Development of a system for landslide risk assessment for Cuba

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ABSTRACT: In many developing countries, such as Cuba, landslide-affected areas are not systematically mapped in a national inventory and no "regional to local" approach for landslide hazard and risk assessment has been carried out so far. Most of the conventional landslide studies in Cuba are qualitative in nature and focus on description of phenomena or on landslide susceptibility assessment. Moreover, most of the quantitative landslides risk assessment methodologies that have been developed elsewhere are very case-specific and require many types of data, on landslide occurrences and impacts, most of which are not available in Cuba. This research is aiming at the development of a methodology for spatial landslide risk assessment for the Civil Defence in Cuba, taking into account the conditions of Cuba regarding the required levels (scales) of analysis, the triggering factors and the data availability. It aims at implementing the methodology in four case study areas at national level (1:1,000,000 scale), provincial level (1:100,000 scale), municipal level (1:50,000 scale) and local level (1:25,000 scale). This hierarchical approach will allow comparing the suitability of risk assessment methods at each level for the specific conditions of Cuba. The research will focus on the generation of a national landslide inventory database, which should provide the magnitude and frequency information needed for risk assessment. The landslide inventory will be carried out by setting up a landslide-reporting system by staff from the 169 local Civil Defence branches in Cuba, and by multitemporal airphoto and satellite image interpretation, using visual stereoscopic interpretation methods.

1 INTRODUCTION

Landslides are recognized as the third or fourth type of natural disaster in importance worldwide, depending on the region (Zillman 1999). However, this is often not very well reflected in the official statistics, where landslide damage is often grouped under the triggering events that caused them (e.g. hurricanes, earthquakes). According to the statistics of the EM-DAT database (OFDA/CRED 2004) landslides have caused 53,693 deaths and affected 9,560,090 peoples around the world in the period 1903 to 2004. According to the same database, the quantification of damage in this period reaches over 3,5 billion US dollars, whereas such amounts are reported in other literature as yearly losses in a single country like Japan or the US (Schuster 1996).

In Cuba, most landslides are associated with hurricanes, tropical storms or prolonged rainfall periods (Viña et al. 1977, Formell & Albear 1979, Pérez 1983, Díaz et al. 1983, Magaz et al. 1991, Iturralde-Vinent 1991, Castellanos et al. 1998, Pacheco & Concepción 1998, Castellanos, 2000). As the landslide damage is associated to the main disaster there is generally no record about how many landslides have happened and where they are located.

To illustrate the frequency of the meteorological events in Cuba, since 1785 up to 1984 the national territory had a total of 108 reported hurricanes (Rodriguez 1989). Out of a total of 240 hurricanes from 1983 to 2003 in the Atlantic basin, Cuba was hit by approximately 50 (Thompson & Gaviria 2004).

However, there are no official records for landslides related to these events. All disasters damage that occurred was recorded as been caused by the hurricanes and no detailed description was made for the subsequent disasters like flooding or landslides. Even though, in a report presented by the National Civil Defence Headquarter it was recognized that 45,000 inhabitants in Cuba are vulnerable to landslides (EMNDC-Estado Mayor Nacional de la Defensa Civil 2002).

By a simple analysis of the database EM-DAT (OFDA/CRED 2004), during the XX Century (1900-2004) 56 important natural disasters have been registered in Cuba, from which 21 were hurricanes or cyclones, 18 flooding, 5 storms, 6 droughts, 2 earthquakes, 2 forest fires and 2 epidemics. During this period 5,110 peoples had died and 2,1 billions of US dollars in losses have been registered. The damage caused by the hurricanes Charley and Ivan, which occurred in August and September 2004 have not been included in this figures.

Due to the lack of a landslide inventory, the knowledge about geological, geomorphological, tectonic and hydrological conditions in landslide areas in Cuba is limited. Limited work has been done where landslides have been correlated with multiple environmental variables like soils, slope, etc. in order to produce hazard maps. Even more limited are studies on landslide risk assessment in Cuba.

To cope with the mentioned problems the National Civil Defence and the Ministry of Science, Technology and Environment have decided to establish a system for landslide risk assessment in the Cuban Archipelago. The system includes the design and implementation of a national landslide inventory database and landslide risk assessment procedures at different disaster management levels. This paper presents a brief overview of these topics and the design for its implementation based on the conditions of Cuba.

2 LANDSLIDES IN CUBA

In this section an overview is given of the major landslide areas of Cuba described in the published literature, and some unpublished reports from the main research institutes in Cuba.

No landslide studies are available from the period before the revolution in Cuba, although there are some older publications with general geographic descriptions on landslide processes.

In figure 1 an overview is given of the most important known landslide events in Cuba in the last 50 years. The most catastrophic landslide happened in the Sierra de Caujerí scarp (Fig. 1, number 1 and Fig. 2, number 1); specifically in the locality Los Jagueyes. This landslide occurred after three days of heavy rain during the passing of cyclone Flora on October 8 1963, which was the most devastating meteorological event, which had affected Cuba. During this event a total amount of 1,100 mm of rainfall in three days was recorded in the Sierra de Caujerí area (Trusov 1989). The successive rotational rockslide occurred in two pulses with about 45 minute intervals, which allowed some of the inhabitants to escape, whereas 5-10 others were killed. There is no technical report made directly after the event although some data was recorded during a fieldwork with interviews of the survivors in 1999 (Castellanos & Van Westen 2001a).

The highest landslide risk in Cuba related to a continuous slow landslide movement is the Mariel landslide (Díaz et al. 1983, Formell & Albear 1979, Pacheco & Concepción 1998). Mariel hill (Fig. 1, number 2), the site of the old Navy Academy, is located over a slip surface which has moved intermittently. Recordings show 19 cm movement for 99 hours (in 1979 after hurricane "Frederic") and 32.5 cm for 51 hours (in 1985 after 115 mm rainfall in three days). According to the reports small movements are recognized since 1918 and the crown of the landslide is about 40 m wide. The site is continuously monitored because, in case of a complete collapse, a large number of people might be affected.

