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DEVELOPMENT OF A METHOD FOR MULTI-SCALE LANDSLIDE RISK ASSESSMENT IN CUBA

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Abstract: *This paper presents a summary of the method and the results of landslide risk assessment carried out in Cuba as a contribution to the system of multi-hazard risk assessment by the Civil Defence authorities. The method is developed at four different scales, national, provincial, municipal and local, each with specific objectives. At the national level a landslide risk index was generated, using a semi-quantitative model with 10 indicator maps using spatial multi-criteria evaluation techniques in a GIS system. Each indicator was standardized according to its contribution to hazard and vulnerability. The indicators were weighted using direct, pairwise comparison and rank ordering weighting methods and weights were combined to obtain the final landslide risk index map. The results were analysed per physiographic region and administrative units at provincial and municipal levels. The hazard assessment at the provincial scale follows a method for combined heuristic and statistical landslide susceptibility assessment, its conversion into hazard, and the combination with elements at risk data for vulnerability and risk assessment. The method is tested in Guantánamo province. For the susceptibility analysis, 12 factors maps were considered: geomorphology, geology, soil, landuse, slope, aspect, internal relief, drainage density, road distance, fault distance, maximum daily rainfall and peak ground acceleration. Five different landslide types were analyzed separately (small slides, debris flows, rockfalls, large rockslides and topples). The susceptibility maps were converted into hazard maps, using the event probability, spatial probability and temporal probability. Semi-quantitative risk assessment was done by applying the risk equation in which the hazard probability is multiplied with the number of exposed elements at risk and their vulnerabilities. At the municipal scale, a detailed geomorphological mapping formed the basis of the landslide susceptibility assessment. A heuristic model was applied to a municipality of San Antonio del Sur in Eastern Cuba. The study is based on a terrain mapping units (TMU) map, generated at 1:50,000 scale by interpretation of aerial photos and satellite images and field data. Information describing 603 terrain units was collected in a database. Landslide areas were mapped in greater detail to classify the different failure types and parts. The different landforms and the causative factors for landslides were analyzed and used to develop the heuristic model. The model is based on weights assigned by expert judgment and organized in a number of components such as slope angle, internal relief, slope shape, geological formation, active faults, distance to drainage, distance to springs, geomorphological subunits and existing landslide zones. At the local level, digital photogrammetry and geophysical surveys were used to characterize the volume and failure mechanism of the Jagüeyes landslide. In order to improve the temporal probability information for Cuba, the generation of a national landslide inventory database is essential.*

INTRODUCTION

Due to natural conditions or man-made actions, landslides have produced considerable human and economic losses (Schuster & Fleming 1986; Guzzetti 2000). Individual slope failures are generally not so spectacular or so costly as earthquakes, major floods, hurricanes or some other natural catastrophes. However, they are more widespread, and over the years they may cause more damage to properties than any other geological hazards (Varnes & IAEG-Commission on Landslides and Others Mass Movements on Slopes 1984). In Cuba, most of the studied landslides are associated with hurricanes, tropical storms or prolonged periods of rainfall (Viña et al. 1977; Formell & Albear 1979; Díaz et al. 1983; Pérez 1983; Iturralde-Vinent 1991; Magaz et al. 1991; Castellanos et al. 1998b; Pacheco & Concepción 1998; Castellanos 2000). Since the landslide damage is recorded as associated to the main disaster, there is no information on how many landslides have happened and where they are located. From 1785 up to 1984, a total of 108 hurricanes have passed over Cuba, of which 23 were of high intensity (>200 km/h), 38 of moderate intensity (151-200 km/h) and 47 of low intensity (118-150 km/h) (Rodríguez 1989). So far there are no official records for landslides related to hurricane events. All disasters damages were included in the hurricane data and no detailed description was made for the secondary disasters like flooding or landslides. Even though, in a report presented by the National Civil Defence Headquarters, it was recognized that 45,000 inhabitants are vulnerable to landslides (EMNDC 2002). Due to the lack of a landslide inventory, the knowledge about geological, geomorphological, tectonic and hydrological conditions under which these events could happen is limited in Cuba.

This research is intended to contribute in reducing the lack of knowledge about landslide problems mentioned by Cuba as well as in applying innovative spatial analysis for landslide risk assessment at different scales, taking into account the specific situation with respect to data availability and landslide types in Cuba. Various methods and models for landslide hazard and risk assessment have been applied in other countries, but they need to be translated to the Cuban situation. This research is dealing with multi-scale landslide risk assessment in Cuba. The main objective is to design a framework for spatial landslide risk assessment in Cuba, considering a multi-level approach and the specific characteristics of Cuba related to landslide types and distribution, availability and organizational structure. To do so, a set-up of a national landslide inventory database was made and landslide risk assessment methodology was worked out for four administrative levels and study areas, each one with a different scale, objectives, available datasets and analysis techniques.

This paper gives a summary of the methods used and main findings of landslide risk assessment of 4 different scales. More detailed descriptions can be found in Castellanos & Van Westen (2001a, 2001b, 2005, 2007a, 2007b, 2008). Before presenting the case study results, the general framework for spatial landslide risk assessment in Cuba and the location of the case study areas are presented.

CUBAN CIVIL DEFENCE SYSTEM AND MULTI-HAZARD RISK ASSESSMENT

Cuba is considered a model in hurricane risk management by the United Nations (Sims & Vogelmann 2002; ISDR 2004) because hurricanes in Cuba cause considerable less casualties as compared to neighboring countries with a different economical, social and political context such as Haiti, Jamaica or even compared with the USA (Wisner et al. 2006). The reasons for this relate to “an impressive multi-dimensional process” using as foundation of “a socio-economic model that reduces vulnerability and invests in social capital through universal access to government services and promotion of social equity” (Thompson & Gaviria 2004).

The disaster reduction in Cuba is controlled by the Civil Defence, an organization which has its roots in the revolution of 1959. The National Revolutionary Militia (MNR in Spanish) was created, and in 1961 the Military Organization of Industries (OMI in Spanish), and its main duty was vigilance and protection of economic and political targets in the Country. In 1962, OMI transformed into the Central Headquarter of Popular Defense, commonly known as Popular Defense, which was organized in all different levels (provinces, regions, municipalities, etc.) and later renamed into Civil Defence. The first main test with respect to natural disasters was in October 1963, when the country was severely affected by hurricane Flora, causing about 1200 casualties. This event changed the responsibilities of the Cuban Civil Defence and natural disasters response was added. The tasks of the Civil Defence at that time included the organization of a warning system, emergency response planning and to plan how to continue production during military aggressions and natural disasters. Since 1986 an annual disaster response simulation exercise, called “Meteoro”, is conducted on an annual basis. Initially the exercise was designed to be better prepared for cyclone season (June-November), but gradually started to include all other disaster types in all disaster management levels with high involvement of local population.

In the past decades, the Civil Defence had to deal with numerous natural, technological and sanitary disasters which lead to a substantial improvement of the organization. Since then, the territories and local authorities started to have a broader view of disasters considering all different scenarios including dam breaks, chemical contamination, epidemics, etc. Also authorities and Civil Defence started to pay more attention to prevention measures besides the original focus on response. In 1997, the structural organization of the Civil Defence was established as shown in Figure 1.

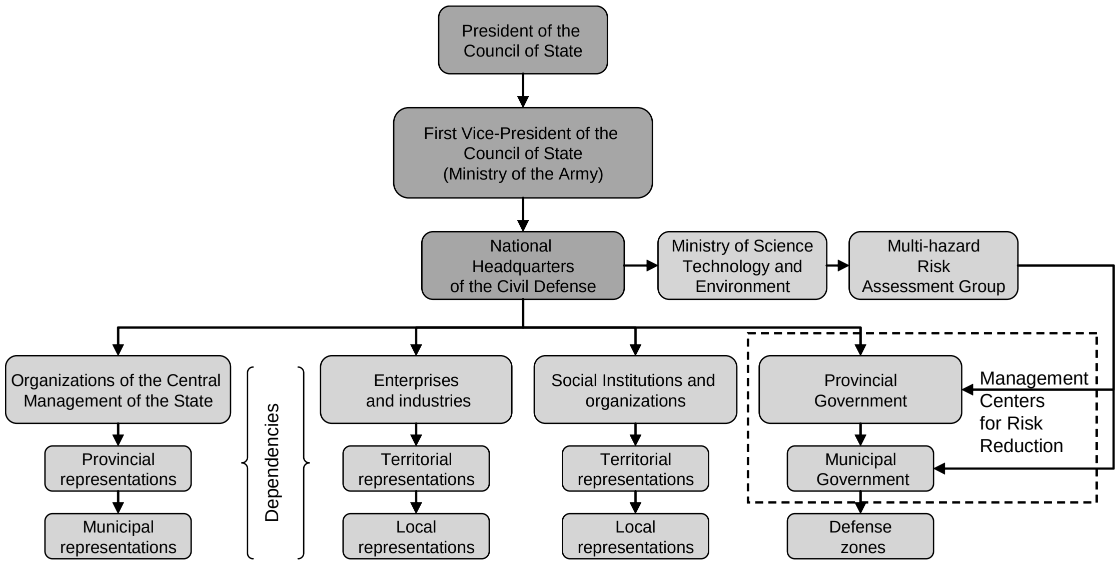

Figure 1: Structural organization of Civil Defence System in Cuba and risk assessment (after EMNDC 2007)

The role of the Civil Defence was re-established with several functions. The first one was to identify and evaluate, in coordination with the organizations, enterprises and social institutions, the hazard, vulnerability and risk factors as well as to provide the planning needed to cope with them. Many laws have articles related to natural disasters reduction. In 2004, Cuba was hit by two major hurricanes in a relative short period: Ivan and Charley.

After this it was decided that each territory should have a disaster reduction plan and disasters reduction measures will be included in the social-economic plan every year. The importance of the Civil Defence system in Cuba is illustrated in Table 1, which gives some statistics related to the major hurricanes that have affected Cuba.

Table 1: Statistics of disaster management in Cuba for 11 selected storms. DT: Tropical depression. (Source: National Civil Defence)

Cyclone	Year	Evacuated	In shelter	Transport	Mobilized	Deaths
Kate	1985	473,400	143,200	14,600	41,800	2
Lili	1996	421,200	276,700	5,600	74,500	0
Georges	1998	818,800	215,200	10,300	118,100	6
Mitch	1998	50,600	1,900	1,800	22,400	0
Irene	1999	33,600	11,200	1,500	12,600	4
Michelle	2001	783,400	166,300	6,100	102,400	5
Isidore	2002	307,000	34,500	2,700	48,800	0
Lili	2002	385,300	56,300	5,000	81,700	1
DT No. 14	2002	70,000	3,300	1,500	20,900	0
Charley	2004	224,449	35,749	2,444	45,082	4
Iván	2004	2,226,066	416,123	13,016	215,122	0
	Total	5,793,815	1,360,472	64,560	783,404	22

The official responsibility as main coordinator for conducting risk assessment in every municipality (169 in all) was assigned to the Ministry of Science, Technology and Environment (CITMA in Spanish) as shown in Figure 1. Many other organizations are involved depending on the hazard type, making a multidisciplinary team for risk assessment. The minimum spatial unit was set up at the Popular Council or Defense Zone, a spatial administrative unit lower than a municipality. The main idea was to establish a methodology where risk could be compared spatially (among municipalities) and temporally (during years) in order to provide priorities and to monitor the progress in risk reduction. The management of risk reduction is seen as an obligation of the State which includes all organizations involved. For its implementation every municipality and province should have a Management Centre for Risk Reduction (Figure 1) with financial support from UNDP. These centres have the following main functions i) periodic assessment, evaluation and monitoring of the risk in the territory, ii) support with equipment and information the Council of Defense (municipal and provincial) during respond and recovering phases, iii) record actions taken in disaster reduction and iv) contribute in training local people as well as dissemination of measures for disaster reduction (EMNDC 2002). These centres should also collect historic data about previous disasters besides receiving periodic information from the different early warning systems. In 2006, CITMA started the multi-hazard risk assessment with the 15 municipalities of the province of Havana City. Initially, events were mainly associated with tropical cyclones or intense rainfalls which included: flooding, sea surge and strong winds. The general procedure has 4 stages (AMA 2007) as indicated in Figure 2.

