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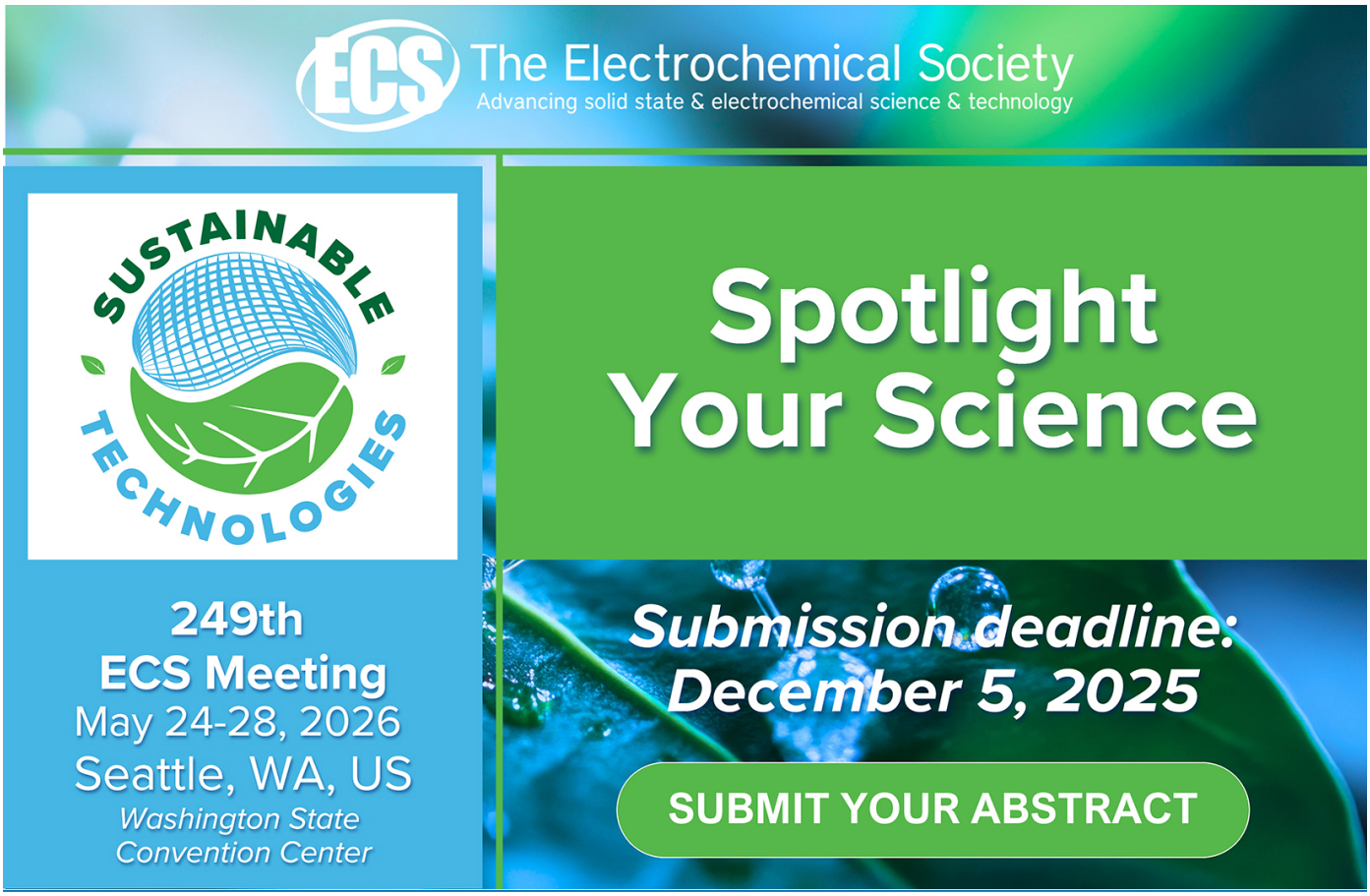
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Identification of conditioning and triggers factors of mass removal processes in the city of Ocaña, Colombia

