Risk indicators of mass removal phenomena according to the Mora - Vahrson method, applied in Pitalito and Campoalegre municipalities

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Abstract. The massive removal phenomena have been one of the most frequent natural disasters in the world, causing thousands of deaths, victims, damage to homes and diseases. In Pitalito and Campoalegre, municipalities of Huila department in Colombia have occurred various events such as heavy rains, earthquakes, which have caused landslides, floods, among others, to affect the economy, the community and transportation. For this reason, a study was carried out on the area's most prone to suffer these phenomena to take preventive measures in favor of the protection of the population, the resources of management and the planning of civil works. For the proposed object, the Mora-Varshon method was used, which allows classifying the degree of susceptibility to landslides in which the areas are found. Also, various factors or parameters was evaluated such as the soil moisture, lithology, slope, seismicity and rain, each of these indicators were obtained using information from IDEAM, Servicio Geologico Colombiano (SGC) and using geographic information for geoprocessing in the ArcGIS software to realize a mapping to indicate the susceptibility to landslides, classifying the areas of the municipalities such as very low, low, medium, moderate, high or very high.

1. Introduction
The mass removal phenomena are events that have been generated over the years, many of these phenomena are stronger than others, causing landslides of great magnitude directly affecting the economy, mobility, the community, the environment and also causing human losses. These are caused by various variables that are linked to natural and anthropic factors, which must be thoroughly studied to prevent any disaster that may be generated, and thus, protect the community, informal settlements and for the possible development of civil works; these is because a study is carried out on the susceptibility of landslides that can be generated in the municipalities of Pitalito and Campoalegre, belonging to the department of Huila.

The article is focused on determining the level of mass removal of Pitalito and Campoalegre municipalities, for this will be made the creation of a geodatabase that will allow a mapping in ArcGIS in order to evaluate which is the indicator of seismicity in these areas, taking into account factors such as precipitation, lithology, soil moisture, slope and seismicity, which will be obtained through data from IDEAM, the Servicio Geologico Colombiano and through the use of geographic information; It is important to emphasize that the Mora-Vahrson method is developed through the aforementioned factors, which originated in Costa Rica as a consequence of an earthquake that occurred in that place and seeks to be able to make decisions regarding the planning of land use, exploitation of natural resources, the planning of infrastructures, urbanism and roads. In this way, the methodology shown in figure (1) is
proposed and implemented, which is composed of three stages, in the first instance, the study of the mora-Vahrson method, in the second instance the elaboration of the different maps to identify the triggers in the ArcGIS software, finally, the assessment of the area’s most prone to landslide susceptibility.

![Figure 1. Methodology Used.](image)

2. Location of the municipalities

2.1. Pitalito

Pitalito is a municipality that belongs to the department of Huila, which has a territorial extension of 653 km², located at 1° 51’ 16” North and 76° 3’ 6” West and is approximately 196 km from the capital of Huila It is also located south of the department at 1,318 meters above sea level, with an average temperature of 20 ° C. Pitalito limits to the north with the municipalities of Saladoblanco and Elias, to the south with the Municipality of Palestina, to the east with the Municipalities of Acevedo and to the west with the municipalities Isnos and San Agustín. Pitalito is part of the highest basin of the Magdalena River and as water currents are the Osoguico, Narajos, Balseros, Granadillos, and clear rivers, among others [1]. In terms of soils, the municipality is characterized by having six different types, among which are: mountain soils in a cold and humid climate, mountain soils with a medium humid climate, additionally it has the presence of piedmont soils with a climate medium and humid, lowland soils with a medium and humid climate, highland soils with a medium and humid climate and finally with valley soils with a medium and humid climate [2].

The territory is formed from a system of geological faults of probable activity, the most likely faults are the Chillurco faults, heading east-west along the southern foothills of the Chillurco ridge, the Guachicos fault heading northeast-southwest through the valley of the same name and the Suaza fault to the east of the municipality through the Suaza - Acevedo valley [2].

2.2. Campoalegre

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The article is focused on determining the level of seismic threat of the municipalities of Pitalito and Campoalegre, for this will be made the creation of a geodatabase that will allow a mapping in ArcGIS in order to evaluate which is the indicator of seismicity in these areas, taking into account factors such as precipitation, lithology, soil moisture, slope and seismicity, which will be obtained through data from IDEAM, the Servicio Geologico Colombiano and through the use of geographic information; It is important to emphasize that the Mora-Vahrson method is developed through the aforementioned factors, which originated in Costa Rica as a consequence of an earthquake that occurred in that place and seeks to be able to make decisions regarding the planning of land use, exploitation of natural resources, the planning of infrastructures, urbanism and roads. In this way, the methodology shown in figure (1) is proposed and implemented, which is composed of three stages, in the first instance, the study of the
mora - Vahrson method, in the second instance the elaboration of the different maps to identify the triggers in the ArcGIS software, finally, the assessment of the area’s most prone to landslide susceptibility.

