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Landslide Susceptibility in the Community Neighborhood Road, the National University of Loja to 0.9 Km Stretch, the city, Canton, and Province of Loja.

F. González, W. Tambo, M. Valarezo, l. González, J. Romero, J.Benavides

Abstract— ***This article has as the main purpose to identify landslide prone areas in the Community Neighborhood Road, in the section between the Julio Ordoñez Urbanization and the National University of Loja in about 0.9 kilometers in Loja city-Ecuador. The implementation needed to develop in two phases of field and office: the first was to use specialized equipment to carry out the survey of the topography, geology, land use, geomorphology and geotechnical investigation directly scan standard penetration tests (SPT), and indirectly with vertical electrical sounding (SEV). This information after being analyzed entered into software (ArcGIS 10.1. Ilwis 3.06 and ArcView 3.2) and then perform modeling using susceptibility calculation methods to landslides. The methods utilized in this investigation for determining susceptibility are, deterministic based on the computation of safety factor (FS) and heuristic method with the combination of factors maps whose weights assigned according to the knowledge of the actual conditions of the sector which obtained from the SEV, SPT, and bibliographic sources. The heuristic method was systematized in ArcGIS 10.1 software by applying the model tool builder for combining raster maps using the tool weighted sum, through the assignment of values to each of the variables that are: Geology 0.4, slope 0.3, geomorphology 0.2 and vegetation cover 0.1. In contrast, to the deterministic method, a digital terrain model (DTM) in Ilwis software was developed, after calibrated and modeled in ArcGIS 10.1 software, being the most relevant parameters angle of internal friction and soil cohesion. Moreover, an inventory of landslides was performed, which were located within the area of high susceptibility to match the physical-mechanical characteristics of the soil resulting from SPT and SEV analysis.***

Index Terms— ***Sensitivity, SPT standard penetration test, Vertical electrical sounding SEV, Deterministic, Heuristic, Model builder, Weighted sum, DTM.***

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I. INTRODUCTION

Susceptibility is the ability or potential of a geological/ geomorphological unit to fail at any moment, due to the conditions intrinsic to the that is subjected, in this case, expresses the possibility that a landslide occurs in a particular area. There are different methods of assessment of the susceptibility to the landslides through GIS. Soeters and Van Westen (1996), among other authors, provide a broad overview of the most used, which include mainly the heuristics, deterministic, direct statistical assessment of susceptibility and others. The applicability of each method in an area depends on all of the characteristics and extents of it, the type and magnitude of the existing landslides, geotechnical and hydrological data available and on the scale of work.

The zoning of the susceptibility of an area corresponds to only a period and not expected future conditions of instability but contributes to determinate zones or zones that require measures of prevention, control, and immediate mitigation.

Produce a map of susceptibility referred to slope instabilities in general, it is necessary to take into account a large number of factors of the land. This kind of maps shaded areas by their potential exposure to these processes. The most efficient way to perform this zoning is making a multivalent analysis of the different determinants and triggers factors. Currently, the geographic information systems (GIS) enable the analysis to breakage by sliding, as well as the elaboration of faster and more efficiently maps. One of the vital tools for the zoning to landslides according to Gonzalez (2005).

Is the generation of inventory maps of landslides, for example, allow to have a first notion of the susceptibility of a site, in particular, considering that in areas where have happened natural phenomena (landslides, flows, lateral expansions, and tipping) there is the possibility that again occur. GeoLoja 2008. In the city statistically, the phenomena that show the highest degree of recurrence are the mass movements; caused by hydro-meteorological events and to a lesser extent by the seismic activity so that in last years has been invested a lot of resources to mitigate and reduce the damage caused.

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The study area covers the Community Neighborhood Road Angel Felicisimo Rojas between the sector National University of Loja and Julio Ordoñez. Urbanization, which is being affected by landslides, where it is currently in the process of completing the construction of the pathway, with all the measures to prevent landslides, but its occurrence is still evident in the journey of the road. The results of the present article converted into a tool for the municipality and construction companies for the planning of future urban projects and the regulation of land use and the elaboration of development plans.

II. METHODOLOGY

2.1 Materials

For carrying out the present article was necessary to have the following elements of field and office is described in Figure 1.