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Abstract: The occurrence of mass removal phenomena has generated large losses in economic, infrastructure and human lives in various parts of the world. These events are closely related to the anthropic intervention that is made to areas of high geomorphological susceptibility. The Municipality of Ocaña, Norte de Santander, Colombia, is no stranger to this problem because its hillside areas, especially those of the urban perimeter, are very susceptible to suffer from landslides, due to topography, geomorphological susceptibility, soil conditions, deforestation levels, winter periods and above all the incessant growth of human settlements made up of displaced and rural population seeking better living conditions in the city. The purpose of this research is to have more detailed information on the conditioning and triggering factors of the problems due to phenomena in mass removal that present the hillside areas of the city of Ocaña, Colombia.

1. Introduction

Many cities in the world and especially those of Latin American countries face an accelerated growth, which, in most cases, is not supported by adequate planning of the territory, which allows urbanized areas to be generated in sectors with high geomorphological susceptibility [1]. These zones are characterized by a strong topography, highly weathered rocky massifs and adverse conditions of seismicity and rainfall regime [2].

The phenomena of mass removal (MMP) are processes in which there is a displacement of materials (soil and rock) that can occur slowly or quickly, essentially controlled by gravity and generated by factors of various kinds [3]. The factors that influence the formation of the phenomena of mass removal are divided into: determining factors and triggers, Table 1; the former depend on the intrinsic characteristics of the slopes, and the latter, also known as external factors associated with the region where the hillside zone is located [4,5], sometimes the same factor can act as a conditioning factor or as a trigger factor [6].

The combined action of many of the factors mentioned in Table 1 have meant that the city of Ocaña, Colombia, has a high susceptibility to the occurrence of mass removal phenomena, for this reason this problem has been investigated in order to establish the main influential factors in the occurrence of these events that generate threats on settlements of vulnerable population of the city.

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Table 1. Characteristics of precipitating and conditioning factors, adapted from [7].

Agents	Description	Characteristic
Conditioners. They depend on the characteristics of the hillside	Lithological	Weathered materials. Low cohesion of the materials that make up the rock. Stratified soils.
	Structural	Stratification planes or diaclases in the direction of slope or hillside gradient.
	Climate	Alternation of rain-summer periods.
	Hydrological	Less infiltration and faster runoff. Variations in the water table. Strata with materials of different permeability condition.
Triggers. External factors responsible for the instability	Topographic and Vegetation	High slopes. Absence of protective vegetation.
	Induced	Overloads Movements of earth - excavations in some sector of the hillside and conformation of slopes. Increase of humidity of the slope or slope materials. Changes in land use in hillside areas.
	Natural	Seismic activity. Torrential rains. Volcanic activity. Expansion or contraction of the soil present in the slope or slope.

2. Study area

The municipality of Ocaña, Colombia, as shown in Figure 1, makes up 1 of the 2 provinces of the Department of Norte de Santander and is located in the northeastern part of it.

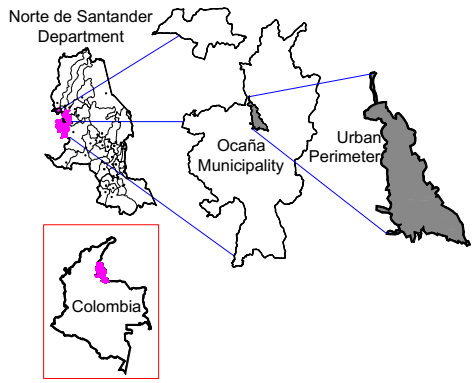


Figure 1. Location of the municipality of Ocaña, Colombia.