3. Mass removal phenomena
The mass removal phenomena or also known as slope failures, landslides, among others, are displacements from a higher to a lower level of rocks, fine material, rubble and earth [5], either quickly or slowly, which are presented essentially as a consequence of the force of gravity and with the help of other factors such as precipitation, seismicity, slope, the impact of human action, among others.

Mass removal phenomena are classified into several types, which according to their magnitude can generate disasters in communities, directly affecting homes, people's lives, communication routes and the economy; To avoid these consequences, it is necessary to monitor the disasters that have occurred in the area in the past, in order to prevent possible disasters in the future, however, their prediction turns out to be highly complex, since it is not possible to determine exactly the time, day, place and magnitude [6]. Table (1) shows the classification of the types of mass removal phenomena according to Cruden & Varnes [7][23].

| Type of movement         | Type of material                      |
|-------------------------|---------------------------------------|
| Fall                    | Rock – Soil                           |
| Toppling                | Rock – Soil                           |
| Rotational Sliding      | Rock – Soil                           |
| Translational Sliding   | Rock – Coarse Grain – Fine Grain      |
| Flows                   | Rock – Coarse Grain – Fine Grain      |
| Lateral Extensions      | Rock – Coarse Grain – Fine Grain      |

In the first instance, according to the previous classification, falls are defined as the detachment of material of various sizes from a slope in a rapid manner, presenting rock falls in free fall, also generating jumps and bearings; These characteristics depend on the slope in which the slope is, in the second instance the overturns (topples) are identified as the rotation of soft rocks or detrital materials towards the outside of the slope and according to the slope they depends on whether they are fast or slow, these movements are propagated by the presence of water, ice in the joints, by expansion and by seismicity [8].

Additionally, in the third instance of the aforementioned classification, it can be evidenced that the landslides that are rapid movements are generated by the low cohesion of the soil, predominantly blocks, sands and gravels, where the material moves along the fault surface and reaches the bottom of the slope without any form, these movements contain mostly solid material and what remains is water [3], these landslides can be classified as rotational where the fault surface is curved or concave and transnational that Unlike the rotational ones, the fault surface is flat [9]. On the other hand, with regard to flow, it is characterized by the sliding of rock, soil or small-sized earth along the slope. This flow can be wet or dry and in many occasions this phenomenon is generated after landslides, which causes water to be absorbed very easily in the faults. Finally, with regard to the lateral extensions, these are characterized by presenting themselves in two types of movement, where one of them completely alters the material traditionally in rocky material while the other occurs only in cohesive soils when previously liquefaction has already occurred [10].
4. Mora – Vahrson Method

The Mora-Vahrson method was born in Costa Rica, created by Sergio Mora and Wilhelm Vahrson, exactly in 1991. This method has been widely used in Central America [11] given its accuracy in predicting the threats of phenomena in addition, mass removal is used to obtain the degree of susceptibility to landslides of a place, in order to identify the magnitude to which the area is prone. This method considers several factors provided by the observation and measurement of morpho-dynamic parameters [12], where it proposes that some parameters help in particular to predict the instability of the slope, which are divided into two groups that can be found in the literature with different names such as susceptibility factors or passive elements (P) and trigger factors (D) or active elements, equation (1) illustrates how to determine the susceptibility to landslides (S) according to Mora - Vahrson.

\[ S = P \times D \]  

According to the previous equation, the passive elements (P) are constituted in the first place by lithology (Sl), which is the study of rocks, where characteristics such as the size of the particles and the grain are taken into account, the physical-chemical characteristics, the type of transport and the texture; as a second constitutive parameter is the soil moisture (Sh), which depends on the air temperature, the rains that have occurred, if it is near the sea, if there are plants, among others [13]. It is also known as the relationship between the weight of water contained in it and the weight of its solid phase [15], and the last factor is the slope (Sp) that covers the dynamic morphology of the relief, that is, it is that parameter that symbolizes the natural roughness of a zone [22], which is characterized according to its geometry, so the more slope there is, the frequency of landslides also increases, so it is pertinent to take into account the five categories of slope that can be found: flat from 0 ° to 1 °, slightly smooth from 1 ° at 3 °, mild from 3 ° to 5 °, moderate from 5 ° to 15 ° and strong greater than 15 ° [13], in such a way that taking into account these three parameters (P) is determined, as shown below in equation (2).