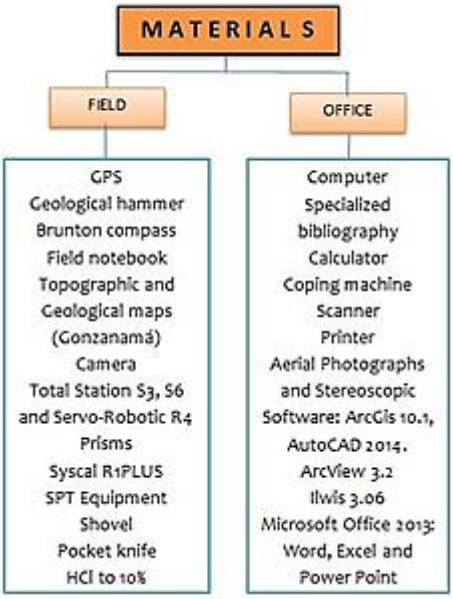

Fig 1. Field and Office Materials

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2.2 Methodology

The methodology applied in the research is based on a Geographic Information System that involves inserting data obtained from laboratory and technical inspections of field, Where for the assessment of the susceptibility was applied two methods: heuristic and deterministic, integrating the information in both determinants and triggering factors that influence in the instabilities of the hillsides and batters of the Community Neighborhood Road Angel Felicisimo Rojas.

2.3 Topographic Survey

The topographic survey was carried out to 200 meters on each side of the road to know the conditions and configuration of the field representing infrastructure such as roads, houses, rivers, landslides among others using as a basis the Datum WGS84.

In this process, was used 3 Trimble topographic equipment (Total Stations): The Servo-Robotic R4 for its precision (works with satellite signal),

It allows georeferencing from the IGM point located in the rondure of the National University of Loja and then find the starting points of the Trimble S3 and S6 total stations, to lift the mountainous part and high vegetation with the highest amount of points strategically located to facilitate the speed and accuracy.

Besides the station, Servo-Robotic R4 was also used for the precise mapping of roads submit your final version, after your paper has accepted, prepare it in two-column format, including figures and tables, see Table 1.

Table 1. Starting point coordinate of the topography

LOCATION	COORDINATES		
	NORTH	EAST	ALTITUDE
Point IGM (Circle Argelia)	9554036.18	699571.104	2130.823

It should emphasize that during the topographical surveys on a regular basis was a review of the data generated from the various stations expels them in a computer and through the software ArcGis 10.3 display information to correct and prevent future errors. Culminating the field work, we proceeded to the download of files generated in the Servo-Robotic station R4 and Totals: Trimble S3 and S6, for Excel files, uniting them in a single database in TXT format. Which was then processed in the software Foresight 2.2.1 that generated the level curves to 1 meter on a DWG format, then in the AutoCAD software 2014 was displayed in 3D the level curves where was corrected some errors, and in the software, ArcGIS 10.1 DWG files are converted to format SHP. Finally, was verified that interpolation given by software matches to the real highlight of the lifted area using aerial photography to scale 1: 5 000 (NVII-B2A-E1) and Topographic Map (NVII_E2) provided by the National. The system of Information and Management of Rural Lands and Geological Infrastructure (SIGTIERRAS), drawing the infrastructure such as roads, buildings, water network and the landslides among other information generated.

2.4 Geological Survey

With the database (geological, geomorphological and structural) obtained from the photo-interpretation, bibliographic collection and with the topographic map, have a technical observation of the study area, and is corroborated the contacts of the geological formations, structures, lithology and hydrogeological in natural and artificial outcrops. With the topographic map was observed the entire area, with a total of 3 technical inspections of which obtained on the inventory of the lands. Landslides (classifying them according to their magnitude and type of movement) and geological faults existing with its structural data and geometric making a detailed description to stratigraphic and its location in UTM coordinates. To this effect are used technical sheets, GPS, field notebooks, Brunton compass, geological hammer, a measuring tape, and camera. Subsequently, as in a cabinet, all generated data is inserted into the software ArcGis 10.1 that facilitates the representation of geological structures as failures and landslides for their interpretation and mapping for the description of the geological cuts, as well as the symbolism of the geological formations individual.

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2.5 Standard Penetration Testing (SPT)

A penetration test standard is a tool which allows determinating the following.

- The relative compactness of granular soils and consistency of cohesive soils through correlations.
- The stratigraphy of the site and the altered sampling for laboratory use.

Procedure

Following ASTM 1586-84 in summary form, the process consists of the following steps.

- In the first place there was a survey to the depth of 20 cm, and then takes a fund of the perforation by blows to percussion with a standard bucket that is piling 15 cm in the layer to recognize, to eliminate the partially altered surface area.
- This followed by a signal on the linkage and counts the number of strokes (N) necessary to pierced back bucket, the depth of a foot (30 cm.). As mentioned previous, the mass of which used for the piling weighs 140 lb. And its height of drop is 30 PLG., which corresponds to a job of 0.5 KJ per stroke, approximately, this process is carried out by each meter drilled.
- Therefore obtained N = N1 + N2, where N1 corresponds to the number of hits needed to sink the socket-samples 15 cm and N2 is in some strokes that are necessary to shrink the 15 cm.

2.6 Vertical Electrical Sounding (SEV)

Performing the test of geophysics used the Schlumberger settlement was conducted four lines SEV in the places chosen according to its topography and geology, see Figure 2.

