PROCESSING SRTM DEM DATA FOR NATIONAL LANDSLIDE HAZARD ASSESSMENT

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RESUMEN

Este trabajo describe el procesamiento llevado a cabo durante la edición de los datos del SRTM para el Archipiélago Cubano, el análisis para producir los mapas derivados del Modelo de Elevación Digital (DEM) y la evaluación geomorfométrica de amenaza de deslizamiento de terreno. Debido a que los datos primarios no están editados, se realizó un intenso trabajo para borrar/disminuir los numerosos vacíos y los puntos falsos tales como valores anómalos altos (picos) o bajos (hoyos). Esto calibración fue especialmente necesaria en los cuerpos de agua, en las áreas montañosas sombreadas y en las zonas costeras donde la señal de retorno del radar produce valores considerados como errores. El análisis y procesamiento fue realizado empleando técnicas espaciales en SIG y software de sensores remotos.

Las condiciones geomorfométricas es uno de los aspectos más importante en la ocurrencia de deslizamientos de terreno. La susceptibilidad geomorfométrica del Archipiélago de Cuba fue realizada para posteriormente hacer una evaluación nacional de amenaza de deslizamiento de terreno. Para producir la susceptibilidad geomorfométrica de deslizamiento de terreno fueron empleados los mapas derivados del DEM tales como: el ángulo de la pendiente y el relieve interno (disección vertical). La combinación de estos mapas muestra las áreas donde los deslizamientos de terreno pueden ocurrir con mayor posibilidad pues los factores geomorfométricos tienen los valores más altos. Como se esperaba, estas áreas tienen coincidencia con los sistemas montañosos en Cuba. Empleando este análisis, estas áreas pudieron ser comparadas a nivel nacional y se encontraron los detalles de las zonas más susceptibles en cada sistema montañoso.

ABSTRACT

This paper describes the processes carried out during the editing of SRTM data for the Cuban Archipelago: the analysis for producing Digital Elevation Model (DEM) derivative maps; and a geomorphometric landslide hazard assessment at national level. As the base data is unedited, intensive work was done to remove/diminish the numerous voids and other spurious points such as anomalously high (spike) or low (well) values. Calibration was especially necessary in the water bodies, shaded mountains areas and in coastal zones where radar backscatter signal produce values considered erroneous. The processing and analysis was achieved through the utilization of GIS spatial techniques and remote sensing processing software.

Geomorphometric conditions are one of the most important aspects in producing landslides. In order to make a national landslide hazard assessment the geomorphometric susceptibility of the Cuban Archipelago was produced. Slope angle and internal relief (vertical dissection) DEM derivative maps were used for producing the landslide geomorphometric susceptibility. The combination of these maps shows areas where landslides are most likely to occur; proportional to the level of the value assigned to the geomorphometric factors. As expected, areas prone to landslide coincide with the main mountain systems in Cuba. Using this analysis, these areas could be compared at the national level and details of more susceptible zones were found in each mountain system.

Keywords: SRTM, DEM, CUBA, LANDSLIDE, GEOMORPHOMETRY

INTRODUCTION

Since the announcement of Shuttle Radar Topography Mission (SRTM) in 1998 (NASA-JPL, 1998a; NASA-JPL, 1998b) great expectations were increased within the scientific community for its numerous environmental applications. Antecedently the most frequently used global DEM was the Global Digital Elevation Model (GTOPO30). However this system was restricted by its numerous limitations such as the combination of different elevation data sources with different vertical errors and the spatial resolution of 30 arc-seconds. Although some research was carried out using this data (Miliaresis and Argialas, 1999; Miliaresis and Argialas, 2002), it presents constrains especially at the modeling stage.

The STRM elevation data is the first ever opportunity for processing continuous and homogenous elevation data covering 80% of the Earth's land mass between 60°N and 57°S. It was produced with the synthetic aperture radar (SAR) interferometry technique. The digital elevation model (DEM) was produced at 1 and 3 arc-seconds spatial resolutions. The 3 arc-seconds DEM is available on Internet. Although some authors describe this data set as a high-quality DEM (See Rabus et al., 2003) problems like voids and unexpected negative values were found during its processing.

Digital Elevation Model has been utilized within the field of geomorphology for many years, within a diverse range of studies. However producing digital elevation data over large areas is a time consuming task which may be impossible for certain areas due to data availability and quality problems. Therefore many applications use relatively small areas or subsets of larger regions. Any assessment related to landslides requires that DEMs are utilized to create derivatives maps such as slope angle or internal relief. The use of STRM elevation data appear as new opportunity for geomorphometric studies at national scale such as landslide susceptibility assessment countries like Cuba with an archipelago of 110,860 km^2.

