LANDSLIDE HAZARD ASSESSMENT USING THE HEURISTIC MODEL

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ABSTRACT

The landslide hazard maps can be created by many different ways. There are various methods groups more common including the heuristic, statistics and deterministic methods. The implementation of these methods it is always affected by the data availability with the required precision for the final scale. On the other hand, the optimum model for the hazard mapping should be able to map areas with certain probability of occurrence for certain period of time and with certain magnitude. In other words: to combine spatial, temporal and magnitude probability in only one model considering the possibility of more than one triggering factor. Such models are still under research and still can take some time to be really operational.

More frequently, the landslide hazards maps show qualitative classes like LOW, MODERATE, HIGH. These maps present some how the expert knowledge in these subjects. This work explains the development of a heuristic model from which landslides hazard maps can be created. The heuristic model considers a hierarchical organization of the components and different methods for weight assignment for the expert.

The hierarchical heuristic model is part of the decision support systems (DSS). In this case it is propose for spatial decisions, where the components of the decisions are georeferenced variables by themselves. For this the resulting algorithm of decision support systems is generic and may be apply to other fields like the evaluation of potential mineral for certain industrial mineral or as a decision support system for natural disasters. The algorithm can be implemented in any geographic information systems, depending on its possibilities for overlay maps in raster format and its capacity to process multiple variables.

Introduction

Mapping landslide hazard has become a complicated matter when the purpose is to do it seriously. Although many methods have been implemented a reliable determination of areas with different probabilities of landslide occurrence is always affected by the availability of the data. Most of the time the available data are not enough or the accuracy is not appropriate. On the other hand, the optimal hazard-mapping model should be able to map areas with certain probability of occurrence for certain period of time and with certain magnitude. In other words, combine spatial, temporal and magnitude probability in one model considering also the possibility of more than one triggering factor. Such models are still under research and may take some time to be really tested.

Most often the landslide hazard maps show areas with qualitative classes as LOW, MODERATE and HIGH and some considerations regarding the landslide expectancy and the land use development in such areas. To consider that these maps are not useful may be a wrong approach since these maps somehow present expert knowledge on the subject. To reach the hazard-mapping goal different ways may be used. In this research a Heuristic Analysis method was used in order to obtain the final hazard map. The selection of this method was done considering that:

1. Once a TMU map has been created, the use of this map in the statistical analysis methods will produce a biased results because of the strong spatial correlation between the landslide inventory map and one (or some) class(es) in the TMU map.
2. The use of any deterministic analysis methods needs more detailed scale maps and some engineering parameters. Both of them were not available in this research.

Due to the geological and geomorphological characteristics of the evolution of Cuba, the territory presents a "mosaic-type" configuration (Magaz, 1996). Meaning that in relative small areas the physic-geographic conditions have a high variability and therefore, the morphogenetic processes and landforms have large spatial and temporal diversity.

Large landslides are not predominant in Cuba, which is different from many other countries. Large landslides are not expected to be of regional importance because there are not enough weak materials like volcanic ashes. Also the thickness of the weathering crusts and the layers of detritus are not large enough. In Cuba denudational surfaces are predominant with a shallow weathering crust. These surfaces are related with a strong "erosional period", which occurred since early Paleogene during the three transgression-regression phases. For that reason landslides in large proportions causing significant damage or changing abruptly significant landforms are less possible. However, small landslides associated to slopes are more common in mountain regions where weathering processes have played an important role. Although the average size of individual landslides is small, in some parts many landslides have occurred related to tectonically weak areas generating regional or large problems. This is especially true for the study area where a large tectonic scarp (Caujerí Scarp) together with other factors have produced a large landslide zone.

This paper explains the implementation of a Heuristic model for landslide hazard mapping. The study area, San Antonio del Sur municipality and its surrounding contain such contrasting characteristics. The area is located at 60 kilometers of the capital’s province Guantánamo with an extension of 600 square kilometers. The figure 1 shows the location of the study area.

The Main Causative Factors for Landsliding

The study area presents particularities in relation with the landslide occurrence in the sense that most of the landslides are concentrated in specific regions. The existing landslides can be found in the regions like: Coastal hills, denudational slopes boundary and Caujeri scarp. From this geographic behavior it can be inferred that the causative factors for the landslides are also located in these three areas.