3. Historical data

The geological phenomena of mass removal are not exclusive of the Colombian territory; they occur in all the countries of the world where there are mountains. Worldwide there are records of the occurrence of these phenomena with the greatest number of loss of human lives: Indonesia (1919) with 5.160, China (1933) with 6.800, Japan (1958) with 1.094, Peru (1962) with 4.500, Brazil (1967) with 1.200, Peru (1970) with 18.000, Ecuador (1987) with 1.000, Venezuela (1999) with 30.000 [8,9]. In Colombia, these phenomena have also caused major disasters, one of which occurred on September 27, 1987 in the Villatina sector of the city of Medellín, according to [10] the phenomenon left 500 people dead, 1.500 injured, 80 homes destroyed and 1.300 people affected.

The hillside areas of the city of Ocaña occupy 35% of its surface with around 35.000 inhabitants and are occupied by important settlements of displaced population.

Between 1979 and 2018, in the city of Ocaña, Colombia, there have been around 800 MMF events in which there have been unfortunate losses of lives and several injuries, generating more than 3877 victims with damage to their material assets [11]. It can be seen in Figure 2, that the greatest number of landslides occurred in the year 2010, this is due to the occurrence in that year of the "La Niña" climatic phenomenon.

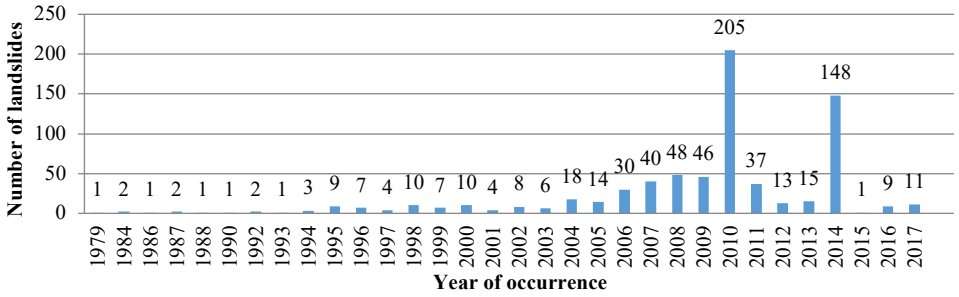


Figure 2. Historical of events due to instability of slopes and slopes in Ocaña, Colombia.

4. Methodology

The characterization of the hillside zones of the city of Ocaña, Colombia, was carried out through the design of two files for information collection; the first file was structured to obtain information on the dwellings in the hillside area, their degree of fragility (in these items the Medvedev-Sponheuer-Karnik (MSK) scale was used [12], characteristics of the population that inhabits them, type of threat to which is exposed, whether it is of the geodynamic or hydro meteorological type, the type of geological formation on which it was built, the level of susceptibility in relation to the location of the house on the slope, form of discharge of the rainwater from the roof of the house on the slope or slope, and the compilation of historical information on problems of instability, damage caused, date of event, number of affected homes, people affected (victims and injured) and cost of damages. The second file was designed to collect information on two important aspects: failure mechanism (either for events that have occurred or are likely to occur) and stabilization works (implemented or to be implemented).

5. Results and discussion

The main information collected from the files, photographic records and direct field observations, corresponds to the identification of the factors that have the greatest incidence in the occurrence of mass removal phenomena in the city of Ocaña, Colombia.

5.1. Determining Factors

The main factors identified are described below.

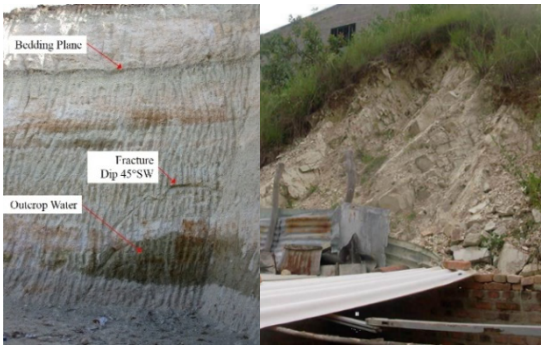
5.1.1. Morphology and topography. The hillside sectors of the city of Ocaña, Colombia, correspond morphologically to mountainous terrains with a steep slope (> 30°). The characteristic forms correspond to rounded hills, constituted in part by unconsolidated materials very susceptible to erosion and to suffer landslides.

