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Assessing Disaster Risk of Building Stock

Methodology based on Earth Observation and Geographical Information Systems

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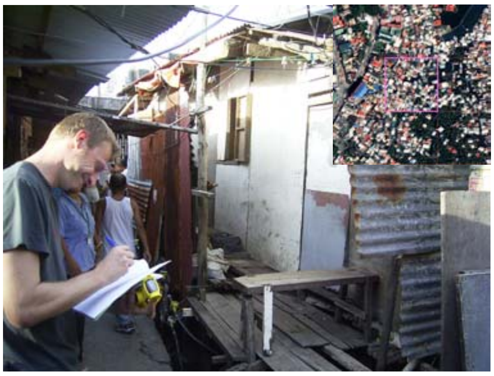

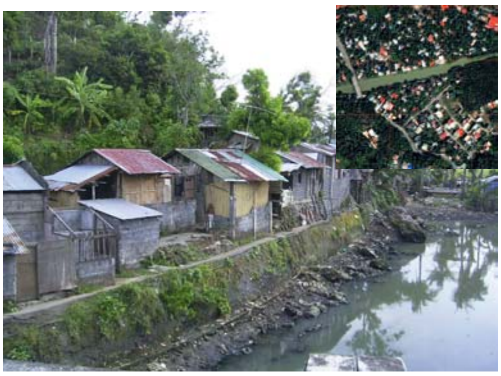

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Context

This work is part of JRC activities on the use of Earth Observation and geo-spatial information in crisis management. The work focuses on assessing disaster risk in built up areas and on the development of a methodology to assess the spatial distribution of risk factors and exposed elements. This contributes to the establishing of preparedness and mitigation measures in developing countries that are receiving renewed attention by the donor community and civil society.

This research is conducted in cooperation with the Development Research Group's Sustainable Rural and Urban Development Team (DECRG-RU) of the World Bank that is carrying out a policy research activity on the identification and analysis of urban disaster risks. This activity is part of the work on mainstreaming disaster risk issues in poverty reduction strategies under the Global Facility for Disaster Reduction and Recovery (GFDRR).

The work contributes also to European Commission development policies. Recent COM communication stresses Disaster Reduction in development countries as key to development (COM 2008). It is increasingly recognized that risk reduction is an essential step in the development process and that development, peace and security are interlinked.

1. Abstract

This work describes a methodology to assess **"risk to disaster"** due to natural hazards, particularly in data poor communities. It is to be used by (1) international organizations and donors to size development programs aiming to reduce risk to disasters and (2) by local authorities as a disaster management tool for implementing risk reduction, mitigation and preparedness programs. The methodology provides the guidelines to assemble a disaster risk information system that incorporates knowledge on natural hazards, construction science and disaster dynamics and is aimed for use by decision makers with the support of technical staff.

The methodology is based on Geographical Information System (GIS) technology for the development of a database of disaster related information including built-up infrastructure, population, vulnerability and the occurrence of natural hazards. It integrates Earth Observation (EO) and information collected in situ for generating essential information such as building stock and indirectly population distribution in hazard affected areas.

The database can also be used for generating damage assessment in the immediate aftermath of a disaster based on information on the hazard location and its intensity. Damage information can in turn improve the information content of the database to support more accurate risk assessments in the future. The information layers could then become important information that supports the development and urban planning projects.

2. Introduction

Natural disasters are on the increase and the demand for post disaster aid in low income countries is steadily rising. There is general concern within the international and donor community that insufficient resources will be available in the future to respond to all disasters. International organizations and donors, while continuing to respond to mass disasters, have started to actively address risk reduction, preparedness and mitigation. The most notable example is the establishment of the Global Facility for Risk Reduction by the World Bank.

Disasters can wipe out hard-won development gains in a matter of seconds (IEG 2006). In fact, there is a growing consensus that more should be invested in risk reduction, mitigation and preparedness programs that can reduce the impact of hazard and therefore the damages that may ensue. Only by identifying and measuring risks and vulnerabilities before a disaster occurs will we be able to address effective and long term disaster risk reduction (Birkmann 2007).

Disaster risk assessment in natural hazard prone high income countries typically relies on hazard maps. Hazard maps describe the probability and the intensity of a hazardous event to occur. The hazard maps are then combined with the exposed assets to produce disaster risk and pre-calculated damage for a given hazard intensity. The most notable example of loss estimation systems that combine hazard information, assets at risk and vulnerability is the HAZUS methodology supported by the Federal Emergency Management Agency (FEMA) of the US (FEMA 2003).

Low income countries - which are often very severely affected by disasters - do not have the extra resources to mitigate the impact of disasters. In fact, risk assessment is now being used to size development aid in countries that are affected by natural disasters. Hazard maps may be available from hazard specialists but these are often not combined with information about the elements at risk and their vulnerability to produce comprehensive disaster risk information. In fact, one of the main obstacles in disaster risk assessment is the unavailability of data on the assets at risk and their vulnerability as well as the lack of a capacity to model the combination of hazard, assets at risk and vulnerability information.

An international endeavour between the World Bank and the United Nations Development Programme (UNDP) made the first attempt to asses disaster risk globally (UNDP 2004). The work focussed on population and economic losses using countries as the unit of investigations. The disaster risk analysis continued with a global analysis of disaster hotspots (Dilley et al 2005). While providing an overview on likely regions of the world to experience risk the study pointed out the need to focus more on local studies that can more precisely asses risk. The development of a methodology for the fine scale analysis of risk is the objective of this paper.

The section below provides an overview of concepts on risk and damage assessment. The authors then propose a methodology to assess risk based on the stock of built up measured through remote sensing and hazard information obtained from existing sources and field work. The information is to be combined in a GIS that is then used to model, query and provide scenarios of damage. The methodology may be useful especially in low income countries since it can be sized to the resources available in local authorities. The methodology aims to assist both international and local decision makers.

3. Background and Terminology

A number of disciplines contribute to what has become the disaster literature. Each discipline brings inevitable its own point of views and terminology. Terms used in one discipline may be used with different meaning in a second discipline. The section below aims to summarize the terminology that can be used for damage assessment and disaster risk assessment. The clarification of terms aims also to provide an overview of variables that need to be measured and that can assist in quantifying damages and losses.