The most important scientific publications about landslides in Cuba are related to those in the Eastern part of Cuba, such as the coastal landslides from Baitiquirí up to Maisí (Fig. 1, number 3), in Guantánamo province (Magaz et al. 1991) and the ones in the Sierra Maestra (Iturralde-Vinent 1991).

The Baitiquirí-Maisí landslides are associated to the marine terraces, and may be considered as paleo-landslides since there is no historical record of movements. Besides, some of these paleo-landslides have been sealed in the front part by a coral reef ring which is also uplifted in the lowest marine terrace level. This is an indication that the landslides occurred in submarine conditions and the area was

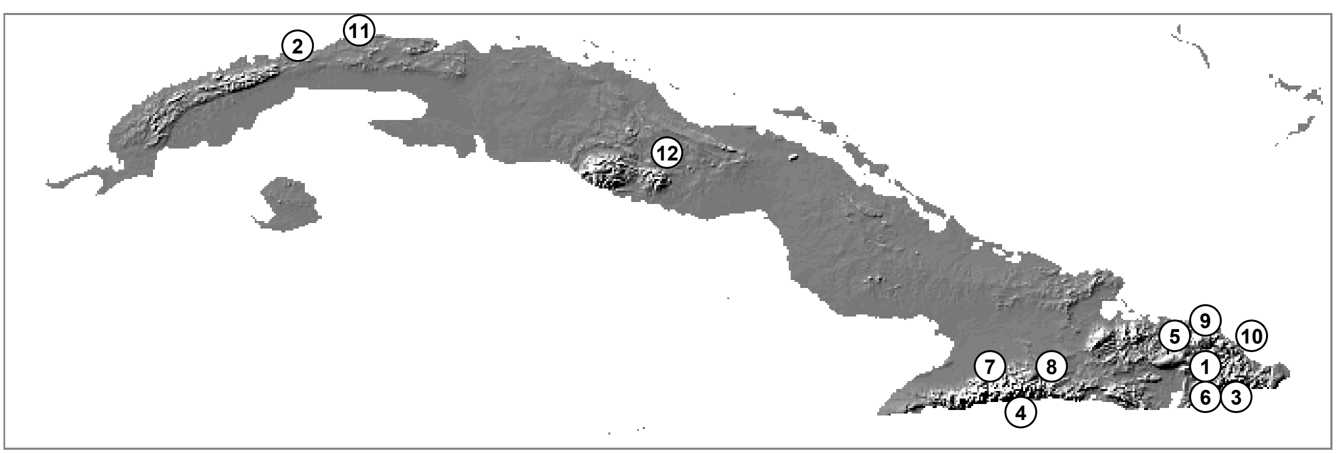

Figure 1. Location of major landslides in Cuba, according to existing publications. Numbers are referred to in the text.

later uplifted. Large gravitational landforms were described in the southern slope of the Sierra Maestra (Fig. 1, number 4) mountain system by Iturralde-Vinent (1991), and Orbera (1996). They were mapped as rotational rock slides, and although they are considered old, some of them have been reactivated during rainy periods, and have interrupted the single coastal road in the Southern Sierra Maestra.

In Moa-Baracoa and the Sierra del Purial mountain system (Fig. 1, number 5) multiple old and recent landslides have been surveyed (Castellanos et al. 1998). The landslides, located in highly dissected mountains, were identified in aerial photographs from 1974 and digitized in a GIS. A statistical analysis was carried out comparing the landslide frequency with different environmental parameters, and a landslide susceptibility map was made at 1:100 000 scale in an area of 14,000 km^2.

A landslide hazard assessment at a more detailed scale (1:50,000) has been carried out in the San Antonio del Sur municipality (Castellanos 2000, Castellanos & van Westen 2001a,b). More than 50 landslides were recorded in a database (Fig. 1, number 6).

Unstable slopes have been found in the northern slope of Sierra Maestra mountain system, specifically in Guisa Municipality (Fig. 1, number 7), San Ignacio locality (Viña et al. 1977). On June 10, 1977 a landslide occurred here, which was about 350 m long and 100 m wide. The vegetation and constructions on the landslide were relatively intact after being displaced for about 80 to 100 meters. Prior to the landslide there was an intense drought and later during May rainfall reached 737,2 mm, and 106,8 mm on June 8, two days before the event. The 1977 landslide was a reactivation of an older one with reported activity in 1951 and 1960.

During geological mapping at 1:250,000 scale carried out in the Eastern part of Cuba small and medium size rockfalls and landslides were reported (Pérez 1983). They were located mainly along the rivers and happen mostly during the rainy season. Examples areas are Guanábana, close to Solongo, in Sierra Maestra (Fig. 1, number 8) and the highland Yuraguana, close to La Tagua.

Some landslides that had happened in the mountain areas are due to road construction in unstable or marginally stable slopes. Also, the mining activity has triggered different types of landslides as the one described in the Punta Gorda Nickel ore deposit (Almaguer & Guardado 2003, Guardado & Almaguer 2001a). A remarkable event was the landslide in the Cromite ore deposit in Merceditas (Fig. 1, number 9), at 8 km of La Melba locality in Sierra Cristal. A translational rockslide occurred with a width of 100 meters, due the underground mining activity, which generated large dimension chambers close to the slope. The landslide blocked the Jaraguá River, but no lake was formed due to the large size of the rocks and the high permeability. However, from this point and 200 m downstream the river is running underground.