After analyzing the three existing landslide areas it is recognized that the extensional faulting has played an important role in the location of the current landslides especially in the Denudational slope boundary and in the Caujerí scarp. Both areas present large tectonic scarps. In denudational slope boundary instead of one fault scarp there are a number of scarps (at least three) due to a sequential normal faulting. Although tectonic features are present in the coastal hills it does not appear to be the most influencing factor. Dating these fault systems requires a detailed structural tectonic study, which will be also useful for describing in more detail its influence on the landslide occurrence.

In relation with the tectonics the general and recent uplifting of the area is important. This vertical movement seems to have created an imbalance between the landform generation (by the uplift) and erosional processes. As a consequence the instability of the slopes generated gravitational movement as landslides. This phenomenon happens especially in the coastal hills.

The lithology plays an important role in landslide occurrence especially the limestone layers, which are near horizontally overlaying the terrigenous material of the Maquey formation. Karst processes are present in the limestone rocks with different intensities following the joint and fault directions. When the karst processes have dissolved enough limestone the surface water start to have direct influence on the underlying terrigenous material.

Groundwater is also an important factor in the study area. Due to the active tectonics the area can be subdivided in different blocks with different groundwater levels. The groundwater in the Limestone Hill area is affected by the karst processes but in general the water table is much higher than in the surrounding: the Caujerí Depression and the Denudational slopes. It can be recognised by the positions of the springs along the Caujerí scarp and even in the Limestone Hills itself. It seems when the water table rises in the rainy season the lateral hydrostatic pressure in the Limestone Hills can generate landslides (Figure 2), especially during intensive rainfall usually associated to the hurricane season in October and November.

The influence of the precipitation can be analyzed in two ways: in the short term, during intensive rainfall and in the long term, during the annual seasons. The precipitation is recorded as one triggering factor for landslides in the study area. In fact intensive rainfall during a hurricane triggered the only two landslides with known dates in the study area. During the year the area has extreme different conditions. In the dry season it is very dry (few centimeters rainfall per month) and in the rainy season it is rainy almost all days. This situation, together with the high temperature and humidity contributes strongly to the chemical and physical weathering fragmenting the rocks into blocks, which later fall down slope.

As was mentioned before earthquakes have been recognized as one of the triggering factors and for that reason they are also considered in the research. However, there are no landslide records that allow to establish a relationship between earthquakes and landslides in the study area.

Summarizing the main causative factors it is possible to separate them into two groups. The triggering factors, which act suddenly, and the intrinsic factors, which during a long term period "prepare" the landforms conditions for landslide occurrence. Figure 3 shows a diagram in which these factors are separated in these two groups. As can be seen, there is a certain relation between both groups because the rainfall has a strong influence on karst processes, the seasonal climatic changes and the groundwater table and earthquakes are related with the general uplift and the tectonic faulting.

The Heuristic Landslide Prediction Model for the Study Area

For evaluating the areas where landslides can occur a heuristic analysis was used. The method was classified as a Qualitative Weighted method (van Westen, 1993). The general idea is to assign weights to a number of maps, which are considered as important variables in the occurrence of Landslides. After assigning weights a combination formula is used to integrate all the weights and produce a final map. The final map is classified into a number of classes and the hazard areas are mapped according to the expert opinion.

The general procedure is shown in Figure 4. The different steps follow more or less the decision support system (DSS) methodology (Saaty, 1996). The first step was to select the components of the model and characterized them. The components of the used model for landslide hazard mapping in the study area are shown at the lower level of the tree structure in Figure 5. The components were organized in a tree-shaped structure and ranked according to their importance to generate landslides. The upper level of the components was called *criteria* (in ranked order): 1) Geomorphology, 2) Topography, 3) Geology, 4) Tectonic and 5) Hydrology. The *variables* (components) with sub-ranking per *criteria* are as follows:

For geomorphology: 1.1) Landslides zones and 1.2) Geomorphological subunits

For topography: 2.1) Slope, 2.2) Internal relief and 2.3) Shape

For hydrology: 5.1) Spring and 5.2) Drainage distance

Because the other *criteria* only have one variable they do not need to be ranked. The *variables* used are described in Table 1. The description "**relation**" can be either *benefits* or *costs* depending on the relation of the variable with the possibility of landslide occurrence. Consequently *benefits* means "the higher the better" (for example: high slope, high possibility of landslide occurrence) and *costs* "the higher the worst". The class boundaries in case of numerical *variables* were selected taking 25 cumulative percentage of the histogram. The *classes* are shown in Table 4. The description "**Scale**" is referring to the scale of measurement (Bonham-Carter, 1996).