This paper describes the processing of SRTM data for Cuban Archipelago and as an example of its use, a national landslide geomorphometric susceptibility was carried out. The research is part of a larger project for national landslide risk assessment. During the processing a detailed description of the problems found in STRM data and the solutions applied are explained. The new edited version of the DEM may be used for other geomorphometrics applications. High landslide geomorphometric susceptibility areas found within each mountain systems are described as well.

MATERIALS AND METHODS

The SRTM data and its quality

As a combined effort of EUA, German and Italian space agencies, on February 11th, 2000, the SRTM or Shuttle Radar Topography Mission took off for 11 days. Data collection instrumentation consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware which was modified with a 60 meter long mast and additional antennae to form an interferometer. The flight was programmed to be within the Space Station into a 233-km orbit. The principle data retrieval technology is based upon the transmission of one radar signal and receiving the signal in two SAR instruments with a separation of the flight path called baseline B. Every single point imaged on the Earth's surface can be mapped from the images back into space by triangulation

(Rabus et al., 2003). The same methodology was used before by a single SAR instrument mounted in a satellite, which visited the same area twice with a time lag of about a month. However, errors were reported in the interferogram due to temporal and spatial variations in water vapor (Hanssen, 2001). The instrument collected interferometric data continuously for 222.4 hours, imaging 99.96% of the landmass at least one time, 94.59% at least twice and about 50% at least three or more times.

Data were mosaicked into approximately 15,000 one degree by one degree cells or tiles. Sample spacing for individual data points is either 1 arc-second (about 30 m) or averaged 3 arc-seconds (about 90 m), referred to as SRTM-1 and SRTM-3, respectively. Unedited SRTM-3 data are being released continent-by-continent through internet (http://srtm.usgs.gov/ or ftp://edcsgs9.cr.usgs.gov/pub/data/srtm/A.Norte/). The 3 arc-second data were generated in each case by 3x3 averaging of the 1 arc-second data – thus 9 samples were combined in each 3 arc-second data point. Since the primary error source in the elevation data has the characteristics of random noise, this reduces that error by roughly a factor of three. Each cell or tile is projected in geographic coordinates using the WGS84 EGM96 geoid. The elevation data is provided in meters as 16-bit signed integer data. Therefore the elevations can range from -32767 to 32767 meters. The voids – where there is not data – pixels are flagged with the value -32768, meaning that they are out of range or undefined by certain systems.

There are some studies about STRM data quality (Koch and Heipke, 2000; Koch and Lohmann, 2000; Rabus et al., 2003; Sun et al., 2003) with different horizontal and vertical accuracy results. The horizontal accuracy has been recognized to be lower than ± 20 m as a requirement for the 90% of the data. The DEM vertical accuracy requirements are ±16 m absolute and ± 6 m relative vertical accuracy. The relative accuracy describes the error in a local 200-km scale while the absolute value stands for the error budget throughout the entire mission. The precision shall be valid for 90% of the data, i.e. the error represents about 1.6 S.D (Rabus et al., 2003). Both requirements were meet after processing the data with ± 10 m and ± 5.86 m for absolute and relative vertical accuracy respectively. Despite these achievements, the error was found higher on vegetated areas due to the tree canopy. However, the positive bias that this produces may be estimated if the vegetation structure information is available (Sun et al., 2003).

Since the data was delivered for download without final edition, problems associated to voids and negative values were found in almost all tiles belonging to Cuban Archipelago. Processing will need to be carried out prior to the data being used for any application in Cuba.

Processing SRTM for Cuba

The processing of the SRTM data has three major steps: mosaicking the tiles, masking the land areas and removing the voids and negative values. Mosaicking is the process of joining georeferenced images together to form a larger image or a set of images (Leica Geosystems, 2003). The Cuban Archipelago is covered by 33 files of SRTM-3 data with 1201 x 1201 pixels. Each tile was imported in ERDAS IMAGINE 8.7 and the projection WGS84 and pixel size 0.0008333 parameters were setup. The mosaic has 6002 rows by 13202 columns (Figure 1).

The initial statistics show the minimum value is -120 m: which clearly an error. On the other hand 1.40% of the pixels were voids or undefined values including those on land and the sea. However, the maximum value was 1970 m, which is only 4 m less than the maximum height officially recognized in Cuba (Díaz et al., 1990). Since there are not any known inland areas which have an altitude below the sea level, all the negative values inland were also converted into undefined values. For masking the land from the sea, a coastline digitalized from a Landsat TM mosaic at 30 m spatial resolution in WGS84 geoid was used (Reyes, 2004). After masking the land area, the undefined values obtained (including voids and negative pixels) were the 0.829 percentage of the Archipelago (114,444 pixels).