Close to the Baracoa village (Fig. 1, number 10), specifically 500 m from the airport an earth-rock slide happened in 1997 (Castellanos et al. 1998), blocking the road that communicates the town with the airport. The landslide seems to be rotational over marls and limestone. The main factors involved may be the continuously rainfall, the cut at the foot of the slope for road construction and the tunnel construction inside the mountain.

There are other studies about landslides in Cuba such as the one related to the Via Blanca geological formation (Fig. 1, number 11) in Havana City (González et al. 1994), the radiometric age dating of landslide zones (Chang et al. 2003), landslide hazard analysis in Sancti Spiritus (Fig. 1, number 12) province (Reyes & Quisbert 1998) and general publications about the landslide conditioning and triggering factors in the country (Guardado & Almaguer 2001b, Rocamora 1994, Rocamora 2001, Rocamora 2003).

3 PROPOSED LANDSLIDE RISK METHOD FOR CUBA

The volume of literature on landslide hazard assessment is overwhelming, especially when compared with that dealing with landslide vulnerability and risk assessment, which are still relatively few. There is a general consensus on the classification in four different approaches for landslide hazard: landslide inventory-based probabilistic approach, heuristic approach (which can be direct Geomorphological mapping, or indirect qualitative map combination), statistical approach (bivariate- or multivariate statistics) and the deterministic approach (Soeters & Van Westen 1996, Guzzetti et al. 1999). The landslide risk assessment methods are classified into three groups, as qualitative methods (probability and losses expressed in qualitative terms), semi-quantitative methods (indicative probability, qualitative terms) and quantitative methods (probability and losses quantified)(AGS 2002, Lee & Jones 2004).

The aspect of scale has not played a dominant role in the reported methods of landslide risk assessment as most of the published work is at site investigation scale or at relatively large mapping scales. However, the landslide risk assessment methodology for the Cuban situation will need to address different requirements for the various risk reduction activities by the Civil Defence at various levels of detail. These may vary from landslide warnings given at national level upon the approaching of a hurricane, to the detailed land use planning in landslide-affected localities (EMNDC 2002).

Figure 2. Some typical landslides in Cuba. Locations with the same number are in Figure 1 and the explanation is in the text. 1: Los Jagueyes landslide in Caujerí valley. 2: Los Aposentos coastal landslide between Baitiquirí and San Antonio del Sur. 6: Landslide in San Antonio del Sur area. 5 : Landslide in Puriales de Caujerí. 9: Landslide in Merceditas chromites mining area. 10: Baracoa landslide.

Experience in the rest of world has shown that the assessment of landslide hazard and risk requires:

- A hierarchical approach, with different levels of study that implies different objectives, scales, methods and results;
- An acceptable cost/benefit ratio, in order to make the methods affordable by the implementing organisation;
- A technical applicability, were the methods are technically feasible to be carried out by the implementing organisation (Soeters & Van Westen 1996).

Each country adopts its own strategy for landslide risk assessment and different levels of analysis with specific scales in accordance with:

- The geographic extension and population distribution of the country.
- The management and political structure of the country and the extent of each management level (province, departments, county, etc.).
- The magnitude and frequency of the landslides that occur in correspondence with the relief of the country.
- The human and technological resource capacity to carry out the assessment.

One misunderstanding in developing a national landslide hazard and risk assessment has come for having copied assessment frameworks from countries with different natural and political-administrative characteristics. In Cuba there is a dense management division and it is homogeneous enough to make these coincidence with the landslide risk assessment levels. Every Organization of the Central State Management (OACE by its initials in Spanish) has provincial representation and many of them also have it at the municipal level. This allows identifying support and responsibilities in the management structure, and to locate and manage financial and material resources on each administrative level (municipality, province, region, country).

According with the above considerations the following levels for landslide hazard and risk assessment are proposed for Cuba (see Fig. 3):

- National level, 1:1,000,000 scale.
- Provincial level, 1:100,000 scale.
- Municipal level, 1:50,000 scale.
- Local level, 1:25,000 scale.

The proposed scales coincide with the topographic maps that are produced and regularly updated. Many natural regions of Cuba are not limited to the provincial and municipals boundaries (e.g. Sierra Maestra mountain area is located in Santiago de Cuba and Granma provinces). The hazard and risk assessment at 1:100,000 and 1:50,000 scales could be feasibly carried out by subdividing the territory in natural units of the relief. Similarly, a local level 1:25,000 scale study could contain areas that may include the administrative boundary of two municipalities.