Variable	Origin	Scale	Units	Relation
Slope	From the original DEM using the methodology of ILWIS	Interval	Degrees	Benefits
Internal Relief	From the original DEM using the methodology of ILWIS	Ratio	Meters/hectares	Benefits
Shape	From the original DEM using the methodology of ILWIS	Ratio	No meaning. >o concave, 0 straight, >0 convex.	Benefits
Geology	By reclassifying the TMU map	Categorical	N/A	N/A
Faults	Calculating a distance from the fault map and classifying in four classes	Ratio	Meters	Costs
Springs	Calculating a distance from spring points and classifying in four classes	Ratio	Meters	Benefits
Drainage Distance	Calculating a distance from the drainage map and classifying in four classes	Ratio	Meters	Benefits
Geomorph. Subunits	By reclassifying the TMU map	Categorical	N/A	N/A

Landslides subzones	By reclassifying the TMU map	Categorical	N/A	N/A

Table 1. Variable used in the prediction model. See text for explanation. (N/A-No Applicable)

The methodology for assigning weights in different levels is according to the Analytic Hierarchy Process (AHP) developed at the Wharton School of Business by Thomas Saaty (1996). The advantages of this method include:

- Allow the application of data, experience, insight and intuition in a logical and thorough way.
- Enables derive ratio scale priorities or weights as opposed to arbitrarily assigning them.
- Accept to incorporate both objective and subjective considerations in the decision process.
- The heuristic model is better structured and easily to compare group of elements.
- Avoids more humans' mistakes because the assigning weights consider fewer elements.

Once all the variables were characterized and classified in four classes the weights were assigned in the three corresponding levels: the criteria, the variable and the classes. For assigning the weights a Microsoft Excel application was created. In the application all the criteria, variable and classes with their weights were listed in tables and a simple weight summation formula was applied to test how the weights will result in the final landslide hazard map. Changing weights interactively permits to have an idea how the model will run for a single pixel and it is possible to check the extreme values and the average conditions. Weights were assigned by expert opinion, which is called Direct Method in decision support system jargon. For checking the weight assignment a decision support system called Definite was used (Janssen, 1994). The idea was to use two more weight methods and compare those methods with the expert opinion. The methods are the pairwise comparison matrix and the ranking methods (Janssen, 1994).

	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	
Spring		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 2. Weights for criteria and variables using three methods

The pairwise comparison matrix is a matrix where each variable (or criteria) is compared to all other variables in order denote whether they are equally significant, or whether one of them is somewhat more significant / better than the other for the goal concerned. The ranking method simply means that the variables are ranked. In addition, it is assumed that theses ranking can be considered as units on a cardinal scale. Consequently the weights can be easily found by standardizing the rank order (Voogd, 1983). Table 2 shows a comparison of the three methods, as can be see the results are very similar. For the pairwise comparison matrix method the inconsistency value was 0.08%, demonstrating that the weights are reliable enough. The inconsistency is a parameter to measure how randomly the expert judgements are. The value has a range from 0 to 100% and normally, inconsistency values below 10% area acceptable. As a conclusion the initial weights assigned by expert opinion were taken for the analysis.

Classes	Weights intevals for the Hazard map				
	4 classes	6 classes	10 classes		
	Intervals	Intervals	Intervals	Area	TMU
1	0.500-12.275	0.500-8.350	0.500-5.160	14189.310	88
2	12.275-24.050	8.350-16.200	5.160-9.820	4176.3	40
3	24.050-35.825	16.200-24.050	9.820-14.480	18106.85	125
4	35.825-47.100	24.050-31.900	14.480-19.140	18360.87	97
5		31.900-39.750	19.140-23.800	2013.13	85
6		39.750-47.100	23.800-28.460	1702.47	87
7			28.460-33.120	968.78	77
8			33.120-37.780	718.59	59
9			37.780-42.440	291.42	36
10			42.440-47.100	439.36	24

