Landslide hazard assessment in Yateras municipality, Cuba

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Abstract. The main objective of this study in the Yateras municipality was the landslide hazard zonation (LHZ). The multi-criteria decision method used by Saaty (1980) was adopted, considering the factors; slope angle, elevation, distance to rivers, distance to the fault, average annual rainfall, lithology, soil depth and soil type. The weights of the factors were determined using the Analytical Hierarchy Process (AHP), determining that average annual rainfall, lithology and soil depth obtained the highest weights in the process, being 0.24, 0.19 and 0.16 respectively. Landslide susceptibility indices were determined based on a continuous numerical scale developed for this purpose. It was found that the high and medium hazard zones corresponded to the northeast and east of the municipality. These zones are mainly made up of rocks of the ophiolitic complex, very affected structurally, which are characterized by a high density of faults and a dense hydrological network, shallow soils with a predominance of brown soils with a clayey matrix.

1 Introducción

In the northeastern region of Cuba, landslides are frequent, producing changes in environmental conditions and in the habitat of species. These alterations caused by these phenomena can affect the intrinsic characteristics of the ecosystems, their development dynamics and the successional processes of the species [1]. In general, the development of landslide susceptibility models is based on topographic, geomorphological, lithological [2] land use data, geomechanical properties of rocks [3] hydrogeological and hydrological conditions, among others.

The study area is located in Yateras municipality of Guantánamo province, it limits to the north with Holguín province, to the south and west with Manuel Támes municipality and to the east with San Antonio del Sur municipality. It has a territorial extension of 625 Km2, which represents 10.74% of the total territory of Guantánamo province. This municipality has more than 70% of its territory within the Cuchillas del Toa Biosphere Reserve, declared in 1987 by the United Nations Educational, Scientific and Cultural Organization (UNESCO).

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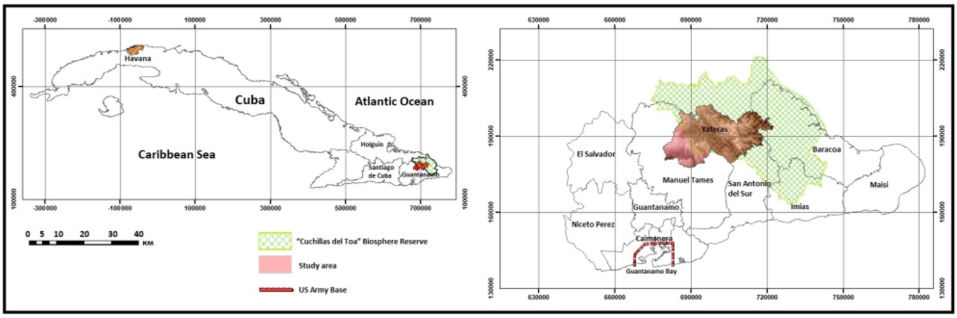

Fig. 1. Geographic location of the study area.

From the lithological point of view, there are rocks of the ophiolitic complex, mainly harzburgites and lherzolites; there are also rocks of the Cretaceous basement represented mainly by sericite and albite schists and andesitic-basaltic lavas, rocks of the Paleogene insular volcanic arc with a predominance of tuffs. There are also Neogene-Quaternary sedimentary rocks composed mainly of alternating sandstones, shales, calcareous shales and biodetritic limestones [4]. The relief is constituted by mountains, premountains and tectonic erosive heights, of horst and very dissected blocks, whose altitude does not exceed 900 m.

In the area, there are more than 10 types of soils [5] and it is located in the rainiest zone of Cuba, characterized by a Tropical Rainy or Rainforest climate (Af) according to the classification of (Koppen,1991), conditioned fundamentally by the topography and with accumulated rainfall that oscillate between 1000 and 3000 mm per year. It is the area of greatest biodiversity of the Cuban archipelago, with several endemic species of these localities [6]. It is also considered an Important Bird Conservation Area [7].

2 Materials and methods

The factors elevation, slope, lithology, soil type and depth, distance to faults, distance to rivers and mean annual rainfall were evaluated. The main geological formations that have a lithological behavior susceptible to the occurrence of landslides were defined using morphometric and structural criteria. The thematic layers of terrain elevation in meters above sea level and slope angle in degrees, derived from a digital elevation model (DEM) with a resolution of 25 m per pixel, were used. The DEM vertical uncertainty is in the range of 10 m.

The thematic soil layer was used according to the classification of the Unified Soil Classification System UCS. Buffer analyses were carried out at 500 m for the thematic layer hydrography of the area and at 1000 m for the thematic layer faults, in order to determine the zones of influence of these with respect to the occurrence of landslides.

To better understand the behaviour of rainfall as a triggering factor, rainfall data from 1-hour rainfall gauging stations operated by the Cuban Institute of Meteorology (INSMET) and 24-hour rainfall gauging stations operated by the National Institute of Hydraulic Resources of Cuba were used.

The Analytical Hierarchical Process (AHP) technique proposed by Saaty (1980) was applied to determine the weight and geometric mean of the conditioning factors, based on expert knowledge [8] (Figure 2).

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1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely
Less important						Very important		
Intermediate values				(2,4,6,8)		Preference made halfway		

Fig. 2. Nine-point hierarchical importance scale, according to Saaty (1980).