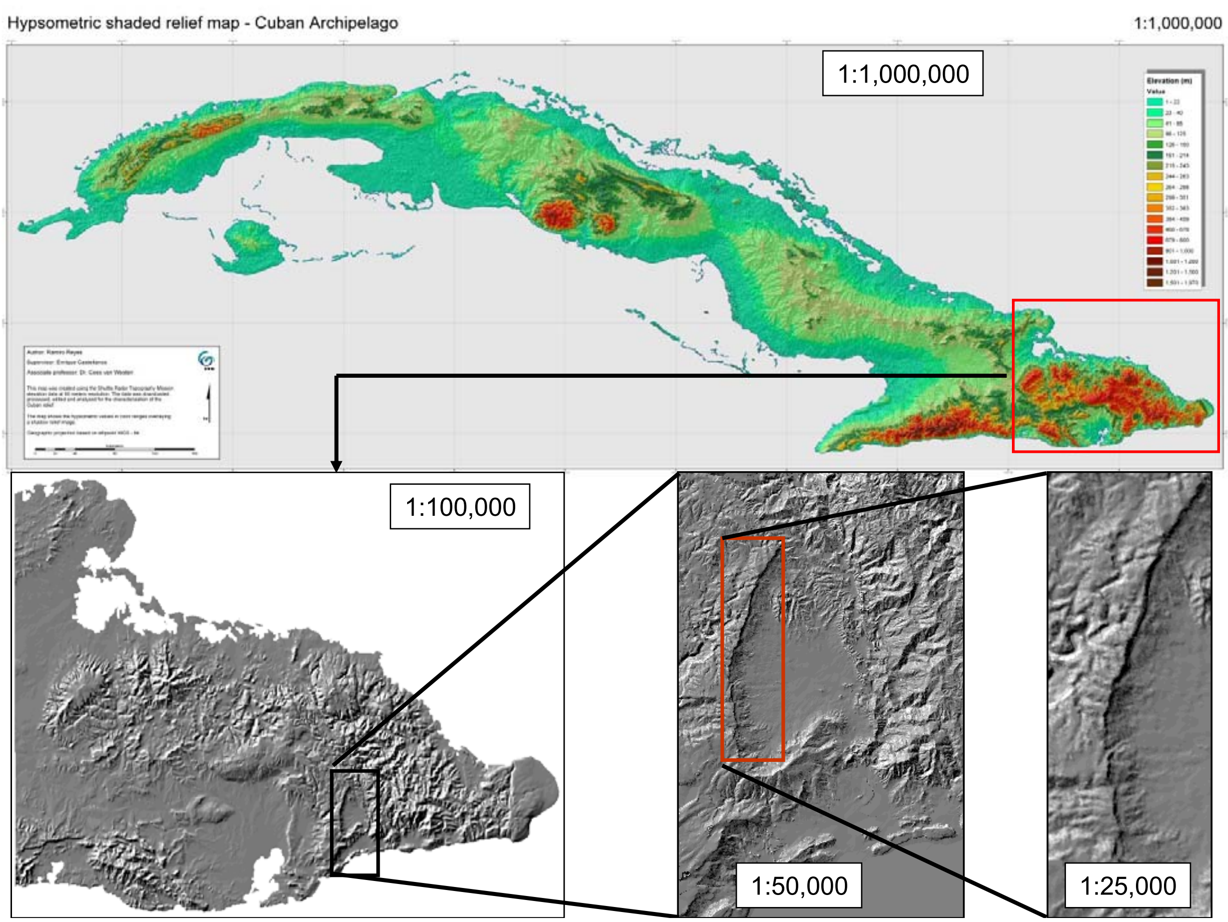

Figure 3. Case study areas at different scales for the development of the methodology for risk assessment in Cuba.

Figure 4 shows a list of the different types of information required for landslide hazard and risk assessment at the 4 levels of analysis (based on Soeters & Van Westen 1996). The methods that are commonly used for collecting the data are indicated, as well as the possibility of obtaining sufficient data at a reasonable cost/benefit ratio in Cuba. Landslide inventory maps are the key component of a landslide risk assessment, especially if they represent landslides with date, type and volume, and if they are updated after major triggering events (Coe et al. 2004). Most of the landslide information has to come from remote sensing, where medium resolution systems, such as LANDSAT, SPOT, and nowa-

Data layer and types	Accompanying data in tables	Used methods for data collecting	Levels of analysis			
			Nat. 1:1M	Prov. 1:100K	Mun. 1:50K	Local 1:25K
Landslide occurrence						
Landslides	Type, date, volume, damage	API, fieldwork, national inventory	2	2	3	3
Environmental parameters						
Geomorphology	Geomorphological description	AP, fieldwork	2	2	3	3
Lithology	Lithology, engineering rock/soil mass classification	Existing, API, fieldwork and laboratory testing	2	2	3	3
Structural geological map	Fault type, length, dip, dip direction, fold axis, etc.	SII, API, fieldwork	2	3	3	3
Soils and material sequences	Soils types, materials, depth, grain size distribution, bulk density, *c* y φ	Modeling from lithological map, geomorphological map and slope map, fieldwork and lab. analysis	2	2	2	3
Landuse map	Land use types, tree density, root depth	SII, API, fieldwork	2	2	3	3
Digital Elevation Model (DEM)	Altitude classes	SRTM DEM data, topographic map	3	3	3	3
Slope map	Slope angle classes	With GIS from DEM	1	2	3	3
Aspect map	Slope direction classes	With GIS from DEM	2	2	3	3
Slope length	Slope length classes	With GIS from DEM	2	2	3	3
Slope shape	Concavity/ convexity	With GIS from DEM	1	1	2	3
Internal relief	Altitude/area classes	With GIS from DEM	3	3	3	3
Drainage	Type, order y longitude	With GIS from DEM	3	3	3	3
Catchment areas	Order, size	API, topographic map	3	3	3	3
Triggering factors						
Hurricanes & Rainfall	Precipitation, duration, frequency	Meteorological stations and modeling	3	3	3	3
Water table	Depth of water table in time	Hydraulic stations and dynamic modeling	1	1	1	2
Earthquakes and seismic acceleration	Earthquake database and maximum seismic acceleration	Seismic data, engineering geological data and modeling	2	2	2	3
Elements at risk						
Buildings	Type of structure, use, nr floors	Topographic map, Housing information	1	2	3	3
Population	Number, sex, age, etc.	Census and statistics information	3	3	3	3
Transportation systems and facilities	Roads and railroads types, facilities types	Atlas, topographic map, local information	3	3	3	3
Lifeline utility systems	Types of lifeline network and capacity of facilities	Atlas, topographic map, local information	2	3	3	3
Industry	Industry production and type	Atlas, topographic map, local information	2	3	3	3
Services facilities	Number and types of health, educational, cultural and sport facilities	Atlas, topographic map, local information	3	3	3	3
Tourism facilities	Type of tourist facilities	Atlas, topographic map, local information	3	3	3	3
Natural resources	Areas with natural resources combined	Atlas, topographic map, local information	3	3	3	3

Note: the last columns indicate the possibility of collecting data for levels of analysis: 3 = good, 2 = moderate and 1 = poor. Abbreviations used: SII satellite image interpretation, API = aerial photo interpretation, DEM = digital elevation model, GIS = geographic information system.