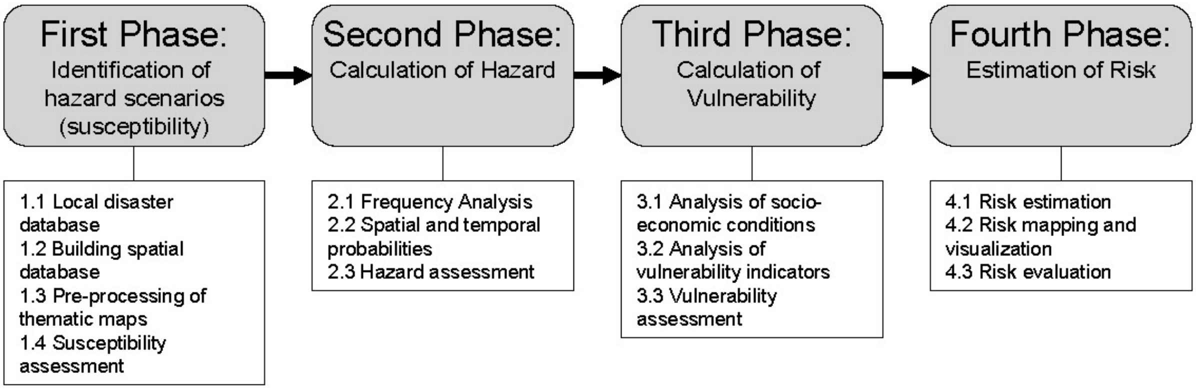

Figure 2: Stages for multi-hazard risk assessment in Cuba (after AMA 2007) and main tasks for landslide risk assessment. Terminology used as in the reference

SPATIAL LANDSLIDE RISK ASSESSMENT

Figure 3 presents the proposed methodological framework for spatial landslide risk assessment which was used in the different scales, with specific adaptations according to the scale, objectives and available data. Four major steps have been identified. Data collection for landslide risk assessment is the starting point where frequency analysis could be carried out to landslide inventory, rainfall or earthquake databases. This part usually consumes most of the time in a landslide risk assessment project. The landslide susceptibility and hazard assessment is the best known part for landslide studies. Landslide vulnerability assessment is probably the weakest part in the whole process since relatively little work has been done on the quantification of physical vulnerability due to landslides (Van Westen et al. 2005).

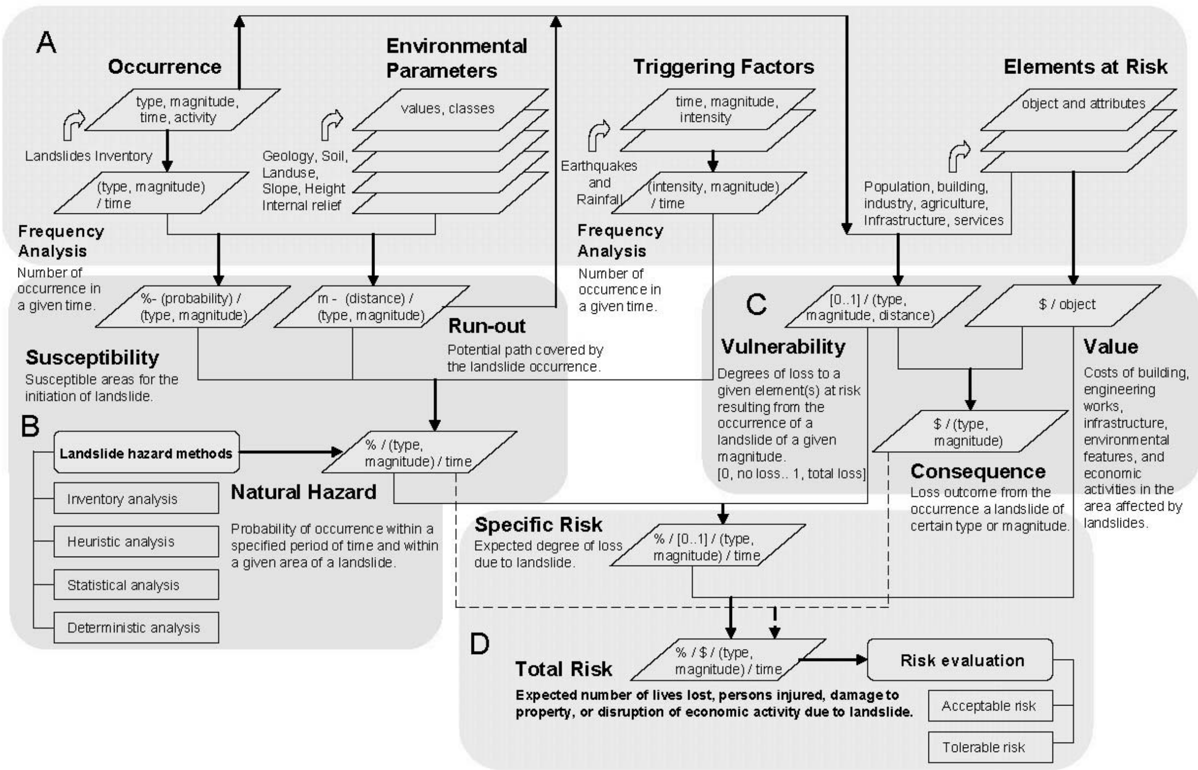

Figure 3: Methodological framework for spatial landslide risk assessment (Castellanos 2008)

CASE STUDY AREAS

The multi-scale assessment methods were applied at national, provincial, municipal and local levels (See Figure 4). At national level, the whole country was analysed for landslide risk. At this level, the main objective was an initial screening process to recognize main administrative areas of national interest for landslides studies. The data used came mainly from national data providers and the DEM derivatives were obtained with SRTM data. The method and results are mainly qualitative by implementing spatial multi-criteria evaluation techniques. National risk index map was compared with provincial and administrative units for ranking priorities in landslide research policies. As this level of analysis is very general, only broad considerations are taken into account and the results should be considered as “indicative”.

For the provincial assessment, the Guantánamo province was selected with half a million population and very diverse natural environments. In this case study, a more semi-quantitative approach was carried out supported by a landslide inventory. Landslides were divided by five main types of movements and also five types of elements at risk were considered. Artificial neural network, weight of evidence and spatial multi-criteria evaluation methods were applied. The analysis explored qualitative and semi-quantitative approach for producing different results with the objectives of locate high risk areas, identify main causes and alert provincial and municipal authorities for further actions.

At municipal level San Antonio del Sur, a municipality located inside Guantánamo, was selected (see Figure 4). The objective at this level was to identify specific hazard probabilities and landslide risk associated to delineate areas for disaster risk reduction plans. In this scale, a more detailed photo-interpretation identified individual features as well as historical events that could be classified. Heuristic approach supported by many fieldwork campaigns allowed applying multi-criteria evaluation techniques using semi-quantitative and quantitative approaches depending on the element at risk. The results were integrated into the municipal disaster reduction plan. Inside this municipality, there is long escarpment called Sierra de Caujerí which was the study area at local level. This level actually includes two areas at two scales, the escarpment and the Jagüeyes landslide located in the centre of the escarpment. Analysis carried out in both areas complement each other by making geophysical survey and photogrammetrical analysis. The reconstruction of Jagüeyes disaster back in 1963 and a detailed survey of elements at risk in the escarpment allowed a more quantitative landslide risk assessment establishing risk buffer zones.

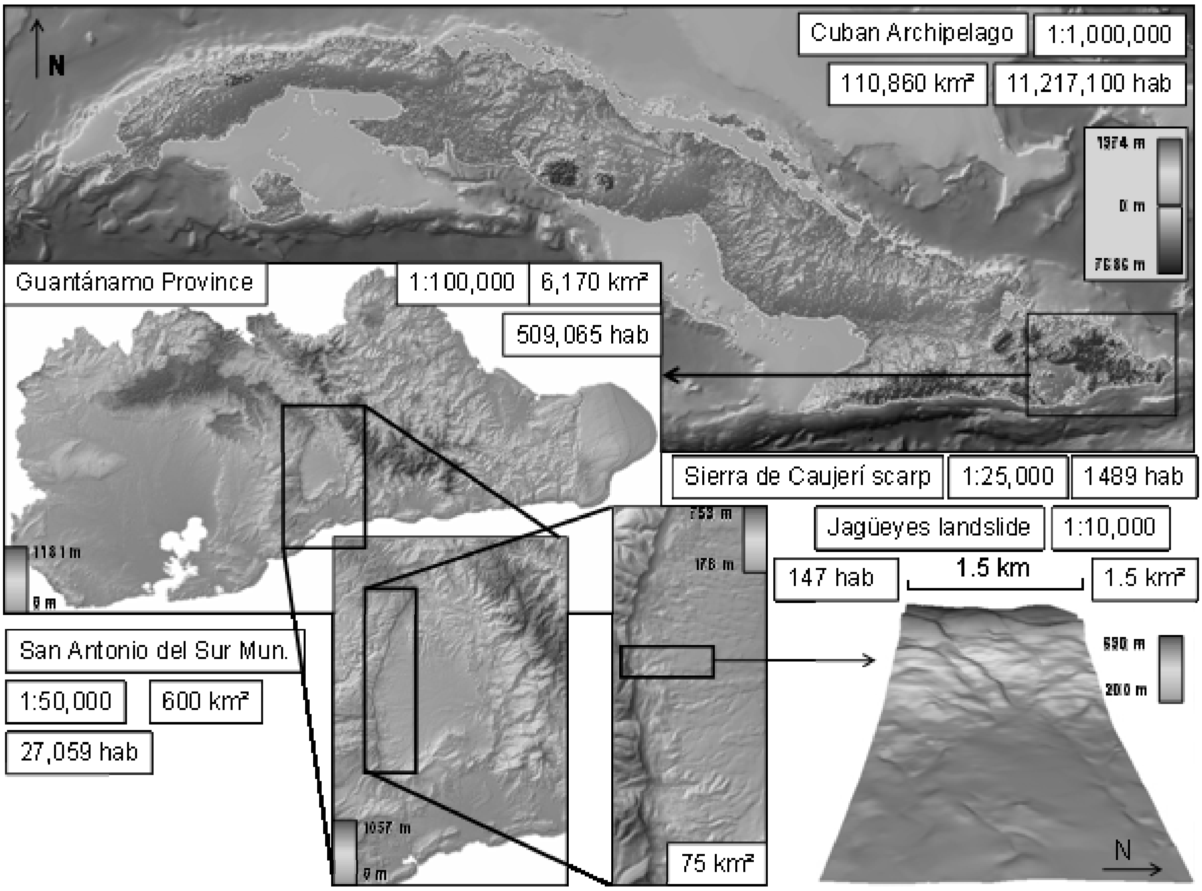

Figure 4: Case study areas for multi-scales landslide risk assessment (Castellanos 2008)

SPATIAL DATA

Although Cuba is a developing country, the context regarding information for landslide risk assessment could be different than in other developing countries. In Cuba, the situation may be less problematic concerning the existence of the data but more difficulties are present in access and format of the data. Landslide risk assessment requires an extensive and multi-disciplinary dataset (Van Westen et al. 2008). During this research, many dataset were collected from diverse organizations.

