APPLYING REMOTE SENSING TECHNOLOGIES TO NATURAL DISASTER RISK MANAGEMENT–IMPLICATIONS FOR DEVELOPMENTAL INVESTMENTS[1]

B. W. Luscombe and H. Hassan
The World Bank
Washington, D.C., USA

Abstract

Remote sensing and geographic information management technologies provide tools by which data can be collected and analyzed to support pre-disaster preparedness programs, in-disaster response and monitoring activities, and post-disaster reconstruction. The paper examines the informational requirements for disaster risk management, assesses developing country capacities for building the necessary informational decision-support systems, and evaluates the role of remote sensing as a source of information. It discusses the relationships between development investments and natural disaster risk management. It describes several examples of initiatives from developing countries which have attempted to build a disaster preparedness and response program using remote sensing data and other geographic information management techniques. It concludes with suggestions and recommendations for strengthening systems for risk management as a part of standard investment procedures.

Introduction

Many investments in developing countries are often at risk because of potential impacts from natural disasters. Disasters such as earthquakes, volcanic eruptions, intense weather systems, droughts, floods, and insect infestations are often of short to medium term duration, but can have long-term impacts on human and environmental systems. It is usually not possible to prevent the tremendous physical forces behind these phenomena, but it is possible to manage the potential risks by developing disaster early warning strategies in anticipation of, and to brace against, pending calamities. Preparedness can help to minimize the effect of a disaster, although it cannot totally eliminate the costly impacts (Hassan and Luscombe, 1990). Post disaster reconstruction must then begin to rebuild in the wake of a catastrophe. Usually, much needs to be done in a short period of time with very limited resources. It is important to be able to identify priorities and rationalize the choices of investment alternatives. The development of an effective mechanism for analyzing and monitoring hazard problems is key to the assessment and management of a risk. It must be supported by accurate baseline information about natural and human resources, by knowledge about physical and institutional infrastructures, and by timely data concerning dynamic changes in environmental conditions. Reconstruction efforts are also driven by decisions supported by a similar base of information.

Information Requirements for Disaster Risk Management

Over the past several decades, improved data collection and information dissemination has already been proven valuable in the management of natural disaster risks. Unfortunately, the ability to collect information and understand the potential impact of a calamity varies with the type of natural disaster. Our ability to predict and monitor, with any degree of certainty, such events as earthquakes and volcanoes–both of which manifest themselves very abruptly–is more restricted than it is for draughts, hurricanes, and other events which are more slowly developing and longer in duration.

Pre-disaster preparation

To manage effectively the risk associated with a natural disaster, ideally, information is required before the disaster strikes to assist with preparation activities in order to minimize the impacts. This information needs to identify the potential magnitude of the pending events, the areas which will likely be affected, and the human and economic resources which will be impacted. Disaster preparation typically takes place in two forms. First, a long term strategic approach to deal with pending disasters assesses the potential risk for damage to life and property in an area and develops response plans. These plans may include, for example, implementing building codes, restricting development, and equipping institutional programs, such as medical and emergency response facilities, to be able to cope when a natural disaster strikes.

The second form of disaster preparation is an immediate response to a known threat. When an event is in progress or is imminent, preparation shifts to taking the necessary immediate actions to minimize the impacts. If the threat is great, the response may be to evacuate people and property. A less severe response may be to take extraordinary precautions to protect property through such measures as sand-bagging around buildings, securing easily moved objects, and reinforcing walls and windows of structures that will be affected.

At present, the latter type of preparation response is not possible for disasters that are rapidly occurring and of short duration, such as earthquakes, volcanic eruptions, and flash floods. For these, and others, there is little or no advance warning of the impending event. Preparation must rely totally on the long term strategic plans for dealing with such calamities. That is why it is critically important to understand which areas are at risk and what the probabilities are for a destructive event to occur. Information collected from various sources, for instance from historical records, ground monitoring equipment, and remote sensing, can be used to prepare maps showing areas of differential risk assessment.

In-disaster response and monitoring

While a natural disaster is in progress, information is required about its severity, areas of impact, and extent of damage. This is used to establish priorities for targeting response actions and for identifying other areas which may yet be impacted. For example, droughts are often long-term events that creep over extended areas. It is important to be able to identify those areas that are being most severely affected, from the standpoint of human, economic, and environmental conditions, in order that relief can be attempted in a timely manner. A failure to assess the impacts as they are occurring may result in increased casualties, economic losses, and environmental destruction.

The requirement for information is in near real-time so that appropriate responses can be planned. A delay in the collection, analysis, or dissemination of information will almost certainly exacerbate the problem. For example, as flood waters rise, it is important to identify, very quickly, which areas will be affected and what measures need to be taken to minimize the impact.

