Exploiting municipal data infrastructures for vulnerability assessment

Verónica Botero Fernández
Department of Earth Systems Analysis
International Institute for Geoinformation Science and Earth Observation (ITC), *botero@itc.nl*
+31-53-4874444
Escuela de Geociencias y Medioambiente
Universidad Nacional de Colombia, *vbotero@unal.edu.co*
+57-4-4255141

Richard Sliuzas
Department of Urban and Regional Planning and Geoinformation Management
International Institute for Geoinformation Science and Earth Observation (ITC), *sliuzas@itc.nl*
+31-53-4874444

Henk Ottens
Faculty of Geosciences - Utrecht University, *h.ottens@geog.uu.nl*
+31-30-2533206

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Abstract

Vulnerability assessment is a fundamental component of determining risk and planning in hazard prone environments. Vulnerability assessment often relies on a one-off survey. This provides a snapshot of vulnerability, but it may become quickly outdated, more uncertain and less useful over time. An alternative approach to assessing vulnerability is to exploit typical municipal databases. Our assumption is that increasingly municipalities will have access to more and better quality digital data sets. We test the idea that these information resources could be better exploited than is currently the case. For example, databases containing parcel and building data may be used for property taxes, and development control. Some of this data could also be utilised in vulnerability assessment, a more efficient use of information resources that opens possibilities for more frequent assessments, enhanced preparedness and mitigation. Our approach is being tested in Medellin, Colombia, a city of multiple hazards that has invested considerably in municipal information systems. After reporting on the basic concept of the vulnerability assessment system the paper examines its usability in Medellin. Data gaps inevitably require adjustments to the ideal system which could be improved incrementally as data gaps are eliminated. The added value could stimulate the wider adoption of municipal information systems and enhance their daily management capacity as well as their ability to manage risk.

Introduction

The trend during the last decades shows an increase in the number of natural hazard events and of their consequences. All countries suffer after a natural hazard, but those unprepared to cope with its effects suffer the most. Local and national government offices have to manage information concerning natural hazards and vulnerability to define strategies for risk management. We cannot avoid natural hazards from happening, but we can contribute to the understanding and study of the factors that make up vulnerability as the only factor in the risk equation that we can manage. In this endeavour, information is a key factor in vulnerability reduction.

As Municipalities manage the built environment and typically also have a broad range of responsibilities related to the population and their well being, the local economy and the environment, they inevitably collect and use a great amount of data that could be of use for dealing with hazard management. Considerable attention is now given to increasing the organisation and management of information resources at all levels, from local through to global through the establishment of so called Spatial Data Infrastructures (SDI - see for example www.gsdi.org). SDI's make it possible to share data between various applications, thereby adding to the value of each piece of data and offering economies in terms of its collection and maintenance. In this current work we examine the potential for doing just that for assessing vulnerability. Before examining the case itself some attention is given to describing the basic concepts and considerations that underlie this work.

General Concepts - Risk, Hazard and Vulnerability

A clear understanding of the 3 concepts hazard, vulnerability and risk is an essential basis for their measurement. Vulnerability, for example is embedded in complex social relations and processes and concerns more than just physical objects and their conditions (Hilhorst and Bankoff 2003). The following definitions respond to a need expressed for precise definitions to avoid confusion in risk management (UN/ISDR 2004).
Hazard: A potentially damaging physical event, phenomenon and/or human activity, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Each hazard is characterized by its location, intensity, frequency and probability. Hazards can be natural (e.g. a flood or a drought) or technological (e.g. caused by an industrial accident or the spontaneous collapse of a building or structure). *Vulnerability*: Conditions that make any subject or object susceptible to the impact of a hazard having regard to their *capacity* or ability to cope, resist and recover from the impact of the hazard. *Capacity* has to be understood as a combination of all the strengths and resources available within a community, society or organization that can reduce the level of risk, or the effects of a disaster. Capacity may include physical, institutional, social or economic means as well as skilled personal or collective attributes such as leadership and management.
Simplistic notions about vulnerability have been overruled in the past decade, as the complexity of risk has been unveiled. Nevertheless from a geo-information perspective, new forms of measuring the unsafe conditions and the capacities that people have to be developed in order to understand and cope with hazards. These new forms of measuring these conditions and capacities have to reveal, as much as possible, the dynamic nature of vulnerability without becoming mere rhetorical indicators.
Risk: The probability of harmful consequences, or expected loss (in terms of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or technological hazards and vulnerable/capable conditions. Conventionally risk is expressed by the equation:

Risk = Hazards x (Vulnerability/Capacity)

Beyond expressing a probability of physical harm, it is crucial to appreciate that risks are always created or exist within social systems. It is important to consider the social contexts in which risks occur and that people therefore do not necessarily share the same perceptions of risk and their underlying causes. This relationship to the social context is reflected in the definition of a *disaster*: A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community/society to cope using its own resources. A disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of a hazard.
There are basically 2 approaches for the analysis of vulnerability.: the Risk-Hazard (RH) and the Pressure-and-Release (PAR) models (Turner, Kasperson et al. 2003). These models are primarily tools for explaining vulnerability, not for measuring it directly. They do allow researchers to develop new means of measuring the different parameters that underlie vulnerability. In both models, the factors used to measure exposure and capacity, have different use in the disaster management chain. In the pre-disaster phases the knowledge about sensitivity is fundamental for the mitigation and preparedness activities, in terms of identifying target groups (public awareness activities and emergency response planning and training activities) and exposure information is important for building code implementation and strengthening or retrofitting of existing structures.
Defining exposure requires the identification and listing of elements at risk (i.e. the physical elements such as buildings, transportation and communication networks etc. and the population subjected to a probable hazard (according to their day and night time distribution). Different types of vulnerability can be defined, according to the subject/object of interest. All of them appear as key elements at different stages of the disaster management chain and are useful for determining exposure (elements at risk) and capacities.

Vulnerability types

Vulnerability deals with both tangible and intangible assets, from the purely physical and social factors (infrastructure, population, etc.) to more subtle factors like cultural assets and ethnic or gender issues that are more complicated to measure and represent spatially. We define 4 main types of vulnerability that rely on previous work (Anderson and Woodrow 1989; Lavell 1993; Wilches Chaux 1993; Blaikie, Cannon et al. 1996; ICRC 1996; Cardona 2001): 1) *Physical vulnerability* is restricted to tangible elements, basically infrastructure, its location and characteristics; 2) *Social-Cultural vulnerability* includes tangible and intangible elements such as people, households and community; 3) *Economic vulnerability* concerns various levels of economic relationships and functions; it includes economic dependence between different levels (national, regional, local, individual) but also livelihoods and all types of production and income assets; 4) *Political-Institutional vulnerability* refers to basically intangible elements such as government structure and decision making, political participation, disaster/risk related organizations including response and relief organizations. It can also include aspects such as delinquency and armed conflict. Many of these characteristics are not at all straightforward to measure. Their measurement may also require data that is not routinely available. The hypothesis of this research is, however, that much potentially useful data is available for the measurement of vulnerability at municipal level, and that its potential could be tapped if better data acquisition and management practices were adopted.

Measuring Vulnerability: Data Requirements

Various models are used to "measure" vulnerability, a linear weighted sum of indicators (Davidson 1997; Cardona 2001), more complex techniques such as fuzzy logic (García and Hurtado 2003); Bertin matrices, principal component analysis (PCA) and weighted map overlay (Chardon 1999); and decision matrices or decision trees (Dwyer 2004; Smith, Vélez et al. 2005).

We have seen that vulnerability must consider tangible and intangible aspects that give information about the actual state of the physical elements as well as the people who may be affected by a hazard, therefore establishing the basic parameters in the PAR model (Unsafe Conditions), or Exposure (for the RH model and in Pelling's model). Any attempt to measure and understand vulnerability and the factors that control it, should clearly separate exposed "elements" (physical objects) from the characteristics that define those "elements" (infrastructure, population, economical assets, etc.) vulnerable. It should also include some type of measurement of the capacities within a given community to withstand a hazard, sometimes also referred to as *coping*, and recover from it.