Figure 4. Summary of data needed for landslide hazard and risk assessment for the conditions of Cuba. Adapted from Soeters & van Westen (1996)

days especially ASTER, will be used to differentiate bare landslide scars after main rainstorm events based on their spectral characteristics. The use of high-resolution imagery such as IKONOS or Quickbird will be less of an option in Cuba, due to the high price and distribution policy.

One very important additional source for obtaining useful landslide inventory data, also from the past, is the involvement of local staff of the Civil Defence at the 169 municipal centers. A simple landslide reporting form has been designed, and workshops are conducted to train the staff and make them aware of the procedure. Once the local officers report a landslide, a landslide expert from the central office will visit the site and complete the questionnaire in more detail. Such a system for landslide data collection might not be very effective in other countries, due to lack of commitment of the reporting staff at the local level. In Cuba, however, the Civil Defence is well organized and very effective as can be concluded from a comparison of disaster related casualties numbers in Cuba with those of neighboring countries such as Haiti or Dominican Republic (Thompson & Gaviria 2004).

In the proposed methodology it is important to integrate both governments and administrative organizations of the corresponding level before, during and after the assessment is carried out. On the other side, it is possible that after the assessment at provincial level (1:100,000 scale), problematic areas could be recognised to have local assessment (1:25,000 scale) or even geotechnical project assessment (> 1:10,000 scale) without waiting for the inter-level assessments.

In the following sections the various levels of analysis are described in more detail.

3.1 *National level (1:1,000,000 scale)*

The objective of the analysis at the national scale is the zonation of the national territory according to the main landslide conditioning factors and the use of real-time rainfall and hurricane data in the generation landslide warnings. A further objective is the selection of the landslide prone areas for detailed hazard and risk studies.

Most landslides recognized in Cuba have happened associated to hurricanes, tropical storms, or prolonged rainy periods, and relatively few related to earthquakes. The damage is mostly associated to isolated landslide events, or to debris flows in downstream parts. Hurricane warning and rainfall monitoring systems are well developed, but need to be combined with certain rainfall thresholds, which might be different for different environmental settings. The rainfall distribution is very heterogeneous with high contrasts in a few kilometres of distance, like in the Eastern part of Cuba.

A schematic overview of the proposed hazard and risk method is given in Figure 5. The data inventory will use three main sources: the National Atlas of Cuba (NAC), the SRTM DEM data and the National Statistics Office. The NAC maps ranges from 1:1,000,000 to 1:2,000,000 scales and they need to be scanned and digitised. The STRM DEM data has been compiled and processed, and a series of morphometric parameters have been extracted. The landslide inventory will provide both the overview

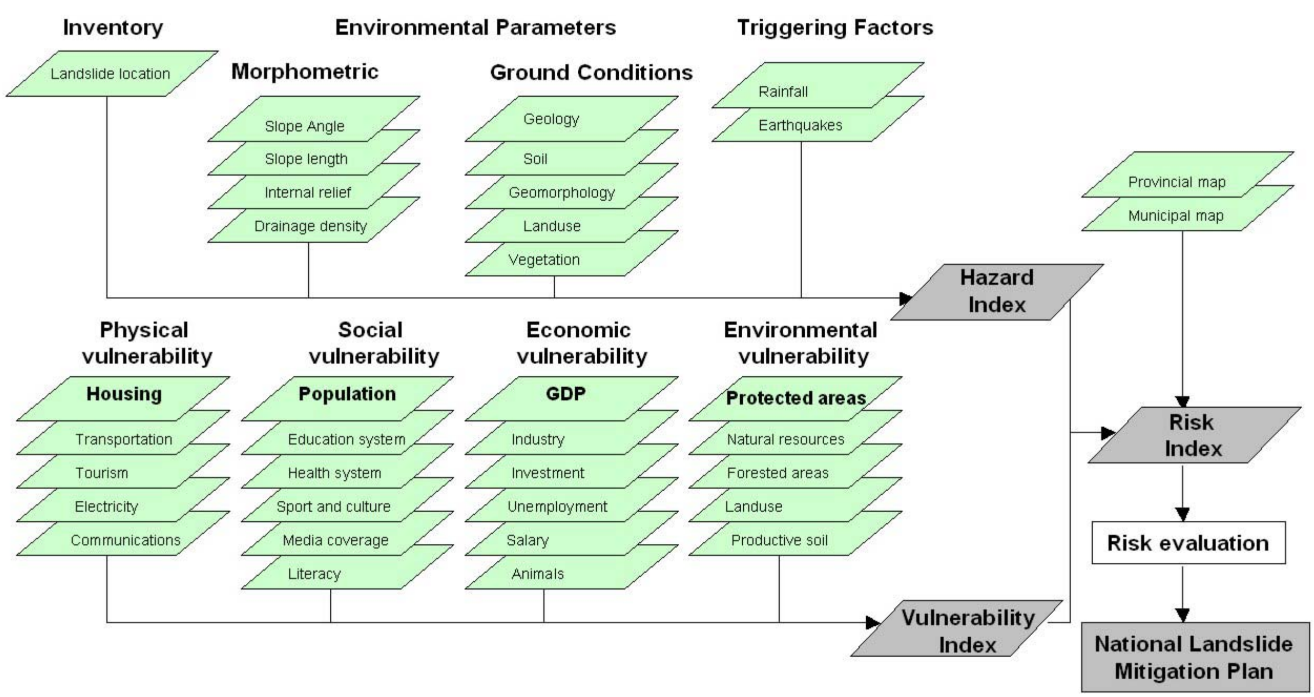

Figure 5. Schematic representation of the proposed landslide risk assessment method at national scale in Cuba. Important inputs are from SRTM DEM, the National Atlas of Cuba, the National Statistics Office, and the proposed landslide inventory database.

used for generating the risk index, as well as the temporal information used for establishing thresholds for general landslide warnings. The classes of the environmental parameters maps will be ranked and weighted using expert opinion criteria. Since landslides at this scale will be only represented by points, a runout map will not be generated. The landslide inventory and environmental parameters maps will be used to produce the landslide susceptibility map, which, combined with the triggering factors maps will generate the landslide hazard map.