\[ P = Sl \times Sh \times Sp \]  

On the other hand, within the category of tripping factors (D) it should be mentioned that it is constituted by the seismicity parameter (Ds) of the area in the first place, which refers to the capacity that a certain area has to experience earthquakes and is closely related to the collision of tectonic plates, and secondly by the data of the intensity of Rain or precipitation (Dp), which refers to the event that occurs when the atmosphere becomes saturated with water vapor, condensing and last rushing. Next, the way to determine (D) is illustrated in equation (3).

\[ D = Ds + Dp \]  

5. Characterization of passive and triggering factors

The elaboration of the corresponding maps in the ArcGIS software of each factor, identifies the value in which each one of these is found. In order to obtain a correct result, each data obtained by mapping must be classified according to the values provided by Mora -Vahrson in the proposed method.

5.1. Lithology (Sl)

The preparation of the lithological map in the ArcGIS software is carried out taking into account the information from the 2015 geological atlas map of Colombia provided by the Colombian Geological Service (SGC), said map shows geological and lithological information found in the study municipalities as illustrated in table (2), according to this information, the correct classification is made with the characterization that Mora - Vahrson expresses in his study as evidenced in table (3).
| Geology Nomenclature | Lithology                                                                 |
|----------------------|---------------------------------------------------------------------------|
| Campoalegre          | Plutonic igneous rock of intermediate composition                         |
| J – Pi               | Alluvial deposit                                                          |
| Q – al               | High-grade metamorphic rock                                               |
| MP3NP1 – Mag2        | Fan deposit                                                               |
| Q – Ca               | Sedimentary rock of continental environment                               |
| e6e9 – Sc            | Volcanoclastic rock of continental environment                            |
| J – VCc              | Sedimentary rock of continental environment                               |
| n4n6 – Sc            | Volcanoclastic rock of continental environment                            |
| N2Q1 - VCc           | Volcanoclastic rock of continental environment                            |
| Pitalito             | Plutonic igneous rock of intermediate composition                         |
| J – Pi               | Terrace deposit                                                           |
| Q – t                | Alluvial deposit                                                          |
| Q – al               | Continental sedimentary rock – transitional - maritime                     |
| C – Sctm             | Pallelud deposit                                                          |
| Q2 – l               | Volcanoclastic rock of continental environment                            |
| N2 - VCc             | Fan deposit                                                               |
| Q – Ca               | Continental sedimentary rock – transitional - maritime                     |
| B6k6 – Stm           | Volcanoclastic rock of continental environment                            |
| J – VCc              | Volcanoclastic rock of continental environment                            |
Table 3. Classification of the lithology parameter according to Mora – Vahrson [14]

| Lithology                                                                 | Physical – mechanical Characteristics                                      | Degree of Susceptibility | Factor Value SI |
|---------------------------------------------------------------------------|------------------------------------------------------------------------------|--------------------------|-----------------|
| Alluviums: thick, permeable, compact, with low water table. Limestones: hard, permeable Intrusive: slightly cracked, low water table. Basalts, andesite, ignimbrites and similar, healthy, permeable and not very fissured. Healthy metamorphic rocks, little cracking, low water table | Healthy with little or no weathering, high shear strength, healthy cracks without fillers. | Low             | 1               |
| Slightly altered sedimentary rocks, solid stratification, little fissures, low water table. Intrusive rocks, hard limestone, lava, ignimbrites or metamorphic medium cracked or altered, water table at intermediate depths. | Medium to high shear strength, sharable fractures. | Moderated         | 2               |
| Sedimentary rocks, intrusive rocks, hard limestone, lava, ignimbrites, poorly welded or moderately altered metamorphic tuffs. Colluviums, lahars, sands, slightly compacted regolithic soils, poor drainage, relatively high-water tables. | Moderate to medium shear strength, significant fracturing. | Medium           | 3               |
| Fluvial lacustrine alluviums, pyroclastic soils with little compaction, sectors of hydrothermal alteration, strongly altered and fractured rocks with stratification and foliations in favour of the slope, with clayey fillings, shallow phreatic levels. | Moderate to low cut resistance. | High             | 4               |
| Alluvial, colluvial and regolithic materials of very low mechanical quality with an advanced state of alteration, poor drainage, categories 3 and 4 are included with very shallow phreatic levels, subject to very high hydrodynamic gradients. | Very low cutting resistance, soft materials with many fines. | Very high         | 5               |