Post-disaster reconstruction

Following a natural disaster comes the stage of "cleaning-up", rebuilding, and a return to normalcy. With this, there must be an evaluation of how well prepared the area is to deal with such disasters. Post-disaster rebuilding involves assessing which areas have been most severely affected and prioritizing the response activities. Often there are very limited funds to support disaster relief programs and it is therefore important to target the relief activities to the most affected areas.

The reconstruction effort requires information about the extent of damage of the current disaster, as well as information about the risk associated with potential future disasters. In order to assess these risks, it is often necessary to know about an area's soils, geology, climate, vegetation, infrastructure, economic activities, and human occupancy.

The Role of Remote Sensing Technologies

Much of the information needed to prepare for and respond to a natural disaster must be collected and analyzed in a relatively short period of time. Manual data collection techniques are often very time consuming, logistically difficult, and very expensive. Remote sensing technologies, broadly defined here to include both airborne and satellite sensors, offer a means for acquiring some of the data in a timely manner and inexpensively. The associated geographic information management technologies including GIS and image processing capabilities provide a means for analyzing the information, assessing risks, and evaluating impacts.

These technologies, however, do not provide a panacea for collecting and assessing information related to natural disaster risk management. They have many serious limitations and are more appropriately used for some types of disaster management than for others (Morgan, 1989).

Satellite imagery, which is relatively inexpensive, is very useful for providing information about large areas, but is constrained by its spatial resolution to provide much detailed information about very small areas. The spatial resolution of existing satellite systems varies from a few meters to many kilometers. It is useful, for example, to track the path of a threatening hurricane, but it is unable to provide the data necessary to assess the extent of damage to individual buildings, vegetation, and physical infrastructure.

During a weather-related natural disaster such as a hurricane or flood-producing rains, satellite remote sensing has the additional problem of not being able to "see" through the associated clouds. This limits its usefulness during the disaster for assessing the damage which is being caused. Recent and planned radar-based systems will partially overcome the cloud-cover problem; however, spatial resolution and revisit frequencies will still limit their usefulness for monitoring and evaluating weather-related hazards. Generally, it is true that, owing to these reasons, satellite remote sensing information alone is limited in its ability to monitor and assess impacts of disaster-related weather patterns. Its primary value is its superior ability to observe the behavior of the weather systems.

Generally, there is an inverse relationship between the spatial resolution and the frequency with which an area is observed by the satellite. Systems that cover large areas (low spatial resolution) provide frequent revisit capabilities to a particular area on the earth's surface; however, systems with higher spatial resolution (e.g., SPOT, Landsat) require from three to sixteen days to revisit an area. For rapidly developing disasters, the long time period between successive observations limits the usefulness of the technology as a provider of monitoring information.

For monitoring purposes of all types of natural disasters, the time sequence of physical changes is important to assess the impacts. Observing the temporal behavior of drought conditions or of volcanic activity, for example, assists in determining the extent of the disaster and in deciding on appropriate response actions.

Airborne sensors have the advantage that they can target an area of interest and can control the data acquisition schedule better; however, they also have difficulties flying in severe weather conditions and observing through clouds. An exception to this is the airborne SAR (Synthetic Aperture Radar) imagery, which can be collected at anytime during the day or night, irrespective of cloud cover.

The wide array of remote sensing technologies provides valuable means for collecting information about the earth's surface and for assessing a variety of environmental impacts. The need for such capabilities is highlighted by the enormity of the damage which can be caused by many of the natural hazards. For instance, the cost associated with hurricane Andrew is estimated to exceed US $30 billion, making it the most destructive hurricane in history, from an economic point of view, to strike North America. The cost and destruction, however, would have been much greater without the aid of information collection and analysis tools, which tracked the path of the hurricane very accurately and pinpointed with some precision those areas which would be most heavily affected. This allowed preparation and response activities to be targeted to specific areas. Much of the information which was obtained to make this type of preparation possible was provided by satellite remote sensing and radar technologies (particularly the new Doppler radar systems recently installed by the US National Weather Service).

Disaster Management in Developing Countries

In most developing countries the capacity to prepare for and to respond to a natural hazard is minimal. Often the problem in these countries is exacerbated by overpopulation in the areas at highest risk for a disaster, such as floodplains, coastal areas, and even subsistence agriculture areas. The extent of existing information about climate, geology, soils, and human occupancy is inadequate to prepare strategic response plans. As a result, when a disaster strikes one of these areas, it usually causes massive destruction and results in large losses of life, sometimes numbering in the hundreds of thousands of people (for example, an earthquake registering 7.8 in 1976 killed more than 400,000 people and destroyed the city of Tangshan in Hebei Province, China (Kreimer, Echeverria, and Preece, 1990)).