Table 3. Weights intervarls for the three hazards maps

Because the weights were assigned in three levels and the GIS used only can process one level at the time, the two upper hierarchical levels (*criteria* and *variable*) were multiplied by the lowest level (the *classes*) in order to get one final weight per class. The ranges of the weights were different. In the *criteria* and *variable* levels the weights ranged for 0 to 1 and the total sum must be equal 1within the level and the criteria. As a result, to sum of all *criteria* weights must be equal to 1 and the sum of weight within the Topography criteria must be also equal to 1. The weights for the *classes* level were ranged from 1 to 100 and the also the total weight values within a variable must be 100. Table 4 shows the initial weights assigned to each class and the final weights after multiply by its correspondent upper levels. For example, the slope class shp4 (>20.37 degrees) have 50 multiply by Slope variable (0.7) and by Topographic criteria (0.3) is equal to 10.5, which is the final weight. When all the weights were assigned to each class the model was completed and executed. As a result several areas received weights in the range from 0.500 to 47.100. The next step was to re-classify the final hazard map in order to get an understandable number of classes.

Variable	**classes**	**Intervals**	**Initial weight**	**Final weight**
Slope	Slp4	>20.37	50	10.5
	Slp3	>15.81,=<20.37	30	6.3
	Slp2	>10.41,=<15.81	20	4.2
	Slp1	>0.00,=<10.41	0	0.0
Internal Relief	Inre4	>19.34	50	3.0
	Inre3	>14.41,=<19.34	30	1.8
	Inre2	>9.49,=<14.41	20	1.2
	Inre1	>=0.00,=<9.49	0	0.0
Shape	Shp4	>0.60	50	1.5
	Shp3	>0.00,=<0.60	30	0.9
	Shp2	>-0.70,=<0.00	10	0.3
	Shp1	>-14.00,=<-0.70	10	0.3
Geology	Maquey	94 TMU	30	6.0
	Colluvial	197 TMU	50	10.0
	Maya	29 TMU	10	2.0
	Yateras	107 TMU	10	2.0
	Otherwise	176 TMU	0	0.0
Fault	Falla4	100	50	2.5

	Falla3	100-500	30	1.5
	Falla2	500-1000	20	1.0
	Falla1	>1000	0	0.0
Spring	Spring4	100	50	1.25
	Spring3	100-500	30	0.75
	Spring2	500-1000	20	0.5
	Spring1	>1000	0	0.0
Drain	Drain4	>735	10	0.25
	Drain3	>304,=<735	10	0.25
	Drain2	>0,=<304	30	0.75
	Drain1	0	50	1.25
Subunit	Landslides	296	50	8.0
	Dissected	18	10	1.6
	Steeply	50	20	3.2
	Marine	3	20	3.2
	Otherwise	236	0	0
Subzone	Scarp	77	40	9.6
	Scarpint	25	10	2.4
	Scarptec	4	20	4.8
	Body	24	10	2.4
	Scarpbody	37	20	4.8
	Otherwise	436	0	0

Table 4. Initial and final weights per classes

Three final maps were prepared with 4, 6 and 10 hazard classes consequently with different arrangement of the weights. Table 3 shows the intervals for the weights for the three maps and the area and number of TMU is for the ten classes hazard map. Checking visually the final maps shows that the maps with 4 and 6 classes have lost much information already. On the other hand, using many classes like ten makes the final hazard map difficult to use for disaster management and planing. Therefore, the decision was to take as final map the hazard map with ten classes and provide in one map the ten classes for technical purposes and three classes for disasters managers which is in fact a grouping of the ten initial classes.

Once the final hazard map was selected the 10 hazard classes were overlain with the TMU map-database in order to get all the information about the attributes per hazard class. After getting the reports the difference between the classes was described using descriptive statistics. Additionally the ten classes were group into three hazard classes: LOW, MODERATE and HIGH hazard and remarks in relation to development possibilities in these areas were analyzed.

Table 5 shows the final landslide map legend with statistics per class. For each hazard class the number of landslides and area of landslides was analyzed. It clearly shows both the number and the area density of landslides is growing from class 1 to class 10.