Once the classification is made, we proceed in Arcgis to add a column in the attribute table of the map obtained by the Colombian geological service, where the respective value for each lithological part of the municipalities will be added, then the shapefiles are transformed. of the polygon to raster according to the given value, thus obtaining the lithological map as illustrated in figures (2) and (3) with
values of Sl 1, 3, 4 and 5, that is, a degree of low, medium, high and very high susceptibility, while in Campoalegre it has a low, medium and high degree of susceptibility.

![Figure 2. Lithological map of Pitalito municipality.](image1)

![Figure 3. Lithological map of Campoalegre municipality.](image2)

5.2. Soil moisture (Sh)

Mora. vahrson sets out some criteria to be able to classify the range in which the soil moisture is found, taking into account the mean monthly precipitation values of the meteorological stations in the area for the years of existence of measurements [16], for the present case They were obtained according to information provided by IDEAM. Table (4) shows the classification of precipitation values according to the monthly average, that is, each monthly data obtained is assigned a value of 0, 1 or 2 depending on the range in which it is found, from In the same way in table (5) the true value of soil moisture is obtained, this is achieved by adding the value assigned at 12 months according to table (4) and according to the result it is classified according to the ranges given by Mora Vahrson.

**Table 4.** Classification of average monthly precipitation values Mora – Vahrson [14].

| Average monthly rainfall (mm/month) | Value |
|------------------------------------|-------|
| < 125                              | 0     |
| 125 - 250                           | 1     |
| 250 <                              | 2     |

**Table 5.** Soil moisture parameter (Sh) Mora – Vahrson [14].

| Accumulated value of precipitation rate | Classification | Sh Factor |
|----------------------------------------|----------------|-----------|
| 0 – 4                                  | Very low       | 1         |
| 5 - 9                                  | Low            | 2         |
| 10 - 14                                | Medium         | 3         |
| 15 - 29                                | High           | 4         |
| 20 - 24                                | Very high      | 5         |
In order to obtain greater accuracy against this parameter, a weighted average is carried out to complement the missing data from each of the stations, for this the height of precipitation recorded in the auxiliary stations (Hpa, Hpb, Hpc), the precipitation height of the missing station (Hpx), the average annual precipitation of the auxiliary stations (Pa, Pb, Pc) and finally the average annual precipitation of the study station, as evidenced in the expression (4).

\[
h_{\text{px}} = \frac{1}{3} \left[ \frac{p_{\text{px}}}{p_{\text{pa}}} \times h_{\text{pa}} + \frac{p_{\text{px}}}{p_{\text{pb}}} \times h_{\text{pb}} + \frac{p_{\text{px}}}{p_{\text{pc}}} \times h_{\text{pc}} \right]
\] (4)

Once the explained procedure, in the ArcGIS software a table with the monthly precipitation values must be inserted, thus generating twelve maps of each month, these twelve maps are used to obtain the IDW tool since through this, they are made isohyets in order to evaluate the different soil moisture parameters in each municipality, which must be reclassified according to table (5), after that they are added using the Raster calculator tool to obtain a single general map, thus obtaining a soil moisture value in the municipality of Pitalito of 1 and 2, classified as very low and low as illustrated in figure (4) and in the municipality of Campoalegre of 2, classified as low, as illustrated in figure (5)

![Figure 4. Soil moisture map in the Pitalito municipality.](image1)

![Figure 5. Soil moisture map in the Campoalegre municipality.](image2)

5.3. Slope (Sp)
The classification of the slope according to Mora Vafrson is illustrated in table (6), which is used in the elaboration of the maps of the study municipalities, so it is necessary to load a satellite image in the software, in order to obtain a DEM, which consists of a digital elevation model and provides content of slopes and elevations of an area. Subsequently, the flows of water present in the municipalities are established taking into account the coordinate (WGS 1984 zone 18N), in order to delimit the basin and extract the morphometric characteristics, where the behaviour of the water currents can be analysed, as well their physical characteristics.

| Equivalence in degrees | Classification | Factor |
|------------------------|----------------|--------|
| 0 – 4.29               | Very low       | 0      |
| 4.3 – 9.93             | Low            | 1      |
| 9.94 – 16.7            | Moderated      | 2      |
| 16.71 – 26.57          | Medium         | 3      |
| 23.58 – 38.66          | High           | 4      |
| >38.66                 | Very high      | 5      |

Table 6. Slope Parameter (Sp) Mora - Vahrson [14].
To continue with the elaboration of the map, now the attention be focused on the construction of the contour lines in the two municipalities, which generate the triangulation to define the mountainous part of the study places, in order to obtain the final value corresponding to the slopes, illustrated in figures (6) and (7), by using the Slopes option which provides information on the range of the slope and the Reclassify tool to classify the slope in the ranges defined in the method Mora-Vahrson.