Table 2 shows the main data sets for landslide risk assessment and the providers for this data in Cuba at different levels used during this research. At national level, most spatial information was collected from the national atlas of the country and from national organizations including the statistics data from the national statistic office. Data collection for the provincial assessment was one of the most extensive. Here, as in other more detailed areas, the data about landslides was collected mainly by extensive photo interpretation and fieldwork campaigns. Elevation data of good resolution was processed to obtain geomorphometric maps. For municipal landslide risk assessment at 1:50,000 scale, most data, including the elements at risk, were digitized from topographic maps.

Table 2: Data providers or source for landslide risk assessment in Cuba (Castellanos 2008)

Data layer and types	Levels of analysis			
	National 1:1,000,000	Provincial 1:100,000	Municipal 1:50,000	Local 1:25,000
Landslides inventory	-	Photointerpretation	Photointerpretation	Photointerpretation
Terrain mapping units	-	-	Photointerpretation	-
Geomorphology	Atlas	Atlas and re-interpretation	Processing	Photointerpretation
Digital Elevation Model (DEM)	SRTM	Group of mountain studies	Topomap	Digital photogrametry
Slope angle	From SRTM	From DEM	From Topomap	-
Slope orientation	-	From DEM	-	-
Slope shape	-	-	From Topomap	-
Internal relief	-	From DEM	From Topomap	-
Drainage (density)	-	EMPIFAR	From Topomap	Photointerpretation
Springs			From Topomap	From Topomap
Geology	Atlas	IGP	IGP	IGP
Soils	-	Soil Institute	-	-
Faults	Atlas	IGP	IGP	
Landuse	Atlas	IPF	From EO	
Water table	-	-	Topomap	Topomap
Rainfall and maximum probabilities	ISMET	ISMET, INRH	INRH	INRH
Earthquakes and seismic acceleration	CENAIS	CENAIS	-	
Population	ONE	ONE/OTE/ Topomap	OTE/OME/Topomap	OME/fieldwork
Roads	Atlas	Topomap	Topomap	Photointerpretation
Lifeline utility systems	-	-	Topomap	Topomap/fieldwork
Housing	INV	Topomap	Topomap	Topomap/fieldwork
Building	-	Topomap	Topomap	Topomap/fieldwork
Production	ONE		OTE/OME	OTE/OME
Facilities	-	OTE/Topomap	Topomap	Topomap/fieldwork-
Protected areas	UICN	CNAP	fieldwork	fielwork-

NATIONAL SCALE ANALYSIS

Only limited research has been done on landslide risk assessment for large areas or entire countries (Guzzetti 2000; Yoshimatsu & Abe 2006). At such small scales, the aim is to produce a landslide risk index which makes it possible to zoom in on the high risk areas for more detailed studies. Risk indexes have been applied in small scale studies either for specific countries (Carreño et al. 2007) or at a global level (Evans & Roberts 2006; Nadim et al. 2006a, 2006b). For designing the vulnerability indicators, it is necessary to take into account the socio-economic conditions, which may vary from country to country. In general vulnerability can be divided in four different types, such as physical, social, economic and environmental which can be combined to derive a qualitative index. There are relatively few publications related to landslide vulnerability assessment and most of them are dealing with large scale studies or on a site-investigation scale (Glade et al. 2005). On a very small scale such as a national landslide risk assessment, it is not feasible to represent the degree of impact depending on the magnitude of the hazardous event and the characteristics of the elements at risk.

Unfortunately there is no national landslide inventory available for Cuba. Recently a project has started to develop such a database. The current national landslide database only contains those landslides where major damage has been reported and is therefore not complete both in space and time. Also quantitative damage information is not available for most of the landslides in the database. For that reason in this study the national landslide database was used with caution as it does not give a complete picture for the country yet. If a complete landslide database would have been available, it could have served as the main input in the landslide risk index. The density of landslides per municipality could then have been used as the main hazard indicators, and the landslide damage per municipality as the main vulnerability indicator. As part of the national landslide risk assessment project for the National Civil Defence, a research project was also initiated to improve the national landslide inventory, making use of local Civil Defence personnel that are trained in reporting the occurrence of new landslides, combined with multi-temporal landslide maps based on Remote Sensing (Castellanos & Van Westen 2005).

Considering the objectives for the assessment of a national landslide risk index map in combination with a large study area and limitations in available data, a semi-quantitative approach was selected. The semi-quantitative estimation for landslide risk assessment is considered useful in the following situations: as an initial screening process to identify hazards and risks, when the level of risk (presumably) does not justify the time and effort or where the possibility of obtaining numerical data is limited (Australian Geomechanics Society and Sub-committee on Landslide Risk Management 2000). Semi-quantitative approaches consider explicitly a number of factors influencing the stability. A range of scores and settings for each factor may be used to assess the extent to which that factor is favourable or unfavourable to the occurrence of instability (hazard) and the occurrence of loss or damage (consequence).

The landslide risk was represented at this scale by a semi-quantitative risk index. For implementing the semi-quantitative model, the spatial multi-criteria evaluation (SMCE) module of ILWIS GIS was used. SMCE application assists and guides users in doing multi-criteria evaluation in a spatial manner (ITC 2001). The input is a set of maps which are the spatial representation of the criteria. They are grouped, standardized and weighted in a "criteria tree". The output is one or more "composite index map(s)", which indicates the realization of the model implemented. The theoretical background for the multi-criteria evaluation is based on the analytical hierarchical process (AHP) developed by Saaty (1980).

As mentioned earlier, the quantification of the expected losses for landslides is not possible, given the limitations in data availability and size of the study area. A schematic representation of the landslide risk assessment model is given in Figure 5. The landslide risk index is high only if both the hazard and vulnerability index maps are high. The hazard component in fact only represents landslide susceptibility, as it doesn't include the time factor required for estimating probability, because of lack of sufficient temporal landslide information for the country. The intermediate map of hazards is constructed again by multiplying two other intermediate maps of Conditions and Triggering Factors. Conditions are the intrinsic environmental parameters of the terrain that lead to particular susceptibility for landslide occurrence and Triggering Factors are the most frequent triggering mechanisms that make landslide event happen. The intermediate map of Vulnerability is generated by combining the four vulnerability types mentioned earlier.

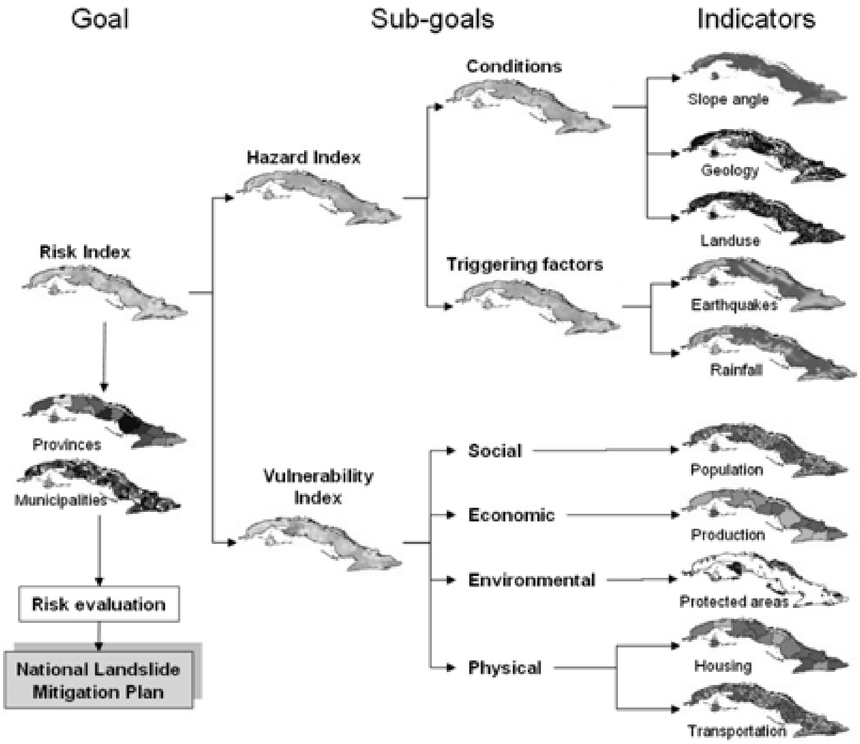

Figure 5: Landslide risk assessment model at national level in Cuba (Castellanos & van Westen 2007a)

After the selection of the indicators, their standardization and the definition of indicator weights, the analysis was carried out using an ILWIS GIS script to obtain the composite index maps and the final landslide risk index map (Figure 6). The frequency of the risk index values is highly influenced by the large number of pixels with zero values, which were introduced using a mask for flat areas. Without considering zeros, the risk index values range from 0.022 to 0.620 with a mean of 0.18, a median of 0.170 and a predominant value of 0.097. These values are low due to the multiplication of the intermediate maps of Hazard and Vulnerability, which were made using the weights as shown in Table 3.

The landslide risk index map shows the spatial distribution of the relative risk values for the entire country. It is possible to recognize the areas with higher values and to query the database of indicator maps to search the causes of these higher values as a backward analysis. Due to the characteristics of the available data sets, it is not possible to avoid polygon boundaries especially with the vulnerability indicators related to administrative units, the geological units and the land use types. For a more detailed study, the risk index values were analysed physiographically and administratively at provincial and municipal level.

The resulting landslide risk index is not a static one, as a number of indicators have a temporal variability, and the landslide risk index map should therefore be updated regularly. Similarly, the model equation could be improved by adding new indicators, once more data becomes available, and by fine-tuning the standardization and weights values. Depending on further requests from the end-user, the model can also be made more complex, and made at a higher spatial resolution. The use of landslide risk index statistics for provinces and municipalities is useful for ranking them in order of importance for landslide risk reduction measures.