3.1. Hazard and disasters and risk

Natural phenomena such as earthquakes, hurricanes, floods, volcano eruptions that regularly occur in nature are referred to as natural hazards when they cause widespread damages to the populated and built-up environment. This damage can severely affect the functioning of a community and when it overwhelms its coping capacity it is generally referred as disaster. Disasters are usually ranked based on the damages to the built up infrastructure that capitalizes the assets of the communities. Disasters are also sized based on the number of people affected.

Disasters are often referred to as rapid onset or slow onset depending on the nature of the hazard. **Rapid onset disasters** are resulting from **violent natural hazards** that release devastating energy abruptly. The most devastating types are listed in Table 1. The most visible effect of violent hazards is widespread damage or total destruction of building and physical infrastructure. This physical damage may cause injury to **people** and the outcome may be increased morbidity or mortality.

Similarly to natural hazards also man made – industrial accidents and violent conflict - can affect infrastructure and people (Table 1). In fact, the release of energy from man made accidents or conflicts can be described and modelled similarly to the energy released from natural disasters. Yet, the processes that generate these disasters are outside the scope of this document. In fact, decision makers and international organization refer to post conflict needs assessment (PCNA) rather than post disaster needs assessment (PDNA) and the two processes are dealt with separately.

The **slow onset disasters** refer to those gradual natural phenomena that adversely affect the health and the nutrition base of the population and therefore their well being. Slow onset disasters include droughts that affect the agricultural resource base and therefore their provision of service and also biological agents – that trigger epidemics - that affect directly the health and therefore well being of people. Slow onset disasters may also be triggered by the disruption in societal functioning in the aftermath of mass disasters. This document discusses violent hazards originating from fast onset disasters and their impact on built-up infrastructure. Slow onset disasters are not addressed here.

Disaster literature addresses the estimation of the damages, the losses that occur as well as the cost for reconstruction. Increasingly, the assessment of the risk to disaster can be used to implement policies that aim to reduce the damages should a disaster strike.

Disaster (damage) risk – as discussed in this document – aims to provide estimates of potential damage for a given hazard striking at a given intensity. Damage assessments – measured after the hazard has struck - are based on observations of damages that have occurred. Damage risk relates to the assessment of hypothetical damage should a hazard strike at a given intensity. Estimating damage risk is thus a modelling exercise that includes also spatially modelling the energy released by the hazard.

Table 1 Natural events and the energy released that may trigger disasters. Shaded boxes show man made and slow onset disaster (gray) that are not addressed in this document.

Rapid onset	**Direct**	
	Violent Hazard	Energy release due to
Natural	Earthquake	Ground shaking (horizontal and vertical)
	Sea level surge	Horizontal pressure of water (cyclones) Sudden displacement of Earth crust from earthquake that generate Tsunamis
	Cyclones	Horizontal Wind speed
	Flash floods	Horizontal pressure from water flow
	Volcano eruption	Horizontal pressure of lava flow Vertical rock falls Horizontal movement of mud flows
	Landslides	Movement of ground
Man made	*Technological*	*Air pressure, explosion, industrial accidents*
	Conflict	*Shelling*
Slow onset	*Other Hazard*	*Effect on people*
	Drought ,floods	*High mortality due to lack of food – Famine*
	Biological	*High mortality due to high morbidity rates such as Epidemics*

Disaster risk may be computed also as the expected losses in a given region having a hazard striking with a given intensity and a given return period. This sort of modelling takes into account the probability of an event occurring in time is not addressed herein.

The following section first summarizes current damage assessment methodologies and then a methodology is proposed to assess risk to damage.

3.2. Assessing damage

The resulting impact of a violent hazard on man made infrastructure and people results in damage and casualties. There are a number of consequences that are common to all disasters. The ones usually measured in mass disasters where the international community is asked to intervene include (1) number of victims, deaths and injured, (2) reduction of the availability of safe housing and built-up infrastructure, (3) damage to health and education facilities, (4) decrease of income in most disadvantaged social strata,(5) temporary interruption of water sanitation, electricity, communication and transport (6) temporary shortages of food and industrial products (7) and macro economic effects that include modification of the employment structure.

The disaster literature has coined a number of terms that are briefly summarized below for the sake of clarification when discussing the damage assessment and reporting methodologies of the next section.

Direct damage is damage resulting from the direct impact of the hazard on a given asset (ECLAC 2003). Direct damage is also referred as direct cost (UNDP 2004). Direct damages are usually expressed as **direct economic losses** (HAZUS, 2003, Scawthorn et al. 2006).
Direct damage is mostly related **damage to physical infrastructure** and man made objects. The direct damages can be further subdivided in building repair and replacement cost to **structural** and **non-structural** damage. Other direct economic losses include building content losess and building inventory losses that when combined with structural and non structural loses are also termed **Capital Stock losses** (Scawthorn et al. 2006).

Indirect damage is damage that ensues from the loss of the function of a damaged asset (ECLAC 2003). Indirect damage is also referred to as indirect cost (UNDP 2004). HAZUS uses **indirect economic losses** to indicate the interruptions of operations of business that are affected by the damages suffered from business that supply them – referred also as backward-linked - or damages to business that use the products –referred also as forward-linked (Scawthorn 2006).

In this document with **indirect damage** we refer to the disruption of the functioning of a damaged building. For example, if a hospital is damaged and can function in reduced capacity, the damage is the decreased services provided to society. Similarly, if a power station is out of service there is an interruption of the service (from ECLAC, 2003). Direct social losses reported in disasters are typically the affected population and the number of casualties.

Damages are usually reported per economic sector (Table 2). Table 2 provides an overview of societal sectors considered in damage assessments, the element at risks and the measures of damages typically implemented. The elements at risk underlined are those addressed in this document.

The measurement and reporting of damage is essential to size emergency response and reconstruction aid programs. A number of methodologies are used for measuring and reporting. Three are addressed in this document: (1) The comprehensive ECLAC methodology for reporting damage - a top down approach aiming to provide a comprehensive damage assessment in all sectors, (2) The micro level HAZUS system, a bottom up approach focusing primarily on losses estimation to the housing sector in the United States and, (3) satellite imagery based assessment increasingly used to provide situation assessments in the aftermath of mass emergencies especially in the developing world.