![Figure 6. Slope map of Pitalito municipality.](image)

![Figure 7. Slope map of Campoalegre municipality.](image)

5.4. Seismicity (Ds)
Mora-Vahrson classifies the seismic activity of a place through the establishment of parameters that are illustrated in table (7), where the intensity on the Mercalli scale is a parameter whose values refer to the qualitative exposure of the consequence of the earthquakes, on the other hand, there are the peak acceleration values (% g) and the PGA acceleration value (m / s²), where the peak acceleration is a percentage of gravity, so that in Colombian regulations, it corresponds to Aa value defined in NSR-10 (Colombian earthquake resistant construction regulations); that is, by multiplying each value (Aa) in percentage with the value of gravity (9.81 m / s²), the value of the acceleration PGA is obtained.

| Intensity | Peak Acceleration (%g) | Acceleration PGA (m/s²) | Classification | Ds Value |
|-----------|------------------------|-------------------------|----------------|----------|
| III       | 1 – 12                 | 0.098 – 1.226           | Mild           | 1        |
| IV        | 13 – 20                | 1.227 – 2.011           | Very Low       | 2        |
| V         | 21 – 29                | 2.012 – 2.894           | Low            | 3        |
| VI        | 30 – 37                | 2.895 – 3.679           | Moderated      | 4        |
| VII       | 38 – 44                | 3.680 – 4.365           | Medium         | 5        |
| VIII      | 45 – 55                | 4.366 – 5.445           | High           | 6        |
| IX        | 56 – 65                | 5.446 – 6.426           | Strong         | 7        |
| X         | 66 – 73                | 6.427 – 7.210           | Quite Strong   | 8        |
| XI        | 74 – 85                | 7.211 – 8.388           | Very Strong    | 9        |
| XII       | >85                    | >8.389                  | Extremely Strong | 10   |
To obtain the Ds value, the threat map of the Colombian Geological Institute (NTC) of the Colombian Geological Institute was identified in order to obtain the value of the effective peak acceleration (Aa) and the value of the threat. From the above, it was determined that the municipalities of Campoalegre and Pitalito are in a high seismic hazard zone of “8” and have an effective peak acceleration of 0.3.

The seismicity factor is classified according to a moderate intensity, identified with the number 4, since when multiply the value of the effective peak acceleration (Aa = 0.3) with gravity (g = 9.81) as illustrated in equation (5). It should be clarified that in order to carry out a more in-depth study of the value of 0.3 in the respective municipalities, an interpolation was made to each map with the Aa values of neighboring municipalities, in table 7.1 the chosen municipalities with their respective effective peak acceleration are shown.

\[ Ds = Aa \times g \left(\frac{m}{s^2}\right) \]  

(5)

Table 7.1 Effective peak acceleration Aa.

| Study municipality | Neighboring municipality | Aa value |
|--------------------|--------------------------|----------|
| PITALITO           | San Agustín              | 0.25     |
|                    | Isnos                    | 0.25     |
|                    | Solado blanco            | 0.25     |
|                    | Elías                    | 0.3      |
|                    | Timaná                   | 0.3      |
|                    | Acevedo                  | 0.3      |
|                    | Palestina                | 0.3      |
| CAMPOALEGRE        | Yaguará                  | 0.25     |
|                    | Hobo                     | 0.3      |
|                    | Algeciras                | 0.3      |
|                    | Rivera                   | 0.3      |
|                    | Palermo                  | 0.25     |

Using the IDW tool in the ArcGIS software, the data is interpolated, thus obtaining two values in each map, these values range from 0.27 to 0.3, which when approximating the closest value for each municipality is 0.3, obtaining, as well as a Ds value of 4 as mentioned above, with a moderate classification as illustrated in figures (8) and (9).

Figure 8. Seismicity map of Pitalito municipality.