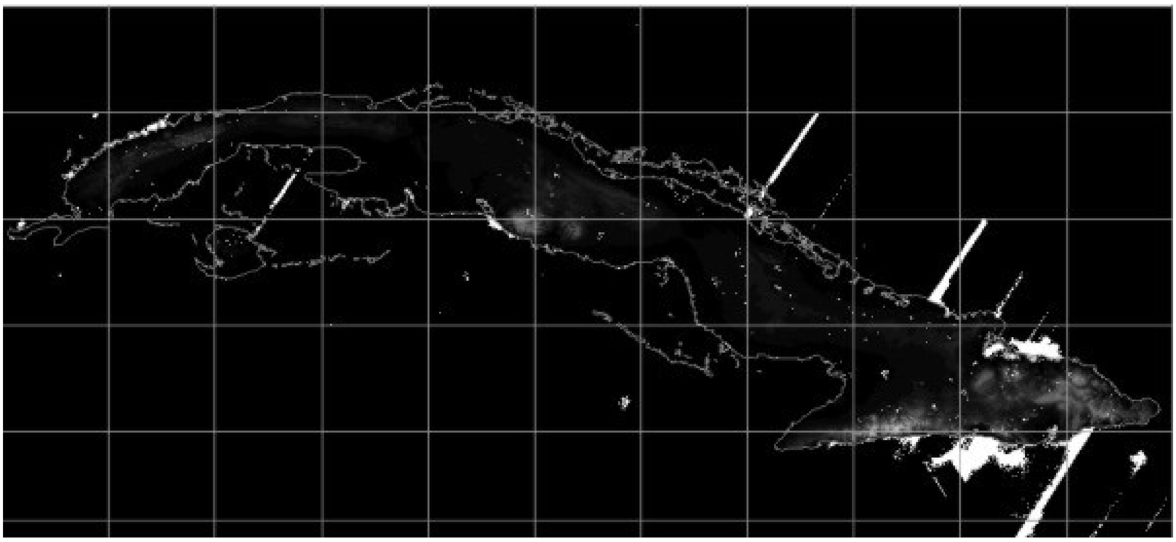


Figure 1. Mosaic with the originals SRTM 33 tiles for Cuban Archipelago. Coastline and 1 x 1 degree grid was added for better recognition.

The undefined values are generally produced by three main causes: shadows, water bodies and instrument noise. The water surface generally produces very low radar backscatter. Analyzing the voids in the Cuba Archipelago highlights the coincidence with these causes. Undefined values are located in small inland water bodies (mostly reservoirs or artificial lakes), lowland coastal areas (usually swamp or marsh zones) and steep slopes in mountain areas (certainly due to shadows). The undefined values are found to be located in a total of 13,916 quite isolated areas; where the largest area is 18.6 km^2, but almost half of those areas (6,749) have only one pixel. Another interesting feature is that the negative values and voids do not appear together.

Different approaches are used for eliminating the undefined values due to voids in SRTM data. Most commonly used are: using another DEM (GTOPO30, local DEM), interpolation (using different surfaces), producing contour, interpolating and patching, resampling and patching, manually assigned and iterative filter (minimum, averaging).

Replacing voids using GTOPO30 was carried out, with not successful outcome. In lowland areas the results may be useful, but in highland areas sharp edges are observed between neighbour pixels of the original SRTM data. In order to remove the undefined values an iterative average filter was use. In this method the filter is applied as many times as needed to close the undefined areas. In this case 13 neighborhood averaging iterations were needed to complete the filling of inland areas. The Table I shows the iterations and reduction in the number of pixels. The drawback of this method is that the water bodies like lakes will have different values instead of one single water level value, as may be carried out using a minimum filter. However, in high and dissected land areas the iterative averaging solution provides good results for geomorphometric applications. Figure 2 shows a comparative result of applying GTOPO30 and the iterative averaging. By comparing the two methods statistically, large differences were found with 89 % of the undefined pixels have different value. The differences range from -236 up to 297 m. This highlight how sensitive is the application of one method by the other.

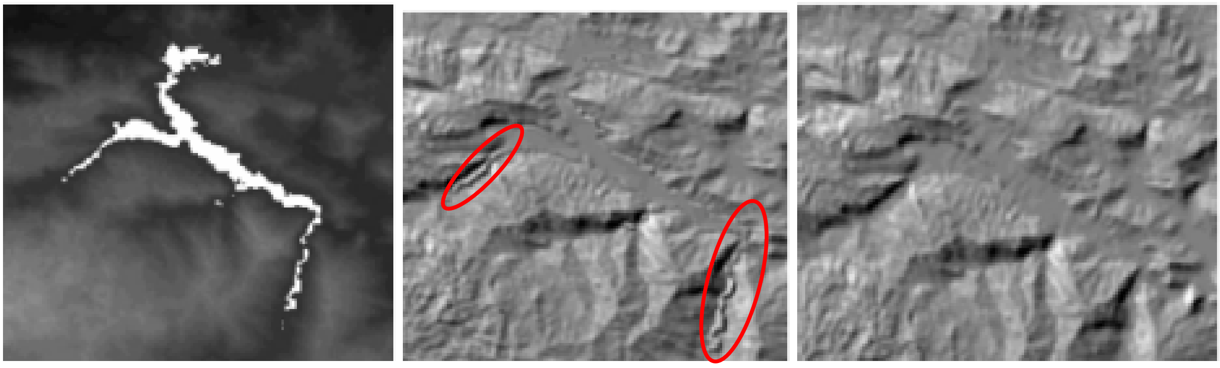


Figure 2. Voids pixels in Hanabanilla Lake of Guamuhaya mountain massif (on the left). Comparison between GTOPO30 patched (on the center) and iterative averaging method (on the right).