Table 3: Overview of indicators (italic), intermediate maps or sub-goals (bold), with their corresponding weight values. The weighting and standardization method is indicated in the right columns (Castellanos & van Westen 2007a)

<table>
<tr><td colspan="3">National Landslide Risk Model</td><td>Weighting</td><td>Standardization</td></tr>
<tr><td colspan="3">Hazard</td><td>Direct</td><td></td></tr>
<tr><td rowspan="4">0.8</td><td colspan="2">Conditions</td><td rowspan="4">Direct</td><td></td></tr>
<tr><td>0.50</td><td>Slope angle</td><td>Concave</td></tr>
<tr><td>0.20</td><td>Land use</td><td>Ranking</td></tr>
<tr><td>0.30</td><td>Geology</td><td>Ranking</td></tr>
<tr><td rowspan="3">0.2</td><td colspan="2">Factors</td><td rowspan="3">Pair-wise</td><td></td></tr>
<tr><td>0.90</td><td>Rainfall</td><td>Maximum</td></tr>
<tr><td>0.10</td><td>Earthquakes</td><td>Maximum</td></tr>
<tr><td colspan="5">Constraint for hazard map, areas with slope angle 3 degrees or less.</td></tr>
<tr><td colspan="3">Vulnerability</td><td rowspan="6">Rank Expected Value</td><td></td></tr>
<tr><td>0.256667</td><td colspan="2">Housing</td><td>Maximum</td></tr>
<tr><td>0.090000</td><td colspan="2">Transportation</td><td>Maximum</td></tr>
<tr><td>0.456676</td><td colspan="2">Population</td><td>Concave</td></tr>
<tr><td>0.156667</td><td colspan="2">Production</td><td>Maximum</td></tr>
<tr><td>0.040000</td><td colspan="2">Protected areas</td><td>Ranking</td></tr>
</table>

Table 4: Percentage of each province with low, moderate and high landslide risk (Castellanos & van Westen 2007a)

Province	Low risk %	Moderate risk %	High risk %
Pinar del Rio	74.8	24.1	1.2
La Habana	88.6	8.4	3.1
Ciudad de La Habana	84.8	4.5	10.7
Isla de la Juventud	97.4	2.6	0.0
Matanzas	96.5	3.0	0.5
Cienfuegos	82.0	17.8	0.3
Villa Clara	86.7	8.6	4.8
Sancti Spitritus	79.1	20.5	0.5
Ciego de Avila	96.5	3.2	0.3
Camaguey	96.9	2.9	0.2
Las Tunas	98.5	1.4	0.1
Holguin	64.3	9.6	26.1
Granma	74.7	3.6	21.8
Santiago de Cuba	35.9	14.3	49.8
Guantánamo	31.6	37.2	31.2

The method allows evaluating which of the indicators is responsible for high risk index values. Local (provincial and municipal) authorities can now be warned about the landslide risk that their areas are facing and since they are part of the civil defence system in Cuba, they can also allocate resources for a local landslide mitigation program. The city of Santiago de Cuba ranks at the top of the landslide risk index list of municipalities as this densely populated area is located along the Sierra Maestra mountainous system.

The results are intended to support national decision makers in prioritizing funding for risk assessments at local, municipal and provincial levels. With the outcomes of the study in Cuba, the Civil Defence organisation will be able to alert local authorities about the risk levels and to link the information to the national hurricane early warning system, allowing also warning and evacuation for landslides prone areas

PROVINCIAL SCALE ANALYSIS

The method for landslide risk assessment at a provincial scale was developed and tested in the province of Guantánamo (see Figure 4), the most eastern province of Cuba. Guantánamo contains both the most humid (in the North) and driest (in the South) zones of Cuba. The province has 10 municipalities and 386 settlements from where 18 are considered urban. Agriculture is the most important economic income for the province which is based on sugar cane, coffee, cacao, wood and coconut. The last four are cultivated in mountainous regions. The industries include an iron foundry, and factories for coffee, agricultural tools, furniture, food, sugar cane and salt. Guantánamo has the record of 49 devastating hurricanes measured over the period 1789-2003, which are more frequent in September and October. Since 1997 to 2002, there were 93 forest fires reported, affecting an area of 3043 hectares. The landslides resulting from these other disasters are rarely recorded in the official statistics. The province also has a substantial earthquake hazard, due to the presence of the Caribbean-North American plate boundary in the south.

A schematic overview of the methodology is given in Figure 7. The method started with a comprehensive landslide inventory, and the collection of input data on landslide causal factors and elements at risk, represented in the upper part of Figure 7. Landslides were photo-interpreted from 300 aerial photos (format 23 x 23mm) from the year 2000 at 1:25,000 scale, covering the entire Guantánamo province. Unfortunately no multi-temporal image interpretation could be carried out, which made it difficult to establish the age of the landslides. In total 281 landslides were identified covering an area of about 19.92 km^2. From this inventory, five main types of landslides were determined: rockfalls, debris flows, topples, small landslides and large rockslides. The next step was to generate a number of landslide susceptibility maps for the five different landslide types, using a combination of a heuristic approach, and of several statistical methods, such as the Weights of Evidence Modeling and Artificial Neural Network analysis. The susceptibility maps were converted into hazard maps, based on the landslide densities of the susceptibility classes and the temporal probability of landslide occurrence. This resulted in five hazard maps (H_slide to H_rockslide, indicated in the middle part of Figure 7.

Elements at risk (EaR) data were collected for population, roads, essential facilities and non residential buildings, agricultural land use, and protected areas. In order to estimate the risk to these elements by the five different landslide types, each of the five hazard maps was overlain with the elements at risk maps to calculate the number of elements per hazard class. In the lower part, the method for the risk assessment is presented. The study was based on raster analyses using ILWIS and ArcGIS© GIS software at 50m resolution taking into account the cartographic rule of a maximum detail of 0.5 mm at the scale of the final map (1:100,000 scale in this case), resulting in maps with 2475543 pixels.

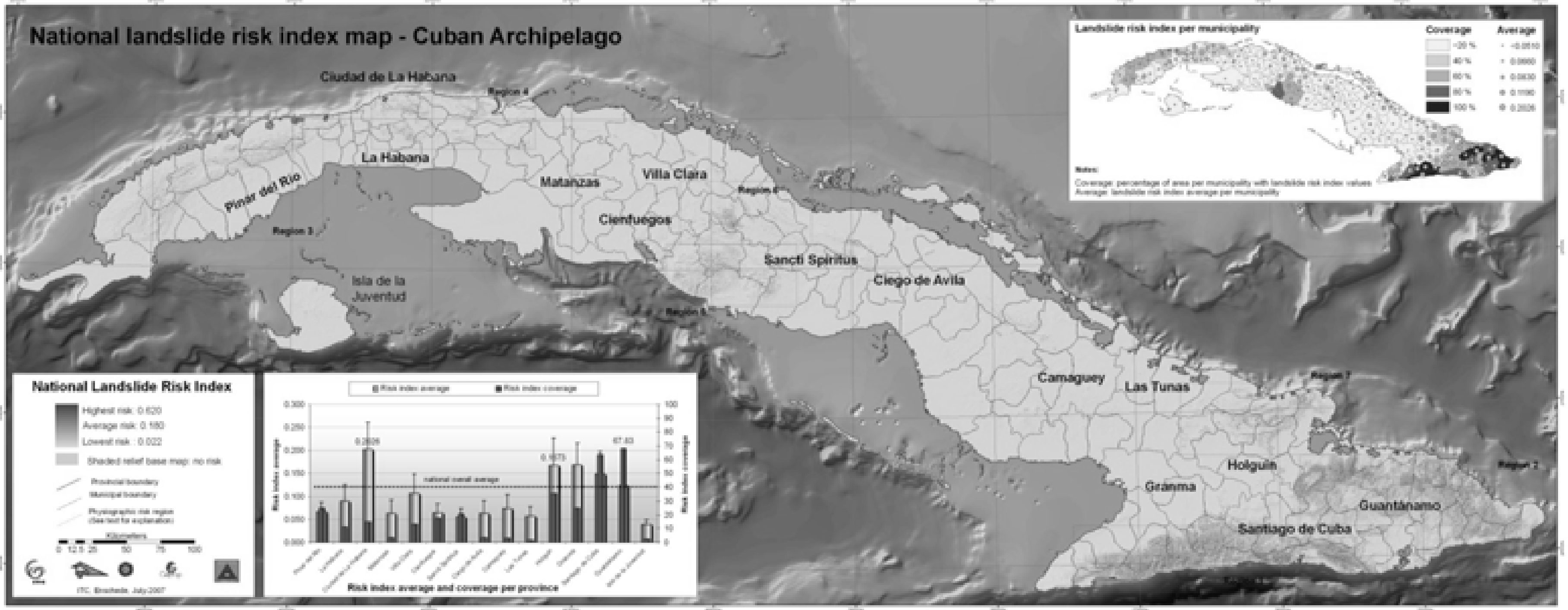

Figure 6: Final landslide risk index map, as presented to the National Civil Defence authorities. Inset map in the upper right corner indicates the landslide risk index per municipality, both as the percentage of area with landslide risk index larger than 0 (coverage) as well as the average landslide risk index. The bar chart shows the landslide risk index values per province (Castellanos & van Westen 2007a).

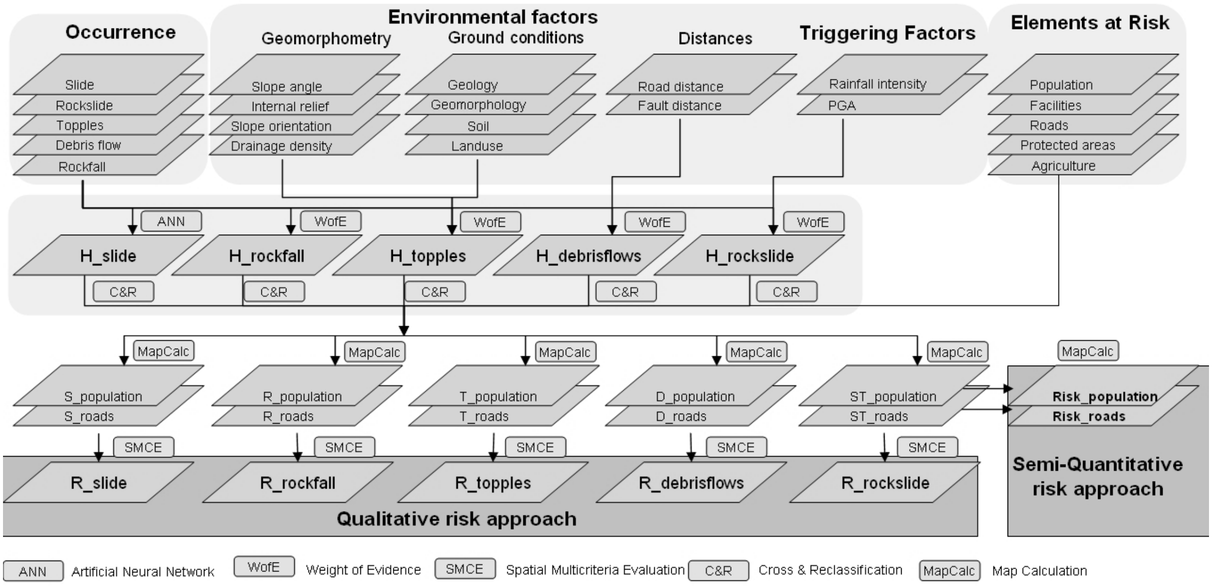

Figure 7: Flowchart for landslide risk assessment at provincial level. The abbreviations in the figure refer to the following aspects: D: Debris flows, R: Rockfalls, S: Slides, ST: Large rock slide and T: Topples. ANN: Artificial Neural Network, WofE: Weight of Evidence, C&R: Map crossing and reclassification (Castellanos 2008; Castellanos & van Westen 2007a)

The casual factor maps were selected based on literature and on the data available in Cuba. They were separated into 3 groups: morphometric factors, ground conditions, distance related factors, and triggering factors. A DEM was created using the ArcGIS© "topo to raster" tool, and four morphometric parameter maps were extracted: slope steepness, slope orientation (aspect), internal relief (vertical dissection) and drainage density. Existing geological, geomorphological and soil maps were used and reclassified by reducing the number of legend units to only those that were considered relevant for landslide susceptibility assessment. The landuse map, which was also obtained from existing maps, was used both as potential causal factor, and as element at risk for estimating the impact of landslides on agricultural production. Two buffer maps were used: distance to main roads in sloping areas, and distance to active faults. Also two triggering factors were used in the landslide hazard assessment. The first of these was a raster map of maximum expected rainfall in 24 hours for a 100 year return period, and the was a map of the peak ground acceleration (PGA) with a 10 percent exceedance probability in 50 years.