Table 2. Disaster outcome assets and population affected

Societal sectors	**Element at risk**	**Type of Damages**	**Measures**
Social sector	People nutrition, health	Casualties (direct) Morbidity (direct)	Loss of lives Injured
Physical infrastructure	Building stock Lifeline systems	Damage to buildings and transport infrastructure (direct) Decreased service (indirect)	Cost of repairing Cost of interruption of economic activity
Agricultural	Physical infrastructure Crop area Livestock	Damage to buildings and infrastructure (direct) Destruction of crop area (direct) Loss of livestock (direct) Decreased agricultural output (indirect)	Cost or repair Cost of loss ag. land Cost of livestock lost Cost to interruption of agricultural output
Environment	Stock of natural assets	Destruction of environmental stock (direct) Disruption of service provided by the stock (indirect)	Direct stock loss Indirect services
Economic	Physical infrastructure Services Economic production	Damage to buildings and physical infrastructure (direct) Disruption of services (indirect) Disruption of economic processes (indirect)	Cost of repair Cost or disrupted services Cost of disrupted goods output

3.2.1. ECLAC

The Economic Commission for Latin America and Caribbean (ECLAC) has developed the most established damage reporting methodology used within the international community. It is commonly referred as ECLAC (2003)and it is destined to provide general information on affected population and economic losses in the different sectors of the economy. It was developed to report damage in Latin America and is now used extensively also to account for damages globally. It is flexible and can be adapted to different disaster types. In fact structures of damage assessment report may be customized to the different local environments.

The ECLAC assessment include the **damages to assets** – i.e. the replacement value of totally or partially destroyed physical assets, **the losses** – the economic losses which arise from the temporary absence of the damaged assets. ECLAC also provides **impact on post-disaster economic performance** with special reference to economic growth, the fiscal position and the balance of payments.

The damages and losses are based on information that is usually made available by local authorities. ELCAC sector field experts meet and get information from the local authorities and through field visits. Information is then compiled by ECLAC staff for use in estimation of development aid from the international community. It is the expert that provides the macro-economic assessments.

Typical sectors that are commonly analyzed in ECLAC reports include.

- **Social sector** encompassing the health, nutrition and education sectors.
- **Infrastructure** including **housing**, transportation, electricity, water and sanitation, urban and municipal and water resources. Housing is one of the most important since it directly affects the well-being of people. In fact, damages to housing also provide an insight in the severity of the disaster.
- **Productive sector** including the agricultural sector, industry, commerce and tourism sectors. The damages to these are further divided into subsections. For example the agricultural sector provides information on the losses to livestock, to the stock of agricultural fields or to the annual production forecasts.
- **Cross country issues –** typically includes damage to the environment

The great advantage of ECLAC – which explains its widespread use – is that it is adaptable to any circumstance and allows the incorporation of damages from different sources. The disadvantage is that it relies on disparate measurement of damages that can not provide a standardized damage assessment. It is a top down approach where information is fed into a system to provide a given overview.

3.2.2. HAZUS

HAZUS (Hazard US Multi Hazard) is the name of a standardized methodology used in the United States to assess losses from floods, earthquakes and wind (FEMA 2003). HAZUS was initially designed to estimated losses for earthquakes (Kircher et al. 1997) and has then been extended to cover losses for floods and tropical storms (Scawthorn et al 2006, Vickery et al 2006).   HAZUS methodology has been implemented as a software tool connected with a geographic database of physical assets. The database records information on every single building in hazard prone areas. The buildings are inventoried based on size and function and also classed based on a typology of 36 building types used to measuring the vulnerability of the building. The building types describe the structural characteristics based on the constriction standards and material.

The vulnerability (fragility) function is developed for each hazard based on the hazard geographical occurrence and intensity and the characteristics of the building infrastructure. The relation between the hazard and the damage for a given typology of building is generally referred to as physical vulnerability function. The hazard building damage relations are also referred as fragility curves in seismic literature (Kircher et, al 1997) and depth-damage functions by the flood community (Scawthorn et al 2006).

The HAZUS data and methodology development are combined in a software implementation (Schneider et al (2006). The software include C++ and Visual Basic routines to implement the loss models, and Microsoft SQL as relational database It also interfaces with ArcGIS and the suites of GIS programs supported by ArcGIS (Schneider et al 2006).

HAZUS can be successfully implemented in the US because (1) US has extensive and complete databases of the assets exposed and the information are available in digital form in a GIS system linked to a database, (2) it covers the typology of buildings of the United States, and (3) it is customized to analyze damages ensuing from the impact of three hazards only.

If the concept from HAZUS has to be ported to developing countries risk assessments it would have to address a number of issues. The building stock database may be simplified to account for less data available. There is an urgent need to develop tools. Vulnerability curves – the linking of type of building with potential damage that ensues from a hazard - may have to be constructed and/or adapted to take into account different type of buildings as well as different construction standards. Hazards typically not addressed in the US may have to be considered. Hazard that wreak great havoc in many developing countries include land slides as well as the effects of volcano related hazards like lahars and pyroclastic rock falls.

3.2.3. Assessing damage using pre- and post-disaster imagery

Satellite imagery has started to be used in damage assessment to support two phases of the crisis (1) rapid physical damage assessment for situation assessments in the emergency response phase of a crisis and (2) more detailed losses estimation in support of reconstruction. Satellite imagery has the complementary potential to be used in rapid damage assessment to provide some quantitative measures and a synoptic overview of an affected area in the immediate aftermath of the disaster.

Rapid damage assessment

The combination of pre-disaster and post disaster satellite imagery analysis is being used more widely today to assess damage to physical infrastructure. Satellite image analysis is used specifically to collect information on areas that are not easily accessible or for which it is difficult to get information. This is typically the case in conflict scenarios and when disasters occur in poorly mapped areas of the world. Post disaster and/or combination of pre-disaster and post disaster imagery has shown to be particularly effective when the damages are so severe that buildings have collapsed. Rapid damage assessment focuses mostly on damage to building and physical infrastructure because (1) buildings are among the most valuable assets for society, (2) damage to buildings can be related to the affected population; (3) the damages can be seen on post disaster VHR imagery.