Iteration	Pixels with voids	Percentage
0	114444	100.00
1	32335	28.25
2	15067	13.17
3	8486	7.41
4	5364	4.69
5	3727	3.26
6	2785	2.43
7	2229	1.95
8	1870	1.63
9	1607	1.40
10	1420	1.24
11	1316	1.15
12	1241	1.08
13	0	0.00

Table I. Iterations for removing the undefined values.

RESULTS

Once the undefined values were removed the final SRTM DEM was used to produce a hypsometric shaded relief map in WGS84 projection at 1:1,000,000 scale (Figure 3). The map was produced using ArcGIS 9. The hypsometric limits were defined by Reyes (2004) based on the histogram changes in the elevation data. The results clearly identify the main mountain systems within Cuba where landslide are most likely to occur as will be shown later. It is also remarkable the relationship between the current relief and the previous geological processes.

That evidences are distinguished in the Paleogene volcanic arc in Sierra Maestra or the folded structure Pinar del Río.

National landslide geomorphometric susceptibility

Among the factors involved in landslide phenomenon, the most important ones are recognized to be the geomorphometric factors; although in certain areas factors like geology or soil may play also important role. The slope angle is used in almost all landslide studies. Landslide hazard assessments can be viewed as the combination of intrinsic factors and triggering factors. The geomorphometric factors are essentially intrinsic factors unless the slope angle is changed through human activities such as road construction. In order to demonstrate the use of STRM elevation data at national level, the landslide geomorphometric susceptibility analysis was carried out. Because only the geomorphometric (intrinsic) factors were used, the term susceptibility was applied in this study. This research is part of the a national landslide risk assessment research (Castellanos and Van Westen, (in press)) currently carried out in Cuba.

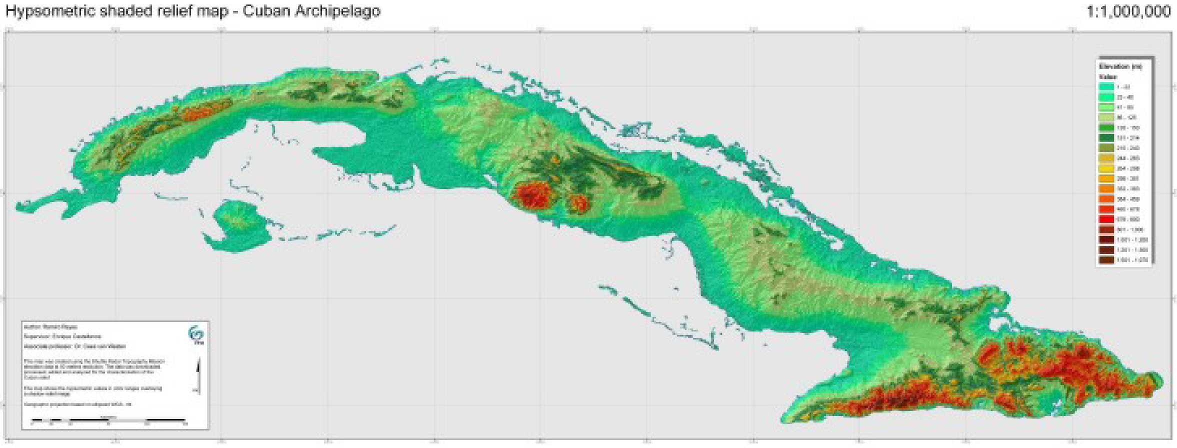


Figure 3. Hypsometric shaded relief map of the Cuba Archipelago using SRTM elevation data.

To facilitate the creation of a landslide susceptibility model two simple geomorphometric factors were used: the slope angle and the internal relief. The slope angle was calculated using ILWIS GIS methodology and an ArcGIS application. A comparison of both methods facilitated the selection of second one. ILWIS calculate the slope angle by calculating first the gradients in X and Y directions and later combining them (ITC, 2001). As a result a general slope angle value between the 8 neighbors is calculated using a quadratic surface.

Another slope angle calculation was processed using the methodology proposed by Hickey (Dunn and Hickey, 1998; Hickey, 2000; Van Remortel et al., 2001) in an “aml” application running over ArcGIS 9. The slope angle is actually calculated as part of RUSLE equation for soil erosion estimation, in conjunction with other factors like slope length. This method is the maximum downhill slope angle which constrains the slope angle calculations to one cell length (or 1.4 cell lengths in the diagonal) in a downhill direction.