As part of the hazard analysis, two methods were applied for estimating spatial probabilities: Weights of Evidence (WofE) modeling (Bonham-Carter 1996) and Artificial Neural Network (ANN) analysis (e.g. Lee et al. 2004). The selection of the relevant causal factor maps for each of the five landslide types was made based on initial results of WoE modeling, and expert judgment. The susceptibility maps for 4 out of 5 landslide types were generated using WoE modeling, as for each of these, the main casual factors could be clearly separated, and also because the number of events for each of these was relatively small. For the generation of the susceptibility map of slide-type movements, it was decided to use the ANN method, because there were several different causal mechanisms for this landslide type, that were difficult to separate, and also because the number of events was substantially larger than for the other types. The landslide inventory database was randomly subdivided in three subsets: a training set (75% of the landslides) used to optimize the weights, a validation set (12.5%) used to stop the network algorithm before the network starts learning from noise in the data, and a test set (12.5%) to evaluate the prediction capability of the network. An equal number of samples was also randomly taken in non-landslide areas. Due to the small scale of the study and the relatively large pixel size it was decided not to include a runout analysis as part of the landslide susceptibility assessment. The five susceptibility maps were validated using the landslide inventory and success rate curves were generated (See Figure 8). The results showed generally a very good fit, especially for the topples, large rockslides and rockfalls that occur under very specific conditions. The success rate curves were also used to classify the susceptibility maps with approximately equal percentages of the total number of landslides (e.g. ~ 70 % of all landslides in the highest class). The susceptibility maps are shown in Figure 9. For the spatial landslide vulnerability analysis, only five types of elements at risk (population, facilities, roads, protected areas and landuse) were used. Also here the approach was to combine them using spatial multi-criteria evaluation (SMCE). As explained before, since it was not possible to obtain monetary values for all elements at risk, the vulnerability was carried out using relative weight values.

The risk assessment was carried out for the 5 different landslide types and 5 types of elements at risk, using both a qualitative and semi-quantitative method.

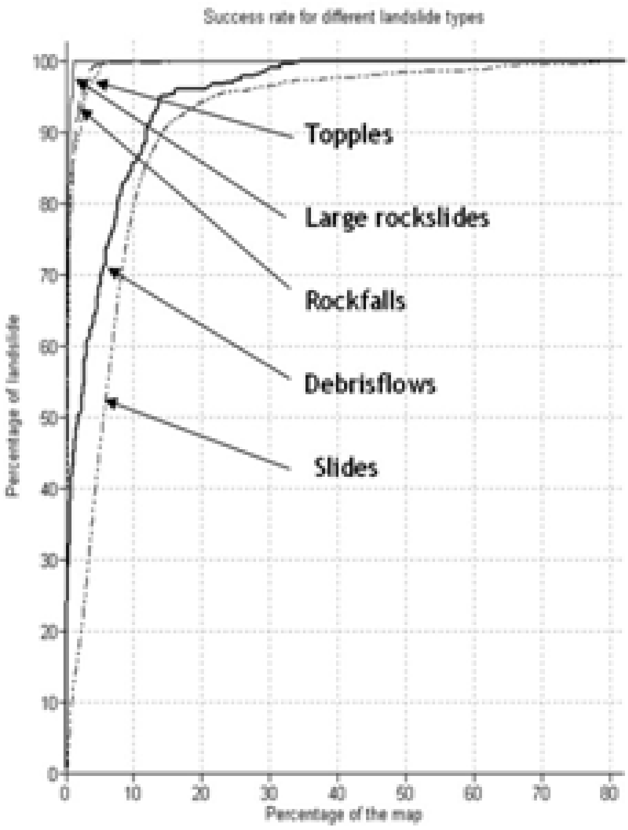

Figure 8: Success rate curves for the five landslide susceptibility maps

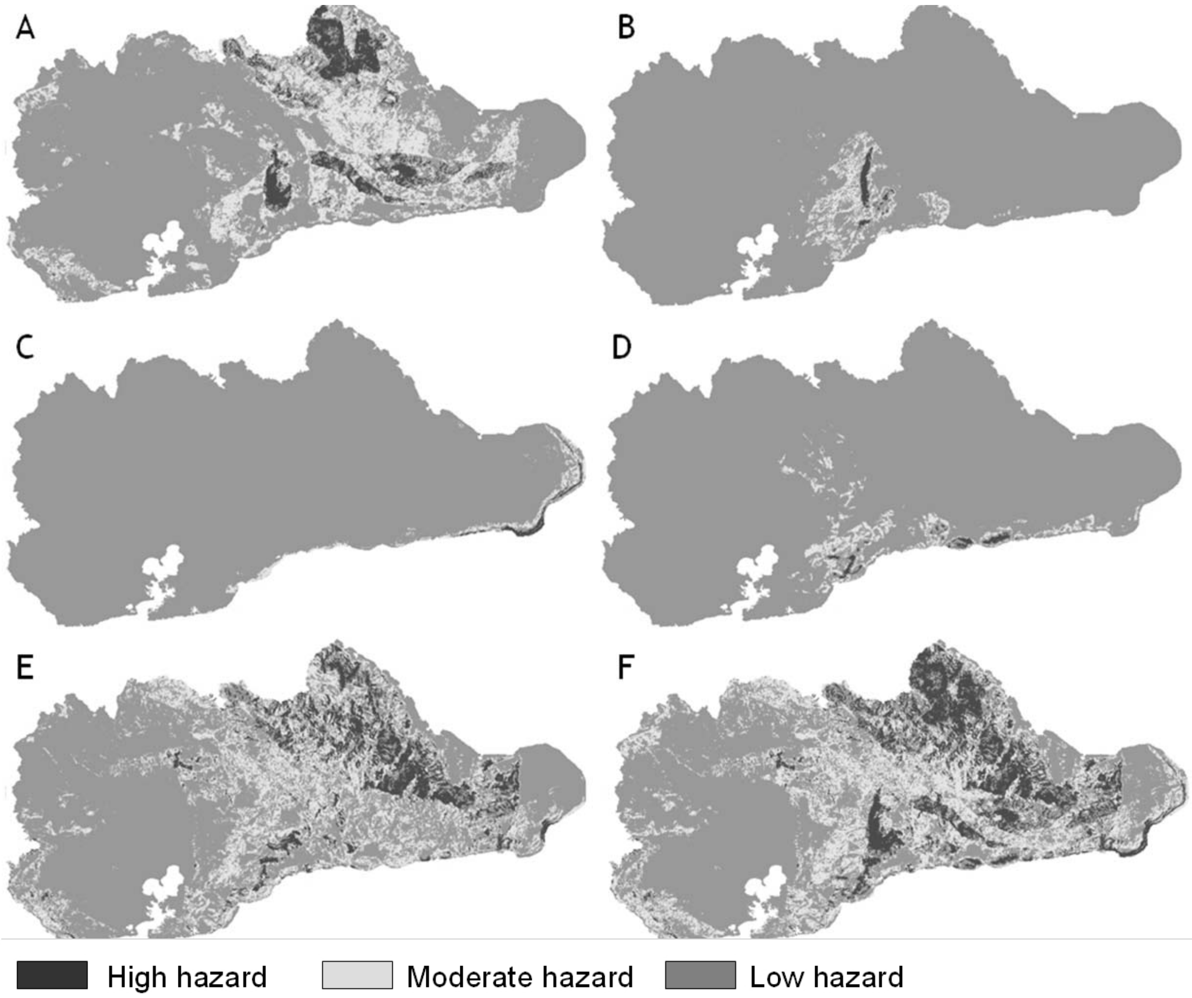

Figure 9: Landslide susceptibility maps. A: debris flows, B: large rockslides, C: rockfalls, D: topples, E: slides and F: all hazards (Castellanos 2008)

Qualitative Risk Assessment

The qualitative landslide risk assessment initiated by overlaying each of the four hazard maps (for each landslide type) with a composite vulnerability map. The map resulting from the overlaying was reclassified considering the hazard and vulnerability classes. In order to be more conservative with the vulnerability assessment, an "expert-based" approach was applied to create the qualitative landslide risk map. The rules used for the combination of hazard and vulnerability classes are given in Table 5. With this approach, the areas with low or even no vulnerability but low hazard, were still considered as risk areas (23.48%). This classification was adopted taken into account the subjectivity and the data problems involved in the analysis.