Hazard	Hazard Class	Characterization	Landslides Hazard Remarks
L O W	Hazard 1 Min. weight: 0.50 Max. weight: 5.16 Number of TMU: 88 Lsd number: 0 Number density: 0 Total area: 8668.86 Lsd area: 4.7 Areal density: 0.000	1. Active, occasional and exceptional submerged floodplain. 2. Lower levels of marine terraces. 3. Swamp deposits and lagoon. 4. Alluvial valleys	No landslides expected in normal situation. Areas can be corridors for mudflows or other intensive mass wasting processes. In some parts small landslides can happen in extreme conditions.
H A	Hazard 2 Max. weight: 9.82 Number of TMU: 40 Lsd number: 0	1. Slightly to moderately dissected slopes. 2. Terrigenous hills complex.	The areas are suitable for development projects. However, it is recommend take into account other natural hazards like flooding.

ZARD	Number density: 0 Total area: 4176.3 Lsd area: 0.75 Areal density: 0.000		
	Hazard 3 Max. weight: 14.48 Number of TMU: 125 Lsd number: 8 Number density: 0.064 Total area: 18106.85 Lsd area: 210.72 Areal density: 0.011	1. Moderate to severely dissected denudational slopes. 2. Limestone hills complex. 3. Accumulational slopes complex 4. Existing landslides zones: • Lower part of transport zone	
MODERATE HAZARD	Hazard 4 Max. weight: 19.14 Number of TMU: 94 Lsd number: 22 Number density: 0.234 Total area: 18360.87 Lsd area: 337.78 Areal density: 0.018	1. Metamorphic hills complex 2. Higher level of marine terraces 3. Existing landslides zones: • Remnants of body surface • Blocks in the body • Side scarp with no recent activity.	Moderate to high possibility of landslides occurrence during intensive or prolonged rainfall.
	Hazard 5 Max. weight: 23.8 Number of TMU: 85 Lsd number: 46 Number density: 0.541 Total area: 2013.13 Lsd area: 901.52 Areal density: 0.447	1. Steeply to very steeply face on the slopes. 2. Existing landslides zones: • Remnants of body surface • Normal bodies • Body-transport combination	These areas contain most of the existing landslide zones. Most of the landslide materials are unconsolidated and susceptible for being reactivated in smaller proportions.
	Hazard 6 Max. weight: 28.46 Number of TMU: 87 Lsd number: 79 Number density: 0.908 Total area: 1702.47 Lsd area: 1427.58 Areal density: 0.838	1. Existing landslides: • Normal bodies • Remnants of body surface • Intermediate scarps • Side scarps 2. Steeply to very steeply face on the slope. 3. North slope of coastal hills complex	No recommended development project or a detailed study needs to be done in the design of the project. Land use changes should be previously studied in relation to landslide hazard problem.
	Hazard 7 Max. weight: 33.12 Number of TMU: 77 Lsd number: 76 Number density: 0.987 Total area: 968.78 Lsd area: 962.44 Density: 0.993	1. Existing landslides: • Bodies and scarp-body zones 2. Moderate slope angles and internal relief	
HIGH HAZARD	Hazard 8 Max. weight: 37.78 Number of TMU: 59 Lsd number: 59 Number density: 1 Total area: 718.78 Lsd area: 715.88 Areal density: 0.995	1. Existing landslides in coluvial deposits: • Back scarp with no recent activity • Bodies and scarp-body combinations 2. Existing landslides in denudational slope scarps	High to very high landslide hazard areas. A high possibility of landslide occurrence during raining conditions.
	Hazard 9 Max. weight: 42.44 Number of TMU: 36 Lsd number: 36 Number density: 1 Total area: 291.42 Lsd area: 289.88 Areal density: 0.994	1. Existing landslides areas in denudational slopes scarp: • Back scarps with recent activity 2. High slope angles and Internal relief. 3. Coastal hills north scarp	No development is recommended in these areas. Possible relocation of land for agricultural use. Highly recommended relocation of existing population in these areas
	Hazard 10 Max. weight: 47.10 Number of TMU: 24 Lsd number: 24	1. Existing landslides in Caujerí main scarp: • Back scarps with recent activity 2. Very high slope angles and	

	Number density: 1 Total area: 439.36 Lsd area: 438.54 Areal density: 0.998	internal relief	

Table 5. Final Landslides Hazard classes its statistics, characterization and hazards remarks

The characterization of the hazard classes was done taking into account the records in the database corresponding to each class. A selection of the particular characteristics was made for each class. Finally some remarks were also described in relation with the hazard degrees and with the development possibilities in these areas

The Landslides Hazard in the Different Areas

Although the landslide hazard zones cover the whole study area it was considered important to make a brief description of the landslide hazard for the three main landslide problem areas: the Coastal Hills, the Denudational Slopes boundary and Caujerí scarp.