Although the potential for a hazardous event, such as earthquakes, hurricanes, and volcanoes, shows no spatial preference based on standards of living, many of the active and vulnerable areas are found in countries with low economic standards. Since the turn of the century, China has experienced over 2,600 destructive earthquakes, more than 500 of them registering above 6 and nine of them above 8 on the Richter scale (Hong, in Kreimer, Echeverria, and Preece, 1990). Nepal has experienced 279 earthquakes with magnitudes of 4.0 or greater between 1963 and 1986 (Asia Institute of Technology, 1990). In other areas such as East Africa, no data are available about the frequency, complexity, or magnitude of disasters, such as droughts, floods, pests, cyclones, etc. except to know that they are many (Don Nanjira, 1990).

The economies in many developing countries are small and relatively specialized, leaving them particularly vulnerable to natural hazards. The effect of a serious disaster can be devastating if it hits at one of the country's primary sectors. Zupka (1988) estimated that between 1970 and 1985 disasters of only three types--windstorms, floods, and earthquakes--cost an average US $18.8 million a day and directly affect nearly a quarter billion people annually.

All stages in the process of natural disaster risk management are constrained by limitations in the countries' abilities to collect, analyze, and disseminate information about a potential hazard. In the preparedness stage, strategic planning is often hindered by the lack of resource, human, and economic data, as well as by the lack of institutional capacity to identify appropriate responses. Many countries do not have effective agencies that can coordinate risk management activities such as developing early warning systems, developing and enforcing building codes, and preparing emergency response plans. A key problem is the lack of financial resources both at an agency level and at an individual level to do the planning and implementation.

Early warning for some types of hazards, such as severe climatic events, is often known even in the least developed of the developing countries, but putting into effect any meaningful response is hindered by poor information dissemination systems and, again, lack of resources. Information that is disseminated is usually done so via the communications media using radio and television, but often there is insufficient time for local areas to respond.

Massive evacuations in heavily populated areas that will be affected by a pending calamity is a daunting task even when sufficient early warning is given and when the organization and infrastructure is in place to coordinate such a response. In most developing countries this would be nearly impossible, therefore the usual response is to do little and to try to survive with a minimum of preparation.

Peoples' perception and response to hazard warnings depend on available options in terms of a particular site, their economic needs, their health, and available information (Schware, 1982). Response options to floods, for example, may be limited to simply moving to the nearest higher ground, which may be a rooftop, a tree, or an embankment. Experience has shown that evacuation from their homes is usually a last resort for most villagers, because they fear that thieves may steal what few belongings they have (Cuny, 1990). This raises an important issue concerning improving early warning information about pending disasters through remote sensing and other data collection technologies, because it is doubtful that, in many cases, the longer lead times will significantly affect evacuation behavior.

Post-disaster relief and reconstruction efforts following major natural catastrophes in developing countries are often met with a rapid response from the international community. This, however, does not always provide the relief needed because efforts are often hindered by incomplete information about where the destruction is most serious, and by a poor understanding of the capacities of local institutions and infrastructures. Because a response to a disaster needs to be rapid to minimize further loss and suffering, there is often little time to properly coordinate relief efforts when no prior coordination program has been prepared. Recent examples of drought relief efforts in several African countries (e.g., Somalia, Sudan) illustrate some of the difficulties with coordinating activities. Large amounts of relief supplies are never distributed to those in dire need because of an inadequate distribution system, political interventions, and ineffective institutions. Efforts by external, foreign agencies are often complicated by local responses and are sometimes counter productive. The reverse is also true as local actions are often rendered ineffective by the foreign efforts (Hassan, 1990).

Following a disaster, relief efforts are best coordinated by the affected country. When local administrative capabilities are not able to cope with the enormity of the problem, it may be preferable for some other independent, international agency, such as the United Nations, the World Bank, or one of the regional development Banks to assume this role. This can be particularly effective when coordination is required amongst various contributing aid agencies; however, the government must feel real ownership of the aid coordination process (Brown and Muhsin, 1990). Multi donor support for post disaster reconstruction activities can create a new set of bureaucratic and administrative problems as each has different procurement, disbursement and reporting procedures.

Development Investments and Risk Management

Disasters cause more than their share of destruction and suffering for the poor in most countries. These are the same people that most critically need development assistance. Anderson (1990) suggests that "by ignoring likely disasters, many development efforts do nothing to decrease [their] likelihood... and many actually increase vulnerability to them". A new approach to development planning is required. Disaster mitigation efforts can no longer be viewed as "unaffordable extras". Anderson further suggests that development spending and disaster spending are not tradeoffs, but that resources allocated to development affects the likelihood of damage from future disasters. Conversely, disaster response strategies have an impact on a country's potential development. Often the distinction between the two types of investments are indiscernible; for example, investment for irrigation projects not only increase agricultural production, but also reduces the threat of drought. Development investment should never increase disaster vulnerability and should include measures that improve the nation's ability to cope with disasters (Anderson, Ibid.).