Table 5: Qualitative landslide risk matrix applied in Guantánamo province. The percentage of the total area for each combination is given in brackets (Castellanos 2008)

Vulnerability					
Vulnerability	High	No risk (0.05)	High risk (0.00)	High risk (0.00)	High risk (0.00)
	Moderate	No risk (0.12	Moderate risk (0.02)	Moderate risk (0.01)	High risk (0.00)
	Low	No risk (3.67)	Low risk (0.48)	Moderate risk (0.17)	High risk (0.06)
	Not	No risk (41.86)	Low risk (23.48)	Low risk (17.27)	Moderate risk (12.81)
		No	Low	Moderate	High
		Hazard			

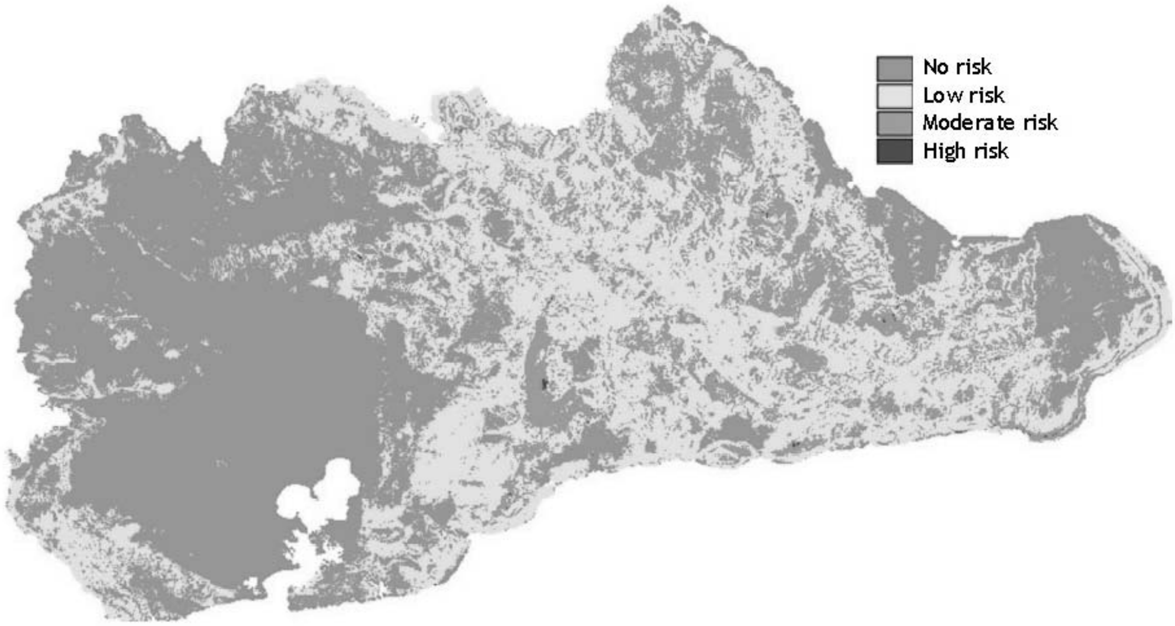

Figure 10: Qualitative landslide risk map of Guantánamo province (Castellanos 2008)

Semi-Quantitative Analysis

The first step in the semi-quantitative risk analysis was the conversion of the susceptibility maps into hazard maps. For this, three probabilities were calculated for pixels belonging to each hazard class within the five maps:

- Event probability, P(E), defined as the probability that if a landslide occurs of a given type, it happens in the particular susceptibility class.
- Spatial probability, P(S), defined as the probability that if a landslide occurs within a given susceptibility class, a pixel in this class might be hit.
- Temporal probability, P(T), defined as the annual probability of occurrence of a particular landslide type.

The event probability and spatial probability were calculated based on the area of landslides within each susceptibility class, in relation to either the total area of landslides (for P(E)) or the total area of the class (for P(S)). Temporal probability was the most difficult to estimate, also in the absence of a historical landslide database. Therefore, based on geomorphological analysis and comparison with return periods for the main triggering events, a return period (RP) of 100 years was selected for large rockslides, a 50 years RP for rockfall and topples, and a 20 year RP for debris flows and slides.

The semi-quantitative analysis of the expected number of people that might be killed by landslides annually in the province was done by overlaying the hazard maps with a population distribution map, indicating the maximum number of persons in buildings per pixel of 50 by 50 m. Outdoor population and temporal variations of population density were not considered. This results in the number of persons per hazard class as indicated in Table 6. The next step was to estimate the vulnerability of people being killed by a landslide while being indoors, based on the type of landslide and the expected magnitude of the event. These values were based on literature (e.g. Glade et al. 2005) and expert judgment, in the absence of historical landslide damage information.

Table 6: Results for the specific risk for population calculated as the product of hazard, vulnerability, and number of persons within a particular hazard class for the 5 different landslide types (Castellanos & van Westen 2008)

	Low hazard	Moderate hazard	High hazard	Total
Rockfall				
Hazard	5.30E-07	1.71E-05	7.52E-04	
Vulnerability	0.6	0.6	0.6	
Population	1616	522	200	2338
Specific risk	0.0005	0.0054	0.0902	0.0961
Rockslides				
Hazard	2.69E-06	5.36E-05	1.67E-03	
Vulnerability	1.0	1.0	1.0	
Population	1265	453	184	1902
Specific risk	0.0034	0.0243	0.3072	0.3349
Topples				
Hazard	1.17E-06	1.36E-05	4.48E-04	
Vulnerability	0.2	0.2	0.2	
Population	2139	745	12	2896
Specific risk	0.0005	0.0020	0.0011	0.0036
Debris flows				
Hazard	1.27E-07	7.40E-06	9.48E-05	
Vulnerability	0.4	0.4	0.4	
Population	8047	553	0	8600
Specific risk	0.0004	0.0016	0.0000	0.0020
Slides				
Hazard	6.24E-07	2.60E-05	3.06E-04	
Vulnerability	0.7	0.7	0.7	
Population	30490	2255	1465	34210
Specific risk	0.0133	0.0410	0.3133	0.3676

From Table 6, it can be concluded that the annual population risk for landslides in Guantánamo province is low (0.8 persons/year). As there are no official records available on landslide casualties it is difficult to validate this at this moment. The method allows also quantifying the risk in monetary values for direct damage to roads, agricultural areas, facilities, and protected areas. The results allow a comparison of annual risks with those from other hazard types, and can form the basis for planning risk reduction measures. In the estimation of the semi-quantitative risk, it is important to keep in mind that there are a number of estimated factors that need to be quantified more in detail in future. These relate specifically to the estimation of temporal probability, and vulnerability. Both require the generation and maintenance of a landslide inventory for the province, which also includes actual damage information. Also a more detailed evaluation of the effect of different landslide magnitudes should be taken into account, as well the use of different return periods for the same landslide type and the inclusion of landslide runout assessment.

MUNICIPAL SCALE ANALYSIS

The study area, within the San Antonio del Sur municipality, is located in eastern Cuba (See Figure 4) 60 kilometers from the city of Guantánamo, the capital of the province with the same name. The main access to the area is by the coastal road connecting Guantánamo and the eastern municipalities.

A geomorphological map, including the landslide inventory, at scale 1:50.000 (Figure 11) was prepared from interpretation of two sets of aerial photographs (of 1:25,000 and 1:37,000 scale) and fieldwork. Both photo sets correspond to a national aerial survey carried out at the beginning of the 1970s. The 1:37,000 scale photos (55 in total) cover the whole study area with four flight lines and were taken from 2-Feb-1972 till 19-Mar-1972. The 1:25,000 scale photos (46 in total) cover south-west part in three flight lines and were taken between 5-Dec-1971 and 21-Dec-1971. The photos were interpreted with a TOPCON stereoscope on transparent paper and transferred to digital format by on-screen digitizing over using other image products for double checking (anaglyph, shaded DEM, Landsat TM true color composite and digital topographic map). The photo-interpreted units were checked in the field by three people during a fieldwork campaign which took three weeks. The area was divided into 603 terrain mapping units (TMU). A TMU can be considered a homogeneous mapping unit on the basis of geomorphologic origin, physiography, lithology, morphometry, and soil geography (Meijerink 1988). A single landslide was considered an individual TMU. In certain cases, when the size was large enough, landslide zones such as scarps, bodies and depressions were also considered a separate TMU.

By far the most striking geomorphological feature in the study area is the large oval shaped depression (Puriales de Caujeri valley), which is considered to be a graben with elevation differences up to 500 meters. The valley is limited on the west by a large scarp of the Sierra de Caujeri, with some active retrogressive mass movements. On the southern and northern parts the valley is also surrounding by major fault scarps. The origin of the Puriales de Caujerí depression can be interpreted as a combination of tectonic and mass wasting processes.

The geomorphological mapping provided in-depth knowledge of the causal factors for landslides in the study area and was used to assess landslide susceptibility. Also at this scale, qualitative weighting, one of the heuristic methods, was selected, given the relative small scale, the available data, and the characteristics of the study area. Besides, the TMU mapping may produce biased results when using a statistical method due to the high spatial correlation between the landslides inventory and some units in the TMU map. The following criteria were used in the susceptibility analysis: Geomorphology, Topography, Geology, Tectonics, and Hydrology. These criteria were further subdivided into nine variables, specific attributes, such as slope, internal relief and slope shape for Topography. The variables are described in Table 7. The variables were standardized and weights were assigned to the corresponding levels of criteria and variables in three different ways: directly by expert opinion, by pairwise comparison matrix and by ranking. The weight values range between 0 and 1 and need to sum up to 1 among the variables within a criterion and among the criteria. For checking the weight assignment, the decision-support system called DEFINITE was used (Janssen & Herwijnen 1994). In the first method, the weights of the criteria and variables were assigned directly based on expert opinion and field experience.

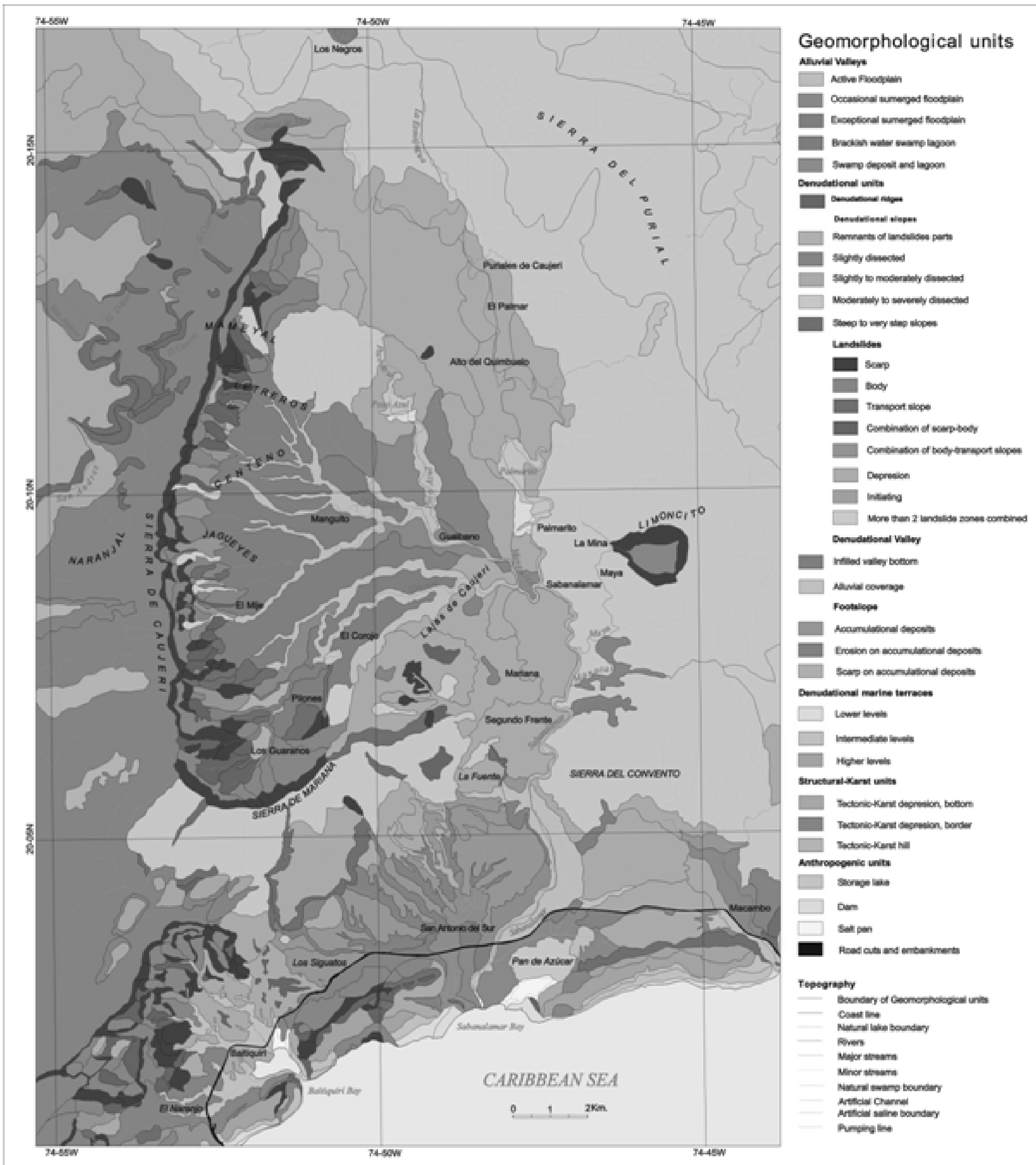

Figure 11: Geomorphological map. San Antonio del Sur, Guantánamo Province, Cuba (Castellanos & van Westen 2007b).