Figure 9. Seismicity map of Campoalegre municipality.
5.5. Precipitation (Dp)
To determine this factor within the municipalities under study, it should be taken into account the precipitation in 24 hours of the stations of the same, however, to determine the value of this parameter, a return period of 100 years is estimated through the final value with the Gumbel distribution as stated by Mora - Vahrson, which allows to determine extreme values for flows or rainfall [17], for which the statistical distributions of hydrology are used, since these mathematical functions are related with the magnitude of an event with its probability of happening [18]. To do this, the factor (F (x)) is taken into account, which indicates the probability that a value lower than (x), which is the return period that will occur in a precipitation or flow, in the same way (Sn) which corresponds to the deviation used to evaluate the dispersion of data as seen in equation (6) and which in turn depends on the sums of the deviations of each point (x) from the previously mean calculated and divided by the number of data.

\[ Sn = \frac{\sqrt{\sum(x-x)^2}}{n} \]  

(6)

In the same way, to complement the Gumbel distribution, the mean is required, which is determined by the average of the maximum values per year, of the values of \( \mu_y \) and \( \sigma_y \), which are obtained from table (8), where the values of According to the number of data to be taken, however, in case the number of data is not found in the table, the values must be interpolated in order to find the exact value; On the other hand, \( \alpha \) and \( u \) are taken into account, which are parameters used to determine the value of the precipitation of each station in a return period of 100 years, these values in turn are established by means of equations (7) and (8), where \( \alpha \) depends on \( \sigma_y \) and the standard deviation, while \( u \) depends on the mean, \( \mu_y \) and \( \alpha \). Finally, the most important value is determined, which is \( x \), which corresponds to the precipitation of each station with a return period of 100 years, for which it is determined by equation (9).

Table 8. Values of the variables \( \mu_y \) y \( \sigma_y \) [19].

| Data number | \( \mu_y \) | \( \sigma_y \) |
|-------------|-------------|-------------|
| 10          | 0.4952      | 0.9496      |
| 15          | 0.5128      | 1.0206      |
| 20          | 0.5236      | 1.0628      |
| 25          | 0.5309      | 1.0914      |
| 30          | 0.5362      | 1.1124      |
| 35          | 0.5403      | 1.1285      |
| 40          | 0.5436      | 1.1413      |
| 45          | 0.5463      | 1.1518      |
| 50          | 0.5485      | 1.1607      |
| 55          | 0.5504      | 1.1682      |
| 60          | 0.5521      | 1.1747      |
| 65          | 0.5535      | 1.1803      |
| 70          | 0.5548      | 1.1854      |
| 75          | 0.5559      | 1.1898      |
| 80          | 0.5569      | 1.1938      |
| 85          | 0.5578      | 1.1974      |
| 90          | 0.5586      | 1.2007      |
| 95          | 0.5593      | 1.2037      |
| 100         | 0.5600      | 1.2065      |
\[ \alpha = \frac{\sigma_y}{S_x} \]  
\[ u = \bar{x} - \frac{uy}{\alpha} \]  
\[ X = -\ln(-\ln(F(x))) \star \alpha + u \]

Finally, once the value of X has been obtained in each station, this value is classified in table (9) established by Mora-Vahrson; to generate the map in the ArcGIS software mentioned above; For this, a table is exported with the precipitation values, that is, with the X values that refer to the maximum precipitation in 24 of each study station, in order to generate an isoyetal map with the help of the IDW tool. Since the isohyets are those that link all the points that have the same precipitation information in a period of time.

### Table 9. Precipitation parameter Mora -Vahrson [14].

| Accumulated value of precipitation index | Classification | Facto Sh |
|-----------------------------------------|----------------|---------|
| < 100                                   | Very Low       | 1       |
| 101 - 200                               | Low            | 2       |
| 201 - 300                               | Medium         | 3       |
| 301 – 400                               | High           | 4       |
| > 400                                   | Very Low       | 5       |

According to the isohyets obtained, a classification is carried out using the Reclassify tool to be able to link the data obtained with the classification provided by the aforementioned authors, as illustrated in figures (10), where Pitalito has a precipitation factor of 2 and 3, classified as low and medium, while in figure (11) a Campoalegre precipitation factor of 1 and 2 is obtained, classified as very low and low.

