabular data. A hazard assessment, including use of remote sensing information (i.e., aerial photographs and satellite imagery), floodplain boundaries, fault lines, and risk zone maps can be combined at this level with available information on soils, topography, land use, water resources, and population and structures density. Synthesis information obtained from these data enable planners to assess the risk posed by natural events, and formulate less-vulnerable development activities and/or mitigation strategies to lessen vulnerability to acceptable levels.

As an example, whereas at national scale GIS can be used to outline the location and extent of possible affected areas by floods, at the regional level GIS analytical capabilities can be applied to information about slope, precipitation regimes, and river carrying capacity to determine maximum flood impact. The synthesis information obtained can help planners determine where to construct a future dam or reservoir in order to prevent flood-induced damages.

OAS/DRD has used GIS at this level for a variety of purposes. One of the most important among these is the use of GIS for natural hazard assessment to show at greater scale where hazardous natural phenomena are likely to occur. Landslide inventories, together with data on slope, bedrock, and hydrology can be combined and analyzed in a GIS to provide planners the likelihood of occurrence of a future landslide event. This specific GIS application is based on the assumption that: 1) all landslides in the future will most likely occur under the same geomorphic, geologic, and topographic conditions that have produced past landslides; 2) underlying conditions that produce landslides are understood; and 3) the relative importance of conditions and processes contributing to landslide occurrence can be determined, and each can be assigned some measure reflecting its contribution.

Although manual techniques for analysis are still valid, the vast number of possible combinations among the factors mentioned usually restrict the study to describe only general landslide prone conditions. With GIS however, the process is not only enhanced in speed and accuracy, but also adds the possibility of introducing other factors into the analysis for the definition of a more unique combination of factors.

The first step in the landslide analysis is to enter the three thematic maps (geology, topography, and hydrology) and the landslide inventory map. Classes or categories within each thematic map are normally grouped (coded) into a maximum of 9 sub-classes, each class receiving a distinctive attribute value range. In the landslide inventory map only two values are assigned to denote either the presence, or absence, of landslide records in the area. A typical example will be:

Factor	Categories
Bedrock:	1, 2, 3, 4, 5, 6, 7, 8, 9.
Slope:	10,20,30,40,50,60,.....90.
Hydrology:	100,200,300,400.......900.
Landslide Inventory:	0 (not present); 1000 (present)

Once the thematic maps have been coded and introduced into the system, the next step is to overlay them by "adding" one to another. The values in the resultant composite map will have values ranging from 111 to 999, each cell indicating what attribute of each factor has been added. Group of cells containing the same combinations and proportion of factor variables are called land units. For example, a land unit with cell values of 456 in the composite map represents the interaction of sub-class 6 in bedrock, 50 of slope, and 400 of hydrology. By adding the landslide inventory to the composite map, it is possible to identify which combinations of factors (or land units) are associated with landslides and which are not.

The next step is to calculate the proportions of area from each land unit covered by landslides. These proportions (ranging from 0 to 1, the greater the value the more area covered by landslides) are sorted and grouped into four different classes: the first class with value equal to zero (0), indicating that no landslides are present; and the remaining three classes are equal intervals obtained from the minimum and maximum values, representing low, high, and extreme landslide hazards. Finally, the values in the composite map are reclassed according to these intervals. The resultant landslide hazard zonation map divides the study area into three susceptibility levels, providing planners with a designation of the degree of landslide propensity for regional areas.

Other regional scale hazard assessments, for instance, may display volcano locations combined with information on land use, slope, and vegetation to depict less hazard-prone areas (e.g., areas outside a 30 km radius of active volcanoes, having less that 25% slope, and having high relief and vegetation cover). Information on other hazards can be further combined to create new sub-sets of data, each one complying with different pre-established minimum standards for development. The identification of existing population and infrastructure in high-risk areas can determine priority areas for mitigation activities.

This kind of analysis was initiated by OAS/DRD for the metropolitan region of Tegucigalpa, Honduras. By entering information on landslide hazard susceptibility, land use, population density, topography, slope, and infrastructure, a GIS database was established to help the newly formed Municipal Office for Control of Hazardous Zones to determine suitable areas for urban expansion. Land units meeting minimum development criteria (i.e., low landslide potential, no more than 20% slope, within 1000 ft. of an access road, etc.) were identified by overlaying appropriate thematic maps with proposed development areas.

NHP has also given considerable attention to the examination of traditional methods for land use capability mapping. Possible modification of these methods were studied to more fully and clearly describe the constraints and opportunities posed by natural events. OAS/DRD applications in this topic have identified limited or restricted hazardous areas in zones previously recognized as suited for their respective production activities.

In Honduras for example, OAS/DRD used a GIS to combine information on floodplains, present and projected landuse, soils, and human settlements, and detected that 66 percent of the occupied land or land planned for intensive agricultural investment were located in flood susceptible areas. Similarly, in Saint Lucia, almost 99 percent of the land occupied by small farms was found to be severely restricted or unsuited for cultivation. The study also showed that two percent of the land for commercial agriculture versus 30 percent of the land for small farms was affected by severe or critical erosion hazard. This analysis, then, served not only to identify current and proposed land uses in conflict with their land capability, but also facilitated the selection and distribution of farming settlement and resettlement sites.

Applications at a Local Scale

At the local level, planners can use a GIS in prefeasibility and feasibility sectoral project studies to formulate investment projects and locate vulnerable lifeline network elements for the implementation of emergency preparedness and response activities. The presence of hazards should affect specific site selection, project engineering design, and economic feasibility of development investment projects.