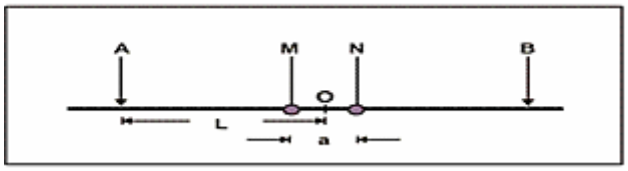

Fig 2. Schlumberger Settlement.

The tests consisted in separate progressively the electrodes injectors A and B symmetrically leaving the electrodes detectors M and N fixed rounded to a center point. The representation of this probe shows the abscissa, the distance AB/2 (m). In this arrangement, the effect of heterogeneities irrelevant is less because only moves the pair of electrodes injectors A and B. For the realization of the Vertical Electrical Sounding made the following phases; this shown in equation (1)

$$k = \frac{\Pi}{4MN}\left(AB^2 - MN^2\right) \approx \frac{\Pi L^2}{a} \qquad (1)$$

Equation for the calculation of the constant geometric K

$$\rho\alpha = \Pi \frac{\Delta V}{I}$$

Equation for the calculation of apparent resistivity

Procedure:

1. Choose the polling place according to the topographical features (relatively flat since it must consider the opening of spools).
2. Locate the center point BSS and the arrangement to ensure its linearity.
3. Will be measured on both sides of the settlement the distances where are placed the electrodes of potential M and N; using the tape measure.
4. After performing the measurements according to the distance AB/2, configuring the appliance to give us the required repetitions of data.
5. The data provided shall be recorded by the device in a format already established.
6. After recording data, plot apparent resistivity data against the distance AB/2 to observe the behavior of materials to resistivity.

2.7 Map Susceptibility

To determine the degree sensitivity of the studied area and the influence of the phenomena for this condition is applied the methods: deterministic and heuristic, developed in the software ArcGis 10.3, ArcView 3.2 and Ilwis 3.06, for the purpose of making a comparison and obtain greater accuracy in the calculation of susceptibility.

Deterministic Method

The geospatial analysis of the digital cartographic information was undertaken with the support of the ArcView 3.2 (Application *Stability Index Mapping* - SINMAP), ArcGIS 10.1 (Module ArcMap).

SINMAP (Stability Index Map) is an extension that not listed in the installation package of ArcGis 10.3. Therefore, it was necessary to download and install a version 2.0 developed by the University of OTAH in the United States, to calculate the stability index. The SINMAP (Stability Index Map) is a model to evaluate the stability of slopes and risks to landslides, projection of future patterns of instability, multivariate analysis of the factors that characterize sites of instability of slopes, Analysis of probability of failures based on models of stability of slopes with stochastic hydrological simulations and in the classification of stability, based on criteria such as pending, lithology, morphology, geological structure summarized in geotechnical parameters in a DTM.For the generation of the map, first from the curves generated in the format shop, in the Ilwis software 3.06 were imported and produced a Digital Model of the terrain (DTM).

With a pixel size of 1 meter, which is the set of layers (raster) that represent different characteristics of the surface of the Earth resulting from the lifts. As an important point, at the time of export to the ArcGis 10.1, the DTM was performed with extension type ***as*** that is the only format that enables to work with the SINMAP. It was applied a model of infinite slope and index of topographic moisture, which is a one-dimensional model that describes the stability of the slopes with a fault plane infinitely high same which was carried out by a pixel that can consider how same units in the maps. Therefore, the neighboring pixels are not regarded giving. As a result, a map of safety factors sees Figure 3.

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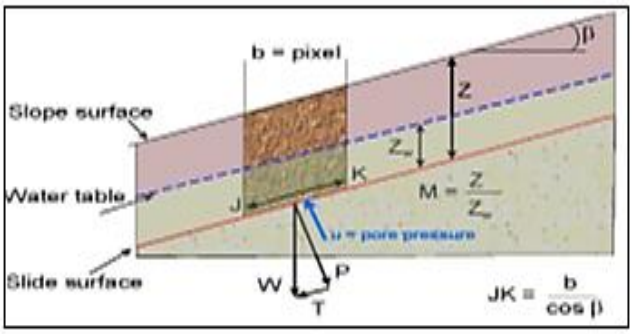

Fig 3. Diagram of the Application in the Program.

In Figure 4 is shown

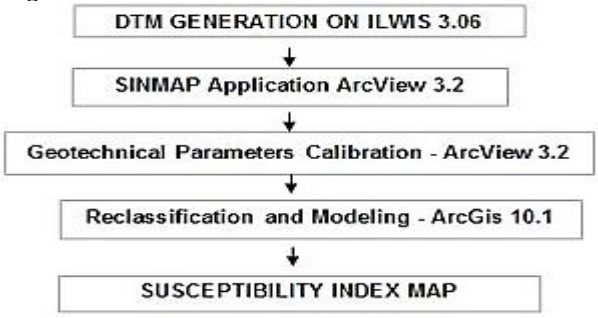

Fig 4. The scheme for obtaining the index of susceptibility map landslides.