It is recognized that there exist large differences between slope angle calculation methodologies (Dunn and Hickey, 1998; Guth, 1995; Skidmore, 1989). Comparing ILWIS and ArcGIS application slope angle methods over SRTM data, was obtained that only the 42 % of the area has equal values. Although this dissimilarity, 50 % of the differences achieved is 3 degrees o less. The slope angle map selected for this study was the maximum downhill slope angle, as it represents the worst situation and no an "averaging" value as ILWIS use.

The slope angle map of the Cuban Archipelago, which was calculated using SRTM data at 90 m shows that 72.7 % of the area has a slope angle with 2 degrees or less, - which is a very flat terrain. The 0.68 % of the area is 30 or more degrees and is located in the main mountain systems. As a result of the reduced percentage of high slope angle areas, this simple technique helps to identify landslide prone areas even within the main mountain systems (Figure 6).

The internal relief is defined as the height difference per square kilometer or per hectare. Due to the fact that SRTM has a spatial resolution of 3 arc seconds which is about 90 m, a window of 11 x 11 pixels (0.9801 km^2) was selected for calculating the internal relief. The internal relief map calculated shows that there are 163.5 km^2 in Cuba with 500 m/km^2 or more and the maximum value is 822 m/km^2. The area with higher concentration is also located in Sierra Maestra mountain system.

To facilitate the combination of both maps, the spatial multi-criteria evaluation module in ILWIS (ITC, 2001) was used, as displayed in diagram of Figure 4. The originals maps were standardized by the maximum value methods and weighted by the ranking method.

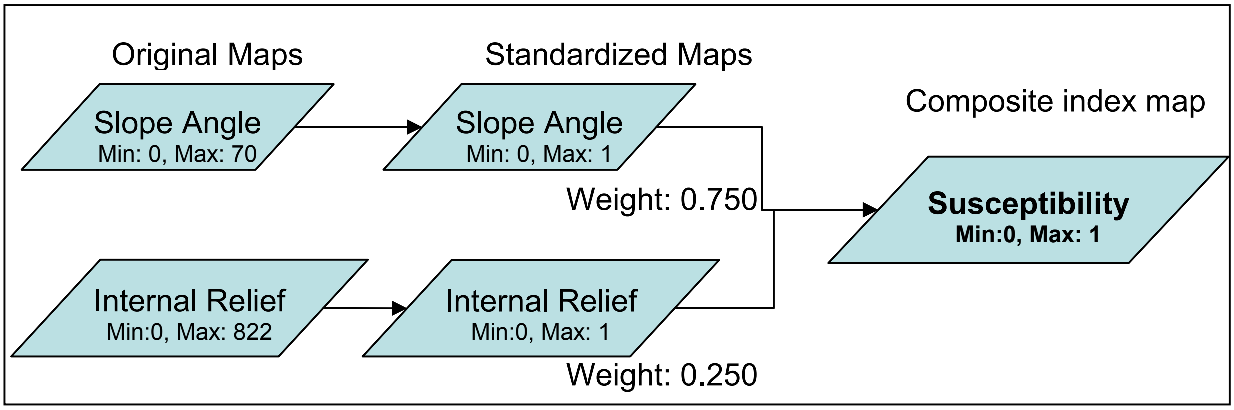


Figure 4. Spatial multicriteria evaluation model for landslide geomorphometric susceptibility.

The final map is shown in Figure 5. It is not possible to recognize the highest value areas due to the scale; but these areas are marked and numbered on the map. As it was expected these areas are coincidental with the main mountain systems in Cuba. A detailed description of these areas is given below (Figures 6 and 7).