In fact, post disaster imagery is used often to assess the severity of the disaster. The satellite analysis is summarized in information products in the form of situation or damage maps that are provided to field officials for navigating in the field and aid implementation agencies to plan their emergency response operation. Satellite derived damage assessments have shown to be also useful to support donor conferences. Rapid assessment – due to the nature of the process – provides physical assessments in the form of number of houses affected or total population affected. These rapid assessments are then followed up with more detailed analysis and field surveys that provide the quantification of damage in monetary terms, the post disaster needs assessments.

Detailed loss assessment

Detailed loss assessment often uses satellite imagery within a geographic information system to provide a geo-spatial database to which to associate loss information. The detailed assessment relies on expertise from the field for detailed damage observations. The satellite imagery provides the capability to spatially extrapolate the damages accurately measured from the field to similar building identified on the satellite imagery.

4. Measuring disaster risk (risk to losses) to physical infrastructure

Disaster risk assessment is a relatively new topic and was first discussed in the "Reducing Disaster Risk" Report of UNDP (2004). The report introduces an important conceptual development with the distinction of the three important variables, hazard, element at risk and vulnerability. The work was in fact followed up by the hotspot risk assessment (Dilley et al. 2005) who analysed the vulnerability of population and economic activity based on the occurrence of natural hazards and the EMDAT disaster database (EMDAT, 2004). The work has been further addressed by Peduzzi (2006). New developments are being evaluated at UNDP and an updated report is expected by June 2009.

Two other projects have addressed disaster risk: MIRISK and the RiskScape projects which are briefly described below.

The Mitigation information and Risk identification system (MIRISK) is produced by the Alliance for Global Open Risk Analysis (AGORA, 2008) a worldwide alliance of civil engineering academic institutions. MIRISK is a tool comprising database, web based software that allows for querying risk values for given infrastructure. It is geographically based. It relies on a database of hazards available for global hazards risk for earthquakes, floods, volcanoes. The assets at risk considered is the infrastructure that is planned to be constructed. The vulnerability is determined by the construction material and standard to be used in the project. It is designed to calculate the risk of projects to be funded in developing countries.

MIRISK does not take into account hazard that have a more local effect like landslides. It relies on a global hazard database that may be too coarse to address local hazards. It is designed to compute risk of planned infrastructure rather than existing infrastructure. In fact, it does not take into account informal settlements. It is an excellent system that assembles information sources collected from different disciplines and provides an insight to decision makers.

The RiskScape regional model (Schmidt et al. 2007) is developed to simulate regional scenarios of disaster and produce estimates of damage expressed in dollars and likely casualties. It is designed for risk reduction and risk mitigation purposes in multi-hazard environment of New Zealand. The methodology is based on assessing the three disaster risk parameters (1) hazard, (2) asset at risk database and (3) vulnerability of the assets at risk. The latter parameter is considered to be the most difficult to estimate (Rees et al. 2007) also in knowledge and data rich New Zealand. RiskScape has the ambition to also assess the impact on social and economic assets. It is based on GIS technology with a sophisticated front end for the user.

4.1. Measuring disaster (damage) risk to physical infrastructure

The objective of measuring disaster risk is to estimate potential damages for a given hazard or the combined effect of natural hazard. The risk is measured to take preventing measures that allows to reducing the impact should a hazard strike. The risk measure is thus related to a hazardous event occurring in a given area with a given intensity.

Disaster (damage) risk relates to the damages that an element at risk may suffer should a hazard strike. Disaster risk can be expressed in general terms (after UNDP 2004, Peduzzi 2006) as:

Disaster Risk = Hazard * Element at Risk * Vulnerability

This document addresses the risk of damages to the stock of built up. The following sections describe the quantification of three variables separately, (1) the element at risk that in our case is the stock of the built up, (2) its vulnerability, and the (3) assessment of the hazard. Important to stress is that the stock of built up includes buildings that may be serving sectors other than infrastructure as discussed in Table 2. This general disaster risk equation is applied locally within a GIS.

4.1.1. The element at risk

The element at risk measured herein is the building stock made up of the number of building of any type. That would include the housing stock but also commercial or agricultural buildings. The building stock can be measured from VHR satellite imagery. Total enumeration of buildings can be obtained by (1) counting buildings, (2) measuring their footprints or (3) measuring their volume. Statistical approaches that sample a number and extrapolate the analysis to larger area are also an option.

The three measures have an increased precision and a higher computation cost associated to it. Count and footprint area can be obtained from analysing single date imagery. Volume estimation requires stereo image acquisition and therefore resulting in, at least, twice as much the cost. A detailed analysis of the potential of VHR satellite imagery is available in Ehrlich et al (2008).

The building stock (B) over an area with buildings (b) can therefore be expressed as

$B_c = \sum b_c$ B_c - stock measured as the sum of buildings

$B_f = \sum b_f$ B_f - stock measured as the sum of the footprint area of each building

$B_V = \sum b_v$ B_v - stock measured as the sum of the volume of each building

The damage that may occur is the measured cost of construction of every single building or the cost of repair. It is a fraction of the cost of construction or in case of total destruction it is the full cost. The damages can therefore be computed if the value of the stock of the built up is available with the value is expressed as the cost of constructing the stock. An example of the quantification of the building stock as measured from VHR imagery as shown in figure 1 and Example 1.

Example 1: Value of the building stock in Legaspi

The image analysis over the 1 km^2 in the city of Legaspi provides a total count of 3111 buildings. The sum of the area of the footprints adds up to 267’120 m^2. The value of the assets can therefore be computed by multiplying the average cost of building times the number of buildings, or as an average cost times per square meter times the sum of the area. A more realistic estimation would take into account the value of buildings. In fact, buildings may be of different materials and therefore value. Buildings in developing countries are often made up of diverse material assembled without following building standards. These are often referred as informal settlements. Other buildings, especially public or commercial buildings do follow engineering standards because their size and function require proper construction. In order to differentiate the building stock, the authors propose to group buildings based on the material and the building standards used. The classification of buildings has two functions (1) to determine the physical vulnerability and the (2) value of the building. An example of the value of building is discussed in the example below.

Figure 1. Footprints of building measured from VHR imagery

The figure 2 A and B show a hypothetical subdivision of the stock of built up in buildings of high value and those of lesser value. The selection was based on the size of the building and expert knowledge. Small buildings are assumed part of the stock of informal settlements. These are usually of poor construction standards often made of assembled material of poor quality. The informal settlements account to 2516 while more formal constructed buildings account to 595.