The attributes that determine vulnerability relate to one of 3 aspects: *exposure, resistance and resilience*. *Exposure* is directly related with the location of the element, therefore, for all the elements, knowledge about their geographic location in terms of the hazard is fundamental, as well as a comprehensive knowledge about the characteristics of the hazard. *Resistance* and *sensitivity* deal with those attributes of the element that define its ability to cope with a given hazard, for example the building characteristics in terms of physical vulnerability or the mobility of a human in terms of social vulnerability. *Resilience* deals with those attributes that define an element's recovery capacity after a hazard event; e.g. it could be related to the level of insurance to pay for the rebuilding of collapsed structures. Each of these elements may also have a set of attributes that explain whether they convey information about unsafe conditions, dynamic pressures, or root causes.

An inventory of these attributes may not directly serve to measure vulnerability, considering that they are not permanent properties, but change with respect to a particular hazard (e.g. homeless people may be more vulnerable to floods than to earthquakes). Therefore, accounting for the data, can allow a comprehensive assessment of vulnerability to different hazards. Checklists can be an important tool in vulnerability assessment but they do not clarify why and how different elements are related and the impact that a hazard may have (Wisner, 2004).

The data needed to perform a vulnerability assessment can be explained from 2 different points of view; a theoretical view that defines vulnerability in terms of Exposure, Resistance/Sensitivity and Resilience and a second one related to Disaster Phases - Impact, Relief and Recovery. The former looks at both the direct impacts on the population that depend on the physical vulnerability of the infrastructure as well as indirect impacts related to issues such as social or cultural vulnerability. In the latter approach a disaster event is analyzed in phases to understand the different events and the information needed to mitigate, prevent, attend and recover. Each phase has a different duration and has different information requirements, in order to tackle specific problems adequately.

Measuring Vulnerability: Data Sources

Municipalities collect data for multiple purposes, in many cases that data corresponds to the data needed to produce vulnerability information. In some other cases, the data has to be collected for the sole purpose of assessing an aspect of vulnerability. However, for the already available and new data collected, there is a need to transform it into useful information and that information into actions.

Beginning in the late 1950s in the world, planners started to develop and use computerized models, planning information systems and decision-support systems to improve performance (Nedovic-Budic 2000). Today it is now accepted that as much as 80% of all the information used by planners today is geographical (Masser and Ottens 1999). Developed countries apply geo-information technology in all aspects of the planning process, including data collection, storage, data analysis and presentation, planning and policy making, communication with the public, policy implementation and administration. Van Dijk (van Dijk 2006) defines an Urban Information System (UIS) as an ensemble of discrete sets of digital data concerning all relevant aspects of a city, accessible to computer processing and analysis. However, many municipalities in developing countries have digital datasets, but fail to make them accessible to computer processing and analysis by others, even to other municipal officers.

An UIS developed for a developed city is not directly transferable to cities in developing countries. Cities in developing countries present specific characteristics that make them different from cities in developed countries, especially in their ability to adopt geo-information technology (Bishop, Escobar et al. 2000). Nevertheless, we observe that geo-information technology is increasingly adopted, even in some of the world's poorest countries. As hazards are found almost everywhere, it is useful to explore how such systems can contribute to enhanced disaster management capacity. This is an issue which is at the heart of ITC's SLARIM project (see www.itc.nl/research for more details), of which this research is a part.

Many of the factors and processes associated with hazards can be measured using data already within the municipality. This data may be located in a structured Municipal Information System, or distributed in different, independent databases with different formats and quality. In both cases a set of tools is needed to produce appropriate information for different scales and levels of decision-making, it is rarely a matter of point and click. From this point on, other issues arise in terms of whom to deliver the information to improve decision making, or whom to make responsible for the systematic collection and administration of the information. Information responsibility is directly linked to the capacities of the municipal institutions that ultimately lead us to information management issues and existing tools and solutions to adequately handle the latter. Our task, however, is to set up a methodology to define which elements are relevant for the assessment, the information sources available; the information quality; and to assess the uncertainty of the assessment done using the information available. Although the research has been carried out in Lalitpur, Nepal and Medellín, Colombia, only the latter case will be considered here as it already has a relatively well developed MIS.