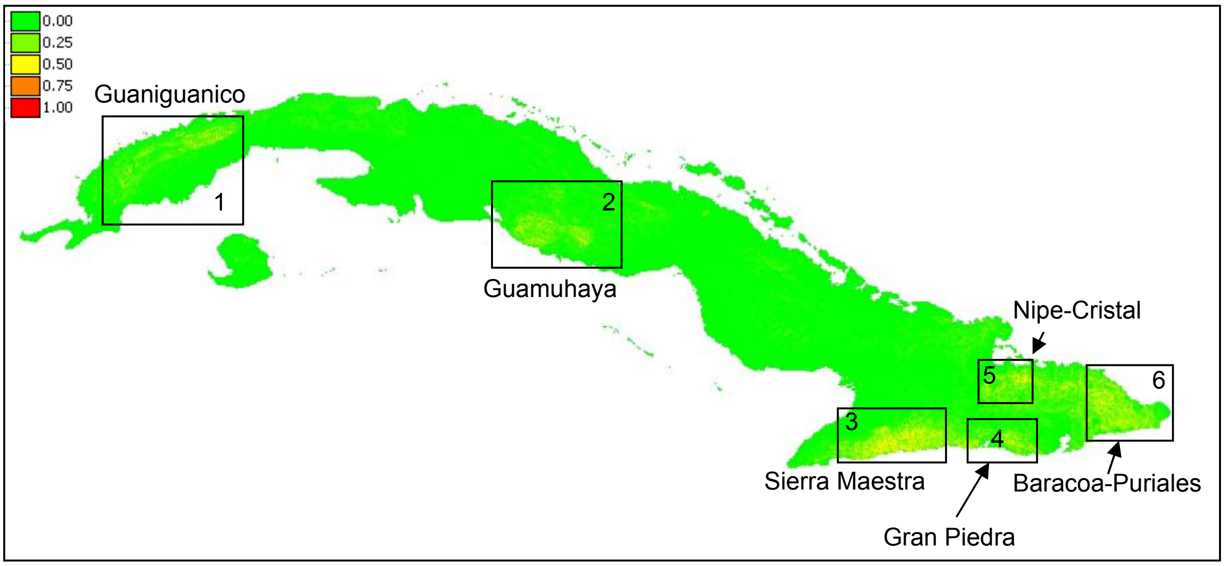
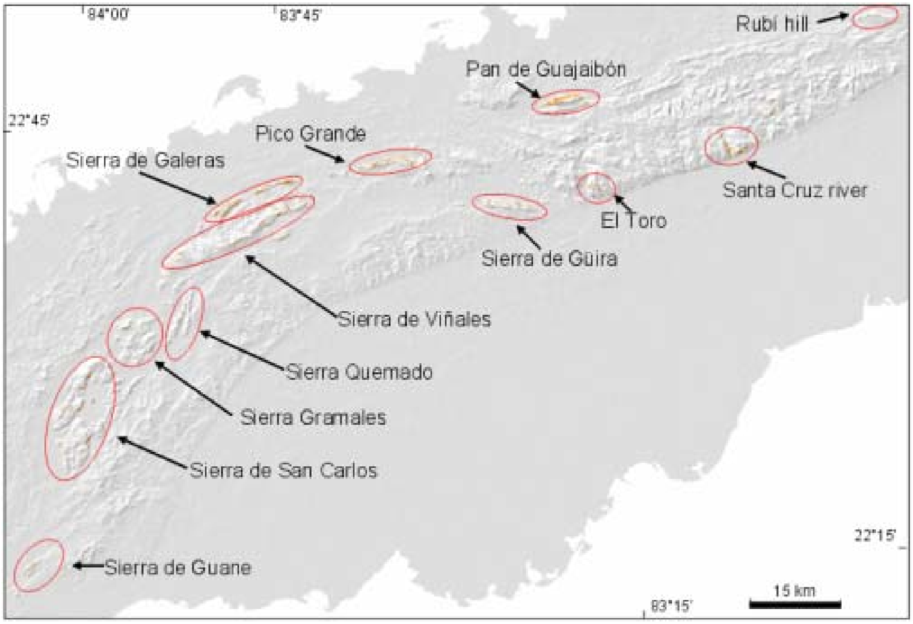


Figure 5. Landslide geomorphometric susceptibility map. Areas marked and numbered are shown in the next figures.