Landslides harzads in the coastal areas

In general the older landslides of the study area can be found in the coastal hills. They are as old as pre-Holocene, when the new marine deposits started to be deposited along the shoreline. In the coastal hills both old and recent landslides can be found.

In the south side of the coastal hills continuously rockfalls and topples can be expected either from the marine terraces to the lower levels and along the small cliff to the sea. The continuation of these landslides is due to the continuos weathering going on in these areas.

In the north side of the coastal hills rotational landslides and debris flows can also be expected. In fact in some of the current north slopes the debris flows are active. It is also common, and therefore, expected to happen, that debris flows occurs in former rotational rock slides bodies.

Landslides hazards in the denudational slopes boundary

As was mentioned before the Denudational Slopes boundary is located in a tectonic scarp of a normal fault system with at least three steps. The fault system seems to be very active and it is the mains cause for landslide occurrence in this area. Because the lithology changes along the fault system, the landslides hazard is also different. The southwest part is characterized by limestone rocks highly influenced by karst processes especially in the upper parts. There, block fall slides and topples can be expected. Because the limestone rocks have been removed almost totally in the lower parts small rotational landslides in terrigenous rocks from Maquey and San Luis formation are expected. In the north-east part of the denudational slopes boundary the landslides are less common and this part seems to be more stable. Here, small rotational landslides may occur during intensive rainfall.

Landslides Hazards in the Puriales de Caujery Scarp

The scarp presents two main parts from the hazard point of view: the actual scarp and the deposited material of previous landslides. The actual scarp is where more dangerous landslides can be expected in the near future. Since the actual scarp is between 70 to 100 meters height on average, the angle of the slope is almost 90 degrees and the material is very susceptible for erosion; the landslides hazard probabilities are very high. The hazard importance is not only related to the frequency of the phenomena but also with the magnitude of the expected landslide. In this area the larger landslides that may happen in Cuba can be expected together with another few areas in the rest of the island.

The second part of scarp in relation to landslide hazard is actually consisting of all landslides that can happen over the existing landslide bodies or rests in the scarp. These landslides are now mapped as colluvial deposits. Because the material is not consolidated this zone is very susceptible for the occurrence of new landslides, with influence in agricultural lands at the foot of the slope.

Conclusions

Two types of causative factors related to landslides affect the study area: the triggering and the intrinsic factors. They are strongly related each other. The Triggering factors are: the rainfall and the earthquakes and the intrinsic factor are: karst processes, general uplift, seasonal climatic changes, ground water table, lithological control and tectonic faulting.

For the landslide hazard map a heuristic analysis methods was used. In the model three hierarchical weights of level were used for classes, variables and criteria. The criteria and variables were ranked according to their influence in the development of landslides, and then all were weighted for 1-100 for classes and 0-1 for criteria and variables. Because the system only can at one level, all the weights were multiplied before the model was executed.

After the model was executed the final hazard map was classified in two ways for disaster management in three major classes and for technical research in ten minor hazards classes. The broad classification includes to the minor classification.

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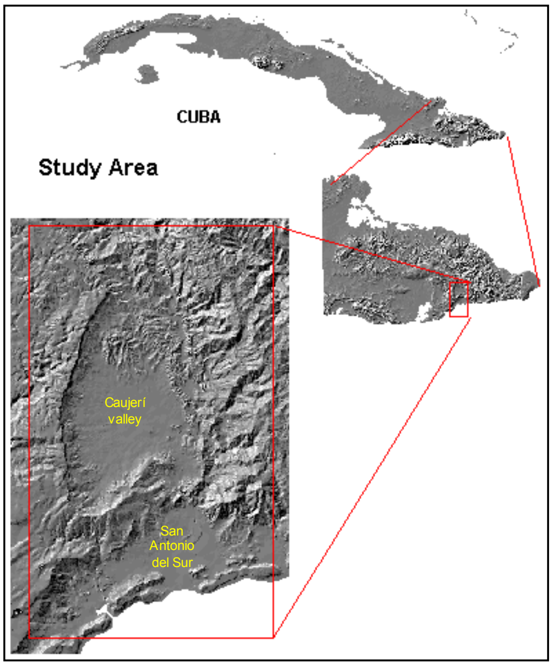

Figure No. 1 Study area. San Antonio del Sur and its surrounding.