Data Rich – Capacity Moderate Case Study: Medellín, Colombia

Medellín is the second largest city in Colombia, and capital of the province of Antioquia. The city is prone to earthquakes resulting from the complex seismic setting of the country, where a triple tectonic plate junction occurs. It is also prone to landslides, debris flows and flash floods, due to the steep slopes that surround it, and the geological and hydrological conditions of the area. Until the 80's, disasters in were considered as random phenomena and the city was planned using only geological maps scale 1:50000 published in 1963. There was no official policy for identifying and managing areas threatened by hazards.

Usability of MIS: Vulnerability Indicators and Information Sources

Once the information sources within the municipality have been identified a list of indicators, attributes and sources can be compiled for the case study. In **Error! Reference source not found.**, the number of indicators per phase and vulnerability type is presented, as well as the attributes used to measure the indicators. Since all the indicators and attributes cannot be discussed within the length of this paper, a couple of indicators will be explained in detail.

In the case of Physical Vulnerability, the indicators needed to measure it are basically inventories of elements. The most difficult to assess is the Building Stock Fragility. This indicator should reflect the complex interaction between structural type (materials, state, and height), location within the block, and facilities. The information used to measure this indicator is basically collected in the Cadastre Office of the Secretariat of Treasury and the Secretariat of Health through the SISBEN surveys. The SISBEN provides access to up-to-date reliable social and economical information about specific groups in the districts and municipalities of the country. It is a basic tool that enables precise social and economical diagnostics of specific groups within the population which can be applied to individual homes. It is very useful in the creation of development plans for the municipalities through the technical, objective, uniform, and equitable selection of benefits for social programs according to their specific social and economical condition, which is represented by the SISBEN index, a quality of life summary indicator. The focusing process requires the periodic update of the database and its use by all the entities that run the social programs at the department, district, and municipal level, which will allow the unification of criteria and beneficiary selection (DNP 2006).

Table I. Number of vulnerability indicators by phase and type in Medellin

Vulnerability Type		Impact	Relief	Recovery	Total
Physical	Indicators	7	4	8	19
	Attributes	12	7	15	34
Socio-cultural	Indicators	2	2	3	7
	Attributes	6	4	6	16
Economic	Indicators	1	1	2	4
	Attributes	1	2	7	10
Political-Institutional	Indicators	1	4	2	7
	Attributes	1	7	4	12
Total	Indicators	11	11	15	37
	Attributes	20	20	32	72

The spatial unit used to measure the building stock fragility indicator is the individual building, but the information collected by the Cadastre office and the SISBEN surveys is related to the Household or the Property (Parcel). The following situations are present frequently, making difficult the data processing:

- Several accesses to the same household (possible errors in address geo-coding)
- Buildings with several households (very common in apartment buildings with different owners)
- Several households in each building storey

The information for Facilities is delivered by the Municipal Facilities Company (Empresas Públicas de Medellín –EPM-) as point data indicating the type of connection (Industrial, Commercial or Residential) or as polygon data indicating coverage by zones. The information about Emergency Services is provided by SIMPAD (Sistema Municipal de Prevención y Atención de Desastres) and about Educational, Recreational and Religious facilities for shelter purposes is provided by Metroinformación. The multiple formats, sources and lack of standards in these bodies for data collection and processing, complicate the task of processing raw data in order to assess the indicators.