The classes of elements at risk polygon maps will be ranked and weighted according to the value or importance of each class. A rank and weight will be also assigned to the point- and line maps of the elements at risk. As at 1:1,000,000 scale it is very difficult to assess the landslide vulnerability, only a relative "consequence" map will be made by combining all elements at risk maps. A selection of vulnerability indicators will be made, grouped into four major classes: social, economic, physical and environmental. The consequence and hazard map will be combined to produce the national landslide risk map, which displays qualitative risk classes per municipality.

3.2 *Provincial level (1:100,000 scale)*

The objective of the analysis at this level is the zoning of the area with respect to recent and old landslides and to produce a semi-quantitative landslide hazard and risk map using a statistical approach. The Guantánamo province, with an area of 6,170 km^2, and a population of 509,065 in 10 Municipalities, has been selected as study area (see Fig. 3). The geology includes ophiolite, which is highly affected by weathering in the North and metamorphic and sedimentary rocks in the South. The relief is relatively young and affected by active tectonic processes. Landslides occur in the different geological formations but most frequently in sedimentary rocks The most frequent types are rotational rockslides and rockfalls .

Image interpretation of the area will be done using aerial photographs and satellite images of different periods. In Cuba there are three aerial photos series with national coverage:

- From 1956, at 1:62,000 scale by The American Survey Corporation (ASC).
- From 1971-1974, at 1:37,000 scale by the Cuban Institute of Geodesy and Cartography (ICGC);
- From 1999-2000, at 1:33,000 scale by Geocuba;

Additionally more than 10 different satellite images will be used (Landsat TM, Spot PAN, Aster). Examples of its use can be found in Castellanos (2000). The main analysis type at this scale will be a statistical combination of the landslide inventory with the environmental parameters and the triggering factors (rainfall and earthquake), resulting in a qualitative landslide hazard map. Landslide runout zones will not be analyzed at this scale, although some emphasis is given to areas that are at risk for debris flows. A limited survey of the elements at risk will be done using the topographic maps and provincial statistical information. Landslide vulnerability analysis will be very basic at this level and the semi-quantitative risk map will display risk levels within homogeneous units, with respect of the environmental parameters.

3.3 *Municipal level (1:50,000 scale)*

The objective of the research on this level is to generate risk maps that can be used as input in municipal development planning. This requires identification of hazard degrees related to landslides of different type, frequency and volume, and the evaluation of the run out zones, the elements at risk and their vulnerability and to produce a quantitative risk map.

The study area consists of the San Antonio del Sur municipality (see Fig. 3), with an area of 600 km^2 that includes coastal hills and mountainous areas in the north, east and western parts. It is an agricultural area with about 25,000 inhabitants. The main part is the Caujerí valley, which is an important food production region for Guantánamo province.

The valley has an oval shape surrounded by Sierra de Caujerí (west), Sierra de Mariana (south), Sierra del Convento (southeastern) and Sierra del Purial (east and north). The coastal area is characterized by isolated hills with apparently tectonic control that regulate its shape, lineation and uplift. The area is covered by terrigenous and carbonated sedimentary rocks and by low pressure-temperature metamorphic rocks. The landslides have occurred in three main areas: in the coastal hills, in the denudational slopes and in the Sierra de Cuajerí main scarp (Castellanos 2000, Castellanos & van Westen 2001a,b).

Hazard and risk assessment starts also with detailed multi-temporal landslide image interpretation and earth observation data processing. The environmental parameters will be crossed with the landslides inventory and with the rainfall data as the main triggering factor. The hazard assessment will be done using a combination of statistical and heuristic methods. A detailed elements-at-risk survey and vulnerability analysis will allow to make the risk assessment using semi-quantitative approaches.

3.4 *Local level (1:25,000 scale)*

The objective of the work at this level is to carry out a detailed study using landslide hazard and risk assessment methods as quantitative as possible.

The study area is the Sierra de Caujerí, located in the western border of the Caujerí valley (see Fig. 3

and Fig. 6). It is a tectonic scarp with an average height difference of 500 meter, containing more than 50 landslides, which are mostly rotational rockslides that end in mudflows. It contains the large landslide in Los Jagueyes area, which occurred during Flora Hurricane in 1963 (Fig. 2, number 1). The scarp consists of horizontally layered limestone of the Yateras Formation and marls of the Maquey formation in the lower part. The limestone presents many karstic features and the rivers system is well dissected. The groundwater flows into karstic aquifers and many springs occur in the accumulation zone or in the foot of the landslides. The area is used mostly for agriculture by private and state-owned farms. There are a few hundreds of farmhouses and several small primary schools. The road system is poor and unpaved one-lane roads predominate. Despite the low value of elements at risk, the economical value of the area is important for the province, as it is the main food production area for more than 200,000 inhabitants.

At this scale geotechnical, hydrogeological and meteorological data will be collected in order to be able to apply deterministic methods using relatively simple slope stability calculations and runout models. Elements at risk will be quantified as much as possible.