For the pairwise comparison matrix, each variable (or criterion) is compared to all others in pairs in order to evaluate whether they are equally significant, or whether one of them is somewhat more significant / better than the other for the goal concerned. In the ranking method, the criteria and variables are simply ranked according to their importance as landslide controlling factors. The rankings can be considered units on an ordinal scale. Consequently the weights can be found by standardizing the rank order. The three weighting methods gave comparable results, as can be seen from Table 7. For the pairwise comparison matrix method, the inconsistency value was 0.08, demonstrating that the weights are sufficiently reliable. The inconsistency parameter measures randomness of the expert judgments, and ranges from 0 to 1. As a conclusion, the initial weights assigned by expert opinion were taken for the analysis. The final weights of the resulting map ranged from 0.5 to 47.1. This map was classified into 10 divisions interactively, during which the relation with existing landslide areas and geomorphological units was evaluated. Although the map gives a good indication of the qualitative landslide hazard in the study area, too many classes might make it difficult to use by decision makers for development planning. Therefore, the hazard map has ten classes, which are grouped into three simplified categories: high, moderate and low (See Figure 12 and Table 8).

Table 7: Weight for criteria and variables for three methods (Castellanos & van Westen 2007b)

Components	Direct Method		Pairwise Matrix		Ranking Method	
Topography	0.3		0.224		0.257	
Slope		0.7		0.7		0.7
Internal Relief		0.2		0.2		0.2
Shape		0.1		0.1		0.1
Geology	0.2		0.131		0.157	
Formation		1		1		1
Tectonic	0.05		0.040		0.065	
Active faults		1		1		1
Hydrology	0.05		0.038		0.065	
Springs		0.5		0.5		0.5
Drainage density		0.5		0.5		0.5
Geomorphology	0.4		0.566		0.457	
Subunits		0.4		0.4		0.4
Landslides zones		0.6		0.6		0.6
Total for criteria	1		0.999		1.001	

Table 8: Characterization of the 10 landslide hazard classes and 2 flooding hazard classes. (See Figure 12) (Castellanos & van Westen 2007b)

<table>
<tr><th>Hazard</th><th>Overall class</th><th>Hazard Class</th><th>Weight range</th><th>Area (ha)</th><th>Number of TMU units</th><th>Number of landslides</th><th>Area of landslides (ha)</th><th>Landslide density (%)</th><th>General hazard description</th></tr>
<tr><td rowspan="10">LANDSLIDES</td><td rowspan="3">LOW</td><td>H1</td><td>0.50-5.16</td><td>8,669</td><td>88</td><td>0</td><td>0</td><td>0</td><td rowspan="3">No landslides expected. Areas can be corridors for mudflows or other intensive mass wasting processes. In some parts small landslides can happen in extreme conditions. The areas are suitable for development projects.</td></tr>
<tr><td>H2</td><td>5.17-9.82</td><td>4,176</td><td>40</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>H3</td><td>9.83–14.48</td><td>18,107</td><td>125</td><td>8</td><td>210</td><td>1.1</td></tr>
<tr><td rowspan="3">MODERATE</td><td>H4</td><td>14.49–19.14</td><td>18,361</td><td>94</td><td>22</td><td>338</td><td>1.8</td><td rowspan="3">Moderate to high possibility of landslides occurrence during intensive or prolonged rainfall. These areas contain most of the existing landslide zones. Most of the landslide materials are unconsolidated and susceptible to being reactivated in smaller proportions. More studies are required for development of the area. Land use changes should be previously studied in relation to landslide hazard problem.</td></tr>
<tr><td>H5</td><td>19.15–23.80</td><td>2,013</td><td>85</td><td>46</td><td>901</td><td>44.7</td></tr>
<tr><td>H6</td><td>23.81–28.46</td><td>1,702</td><td>87</td><td>79</td><td>1,428</td><td>83.8</td></tr>
<tr><td rowspan="4">HIGH</td><td>H7</td><td>28.47–33.12</td><td>969</td><td>77</td><td>76</td><td>963</td><td>99.3</td><td rowspan="4">High to very high landslide hazard areas. A high possibility of landslide occurrence during rainy conditions. No development is recommended in these areas. Possible relocation of land for agricultural use. Highly recommended re-allocation of existing population in these areas</td></tr>
<tr><td>H8</td><td>33.13–37.78</td><td>719</td><td>59</td><td>59</td><td>715</td><td>99.5</td></tr>
<tr><td>H9</td><td>37.79–42.44</td><td>291</td><td>36</td><td>36</td><td>289</td><td>99.4</td></tr>
<tr><td>H10</td><td>42.45–47.10</td><td>439</td><td>24</td><td>24</td><td>438</td><td>99.8</td></tr>
<tr><td rowspan="2">FLOODS</td><td rowspan="2">-</td><td>F1</td><td>N/A</td><td>1325</td><td>15</td><td>0</td><td>0</td><td>0</td><td>Flooding areas up to 5 years return period taken from local Civil Defence authority and updated yearly. Appropriate warning system needs to be maintained. The area could be used for seasonal agricultural products. Land-use planning should consider flooding hazard limits to re-allocated existing infrastructure and avoid new developments.</td></tr>
<tr><td>F2</td><td>N/A</td><td>503</td><td>6</td><td>0</td><td>0</td><td>0</td><td>Dam break flood limit taken from dam project report. Engineering conditions of the dam should continuously be checked. The area could be used for agricultural products. Land-use planning should consider this hazard limit to re-allocated existing infrastructure and avoid new developments.</td></tr>
</table>

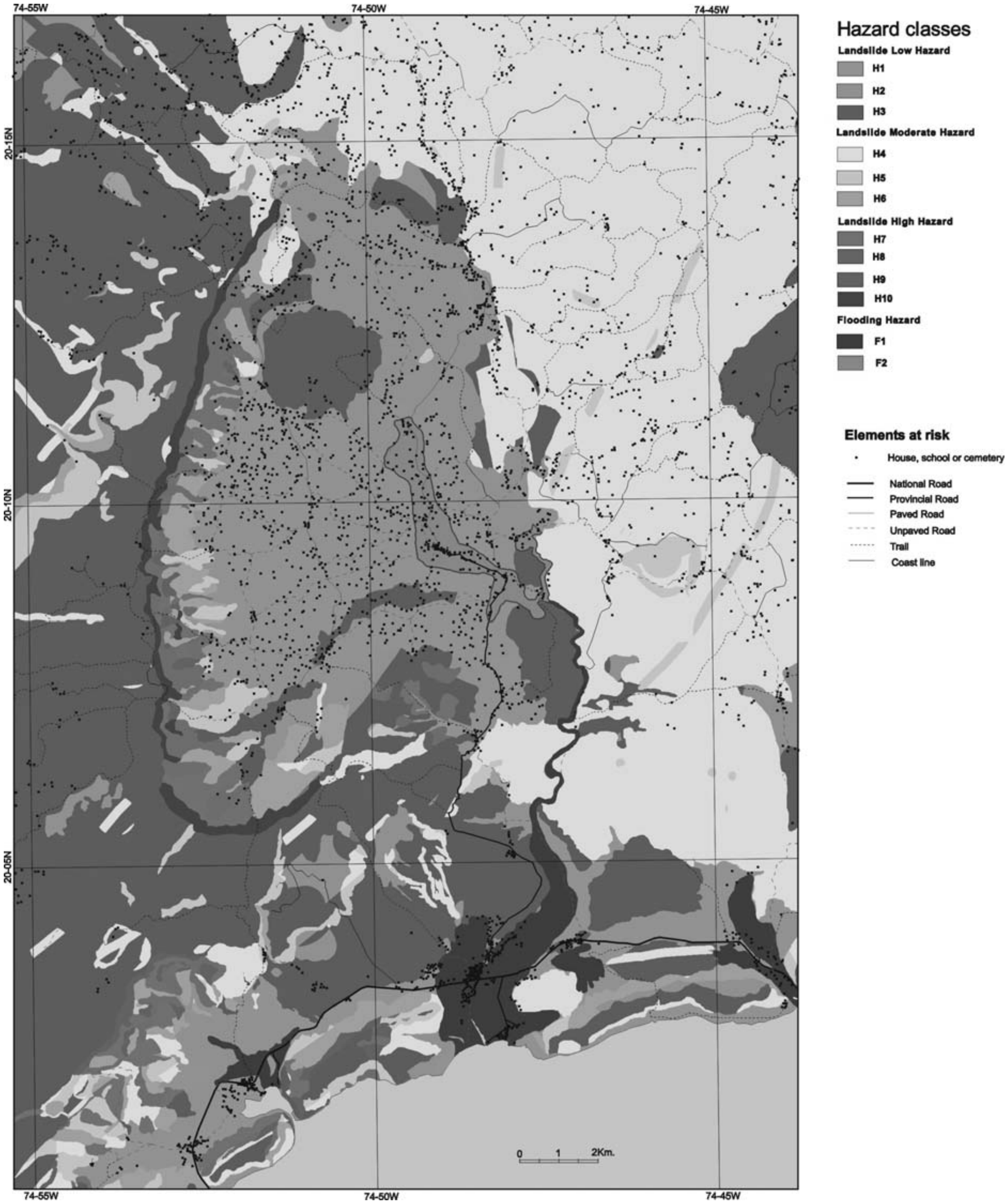

Figure 12: Hazard map, San Antonio del Sur, Guantánamo, Cuba. See Table 8 for explanation of the legend (Castellanos & van Westen 2007b)

Too little information was available to carry out a more sophisticated landslide risk assessment. In particular, there was not enough data on the probability of landslides of different magnitudes to make a (semi) quantitative risk assessment. Therefore only a basic qualitative analysis was carried out through the combination of the landslide hazard map with basic elements at risk. During the fieldwork, information was collected on buildings and roads. As the study area is a rural environment, most of the buildings are isolated farmhouses; a number of small schools and medical centres also were identified. Most roads are unpaved country roads, except for the main road in the south of the study area, which runs along the coast, mostly on the land-side of the coastal hills.