The *Building Stock Fragility* indicator will now be used to show the process of converting raw data to information. To assess building stock fragility, 4 attributes have to known for each building (age, conservation state, number of floors and structural type). The basic data source is the Cadastre Office. The Cadastre Office supplies 2 databases: Database-1 (DB1) has data on Buildings and Parcels with spatial representation (geodatabase); Database-2 (DB2) has data on Parcels but without spatial representation. The two databases use a different coding system for the parcels so a process of generating id codes for each parcel of DB2, using existing fields, in order to coincide with DB1 Parcel's codes has to be done before any spatial analysis can be performed. Once, the coding problem is solved, a second problem is faced. There are multiple parcels in DB2 for each parcel in DB1, since in an individual parcel there can be a multi-storey building with multiple owners. Since there are four attributes needed to assess building stock fragility, values for each parcel must be generated. Data inconsistencies are found all over the databases, so a procedure of determining values for each parcel is done. To assign the age variable to each parcel in DB1, the maximum value of the parcel data from DB2 is selected. To assign conservation state, the worst (minimum) value is selected, in order to represent the worst scenario for each building. To assign number of floors, the maximum value is used, therefore ensuring that the height of each building is correct. To assign the structural type, a similar procedure to conservation state is performed, selecting the worst-case scenario. This means that where there are multiple buildings on a parcel, the most fragile structural type of these buildings determines the overall value for the parcel. In Figure 1, the four attributes are presented. In green the most favourable conditions and in red the least favourable conditions.

Once the 4 individual attributes have been generated, the indicator can be calculated. In the case of Building Stock Fragility a decision tree was defined using the information provided by experts in surveys performed at the municipality. With this decision tree, each variable was given a score and all the possible combinations were given a final value that indicates how fragile each building is. The final values are presented for 2 aggregation levels: building by building and aggregated on a block basis (see Figure 2). The values range from 1 to 5, being 1 the least fragile and 5 the most fragile.