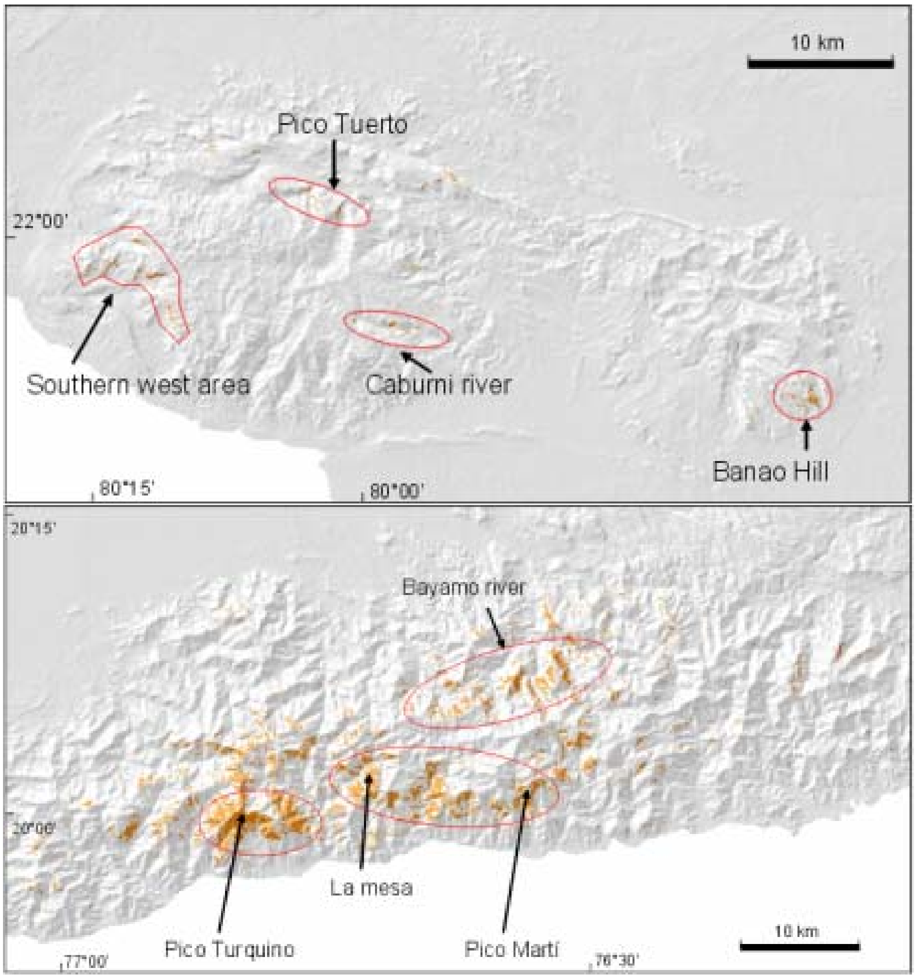
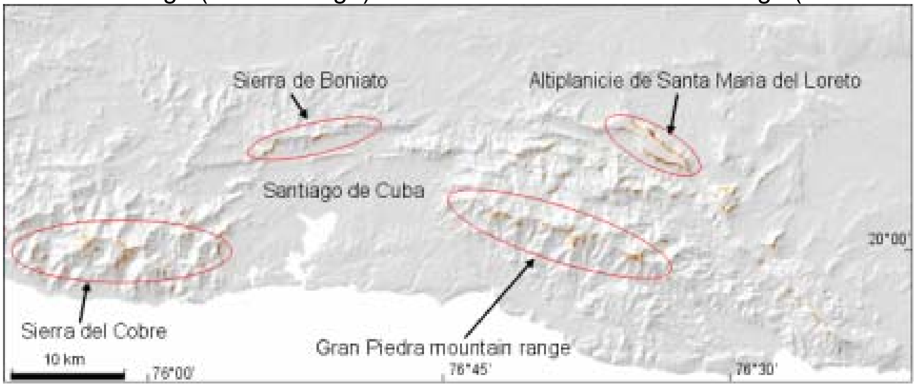


Figure 6. Landslide geomorphometric susceptibility in Guaniguanico mountain range (upper image), Guamuhaya mountain range (middle image) and Sierra Maestra mountain range (lower image).