Heuristic Method

The method consisted of adding maps factors which have an influential occurrence of landslides known physical conditions of terrain. The analysis of the process was made in the software ArcGis 10.1 specifically with the application of Model Builder. First, was grouped the maps factors for the occurrence of slip as a single condition. The criteria based on the knowledge acquired during the geological and topographic survey, geotechnical investigation and bibliographic collection, see Table 2.

Table 2. Grouping of Maps Factors

Condition	Geology
	Geomorphology
	Slope
	Vegetation Cover

Also, to each of the sub-variables certain was assigned pesos according to the following Table 3.

Table 3. Allocation of weights

CLASS	WEIGHT
Minuscule biophysics conditions trigger landslides	1
Less favorable biophysics conditions to trigger landslides	2
Unfavorable biophysics conditions to trigger landslides	3
Sever biophysics conditions which make to geographics spaces with this characteristics very danger to landslides	4
Very severe biophysics conditions which make to geographics spaces with this characteristics very danger to lanslides	5

Source: Tambo, Walter (2011).

For the generation of the map of susceptibility, end was considered four variables, geology, slope, geomorphology and vegetation cover, for which used the method of the sum of ranges (Janssen and Van Herwijnen, 1994)

For the allocation of weights to the variables together through the heuristic method allocating individual weights to components of each variable, applying the tool ***weighted sum*** in software ArcGis 10.1, which in addition to pondering, combined the raster maps incorporating the weights assigned to produce landslides.

The criteria used for the allocation of weights and their application formula by the method of the sum of ranges specified in the following Table 4.

Table 4. Distribution of weight by the method

Criteria	Criteria Weights using Method for Range Sum					
#	W1	W2	W3	W4	W5	W6
2	0.66	0.33				
3	0.50	0.33	0.17			
4	0.40	0.30	0.20	0.10		
5	0.33	0.27	0.20	0.13	0.07	
6	0.29	0.24	0.19	0.14	0.10	0.05

Source: Janssen and Van Herwijnen (1994).

For the reclassification of the degree of susceptibility was based on the criteria of Sarkar and Kanungo 2004, see Table 5.

Table 5. Criteria to determine the susceptibility

CRITERIA	Susceptibility	Catg
Hillsides with fault zones, highly weathered and saturated masses of soil and unfavorable discontinuities where a high possibility of landslides occurring or have occurred before.	Very high	5
Hillsides with fault zones, high to moderate weathered and unfavorable discontinuities where a high possibility of landslides occurring or have occurred before.	High	4
Hillsides with some fault zones, severe eroded or partially saturated materials, where landslides have not occurred, but there are no complete assurances that do not occur.	Moderate	3
Hillsides with some fissures, partially eroded materials, unsaturated, with favorable discontinuities, where there are no grounds to predict landslides.	Low	2
Unweathered hillsides with favorable discontinuities and no hint of possible landslides.	Very Low	1

Source: Sarkar and Kanungo, (2004).

III. RESULTS

3.1 Map Susceptibility

Loja city and its suburban setting located to the south of the Region Interandina (SAW) of the Republic of Ecuador, in the valley of Cuxibamba, 4º south. It has an extension of 5.186,58 ha (52 km^2). Administratively the sector of study limits: North with APUL Urbanization, to the south with the Capuli Neighborhood, to the west of the Julio Ordoñez Urbanization and the west with the National University of Loja. The area of study upon 46.70 ha, is located in the province of Loja and canton of the same name and the time in the parish of San Sebastian, specifically in the sector of the National University of Loja and Julio Ordoñez Urbanization, In Figure 5 this is shown.

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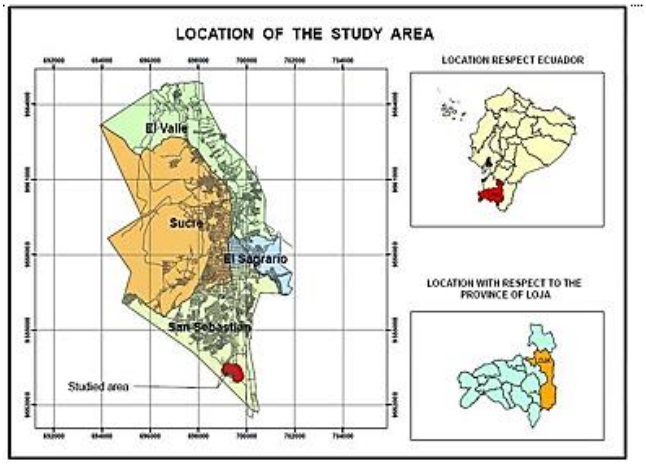

Fig 5. Location of the study area Cartographic information of GLP, eSC.