LOCAL SCALE ANALYSIS

This level of analysis was done on two areas at two scales, the escarpment Sierra de Caujerí located in the western border of Caujerí valley and the Jagüeyes landslide in the centre of the escarpment (See Figure 4). It is a tectonic scarp with an average of 500 meter high difference of sub-horizontal limestone and marls. Along the escarpment, about 40 large landslides were mapped, most of them in dormant conditions (See Figure 11). The limestone presents many karstic features and groundwater flows into karstic aquifers. Many springs could be found in the accumulation zone or in the foot of the landslides flowing into the valley drainage system. The landslides are mostly rotational rock slides that end in mud flows at the valley bottom. Different landslide activity distribution can be observed like advancing and retrogressive and landslide activity styles like successive and multiple.

The most catastrophic landslide (Jagüeyes) in the Sierra de Caujerí scarp occurred after three days of heavy rain during the passing of cyclone Flora on October 8, 1963, the most devastating meteorological event known that affected Cuba (See Figure 4). A total of 1,100 mm of rainfall in three days was recorded in the Sierra de Caujerí area. The successive rotational rockslide occurred in two pulses at about 45 minute intervals, which allowed some of the inhabitants to escape, whereas 5-10 others were killed. No technical report was made directly after the event although some data were recorded during the fieldwork when a number of interviews were held with some of the survivors. However, due to the long time since the occurrence of the landslide this information may no longer be reliable. Most of the landslides in the Sierra de Caujerí scarp consist of a large scarp on the upper part, often up to 100 meters high, which has cut almost vertically the limestone layer of the Yateras formation and the underlying Maguey formation. This scarp is actually the back-scarp of multiple landslides, which change from rockslide to debris flows. The area is used mostly for farms, and private and state-owned organizations. There are a few hundreds of farm houses and small primary schools. The road system is poor and unpaved one lane road predominates. Despite the low value of elements at risk, the economical value of the area is important for the province as here is found the main food production for more than 200,000 inhabitants in the province.

A geophysical survey was carried out in order to recognize the underground conditions and detail photo interpretation was made using aerial photos since 1956 until 2000. A DEM was created by digital photogrammetry techniques. A run-out model was applied in Jagüeyes landslide using probabilistic approximations and retrospective risk assessment was evaluated. In this case, element at risk were surveyed as much as possible house by house. With theses results, the risk model was applied to the escarpment for all houses and people found in the area down slope in order to estimate the risk and define risk buffer zones with particular landuse planning considerations as well as risk reduction plan.

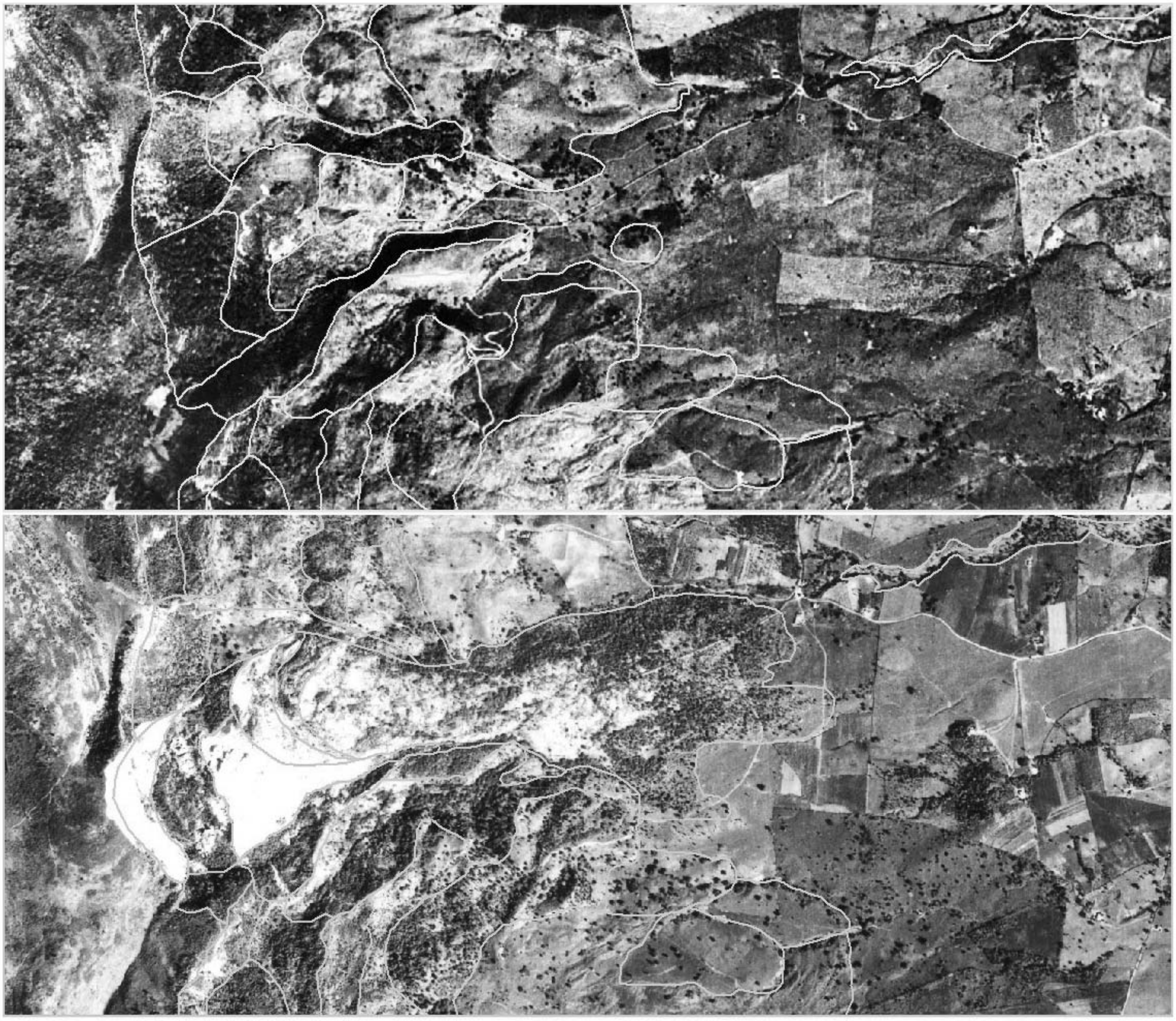

Figure 13: Aerial photo interpretation of photos from 1956 (above) and 1972 (below) in which the occurrence of the Jagüeyes landslide can be clearly observed (Castellanos 2008)

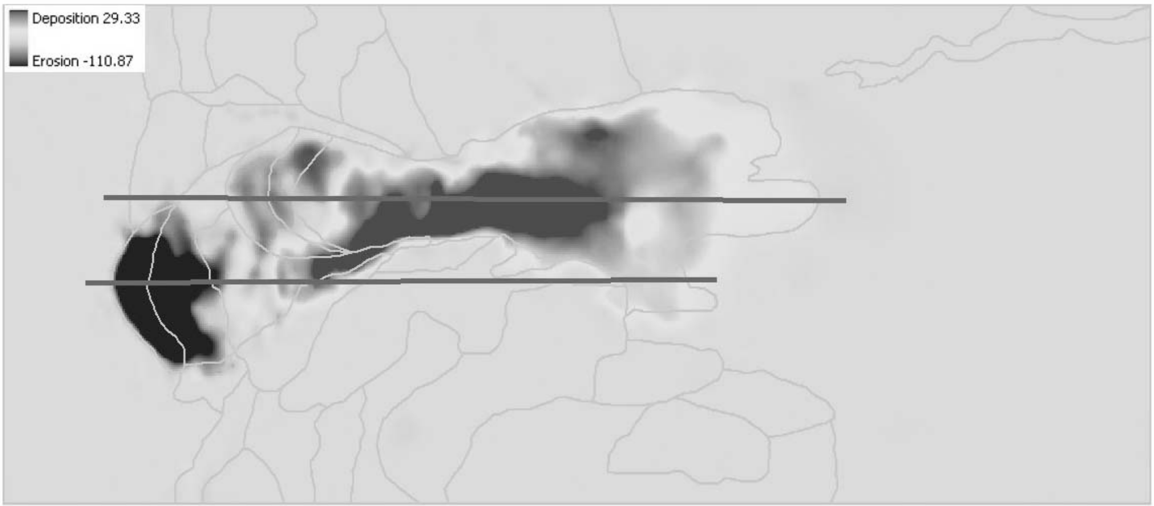

Figure 14: Result of the comparison of two DEMs derived from air photos before and after the occurrence of the Jagüeyes landslide (Castellanos 2008)

CONCLUSIONS

There is still no universally applicable methodology for landslide risk assessment, as each country has its own characteristics with respect to organization, available data and environmental situation. For Cuba, we hope that the methodology which is presented here can form the basis for the landslide risk component of the multi-hazard risk assessment method of the Civil Defence. The multi-hazard risk assessment should be carried out in every province by a team previously trained by the national group and working with their own resources. The establishment of a national system for multi-hazard risk assessment for all the municipalities in Cuba also has large implications in terms of the level of standardization required. In this Geographic Information Systems (GIS) and Spatial Data Infrastructure (SDI) are key components. Information technologies in Cuba have been very much marked by the more than 50 years US Embargo, which forced Cuba to find alternative solutions.

The local authorities at different levels are the final users of the risk assessment. They are responsible for managing the risk supported by the Civil Defence specialists, other organizations and the local communities. As ordered in 2005 by the vice-president of the National Council of Defence, the Ministry of Science, Technology and Environment (CITMA) is responsible for making the risk assessment in the country and the Agency of Environment (AMA) was enrolled in this task to create a multi-disciplinary group on risk assessment. This group started to make risk assessments for flooding, strong wind and sea surges in the municipalities of Havana City and they created a methodology to generalize these studies in the rest of the country (AMA 2007). It is not defined how other disasters will be introduced in this local multi-hazard risk assessment. CITMA specialists and other local researchers in the provinces and municipalities, after trained, are conducting risk assessments in their territories. As they know the area better, they are responsible for data collection as well. Data forms have been created in order to standardize this process. It is expected in the coming years to complete an appropriate set up for data collection including the identification of users incorporating the local centres for risk management.

One of the key components in the data collection for landslides will be historical data. Historical landslide information is not available, except for a few isolated landslides. A national landslide inventory system is now under development. An important component of this system will be the involvement of local staff of the Civil Defense at the 169 municipal centres. A simple landslide reporting form has been designed, and workshops will be 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.

The aim is also to link the landslide risk assessment with the early warning system, which is well developed for hurricanes, and related flooding. Here also rainfall estimates from satellite imagery can be used, such as from Tropical Rainfall Measuring Mission (TRMM) and Multi-satellite Precipitation Analysis (TMPA), which is used to issue landslide warnings based on a threshold value derived from earlier published intensity-duration-frequency relationships for different countries (Hong et al. 2007). Hong & Adler (2007) propose an early warning system for global landslide warnings, based on the TRMM rainfall estimations, combined with the near-real time ground shaking prediction system for earthquakes (Wald et al. 2003) and with generalized landslide susceptibility information, including altitude information from SRTM, and landcover information, derived from MODIS.

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