The area covered by the 2516 buildings of type 1 accounts to $B_f(1) = 107'650\ m^2$
The area covered by the 595 buildings of type 2 account to $B_f(2) = 154'970\ m^2$
If a value of 10 Euros per square meter is attached to the informal buildings and 100 to the formal buildings the value of the stock over the $1km^2$ would account to $\mathbf{B_f(2)} = 15'497'000$ and $\mathbf{B_f(1)} = 1'076'500$ Euro for a total of $\mathbf{B_f(tot)} = 16'073'500$ Euros. This total value is the economic asset at risk to be used in the risk to damage equation.

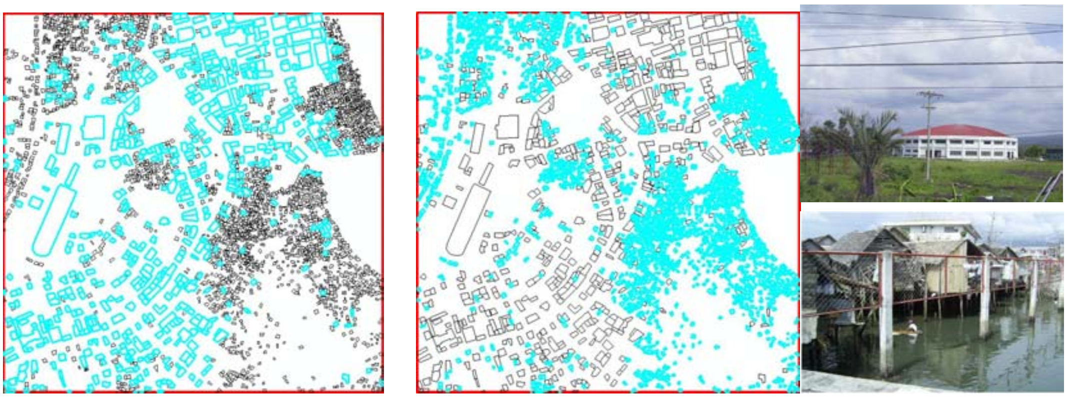

Figure 2. Example on the use of VHR to assess the building stock.

The damages that occur to the building stock when a hazard strike varies according to the quality of material and construction standards used. Formal dwellings that follow engineering standards are usually more robust than informal dwellings found in many developing countries. The type of buildings available in a given area characterized by their physical characteristics determines therefore their susceptibility to suffer damage. This susceptibility is measured by combining physical vulnerability and intensity of the hazard.

4.1.2. The Physical Vulnerability

Vulnerability is the likelihood to suffer losses (damage). The physical vulnerability is the likelihood to suffer damage that can be expressed as cost of repair or of reconstruction. For a given building stock the risk of damage is a function of the intensity of the hazard and the vulnerability of the stock. In construction science structural damages are related to the intensity of the hazard through the **vulnerability curves** or fragility curves as are expressed in seismic science.

The physical vulnerability is related to the quality of construction - construction material and construction practices – which defines the solidity of the physical infrastructure. Poorly built buildings will be more likely to collapse and therefore increase the probability that people are injured. Damages are always hazard dependent. For example, inexpensive structures such as huts may be less vulnerable than masonry buildings to earthquakes. Yet, huts may not cope with the wind pressure of tropical storms and therefore are more vulnerable than masonry buildings.

The discussion on vulnerability of the physical infrastructure is relevant for those **hazards that may release their destructive energy at different degrees of intensity**. For example earthquakes can occur with different magnitude and have their ground motion shaking at different intensities. Similarly, sea level surges can occur with different wave heights. Other natural hazards like lava flows, landslides, compromise completely the built-up structures. In these cases the building characteristics are less relevant for the estimation of the buildings since the structures are completely compromised when the hazards strike. There is no point to build a vulnerability curve. The assessment of the damage would still require the typology of the building that determines its value.

Vulnerability curves are thus developed for those hazards that can manifest themselves with different degrees of intensity. The physical vulnerability is a function of building standards and material. In order to structure the discussion on vulnerability we propose to class buildings based on their construction based into six building types. The aim of the classification scheme is to group buildings that react in a similar way to the impact of a hazard. The typology of buildings is then used to build vulnerability curves. The classes of buildings types are used also to attach a value to the building in order to assess the asset at risk and therefore the damage, should a hazard occur.

The **classification scheme** of **building types** aims to take into account also informal dwellings found in many parts of the developing world. It combines therefore information from civil engineering with empirical observation from researcher for the informal or temporary dwellings for which there is no standard but that form the large majority of dwellings in the developing world. Three classes – class 1 to 3 – include formal buildings that were derived by aggregating the typology available from the World Wide Typology of Buildings (WWTB) and three classes are also reported in Lang (2002). Class 4 and 5 include buildings that are found in informal settlements that arise in the surrounding of the large cities of the developing world, and in rural areas and class 6 the temporary shelters for displaced people (Table 3).

Table 3: Classification of building types based on their material and construction characteristics.

B Type	Definitions	Brief description of structural characteristics of building type.	Where	On Damage
1	Advanced technologies Reinforced concrete and Steel structures	Structures constructed with highest standards. Typically employed for large and tall buildings. Disaster affected areas in developed countries will all comply with these standards. Includes WWBT class 9	Cities and large metropolitan areas	Sustain pressure and vibration
2	Reinforced Concrete Frame Buildings	Building constructed according to engineering standards. Typically on cement pillars with roof/pavements also in cement. By and large WWBT class 6, 7, 8	Settlements, Mostly in high income countries	Sustain pressures, shakes
3	Traditional building with rubble stone, field stone, adobe masonry or wood	Traditional building standards using local expertise and material (mortar, adobe, bricks, wood). It largely varies from geographical areas. The dwellings follow traditional building practices but are not constructed with scientific/engineer criteria. Typically not constructed to absorb shocks to natural disasters. WWBT class 1-4 and 10	Large part of dwellings of the worlds are constructed with these standards	These buildings are typically damaged during catastrophic events
4	Assembled material in informal settlements	Dwelling constructed with assembled material for a lack of resources, typically found in poor neighbourhoods of urban centres and settlements.	Dwelling type in many low income communities	Typically very instable and vulnerable to damage
5	Perishable material	Dwellings from natural material that include wood that need to be constantly fixed and repaired.	Rural settlements in tropical countries	Typical dwellings in farming communities
6	Temporary, Removable	Those made of material that require constant maintenance and those that are regularly removed.	Temporary settlements	Vulnerability very dependent on hazard type

The **Vulnerability curves** relate the intensity of the hazard with the damages that may ensue. Vulnerability curves are often available from scientific literature and referred as fragility curves in seismic science. These are derived often from laboratory experiments that simulate the ground shaking provoked by earthquake and measure the corresponding damage. Vulnerability curves can also be derived empirically by observing the damages that have occurred on past disasters with a given intensity. If damages are not observable, city authorities or hazard experts may provide the information that can be used to relate the potential hazard intensity with the ensuing damage.