Source: Luis González.

3.2 Characterization of Variables.

From works in field were obtained the following maps:

- Topographic Map
- Geological Map.
- Geomorphological Map.
- Slope Map.

To each of them, that served for the generation and modeling of the maps by both the heuristic method and deterministic.

3.3 Geotechnical characterization.

Also, geotechnical exploration was made to determine the features geomechanical of materials focusing on the prevention of problems at the time of building infrastructures by indirect methods with Vertical Electrical Sounding (SEV) and direct with standard penetration tests (SPT),

Where values obtained from field and laboratory respectively allowed for a better understanding of the conditions of land on the moments of applying the methods of the calculation of the sensitivity that will directly serve to susceptibility to the allocation of weights to each one of the sub-variables.

Indirect exploration

Appling the settlement of Slchumberguer of 4 electrodes with a total of 4 lines is interpreted by the program EARTHIMAGER 1D 2010 version that allows using depths and resistivity to minimize the adjustment error and its interpretation the opening AB/2 is 31.60 m.

The results of resistivities showed substantial material from Formation Quillollaco, such as is indicated in the next geoelectric section.

Section 1

It is the product of the interpolation of the electrical probes 1 and 2 with address NW, in which you can watch collation of clays with conglomerates, being the last layer of saturated sandy clays, i.e. permeable and waterproof layers that allow the travel of groundwater, in Figure 6 this is shown.

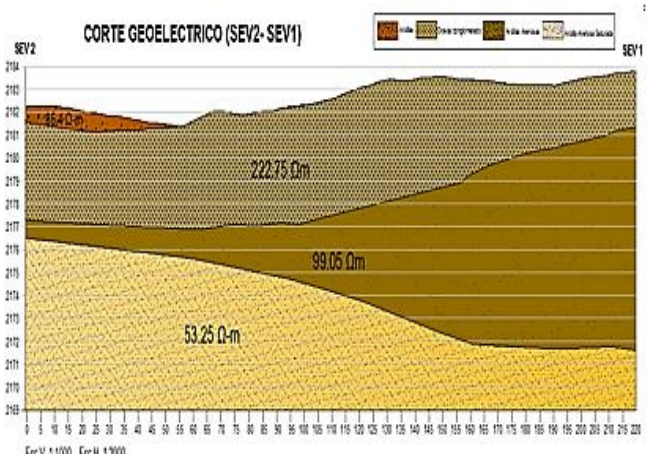

Fig 6. Geoelectric section sev2-sev1.

Section 2

This geoelectric section is carried out based on the interpolation of lines 3 and 4, in the direction of NW crossing the Malacatos River.

Whose results are collations of permeable layers of a conglomerate with class and at the end the presence of groundwater levels for registering resistivity 0.1 as confirmation of the proximity to the Malacatos River? In Figure 7 this is shown.

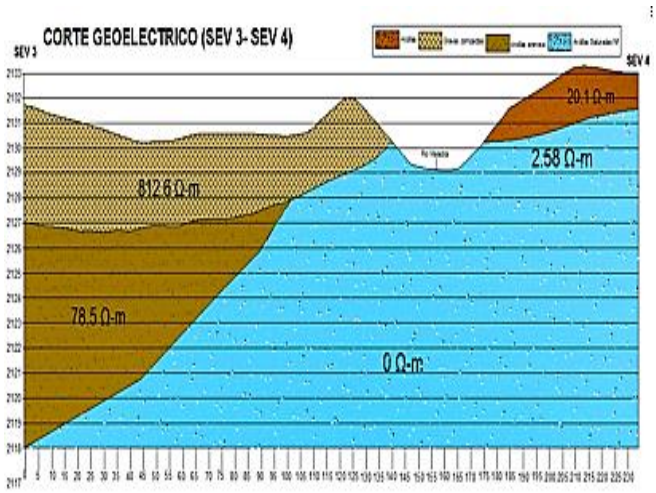

Fig 7. Geoelectric section sev3-sev4.

Direct exploration.

It based on 2 Standard Penetration Testing by applying the standard norm ASTM 1986-84 through the provision of services of the company ESTSUELCON CIA. LTDA, the first in the southern part and the second in the north of the Julio Ordoñez Urbanization both close to the Community Neighborhood Road into approximately 20 meters, which described in the following Tables 6 and 7respectively.