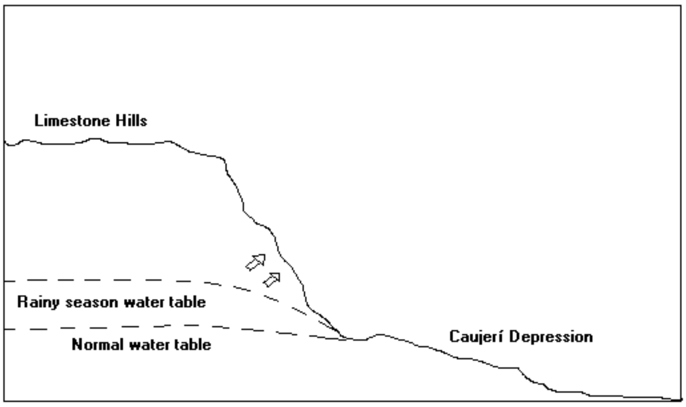

Figure 2. Lateral Groundwater pressure when water table rises.

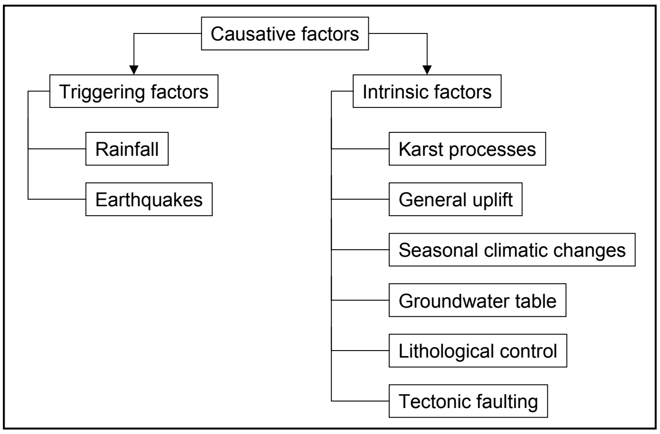

Figure 3. Causative factors for landslides occurrence in the study area.

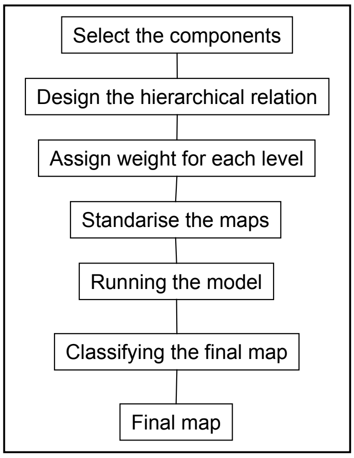

Figure 4. Flowchart for Heuristic landslide hazard analysis.

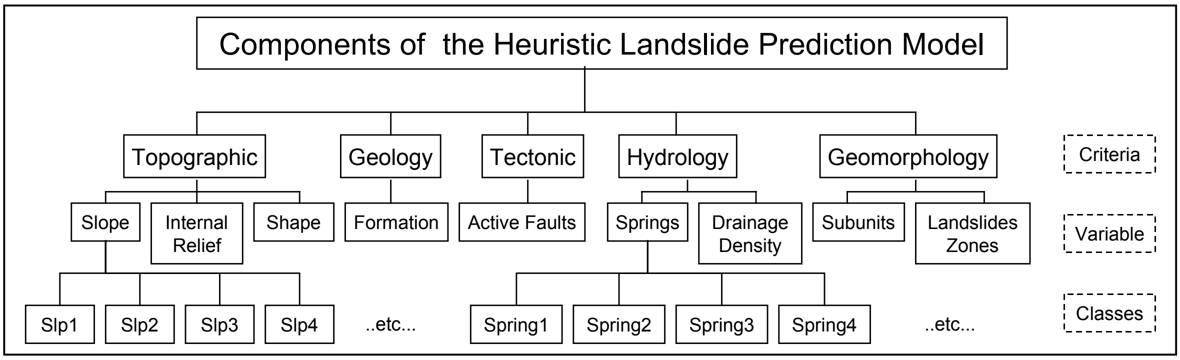

Figure 5. Components of the heuristic landslide prediction model.