The curves may be empirically derived through a matrix as shown in figure 3. The columns provide the hazard intensity while the rows the typology of building. The crossing cell will provide the expected damage expressed in percentage. The information of the table can be plotted to derive vulnerability curves that relate the damage and the intensity of the hazard. Fragility curves will have to be developed for every single hazard type and building type present in a potential disasters area.

For example it may be observed that for a given hazard intensity (i.e. expressed in peak ground acceleration in case of earthquakes) type 3 will suffer 10% damage, while building type 2 will suffer 50% damage and type 1 building types 100%. The information would be filled in the first column of the table. This procedure can be used to estimate the damage of building due to different hazard intensity.

Hazard Intensity

BuIldIng

	.2	.4	.6	.8	1
1					
2					
3					

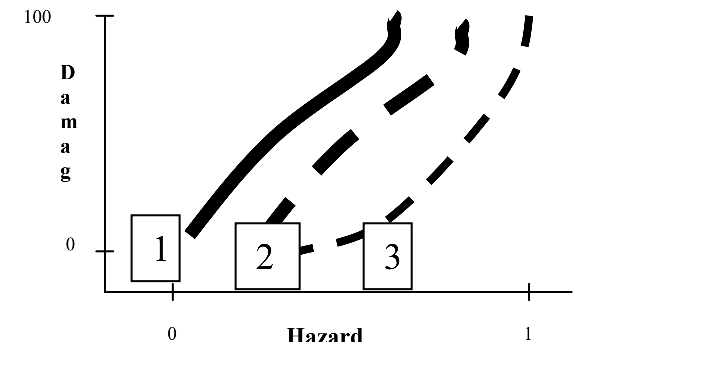

Figure 3: Quantification of the physical vulnerability (fragility) to Hazard A. Left figure shows the matrix used to report damages based on building type and intensity of hazard. The plotted values are used to shown the vulnerability curves that are building type specific.

This procedure for assessing disaster risk requires vulnerability curves formally established for each **building type** and for **each hazard**. The information on the total number of buildings corresponding to a given building type would be provided by satellite image analysis and expertise from the field. In the best example every single building would be measured and classified as a building type. The information that is geographic specific would then be saved into a GIS. For more rapid estimation of risk to damage a statistical approach can be used. In this case a sample of buildings available in a single area and their vulnerability will be measured and the total number of buildings and their vulnerability would be extrapolated through statistical methods.

4.1.3. Measuring <u>indirect</u> disaster risk

The indirect risk to damage used herein refers to the interruption of a service. This indirect damage can not be measured from remote sensing but rather inferred from the typologies of damaged buildings if their use is known. The uses can be classified based on classification systems of which a good example is shown in figure 4. The use of building is also important to determine the location of people and their whereabouts should a disaster happen. In fact, residential areas will be populated at night while building for commercial use and services are more likely to be populated during the (work-)day. Use and occupancy of buildings are typically determined through field surveys that are not addressed herein.

	1	2	3	4	5	6	7	8	9	10	11	12	13
	Agricultural E	**Commerci**	**Dwellings**	**Educational**	**Governm**	**Industri**	**Military**	**Parking Stor**	**Religious**	**Transit**	**Recreation**	**Health**	**Other**
1	Barn	Bank	Apartment bloc	College	Capitol	Factory	Barracks	Aircraft hang	Church	Airport termi	Bathhouse	Hospital	Aqueduct
2	Chicken coop c	Bar	Asylum	Classroom Bu	City hall	Power pl	Bunker	Barn	Basilica	Bus station	Stadium		Arcology
3	Greenhouse	Pub	Condominium	Dormitory	Consulate	Refinery	Blockhous	Boathouse	Cathedral	Metro (subw	Arena		
4	Silo	Brothel	Dormitory	Gymnasium	Courthous	Mill	Castle	Garage	Duomo	Train station	Marina		Low-energy
5	Stable	Casino	Duplex	Students' uni	Embassy		Citadel	Shed	Chapel	Signal box			
6	Storm cellar	Forum	House - see Lis	School	Fire station		City gate	Storage silo	Oratory				
7	Tide mill	Gas station	Nursing home	Library	Palace		Defensive	Warehouse	Martyrium	[edit] Other			
8	Root cellar	Hotel		Museum	Parliament		Fort		Mosque				Triumphal a
9	Hay loft	Motel		Art gallery	Police station		Fortification		Mihrab				
10	Farm house	Market		Theater	Post office		Tower		Imambargah				
11	Well house	Nightclub		Amphitheater	Prison				Monastery				
12	Shed	Jazz club		Concert hall					Mithraeum				
13	Grainery	Office building		Movie theater					Fire Temple				
14	Watermill	Restaurant		Nickelodeon movie theater					Pyramid				
15	Wind mill	Skyscraper		Opera house					Shrine				
16	Horse mill	Shop		Symphony					Synagogue				
17	Pigpen or sty	Shopping mall		University					Temple				
18		Stock exchange							Pagoda				
19		Supermarket							Gurdwara				
20													

Figure 4. Use of buildings and built-up stock available from: (http://en.wikipedia.org/wiki/List_of_building_types_)

4.1.4. Hazard risk

Natural hazard risk refers to the probability of a natural hazard to occur. It is expressed in probability of occurrence at a certain level of magnitude. Hazard risk is addressed by the different hazard disciplines and developed especially within the seismic, cyclone sciences. Global hazard risk includes the G-Shape a global data layer covering the surface of the Earth and indicating the probable intensity of ground shaking due to a seismic event. The community studying tropical storms has developed a database of past tracks of tropical storms with relative intensity. These data can be used to assess the probability of cyclones to occur.