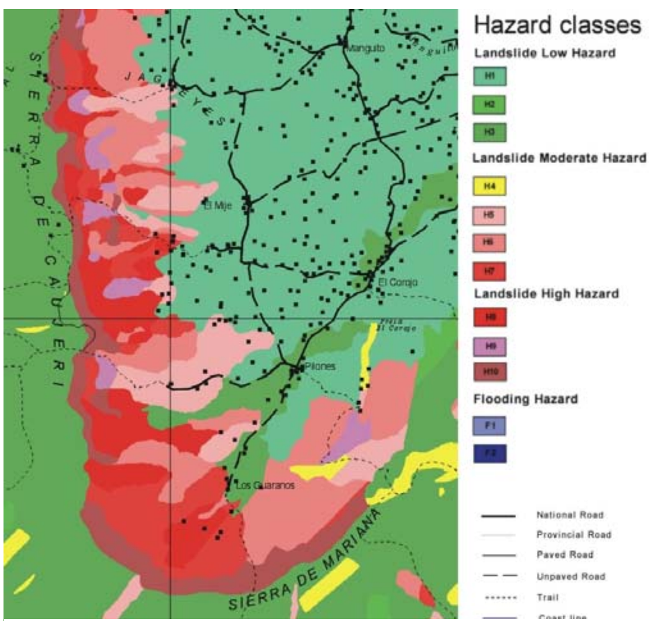

Figure 6. Small section of the Geomorphological hazard map of the Sierra de Caujerí scarp, used as basis in the local level analysis.

4 CONCLUSIONS

The proposed methodology still has to be implemented, as the research is still in its initial phase, although work at municipal and local level has been carried out before (Castellanos 2000). The work on the national level has been nearly completed, with the exception of the generation of the landslide database. The generation of a national landslide database using a combination of earth observation data and landslide reporting by local Civil Defence staff is considered to be the most crucial element of this research. Based on the results of the national landslide inventory and the national landslide risk assessment, a hurricane warning system will be developed, that may include a potential landslide severity index, based on the rainfall forecasting.

The research is coordinated with the National Science and Technological Innovation Program for Civil Defence (PNCIT) in Cuba and with the National Headquarters of the Civil Defence (EMNDC) in Cuba. The Institute of Geology and Paleontology (IGP) is carrying out this research project since January 2004 for the four case study areas with a duration of 3 years. This research is carried out as component of the ITC SLARIM project: Strengthening Local Authorities in Risk Management.

REFERENCES

AGS: Australian Geomechanics Society and Sub-committe on landslide risk management, 2000. Landslide risk management concepts and guidelines. Australian Geomechanics, 35(1): 49-92.

Almaguer, Y. and Guardado, R., 2003. Análisis de Estabilidad de Taludes a partir de la Evaluación Geomecánica del Macizo Serpentinítico del Yacimiento Punta Gorda, Moa, Holguín, Cuba. In: C.N.d.I.G. (CNIG) (Editor), V Congreso Cubano de Geología y Minería, Memorias, Trabajos y Resúmenes. Sociedad Cubana de Geología (SCG), La Habana, Cuba, pp. 9.

Castellanos, E., 2000. Design of a GIS-Based System for Landslide Hazard Management, San Antonio del Sur, Cuba, case study. M.Sc. Thesis, International Institute for Aeroespace Survey and Earth Sciences (ITC), Enschede, 108 pp.

Castellanos, E. et al., 1998. Cartografía de los Principales Procesos Geológicos Amenazantes del Este de la Región Oriental. 14655, Instituto de Geología y Paleontología, MINBAS, La Habana, Cuba.

Castellanos, E. and van Westen, C.J., 2001a. Geomorphology and Geology of San Antonio del Sur, Guantánamo, Cuba: its Contribution in Producing Landslides. In: C.N.d.I.G. (CNIG) (Editor), IV Congreso de Geología y Minería, Memorias, Trabajos y Resúmenes. Sociedad Cubana de Geología (SCG), La Habana, Cuba, pp. 10.

Castellanos, E. and van Westen, C.J., 2001b. Landslide Hazard Assessment using Heuristic Model. In: C.N.d.I.G. (CNIG) (Editor), IV Congreso de Geología y Minería. Memorias, Trabajos y Resúmenes. Sociedad Cubana de Geología (SCG), La Habana, Cuba, pp. 11.

Chang, J.L., Suarez, V., Castellanos, E., Núñez, K. and Moreira, J., 2003. Análisis de Riesgos por Deslizamientos a partir del Estudio de la Migración de los Radioelementos Naturales. In: C.N.d.I.G. (CNIG) (Editor), V Congreso Cubano de Geología y Minería. Memorias, Trabajos y Resúmenes. Sociedad Cubana de Geología (SCG), La Habana, Cuba, pp. 7.

Coe, J.A., Michael, J.A., Crovelli, R.A. ,Savage, W.Z. , Laprade, W.T., and Nashem, W.D. 2004 a. Probabilistic Assessment of Precipitation Triggered Landslides Using Historical Records of Landslide Occurrence, Seattle, Washington. Environmental & Engineering Geoscience, Vol. X., No. 2, pp. 103-122.

Díaz, J.L., Pérez, W., Serrano, S., Fernández, E. and Albear, J.F., 1983. Informe preliminar sobre los deslizamientos ocurridos en el Mariel., Instituto de Geografía Tropical, ACC, La Habana, Cuba.

EMNDC-Estado Mayor Nacional de la Defensa Civil, 2002. Informe Nacional presentado por la delegación cubana en la consulta regional "Gestión local y reducción de riesgo en los asentamientos humanos de la Cuenca del Caribe", ENMDC, Estado Mayor Nacional de la Defensa Civil., La Habana, Cuba

Formell, F. and Albear, J.F., 1979. Deslizamientos de Tierra en el Mariel., Instituto de Geología y Paleontología, ACC, La Habana, Cuba.