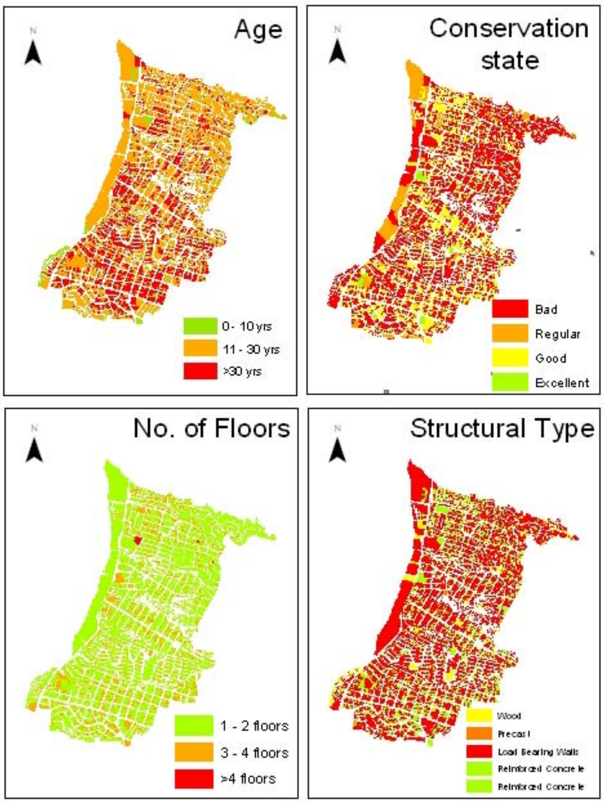

Figure 1. Building Stock Fragility Attributes

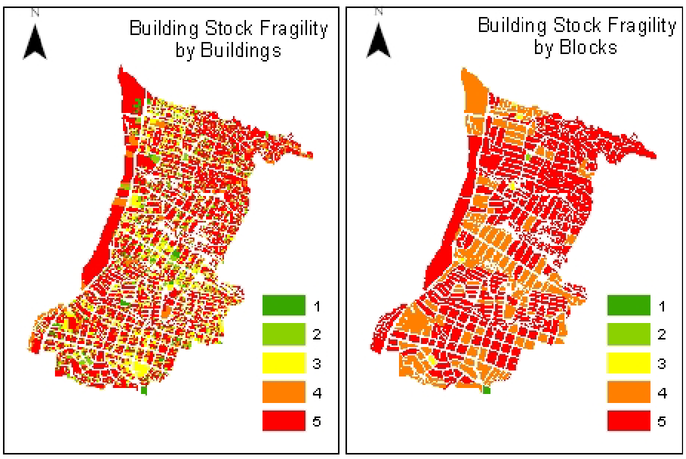

Figure 2. Building Stock Fragility Indicators at building a block level

Gap Assessment

A major problem in analyzing the vulnerability of populations and urban centers to natural hazards is the quantity and quality of information necessary as a tool to prevent, provide relief, and recover from a disaster situation. In this context it is interesting to know about the availability, quality, and quantity of information, as well as the about the possibilities of its analysis and continuous and timely processing.

A general model for the analysis of the information was consolidated. It encompasses the required information for each of the three phases of the occurrence and response to the disaster, and allows us to measure the vulnerability of the population and the possibility to plan and manage in order to reduce the vulnerability or increase the knowledge about this vulnerability in a region through improved data acquisition and management strategies.

The production of the required information poses important challenges at the planning level, since it implies that the necessary data is available and that it organized and managed in a systematic manner. In its raw form, the various datasets have different characteristics, domains and different collection and analysis dynamics (probability, aggregated projections, cartographic information, information with geographic representation, general political information, etc.). This complicates the exercise of analyzing its quantity and quality and ultimately its usefulness for vulnerability assessment.

Vulnerability assessments using existing municipal data, requires a definition a priori of what are the information needs in terms of data collection and information generation. In this sense a 2 way approach was implemented. First, a theoretical approach that gives us insight on what are the information needs based on existing vulnerability models, then what is information is needed (indicators) and finally which data is needed to assess those indicators. Second, a practical approach that deals with the problem in a reverse manner. That means, that each municipality starts with certain data that is already been collected for various purposes, that data is turned into information by multiple processes and finally, that information must be presented to the municipality in order to be used as a decision element when vulnerability reduction and building capacity measures are defined.

Each indicator presents a different challenge. In some cases, the raw data is already the indicator, but in many other cases, a thorough process is required in order to present the final indicators.

Returning to the Building Stock Fragility indicator, several issues arise in the process of producing the indicator. Cadastre data is collected basically for taxation purposes and not for assessing building vulnerability. Nevertheless some cadastral data is useful for assessing vulnerability and if consistent standards for data collection are developed, the amount of cadastral data useful for vulnerability assessment could be increased.

Minimal changes are required in order to produce consistent databases; a set of domains for each field and a set of rules and automatic consistency checks that regulate the quality of data during input procedures.

In terms of information generation, the models used to generate the indicators could be any one of the following: Analytical hierarchical processes, (AHP), Decision trees, Fuzzy Logic. Whatever process is used, the data sets and procedure should be well documented so that comparable future assessments can be made for the purpose of multi-temporal analysis, visualisation and diagnosis. Another factor that needs consideration is the aggregation level at which each indicator is presented. The aggregation of vulnerability data to block level may provide information that supports a more general discussion on intervention programs and plans. A survey with municipal experts has to be performed to define the best aggregation levels, according to the municipal policies for risk management and intervention possibilities. Ultimately such a survey may reveal that the higher aggregation level is less useful than we currently perceive it to be.

There are gaps between the theoretically defined needs for information and the ability to generate it from the actual data available. For each indicator, gaps in the data collection are found, especially in terms of what is required (theoretical approach) and what is actually collected and available (attribute detail). Modelling gaps are hardly found since very few municipalities perform vulnerability assessments in a systematic way, therefore defining the models is a straight forward procedure that only needs the participation of municipal experts. They must comprehend the flaws, gaps and usefulness of the data that they have already collected. Unveiling these aspects will allow the municipality to define an information strategy to improve data collection and information generation processes. To comprehend the flaws, gaps and usefulness, a methodology to define the fitness for use of the data used is needed. This will be the focus of the future work in our research.

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