The coherence coefficient (CR) of the matrix was calculated using equation (1), where Ci is the coherence index and Rci is a random index calculated from randomly generated positive reciprocal matrices of order n.

$$CR = C_i / R_{ci} \tag{1}$$

The landslide susceptibility map was constructed by taking into account the primary weights assigned to the relevant conditioning factors. A continuous scale of numerical values was defined as landslide susceptibility index (LSI) using the equation (2)

$$LSI = \sum_{i=1}^{n} R_i \times w_i \tag{2}$$

Where Ri is the corresponding rating for each factor class and wi is the weight for each factor considered [9]. In the analysis, each of the thematic maps was checked against the landslide inventory [10]

3 Results and Discussion

In the study, all ranges were established for the factors involved. The largest number of landslides detected are found on slopes greater than 32°. Elevation had little significant difference, because there is a wide distribution of landslides in all ranges. The greatest number of landslides are distributed in the metamorphic complex generally composed of schists of volcanic rocks and in the ophiolitic complex. Analysis of the factors distance to rivers and distance to faults showed that a large number of landslides are distributed when approaching faults less than 1 km and less than 500 m from rivers.

A large number of landslides are spread on brown soils, the genesis of which is from rocks of metamorphic and ophiolitic complex. These rocks have clayey and sandy loam textures. Although widespread in all depth classes of soils, landslides are most common in shallow to medium depth soils. Rainfall is the trigger factor that appears to be most significant in this region. Many landslides are shown to coincide with the largest classes of average annual rainfall. These results confirm the relationship between landslide occurrence and heavy rainfall identified by other authors [11].

The results of the AHP comparison matrix presented in Table 1 show that the factors with the highest weight in constructing the susceptibility map are average annual rainfall (0.24), lithology (0.19) and soil depth (0.16). In a completely mountainous area with steep slopes, the factors "slope angle" and "elevation" do not have significant importance.

Table 1. Pair-wise comparison of conditioning factor layers and weight.

Factor	C1	C2	C3	C4	C6	C7	C8	C10	Weight	Consistency Ratio (CR)
Slope angle	1								0.08	-0.0554
Elevation	1/2	1							0.05	
Distance of fault	1/6	4	1						0.08	
Distance of river	1/6	5	1	1					0.08	
Soil type	1/5	5	2	0	1				0.12	
Soil depth	1/7	1/3	3	2	2	1			0.16	
Lithology	1/2	3	2	5	3	1/5	1		0.19	
Average annual rainfall	5	6	5	7	2	1/3	1/4	1	0.24	

Landslide susceptibility index values were calculated and four hazard classes were determined: no hazard, low, medium and highly hazard. Based on this classification, a map of landslide zoning of the study area was compiled (Figure 3)

It is shown that the largest share of the territory with a medium and high degree of hazard is distributed in the northeast and east of the municipality. This zone coincides with the largest number of landslides taken from the latest landslide inventory in this area [10]. The northwestern and southern parts of the study area have a generally low landslide hazard.

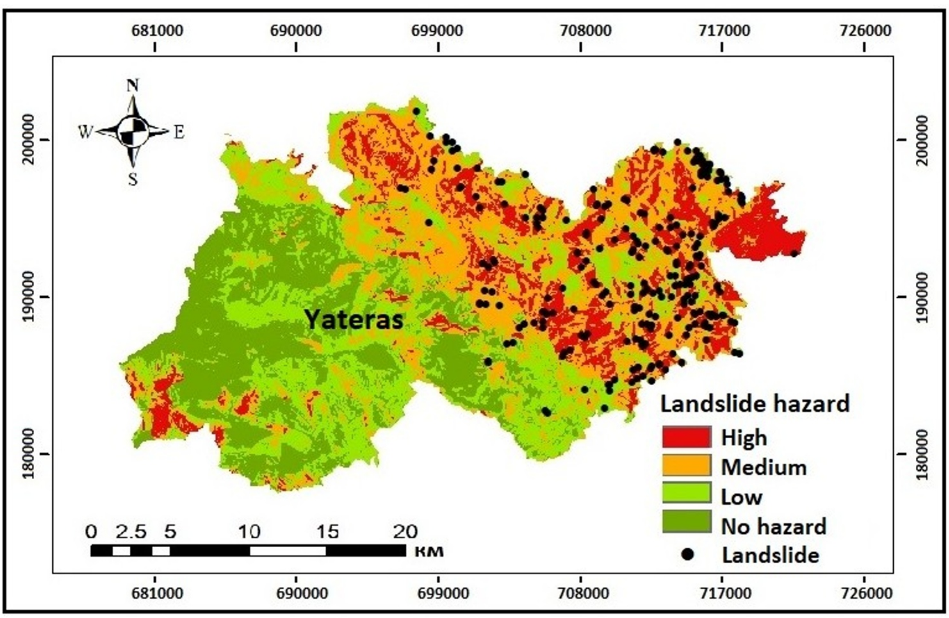

Fig. 3. Landslide hazard zoning map for the municipality of Yateras.

4 Conclusion

The municipality of Yateras is located in one of the most important geo-ecological zones in Cuba. The largest number of landslides are distributed over rocks of the metamorphic complex and rocks of the ophiolitic complex with slopes of more than 32°, with typology of brown soils of shallow and medium depth. The distribution of landslides coincides with the classes of greatest average annual rainfall. The factors that cause the terrain's susceptibility to landslides were weighted and good consistency (CR) of the analysis was obtained (-0.0554); The most important factors for hazard zoning were average annual rainfall, lithology, and soil depth. To compile a landslide hazard zoning map, a landslide susceptibility index was developed. High and moderate hazard classes are distributed in the northeast and east of the study area. The south and northwest are in low danger zones.

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