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Table 6. Results SPT 1

SPT 1							
COORDINATES			X: 699703.92		Y: 9552999.4		
H (m)	Classification SUCS	Classification AASHTO	Atterberg Limits	Granulometry	Description	N	qa kg/cm²
0 – 1	CL	A - 6	LL: 33 LP: 19 IP: 14	Gravel: 0 Sand: 16 Fine: 84	Middle plasticity clay	50	6.89
1 – 2	CL	A - 6	LL: 33 LP: 19 IP: 14	Gravel: 0 Sand: 17 Fine: 83	High plasticity clay	97	6.47
2 - 3	CL	A - 6	LL: 33 LP: 18 IP: 15	Gravel: 0 Sand: 12 Fine: 88	High plasticity clay	20 0	13.3

Table 7. Results SPT 2.

SPT 2							
COORDINATES			X: 699206.83		Y: 9553440.11		
H (m)	Classification SUCS	Classification AASHTO	Atterberg Limits	Granulometry	Description	N	qa kg/cm²
0 – 1	Sc	A-2-4	LL: 25 LP: 20 IP: 5	Gravel: 25 Sand: 46 Fine: 29	Clayey sand of low compactness	2	0.28
1 – 2	Gc	A-1-b	LL: 25 LP: 20 IP: 5	Gravel:55 Sand: 29 Fine: 15	Clayey gravel of middle compactness	18	2.48
2 - 3	Sc	A-2-4	LL: 26 LP: 20 IP: 6	Gravel: 32 Sand: 25 Fine: 33	Clayey gravel of middle compactness	26	3.58
3 - 4	Gc	A-2-4	LL: 25 LP: 20 IP: 5	Gravel: 39 Sand: 31 Fine: 30	Clayey gravel	63	8.68

The geological - geotechnical assessment are based on the interrelationship of lithological criteria and physical - mechanical properties of geomaterials, certain of the geological, SEV and SPT whose geotechnical conditions are:

1. Bearing capacity.
2. Deformability.
3. Scalability.
4. Morphology / Relief.
5. Type of material.
6. Drainage.

The conglomerate is shaky hard and fragile, constituting the entire central part of the area of study and is presented as stable, unlike the archil lolitas that mostly outcrop in the north and the clay in the southeast, exhibiting the transition of the conglomerate to clay. The important point is that it became apparent that the primary trigger for the instability is the water for both the conditions for civil constructions are low, thus, could present problems constant differentials movements and landslides, see Table 8.

Table 8. Valuation Geologic-Geotechnical of information Quillollaco in the study area.

QUILLOLLACO FORMATION.			
GEOTECHNICAL CONDITIONS	Tertiary Clay Mioceno	Argillite Miocene	Terciario Mio-plio-ceno Conglomerado
BEARING CAPACITY	1.0	1.0	2.0
DEFORMABILITY	2.0	1.5	2.0
EXCAVABILITY	2.0	2.0	2.0
MORPHOLOGY	1.0	1.0	2.0
TYPE OF MATERIAL	1.0	0.5	2.0
DRAINAGE	0.0	0.5	1.0
VALORATION TOTAL	7.0	6.5	11.0
CLASIFICATION	ACCEPTABLE	ACCEPTABLE	GOOD
	With restrictions		

About all of the data and their correlation concluded that by clusters are good while that for the class and argillite is acceptable with restrictions.

In response to the categorization of soils for constructions, is obtained that the clays have a valuation of 6.5 by what are acceptable with restrictions, the calculation performed from a foundation whose is a result are 0.7 x 0.7.

The sector of study has a capacity admissible 24.8 ton/m2, for which this soil can withstand a standard vertical construction of 4 floors (31.5 tons), with foundations of 0.7 x 0.7, but not recommended for since according to the norm of constructions the bases must be 1.5 x 1.5 m.

3.4 Analysis of susceptibility.

The analysis of susceptibility to landslides took place through the use of operators and techniques of spatial data analysis as the surface, overlay, reclassifications and sum of maps and through the application of formulas to the maps in the software ArcGis 10.1.

The scale of work was an aspect of high relevance because all data produced and acquired, sought to provide the level of detail on a scale of 1:5000, which ensured the homogeneity in the representation of different characteristics that gave origin to the inputs produced for the modeling of the phenomena in the software.

By the deterministic method

Preparing the map of susceptibility by this method was required the implementation of the extension of SINMAP in ArcGis 10.1 developed at the University of Utah in the United States. Same with which it calculated (stability index map) which gives a projection of future patterns of instability based on slopes, lithology, morphology, geological structure, and vegetation. Obtained the field and laboratory data, as cohesion and angle of internal friction created a large-scale map of susceptibility of agreement with the safety factors. Using the analysis of infinite slope, that within the software is examined with a raster (Digital Terrain Model DTM.asc) pixel by pixel accurately calibrated. The cohesion refers to the ability of the particles to remain together in intergranular and the internal friction angle is the ability of a floor standing unit (lithology) to withstand a certain voltage.

The values used for the variables were taken from the results obtained in the field and of the bibliographic collection (see Annex 7). The safety factor (FS) of SINMAP is an infinite model referred to the stability of slopes, primarily a mathematical ratio of forces that stabilize or destabilize a hillside.