![Figure 10. Precipitation map of Pitalito municipality.](image1)

![Figure 11. Precipitation map of Campoalegre municipality.](image2)

### 6. Susceptibility to Landslides (S)

Mora-Vahrson classifies the susceptibility to landslides of a place using criteria illustrated in table (10). To identify the municipalities in which landslide potential they are, the respective calculation illustrated in equation (1) must be made. To do this, the respective multiplication is done in the ArcGIS software.
using the Raster Calculator tool, so that the map obtained is reclassified according to the values provided by the aforementioned authors.

Table 10. Susceptibility to landslides Mora - Vahrson [14].

| Classification | Sliding Potential | Sh Factor |
|----------------|-------------------|-----------|
| I              | Very low          | Stable sectors, no corrective measures are required, the influence of surrounding sectors with moderate to very high susceptibility must be considered. Sectors suitable for high-density urban use and location of essential buildings such as hospitals, education centers, police stations, fire stations and others. |
| II             | Low               | Stable sectors that require minor corrective measures, only in the case of large infrastructure works, the influence of neighbouring sectors with moderate very high susceptibility must be considered. Sectors suitable for high-density urban use and location of essential buildings such as hospitals, education centers, police stations, fire stations, etc. Sectors with poorly compacted fillings are of special care. |
| III            | Moderated         | No infrastructure should be allowed to be built without geotechnical studies and improvement of the site’s earthworks, groundwater management, land bio-stabilization, etc. Sectors with poorly compacted landfills are of special concern. Recommended for low-density urban uses. condition. |
| IV             | High              | Landslides (<50%) in case of High probability major earthquakes and high intensity rainfall in order to use them, detailed stability studies must be carried out and corrective measures implemented to ensure the stability of the sector, otherwise they must be maintained as protection areas. |
| V              | Very High         | Very high probability of landslides (>50%) in case of major earthquakes and high intensity rainfall Forbidden to be used for urban purposes, it is recommended to use them as protection areas. |

According to the previous table, it can be seen that the study municipalities show a susceptibility to landslide that ranges from very low to high, with the potential for moderate landslides prevailing as illustrated in figures (12) and (13), therefore that it is necessary to have prevention when developing civil works either due to the conditions of the land or when changing its composition when carrying out construction of buildings, bridges and roads, that is to say that the way in which the land is located is evaluated before, having in the same way the urban planning and vital lines [24], since if man comes to modify the components of the surface of land and slopes when cutting, filling, deforestation, among others, can generate as a consequence a destabilization due to the alteration of stresses.

To avoid the aforementioned alterations, it is necessary that infrastructure works respect protected areas such as streams, rivers, among others, mainly in that area with a steep slope, in addition to
implementing adequate water management, in the same way, techniques of engineering using biology and technology in soils in order to reduce impacts and stabilize.

Figure 12. Landslide susceptibility map of Pitalito municipality.

Figure 13. Landslide susceptibility map of Campoalegre municipality.

7. Conclusion
The application of the Mora - Vahrson methodology presents a final map that addresses the factors that impact and influence the development of mass removal phenomena, providing information that leads to an analysis of the presence of morpho dynamic processes in an area; Factors such as lithology and slope are permanent values throughout the study area, so that precipitation, soil moisture and earthquake, which, since they are not constant, are the ones that produce the greatest change at the time of the survey. zoning, that is, they are the variables that have the most relevant influence on the phenomena of mass removal that may occur, however, this method does not address erosive processes, which makes it an approximate but not totally true method. that could be presented.

Taking into account the final maps of susceptibility to landslide in the municipalities of Campoalegre and Pitalito, it can be observed that Mora -Vahrson present a simple way of being able to identify the places with the highest risk of landslides through the use of geographic information, thus finding that in the south and east of the municipality of Campoalegre, exactly in the paths of Otas, Guayabo, Chia, Vilaco bajo, Vilaco alto, Buenavista, El Roble, San Milguel, Palmar Alto, El esmero, Los planes, El Peñon are the areas. The most vulnerable areas, while in the municipality of Pitalito the most vulnerable areas are those at the ends of the municipality, by which exactly the south, part of the east and west of the municipality are affected, thus impacting villages such as El Cedro, Montecristo, La Cristalina, El Alto de la Cruz, El Meson, Las Brisas, El Diamante, Puerto Lleras, Costa Rica, Resinas, Barranquilla, Buenos Aires, Monserrate, among others.