The global hazard datasets may be too coarse to capture the variability of local hazards and therefore not suitable for local studies. Unfortunately hazard maps are often not available for many developing countries exposed to natural hazards where the need would be greatest. Hazards maps are lacking especially for gravity related hazards such as land slides, lava/lahars, flash floods that are very local in nature but their cumulative effect is significant. A detailed discussion of natural hazard risk is not addressed in this document and mentioned only for the sake of completeness.

4.2. Disaster risk assessments within a GIS

The disaster risk for a given building stock is a function of the **intensity of the hazard** in a given place and the **vulnerability** of the building stock. It has to be computed separately per hazard for the different building typology. The disaster risk is best expressed as a loss function where the built up is expressed in monetary value and the losses as a fraction of these values. The losses of a given building (b) of building type "k" –as defined in table 3 -, with reconstruction value "c" to a hazard of intensity Hi and a Vulnerability $\mathbf{V_{(Hi,k)}}$ is

$l(i) = Hi *c_k b_k * V_{H,b(k)}$; (1)

The losses over a geographical area (A) made of M building types (k) is then

$$L(i) = \sum_{k=1}^{M} \sum_{n=1}^{B} l * cb(Hi, V(Hi, bk)) \qquad (2)$$

The total losses will then have to be cumulated for every hazard

$$TL(H) = \sum_{h=1}^{H} L(i) \qquad (3)$$

Example 1 (continued). Hypothetical damage in Legaspi

An earthquake Intensity 6.5 (Richter scale) and with a ground peak acceleration over the area of interest of 2 m/s that causes the following type of damages. We assume – as we have shown in Example 1 - that the value of building type 1 is 10 Euro/ m^2 and the value of building type 2 is 100 Euro/ m^2. Based on the figure value of the stock over the 1km^2 would account to $\mathbf{B_f(2)}$ = 15’947’000 and $\mathbf{B_f(1)}$ = 1’076’500 Euro for a total of $\mathbf{B_f(tot)}$ = 17’023’500 Euros.

The damage would then account to

Building type 1. Damage 30% 4’784’100 Euros

Building type 2. Damage 80%. 861’200 Euros

The damage to infrastructure would therefore be 5’645’300 that is 33% of the total value.

The damage can be related to people affected but there is no direct relation between structural damage and people affected. The number of victims would be more related to the typology of buildings and the casualty function should be independently computed with rules related to the occupancy, the use of buildings and the time of the day when the hazard event took place.

The financial damages (losses) as expressed in example 1 can be easily implemented within a GIS framework when geo-spatial layers are properly adjusted and geographically corrected. Three types of expertise are critical when developing the disaster risk tool described. The **hazard specialist** will provide an energy propagation model, **the structural engineer** that provides the vulnerability (fragility) curves/information that related the intensity of the hazard to the building characteristics, the **image analyst** will provide information on the built up stock and the GIS specialist that will structure the information, encode the knowledge and pre-develop the queries the system is supposed to answer.

For example, for earthquake losses estimation the **seismologist** will provide an ground peak acceleration information based on intensity of the hazards, soil type and conditions and liquefaction potential (Bommer et al 2002); the

structural engineer will have provided the fragility (vulnerability) curves and also the value of the buildings based on the cost of reconstruction. The GIS specialist will integrate the knowledge related to the built up stock, its vulnerability and the hazard information in the GIS and will provide the proper query functions.

Other expertise will be required if the system is asked to provide also socioeconomic losses. The most important other information required by decision makers is the population potentially affected by the disaster. The affected population can be estimated provided occupancy information are available and the use of the buildings. In fact, especially for fast onset disaster that may have different outcome whether they are used during the day or at night.

An overview of the conceptual flow of information used to build the GIS database related to disaster risk is shown in figure 6. The figure illustrates the input data, the GIS layers that can be derived and the queries that can be answered by the system if constructed. The input **data** include Hazard information. - derived from existing databases, field visits and when possible Earth Observation the **built up stock –** that can be derived from EO, and data collected from **field visits** that include building class, use, occupancy and value.

The information layers are then stored in **GIS** layers. The typology use, occupancy and value of buildings are attributes attached to the stock of built up. The typology of buildings is used to derive the physical vulnerability that is also an attribute of the building. The queries allow to assess the total value of the stock of built up, the damage based on a given intensity of the hazard. If occupancy and use of buildings are known, then also the people affected and indirect damage can be estimated.

5. Discussion

Disaster risk assessment is a relatively new topic that requires drawing knowledge from different disciplines. There is a need to reconcile definitions, units of measures and procedures to allow analytical computation of disaster risk.

Quantifying disaster risk requires combining hazard intensity information with the built up stock and its vulnerability. VHR imagery has shown to be useful to assess stock of built up. Its spatial resolution is suitable to identify and measure the majority of buildings. However, the smallest buildings and dwellings such as those in shanty towns can often only be identified and not measured. Despite this limitation, satellite VHR imagery shows to be a excellent data source that can provide standardized built up information globally.