Table 9. Geotechnical Parameters used in SINMAP.

N°	CONSIDERED VARIABLE	VALUE
1	DTM. Digital Terrain Model	1 m
2	thickness Soil (m)	1 m
3	Gravity (m/s²)	9.81
4	Water density (Kg/m³)	1000
5	Soil density (Kg/m³)	1900
6	T/r Min (m)	2215
7	T/r Max (m)	2219
8	Min Cohesion (dimensionless).	0.05
9	Max Cohesion (dimensionless)	0.2
10	Phi Min (°)	22
11	Phi Max(°)	35
12	User Weighing	1

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Table 10. Values of FS and its correlation with SINMAP.

Type of stability	Susceptibility	Stability Index Interval	FS	Influence of stabilizing and destabilizing factors
Unstable		0.0	< 1	Stabilizing factors are required
Unstable upper umbra	High	0.0-0.5	>50 Fs ≤ 1	Stabilizing factors could be responsible of stability. Unnecessary factors
Unstable lower umbra	Moderate	0.05-1.0	≥ 50 de FS >1	Destabilizing for stability. Minor factors.
Nominally stable		1.0-1.25	Maximum FS=1	Destabilizes are required to destabilizing. Moderate factors.
Moderate stable	Low	1.25-1.50	Maximum FS =1.25	Destabilizes are required to destabilizing. Significant factors.
Stable		>1.50	Maximum FS = 1.5	Destabilizes are necessary to destabilizing.

In Figure 8 shown the landslides by the deterministic method.

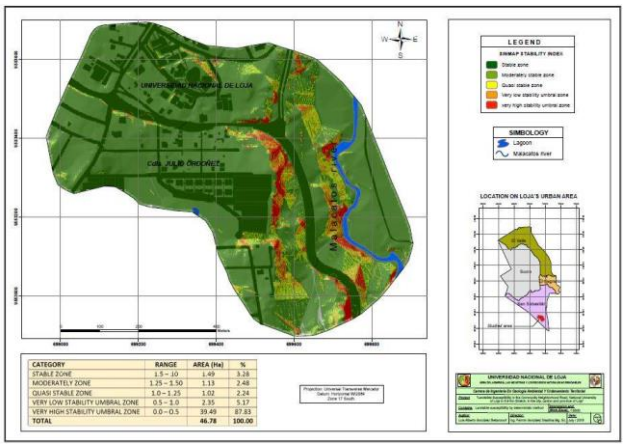

Fig 8. The final map of susceptibility to landslides by the deterministic method.

By the heuristic approach.

The input data inserted in the software ArcGis 10.1, represented by the unit of work adopted to represent the data with a ***Raster structure***. This unit was the cell with dimensions of 1x1m, format to which taken all covers that participated in the final analysis of susceptibility.

The map of vulnerability allowed us to develop an approximation of the degree of occurrence of landslides, from the parameters that present a greater influence on the conditions of instability,

Whose process begins giving the input data as geomorphology, earrings, lithology (types of rocks) and vegetation cover; and to each of its variables a weight of 1 to 5. The weights assigned are the following in response to what recommended by Janssen and Van Herwijnen (1994), see Table 11.

Table 11. Values that show the weights assigned to the variables according to the biophysical condition

Geology	0.4
Geomorphology	0.3
Slope	0.2
Land use	0.1

Source: Luis González.

The values assigned to each of the sub-variables were in a range of 1 to 5 according to the importance of these for the occurrence of a landslide whose criteria based on the following Table 12.

Table 12. Values that show the weights assigned to the sub-variables according to the condition biophysical.

CONDITION FOR WEIGHTS ALLOCATION	WEIGHTS
Very low biophysics conditions to trigger landslides	1
Less favorable biophysics conditions to trigger landslides	2
Unfavorable biophysics conditions to trigger landslides	3
Severe biophysics conditions making geographic spaces with this characteristics very landslides susceptible	4
Very severe biophysics conditions making geographic spaces with this characteristics highly landslides susceptible	5

Index of susceptibility

The sensitivity expressed as the ease with which a phenomenon may occur in local conditions of the terrain.
The procedure applied gives greater preponderance to the weight established in the criteria on the values assigned to the alternatives in the decision-making process (Barredo, 1996). This is equal in our case that the index of susceptibility obtained depends fundamentally on the weight assigned to the factors (assessed because of consistency), and to a lesser extent of the allocation of weights to each class within a factor,

So that the subjectivity and absence of control inherent in the latter process do not affect significantly in the calculation of the final index, whose relationship is as follows

$$S = G + L + V + P$$

Where: G = value of the geomorphological variable, **L** = value of the lithological variable, **V** = value of the vegetation variable, **P**= value of the slope variable, **S**= Susceptibility.
In parallel to the analytical assessment of the susceptibility, three-dimensional display of some of the maps of conditioning factors of instability, and even aerial photographs using your overlay to an MOU of high resolution,
Allowed for a better understanding of the influence that these factors, either individually or in combination with each other, can exert on the conditions of stability in the area.