One of the events that can occur the most and have occurred previously is floods, since these occur more frequently when there are rains, so it can cause overflows in rivers and streams in Campoalegre such as Neiva River, Otas Ravines, Rios Frio Ravines, Magdalena River, among others, thus affecting homes, roads, bridges, aqueducts, crops, among others; However, in the location of these rivers and streams there are few houses that could be affected. On the other hand, Pitalito is among the two municipalities, which has presented the most events since it is more prone to mass removal phenomena, in addition, due to its location it is exposed to flooding by the Yaguilga Ravines, Magdalena River, among others, thus affecting roads and homes.

For the aforementioned, it is necessary to carry out technical studies in order to establish actions that allow correcting and preventing the risk and if it is necessary to carry out a rehabilitation of the areas referring to the forest variety, that is an ecological restoration, in the same way the study is made to be used as a focus when making decisions, whether for planning the places, to carry out in-depth studies,
determine the correct use of the land, and finally so that when carrying out civil works it is taken into account a correct methodology when building, in order to reduce the risks of a landslide.

8. References

[1] Universidad Nacional De Colombia 1999 Plan de ordenamiento territorial (Pitalito - Colombia) p 10-30
[2] Rico M 2016 Plan de desarrollo municipio de Pitalito (Pitalito - Colombia) P 49.
[3] Sercoin 2014 Amenaza por movimientos en masa, plan de ordenamiento territorial (Campoalegre -Huila) p 2-22
[4] Pgirs Diagnóstico integral (Campoalegre – Colombia) p 1-25
[5] Indiger 2020 Caracterización General del Escenario de Riesgo
[6] Ojeda G, Lacreu H and Sosa G 2007 Atlas de recursos geoambientales (Potrero de los Funes) p 43-48
[7] Lara M and Sepúlveda S 2008 Remociones en masa (Chile: Universidad de chile) p 2-4
[8] Lario J and Bardají T 2016 Introducción a los riegos geológicos (Madrid: UNED. Universidad Nacional de Educación a Distancia) p 52-68
[9] Ingeominas 2002 Catálogo nacional de movimientos en masa (Bogotá) p 6-36
[10] Jaramillo J and Pasato J 2016 Aplicación del método mora vahrson para la clasificación de la susceptibilidad a los deslizamientos de la vía macas - Riobamba en la parroquia zuñac (Ecuador: Escuela Superior Politécnica de Chimborazo Extensión Morona Santiago) p 21-25.
[11] Herrera L, Mena Y and Martínez R Aplicación de métodos indirectos para el análisis de susceptibilidad de deslizamiento en la subcuenca del río gatuncillo, panama (Panama) p 4-8.
[12] Barrantes G, Barretes O and Núñez O 2011 Effectiveness of the modified Mora-Vahrson methodology in the case of landslides caused by the cinchona earthquake (Costa Rica: Universidad Nacional Heredia) p 142-149.
[13] Orozco O 2010 Atlas regional de impacto derivados de las actividades petroleras en coatzacoalcos, Veracruz. p 26
[14] Solorzano J and Paz D 2018 Elaboración de un mapa de susceptibilidad a deslizamientos en el cerro San Eduardo de la ciudad de Guayaquil usando el software Arcgis (Ecuador: Escuela Superior Politécnica del Litoral) p 4
[15] Badillo J Rodríguez R 2005 Mecánica de suelos Tomo 1. Fundamentos de la mecánica de suelos (México, D.F) p. 61
[16] Rodríguez J Quintana C and Rivera H 2013 Landslide hazard zoning in urban areas by the mora & vahrson analysis method: Case of study (Pamplona: Universidad de Pamplona) p 15 – 20
[17] Díaz F, Álzate B, González, An and Ruiz G Estudio comparativo de metodologías de zonificación de amenaza por movimientos en masa aplicado al sector rural de Villavicencio (Bogotá D.C: Universidad Nacional de Colombia) p 1-3.
[18] Mujica S and Pacheco H 2013 Methodology for the generation of a model map for ubication of threats of landslides in the river camurí grande, in the state vargas, Venezuela (Revista de investigación vol 37) (Venezuela: Universidad Simón Bolívar) p 215-235.
[19] Sánchez J 2013 Cálculos estadísticos en hidrología (España: Universidad de Salamanca) p 1-11.
[20] Mora S and Vahrson, W (1994). Macrozonation methodology for landslide hazard determination. (Costa Rica), P 49-58.
[21] Cruden D and Varnes D. (1996). Landslides: investigation and mitigation. chapter 3 - landslide types and processes. (Washington) P 40-65.
[22] Mora R, Vahrson W and Mora S. (1992). Mapa de Amenaza de Deslizamientos, Valle Central, Costa Rica. (Costa Rica) P 16.