A rapidly growing world population (most of which is occurring in developing countries) and an almost certain changing global climate will substantially increase the risk of damage from natural disasters in the future. Riebsame (1990) suggests that *"development planners must develop a strategy that reflects (1) the sensitivity of resource systems to variations in climate, (2) uncertainty about climate change and how that uncertainty can be incorporated into an expanded repertoire of responses, so decisionmakers are not pressured into premature action or paralyzed by uncertainty, and (3) awareness of development's effect (good or bad) on the "greenhouse" problem and on social adaptability to climate problems"*.

The economic impact at the local, and often the national, level of a natural disaster is tremendous, particularly in developing countries. It is important that development investment decisions take into consideration issues of managing risks for hazards (Pantelic, 1990). Many countries that have experienced the devastation of a disaster have begun to improve their risk management procedures. China, for example, has focused on reducing the natural disasters by undertaking a number of preparation activities. These include engineering works to control flooding by large rivers, and the development of irrigation systems to combat drought. It has also revised construction codes for buildings and infrastructure to withstand typhoons, floods, and earthquakes, and has improved its disaster prediction and warning capabilities (Hong, in Kreimer, Echeverria, and Preece, 1990).

Reconstruction activities following a disaster in a developing country may cost hundreds of millions of dollars. The Emergency Flood Reconstruction Program which was prepared after the 1988 floods in Sudan, for example, amounted to US $408 million (Brown and Muhsin, 1990). In many cases, the post-disaster reconstruction activities include support for strengthening disaster preparedness programs to prevent similar events from having the same impact in the future.

Key to the efforts of post-disaster reconstruction and to strengthening disaster preparedness is an improvement in the ability to collect and analyze disaster risk information. Knowing which areas are at highest risk should affect what reconstruction and development activities are allowed in those areas. It should also identify what other existing structures and economic activities are in danger from future catastrophic events. Information to be used for the purposes of disaster preparedness will come from many sources. Satellite remote sensing and aerial photography are indispensable tools in providing a base of information for these purposes in a timely and inexpensive manner. They are ideal for identifying geologic structures and fault lines, for recognizing population distributions and patterns, and for determining local relief and topographic features.

The Philippines is a good example of how a country has responded to combined earthquake and volcanic disasters by attempting to assess the risk of future calamities. In July 1990 a major earthquake occurred on the Philippine island of Northern Luzon causing massive damage and loss of life. This was followed several months later by the eruption of Mount Pinotubo, which caused additional damage and destruction. As part of an Earthquake Reconstruction Project financed by the government, IBRD, and ADB, the government acquired radar imagery for the entire island and is proceeding to prepare geohazards maps at various scales from 1:25,000 to 1:1,000,000. This information will be used to help direct reconstruction activities and for risk assessment zoning. Based on the results of these geohazards maps, building codes will be applied for all new construction according to the identified risk categories.

At present little capacity exists within the country to undertake this kind of work. It will take a considerable amount of technical assistance and training from foreign experts experienced with remote sensing interpretation and geohazards mapping. The goal of the program is to ensure that there is a transfer of the technology to the Philippines, so that in the future they will be able to do the interpretation and mapping themselves. This involves strengthening existing institutions by providing the necessary equipment and training to a large number of staff. Although it is not included in the existing Earthquake Reconstruction Project, their intention is to eventually expand the risk assessment work to the entire country, which is particularly vulnerable to earthquake and other volcanic activity.

Summary and Recommendations

Investment decisions for development purposes can no longer rationally ignore the potential risks from natural hazards. Traditionally, disaster assistance programs have provided immediate relief following a disaster. Today we find more of the assistance efforts including longer-term reconstruction and rehabilitation programs with a focus on risk management for future catastrophic events.

Risk assessment and disaster preparedness can only be accomplished with the aid of reliable and timely information. Some of the remote sensing technologies currently available and under development provide a valuable source of information for early warning systems and for assessing potential impacts of natural hazards. The main application of these geographic information gathering and processing technologies would seem to be for disaster preparedness planning and for some aspects of post disaster reconstruction and rehabilitation. For some slow moving disasters covering large areas, such as droughts and massive devegetation, it can also be a useful tool for monitoring the disaster in progress.

All development planning and assistance should make natural hazard assessments and mitigation an integral component in the process. Information required for disaster risk management should be developed as a part of an overall resource information management strategy in order to assure its sustainability. Information alone will be of little use unless skilled staff in the country are able to interpret and use the data in making decisions. It is therefore important for development investments to assure that staff, in addition to being provided with the physical capabilities for data collection and analysis, are also properly trained in using the data for forecasting, monitoring, and reconstruction planning.

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