Lifeline networks for production facilities, infrastructure segments, and support systems to settlements, define those critical segments or components which should have the lowest damage vulnerability or which should be recognized as priority elements for rehabilitation or reconstruction following a disaster.

In Latin America and the Caribbean, few planners will find already-prepared individual or aggregated lifeline network maps. If this is the case, a GIS can be used to overlay and identify critical elements from the production, infrastructure and service sectors to prepare a lifeline network map. This map can be further combined with hazard information for an initial determination of the most vulnerable segments, and for the identification of mitigation measures and disaster preparedness activities.

An example of this is the preliminary lifeline network map prepared by OAS/DRD for Tegucigalpa, Honduras. Maps describing the location of airports, road network (including highways, bridges, underpasses), health facilities (major and secondary hospitals, health centers, drugstore, red cross), energy supply system (electrical transmission lines and gas stations), and high-rise structures, were overlayed using a GIS. Land use and population density information were later added to the database and combined with the landslide hazard assessment map previously prepared by OAS/DRD. The identification of critical elements and high population concentrations in high and extreme landslide hazard areas helped determine priority areas where hazard mitigation should be considered.

USE OF A GEO-BASED DATABASE AFTER A DISASTER

Following a catastrophic event, quick response in analyzing the situation and formulating a workable rehabilitation program is essential. OAS/DRD has also used computerized techniques for disaster relief and post-disaster reconstruction situations. In 1988, after Hurricane Gilbert struck Jamaica, the Government was faced with the overwhelming task of allocating a great variety of relief resources to agencies and population, and of coordinating the rehabilitation effort among all the institutions and agencies involved. At the Government's request, OAS/DRD helped to install a geo-referenced database system to organize the compilation and analysis of damage assessment records which would then be used to help manage rehabilitation and reconstruction efforts.

A geo-referenced database (GRDB) is a microcomputer-based program that combines data management with map display, allowing planners and emergency managers to graphically display hazard impact areas, and relate them to people and property at risk. Although a GRDB also uses points, lines, and polygonal symbols to represent data, it differs from a GIS in that it does not have overlaying capabilities. However, GRDB's ability to manage and combine large databases with map display, automatically relating displayed elements (hazard impact areas, location of shelters, health centers, fire stations, police stations, etc.) with their respective descriptive information, makes it suitable for emergency planning and post-disaster rehabilitation and reconstruction work.

Through a GRDB, information can be accessed for data update and utilization by all involved agencies. In this way, emergency management offices can have almost immediate access to an updated inventory of settlements, lifelines, hazard impact areas, and special emergency needs, facilitating inventory and deployment of emergency resources; sectoral ministries and utility companies can prepare more effective plans and projects by having access to updated population and infrastructure data; and central planning agencies can use the system as a tool for reconstruction planning coordination.

Initial configuration of the system consisted of eight computer maps, ranging from 1:1 million (entire country) to 1:44,000 (enlarged Kingston area) scale maps, with main road network and individual records for each town and settlement. A team of three people built the database and trained its users in four days. The system was immediately put into service providing the basis for coordination among agencies participating in the emergency relief program.

Afterward, the system was expanded to include critical facilities location (health centers, shelters, police, fire) and lifeline networks (water and electricity) for the Kingston area. With assistance from the United Nations Development Programme (UNDP), eleven more systems were installed in key government departments directly involved in relief distribution and reconstruction. Direct phone and radio links were also installed between all systems to allow easy consultation and information interchange. Since then the database has expanded to more than 130 maps covering the entire country at a scale of 1:50,000, with larger scales for population centers and key economic zones.

Similar systems have been established in Costa Rica and Honduras. In Costa Rica, the system was requested by the Ministry of Natural Resources and Mines to monitor the vulnerability of the country's energy infrastructure to natural events. Although it will take some time to quantify the benefits of this system, it is clear that Jamaica, Costa Rica, and Honduras now possess powerful information systems which can be used not only as a decision-support system for emergency management offices, but also as a planning tool that can assist government agencies to better plan and coordinate development planning and emergency preparedness and response activities.

CONCLUSIONS

Based on the experiences of OAS/DRD in the subject area, and the wide array of GIS applications executed, it is possible to outline a number of conclusions about the use of GIS in hazards management in Latin America and the Caribbean, within the context of integrated development planning.

First, geographic information systems can improve the quality and depth of natural hazards assessments, guide development activities, and assist planners in the selection of mitigation measures and implementation of emergency preparedness and response actions. Computerized mapping allows quantitative evaluations and the rapid production of synthesis maps, saving time for the preparation of the most important maps, and at the same time facilitating the assessment of different development strategies, comparing them with respect to present and potential land uses.

Second, use of GIS to combine and analyze readily available information on natural hazards, natural resource, population, and infrastructure, can uncover valuable vulnerability information. This information, although preliminary in some instances, can help planners assess the impact of natural events on existing and proposed development activities.

Third, simple and affordable equipment can be as effective as the large expensive systems, especially for the purposes of map analysis for hazards management. Large and sophisticated systems require more technical skills, may be more difficult to maintain and repair locally, and their added capabilities for hazards management may not be worth the additional cost. Given the typical financial and technical constraints that prevail in the region, it is wise to start with a modest system and later expand it based on the agency's needs.

And, finally, use of a GIS is clearly more advantageous when these systems are used not only for hazards analysis, but also for a wider range of activities related with integrated development. The costs associated with its acquisition, development and use can be distributed among a variety of activities. And the use of the system, of course, need not to be limited to one planning study.

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