González, W., Kindelán, M., Santamaría, C., Décalo, M.I. and Díaz, J., 1994. Factores de Riesgo de los Taludes Naturales en la Formación "Vía Blanca". In: S.C.d.G. (SCG) (Editor), Segundo Congreso Cubano de Geología y Minería, Reuniones de los Proyectos 322 y 308 del PICG., Santiago de Cuba, Cuba.

Guardado, R. and Almaguer, Y., 2001a. Estudio de la Peligrosidad por Deslizamiento en la Mina del Yacimiento Punta Gorda, Empresa Ernesto Che Guevara de Moa. In: C.N.d.I.G. (CNIG) (Editor), IV Congreso de Geología y Minería. Sociedad Cubana de Geología (SCG), La Habana, Cuba, pp. 1.

Guardado, R. and Almaguer, Y., 2001b. Rocas y Suelos como Indicadores Ingeniero Geológicos y Ambientales de Estabilidad y Sostenibilidad de Taludes y Laderas. In: C.N.d.I.G. (CNIG) (Editor), IV Congreso de Geología y Minería. Sociedad Cubana de Geología (SCG), La Habana, Cuba, pp. 11.

Guzzetti, F., Carrara, A., Cardinali, M. and Reichenbach, P., 1999. Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. Geomorphology, 31(1-4): 181-216.

Iturralde-Vinent, M., 1991. Deslizamientos y Descensos del Terreno en el Flanco Meridional de la Sierra Maestra, Cuba sudoriental. In: Colectivo de Autores (Editor), Morfotectónica de Cuba Oriental. Editorial Academia, La Habana, pp. 24-27.

Lee, E.M. and Jones, D.K.C. , 2004. Landslide Risk Assessment. Thomas Telford, London, 454 p.

Magaz, A. et al., 1991. El Complejo de Formas del Relieve Gravitacional en la Franja Costera Baitiquirí-Punta Maisí, Provincia de Guantánamo, Cuba. In: Colectivo de Autores (Editor), Morfotectónica de Cuba Oriental. Editorial Academia, La Habana, pp. 28-43.

OFDA/CRED, 2004. EM-DAT International Disaster Database - www.em-dat.net. Université Catholique de Louvain, Brussels, Belgium

Orbera, L., 1996. Natural Disasters in Cuba., Cuban Contribution to the IGU Commissions and study groups on the 28th International Geographical Congress, The Hague, pp. 94-98.

Pacheco, E. and Concepción, L., 1998. Factores que Originan los Deslizamientos de Tierra. Afectaciones en la Municipio Mariel. In: C.N.d.I.G. (CNIG) (Editor), III Congreso de Geología y Minería. Sociedad Cubana de Geología (SCG), La Habana, Cuba, pp. 528-530.

Pérez, N., 1983. Aspectos ingeniero geológicos del levantamiento geológico de Cuba Oriental. In: Editorial Científico Técnica (Editor), Contribución a la geología de Cuba Oriental. Instituto de Geología y Paleontología. ACC., pp. 173-185.

Reyes, R. and Quisbert, E., 1998. Peligrosidad de ocurrencia de deslizamientos de Tierra en la montañas de Sancti Spiritus., Instituto de Geografía Tropical. ACC, La Habana.

Rocamora, E., 1994. Deslizamientos, consideraciones para su evaluación como fenómeno Físico-Geológico. In: S.C.d.G. (SCG) (Editor), Segundo Congreso Cubano de Geología y Minería, Reuniones de los Proyectos 322 y 308 del PICG., Santiago de Cuba, Cuba.

Rocamora, E., 2001. Particularidades en la Evaluación de Riesgo de Ocurrencia de Deslizamientos de Ladera. In: C.N.d.I.G. (CNIG) (Editor), IV Congreso de Geología y Minería. Sociedad Cubana de Geología (SCG), La Habana, Cuba, pp. 11.

Rocamora, E., 2003. Criterios de Selección del Factor de Seguridad para el Pronóstico de Ocurrencia de Deslizamientos de Taludes. In: C.N.d.I.G. (CNIG) (Editor), V Congreso Cubano de Geología y Minería. Sociedad Cubana de Geología (SCG), La Habana, Cuba, pp. 8.

Rodriguez, M.E., 1989. Sección Clima VI.2.2. 9 Condiciones de la circulación atmosférica. In: Instituto de Geografía Tropical (Editor), Nuevo Atlas Nacional de Cuba. Instituto Geográfico Nacional de España, La Habana, Cuba

Schuster, R.L. (1996) Socioeconomic significance of landslides. In: A.K. Turner and R.L. Schuster (Editors), Landslide: Investigations and Mitigation. Special Report 247. Transportation Research Board. National Research Council. National Academy Press., Washington, D.C, pp. 12-35

Soeters, R. and van Westen, C.J., 1996. Slope Instability. Recognition, analysis and zonation. In: A.K. Turner and R.L. Schuster (Editors), Landslide: Investigations and Mitigation. Special Report 247. Transportation Research Board. National Research Council. National Academy Press., Washington, D.C, pp. 129-177.

Thompson, M. and Gaviria, I. (2004). Cuba, weathering the storm. Lessons in risk reduction from Cuba. Oxfam America Report. Website: www.oxfamamerica.org/cuba. 65 pp

Trusov, I., 1989. Sección Clima VI.3.4. 37 Eventos notables. 37a Flora. In: Instituto de Geografía Tropical (Editor), Nuevo Atlas Nacional de Cuba. Instituto Geográfico Nacional de España, La Habana, Cuba.

Viña, N., Graña, A. and Davila, Z., 1977. El Deslizamiento de San Ignacio, Municipio Guisa, Provincia Granma, Instituto de Geografía Tropical, ACC. , La Habana.

Zillman, J., 1999. The physical impact of disaster. In: J. Ingleton (Editor), Natural disaster management. Tudor Rose Holdings Ltd., Leicester, pp. 320.