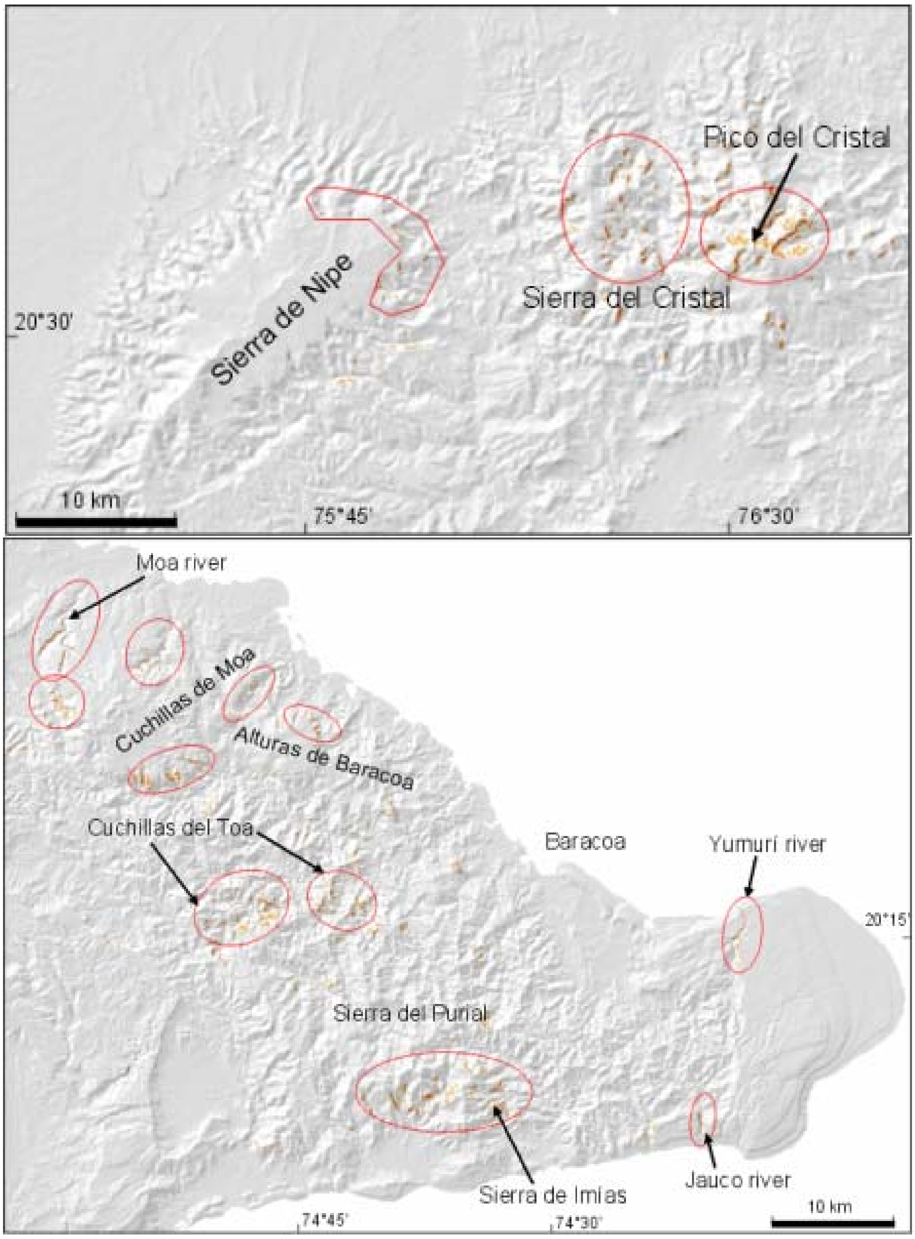


Figure 7. Landslide geomorphometric susceptibility in Santiago de Cuba area (upper image), Nipe-Cristal mountain system (middle image) and Baracoa-Purial area (lower image).

DISCUSION AND CONCLUSION

There are 172.5 km^2 dispersed over the Cuban mountain systems (Figure 6 and 7) with a landslide geomorphometric susceptibility higher than 0.5 in the model applied. In Guaniguanico mountain range (Figure 6 – upper image) the areas with larger size are located in Sierra de Galeras, Pico Grande and Pan de Guajaibón. Few points can be seen in the other zones. In the eastern part, where the relief is more dissected, only Santa Cruz River appears with high values.

In Guamuhaya mountain range (Figure 6 – middle image) four major areas have high values. The southern west area has the largest number of pixels, although, the Pico Tuerto zone may be the most risky since it located in one of the Hanabanilla Lake sides (See Figure 2). Other points were found in the upper part of Caburni river basin as well as Banao Hill on the east.

Coinciding with slope angle and internal relief maps, Sierra Maestra mountain range has the highest values and largest area (Figure 6 – lower image). Within the mountain system the highest values are located in Pico Turquino (the highest elevation in Cuba) and its surroundings. Between La Mesa and Pico Marti the slopes facing to south also present high values. On the northern slopes the upper part of Bayamo River basin is highlighted in different places. In the eastern zone of Sierra Maestra it is observable some high value points in Sierra del Cobre (Figure 7 – upper image). Also the ridges present in Sierra de Boniato and Gran Piedra Mountain Range has high landslide susceptibility values from the geomorphometrical point of view (Figure 7 – upper image). The same feature is observable on the Santa Maria del Loreto plateau close to Guantánamo province.

The northeastern part of Cuba is also marked by areas with high susceptibility. The Figure 7 – the middle image - shows areas located in Sierra de Nipe y Sierra del Cristal which have high values. The lower image in this figure exhibits the areas with high landslide geomorphometric susceptibility located in the eastern corner of Cuba. In spite of the similar rock types it is still possible to discern a disparity in the rating to observe that high values are concentrated in certain parts like Sierra de Imías. Noticeably the high internal relief values of both, the Yumirí and Jauco rivers facilitate with high susceptibility rating.

The model applied allows the identification of areas inside the main mountain systems in Cuba: Sierra Maestra being the most significant region with high landslide geomorphometric susceptibility. The model will be improved by the combination and addition of other factors with perpetrate a landslide hazard, such as; geology, landuse, rainfall and earthquake occurrence. The inclusion of these extra components will utlimately reduces the uncertainty in locating landslide prone areas.

It was concluded that SRTM elevation data needs to be processed before its use for any geomorphometric application. Yet, many processing possibilities are available for improve the unedited data like making a selective filtering for type of geomorphometric feaures including lakes, coastal swamps and shadow in mountain areas. Once the SRTM data is ready to be used the number of possible applications is quite large and it shows high reliability at 90 m spatial resolution. It is important to always take into account the fact that this data type does not necessarily represent the actual elevation ground as may happen in forested or urbanized areas. Whilst in certain regions of Cuba there are local digital elevation models, the coverage is insufficient and as such this study provide for the first time the possibility to use SRTM elevation data at 90 m spatial resolution for the whole Cuban Archipelago.

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