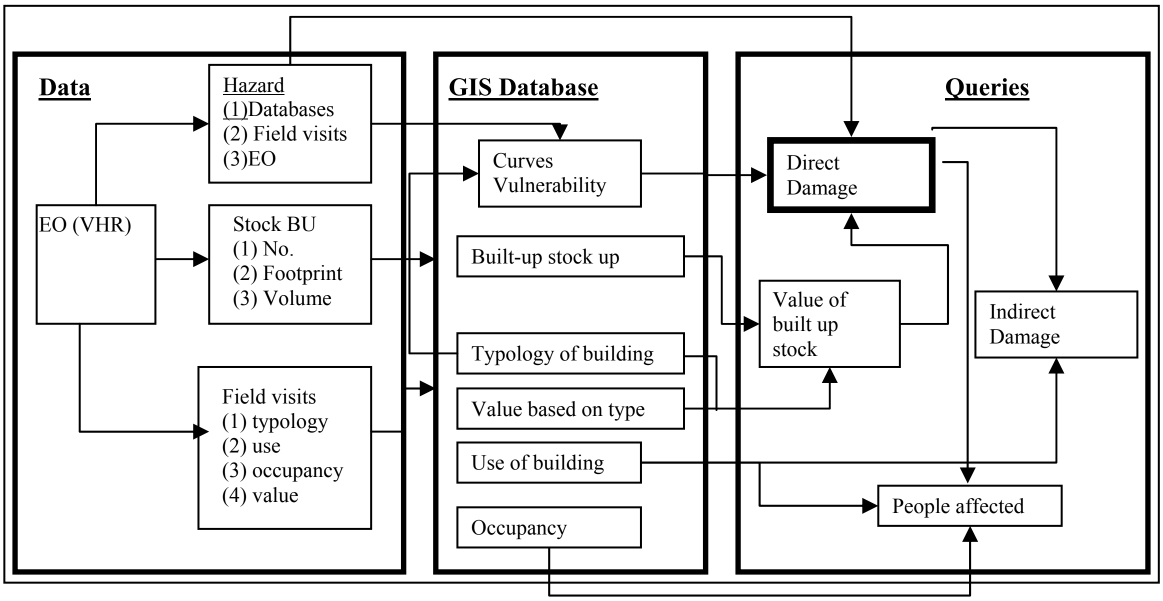

Figure 5. . Source of information, flow of information and products used in disaster assessments

The information on the built-up stock can be extracted using basic photo-interpretation techniques. These are deemed appropriate for the analysis and if rapid results are needed a sampling exercise can be applied to reduce time and costs. More automated ways are being developed and will soon be available from the image processing community.

The physical vulnerability of the stock of built-up can be derived by combining earth observation and field visits. While EO provides the location and the sizes of the buildings, it is the observation of the field that allow to characterizing the buildings. Field visits provide information on the typology and use of the buildings. Those are used to deriving the vulnerability to hazards.

There is a tremendous lack of information on the physical vulnerability of buildings to hazards especially in low income countries. The best vulnerability curves are developed by seismic science. However, even for hazard risk the vulnerability curves need to be re-calculated for every place on earth since construction standards and material differ from country to country and from place to place.

There is also a lack of hazard information available at fine resolution to be used at local scales in many developing countries. Current global hazard risk are too coarse to be used for fine scale analysis such as that used by municipalities. The newly available SRTM Digital Surface Model (DSM) data or Digital Elevation Model provided by high resolution stereo imager may provide finer information to be used to assess the risk of gravity related hazards.

The available disaster databases (i.e. EM-DAT 2004) that could be used to derive vulnerability – these have been used for the global grid hotspots – cumulate direct, indirect macro and micro economic losses estimates.

While invaluable to document trends in disaster these are deemed inadequate for assessing vulnerability at local level.

6. Conclusions

Disaster reduction is not a new issue. However, the quantification of disaster risk through an analytical procedure is relatively new. The quantification of disaster risk was first addressed by UNDP in the Disaster reduction report (UNDP 2004). It is that report as well as the World Bank Reports (IEG 2006) that brought to the attention of the larger international community that disasters can destroy development gains and that urgent action is needed to focus the attention not on response but in reducing the risk. The disaster risk hotspots report (Dilley et al. 2005) provided a global analysis identifying the areas most at risk and asking for more detailed analysis. This report follows that line of investigation and aims to provide a methodology to support risk assessment at local level in support also of local authorities. This document provides a framework that can be used and that uses remote sensing and GIS as important technology.

This report identifies the disaster risk equation that includes hazards, element at risk and vulnerability as the analytical foundation for local disaster risk assessment studies. The report analytically describes the process and identifies the challenge of disaster risk assessment is in combining the expertise and knowledge of different disciplines, natural hazard analysis, civil engineering and Earth Observation, Image processing and GIS.

A complementary report to this (Ehrlich et al. 2008) shows that satellite images can play a very important role in the definition of the built-up stock. This stock can be assessed from remote sensing data alone. The physical vulnerability – to be considered as an attribute to be associated to the built-up - can be assessed through remote sensing and field observation. The hazard information that is often available is usually provided by expert knowledge in the form of existing maps. However, there are a number of gravity related hazards, especially land slides that are rarely addressed. Earth observation in this case can be used to assess the potential hazard.

The disaster risk methodology is based on GIS technology acting as integrator of spatial information of different forms and sources. The GIS provides the analytical frame to conduct analysis and to develop scenarios and the queries that would be used by decision makers.

There are a number of challenges for disaster risk assessment in developing countries include. First, bring together in one system expertise and knowledge provided by different disciplines in a suitable format. Second, develop hazard information at local level. In fact, if hazard information exists, this may be too coarse to be used in local studies or not available at all. Hazard analysis also requires the spatial modelling of hazards over the affected area in order to have the energy released by the hazard at the geographical location of the built up. Third, generate at reasonable cost the information of the stock of built up. Satellite imagery has shown to be a quite reliable datum to provide the information but the extraction of information remains very costly. New and automated image processing techniques are in high demand. Fourth, provide information on the material and the construction standards of the stock of built up that determines the physical vulnerability. This is typically carried out through a combination of remote sensing imagery and field work and this remains the most costly.

The information needed for assessing risk to disasters should be part of a database available at the district and national levels. The development of these layers should be justified by the multiple use these data. In fact, spatial data such as stock of built up can be used in a number of applications that include census tract delineations , urban planning, territorial management, fleet management, hospital location and in cost saving in future disasters should the mitigation and preparedness programs be put in place.

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Abstract
This work describes a methodology to assess "risk to disaster" due to natural hazards, particularly in data poor communities. It is to be used by (1) international organizations and donors to size development programs aiming to reduce risk to disasters and (2) by local authorities as a disaster management tool for implementing risk reduction, mitigation and preparedness programs. The methodology provides the guidelines to assemble a disaster risk information system that incorporates knowledge on natural hazards, construction science and disaster dynamics and is aimed for use by decision makers with the support of technical staff.

The methodology is based on Geographical Information System (GIS) technology for the development of a database of disaster related information including built-up infrastructure, population, vulnerability and the occurrence of natural hazards. It integrates Earth Observation (EO) and information collected in situ for generating essential information such as building stock and indirectly population distribution in hazard affected areas.

The database can also be used for generating damage assessment in the immediate aftermath of a disaster based on information on the hazard location and its intensity. Damage information can in turn improve the information content of the database to support more accurate risk assessments in the future. The information layers could then become important information that supports the development and urban planning projects.

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