Below is the sequence of the elaboration of the final map through the **Model Builder,** whose assigned weights in weighted sum are: in Figure 9 and 10 respectively, shown Geology 4, slope 3, geomorphology 2 and vegetal cover 1.

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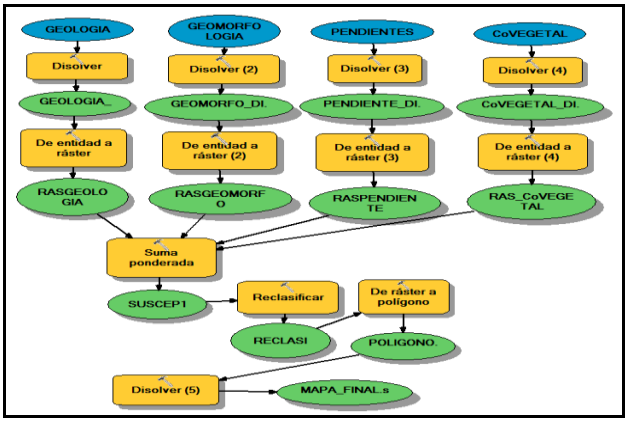

Fig 9. Sequential analysis ´´Model Builder´´ to obtain the final map. Source: Luís González

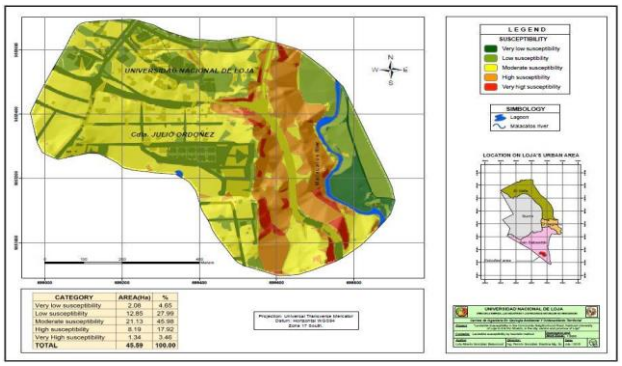

Fig 10. The final map of susceptibility to landslides by the deterministic method.

IV. Conclusions

- The study area located on the Formation Quillollaco, which is compound by sedimentary rocks such as clays, conglomerates, and arcillolitas whose guidance is N 22º W, inclinations to this with 31º east as averages.
- The results of the SPT showed that the clays are soft soils of medium consistency. Consolidated in the dry state and an expandability media with a q allowable 5.58 kg/m2 up to a depth of 2 meters as average.
- The conglomerates have a fragile behavior and little resistance, are easy filtration and permeability whose q admissible is 8, 93 kg/cm^2.
- The heuristic method despite generally used to cover larger scales to 1:50000 results in the present article are viable because with the help of the geotechnical investigation the weights assigned to the different variables were given with greater certainty coinciding that landslide located in areas of high susceptibility.
- The deterministic method is also a method that can be used for both, large and small because that depends on a professional geologist for making interpretations of the suitability and behavior of materials that have to base on existing research and laboratory data.
- Between the relationship and correlation of information in geotechnical exploration, it is concluded that by clusters are good, while that for the class and archil lolitas is acceptable with restrictions with bases of 1.5 x 1.5 meters to withstand a construction of 4 floors with 31.5 ton.
- It showed two landslides both with a movement that if located to translations side of the track The first is new and the second former represents a danger as the safety factors in conditions of saturation were lower than 1 and in the current circumstances in which they found.

V. Recommendations

- Take into account a greater number of factors involved in the processes of landslides as the use of soil, the address of the strata, climate, river erosion, seismicity of the area and anthropic actions, with the purpose to further evaluate the reliability of the results.
- Consider engineering works to give greater stability to the landslides certain, with techniques of bioengineering, drainage ditches, and gutters.
- In the modeling of the maps use a DEM and the ArcScene application to get a better view in 3D at the time of the determination of the landforms.
- Promotes and disseminate the methodology applied in this article as well as the application of other methods of calculation of susceptibility to reduce the socio-economic ordered to natural disasters.
- Considering the results of the present article and another similar study for the generation of databases to be included in the plans for national management and emergency of local government.
- As the geology and topography of the Basin of Loja presents present favorable conditions, so that the construction projects part of the geotechnical and risk assessments of land.
- Promote research with other methodologies for the calculation of different susceptibility of the exposed in this article, such as multivariate statistical and to generate greater geoscientific information and check the approximations of the calculation of the sensitivity of the different methodologies.

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