5.1.2. Geology. The geo materials that make up the slopes and slopes of the city of Ocaña, Colombia, present an appreciable degree of weathering, facilitated by the high fracturing of the rock mass, by anthropic intervention, the alternation of strata of different nature, layout of the stratification planes or the discloses in parallel or very close to the slopes of the slope or slope and the different types of superficial soils of the hillsides of the city derived from the two geological formations present in most of the city (a formation of igneous origin and the other a formation of sedimentary origin) [13].

The residual soils have variable thickness, reaching in some more than 6 m. The soils evolved from the formation of sedimentary origin are very susceptible to the wetting-drying cycles. Figure 3 shows a slope in the sedimentary materials (Figure 3(a)) and one in the igneous type materials (Figure 3(b)).

5.1.3. Hydrogeology. This factor is intimately associated with the rainfall regime that influences the water content of the soil according to its thickness (in some sectors of the city this thickness is very small and does not reach 1m), soil saturation due to the presence of crops of food or uncontrolled tree

weeds and increased surface runoff due to lack of vegetation cover, roof discharges on slopes and slopes, see Figure 4.



(a) (b)

Figure 3. Types of geo materials and disposition of fractures and diaclases.



Figure 4. Sectors of hillside with sowing of crops of food and with removal of vegetal cover.

5.1.4. Vegetation. The presence of trees and shrubs with floating root in the crown of the slopes becomes an overload that affects the stability of these. In other cases, the vegetation of the slope has been removed, facilitating its progressive deterioration by laminar erosion or concentrated water erosion in furrows and gullies.

5.1.5. Erosion and scour. The processes of concentrated water erosion have given rise to grooves and gullies in some slopes whose constituent materials are sandy loam and sandy clay soils of sedimentary or residual origin, Figure 5.



(a) (b)

Figure 5. Processes of concentrated water erosion in (a) furrows and gullies (b).

5.2. Triggering factors

The main factors identified are the following.

5.2.1. Rains. The city of Ocaña, Colombia, presents annual average precipitation values between 1200 mm and 1500 mm, the behavior of the precipitation regime is bimodal, that is, it is characterized by two rainy periods interspersed by a dry one. Figure 6 shows the graph of maximum average rainfall in 24Hrs, monthly and per year, according to data obtained by the "Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)" of Colombia for the Universidad Francisco de Paula Santander (UFPS) station in Ocaña. In this graph there are showers with rainfall of more than 100 mm, although they correspond to the 24-hour rain, in reality they are events of between 2 and 3 hours, constituting torrential downpours preceding mass removal phenomena.

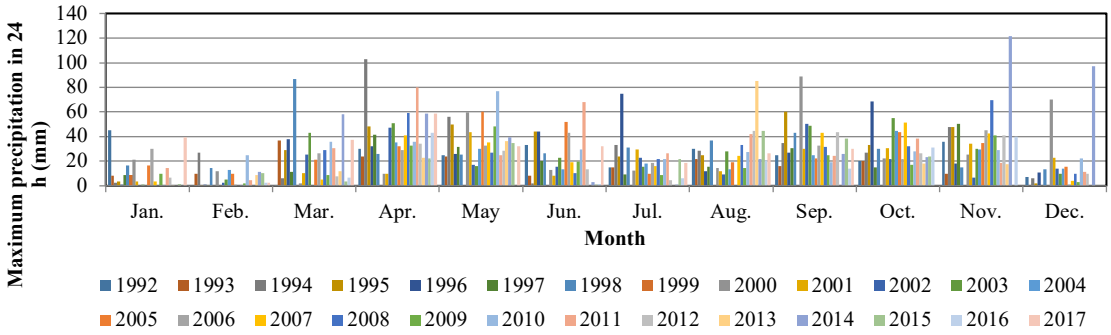


Figure 6. Rainfall variation for an average year, UFPS station, Ocaña, Colombia, (1992-2017).

5.2.2. Seismicity. The city of Ocaña is located in a region where the "sistema de fallas de Bucaramanga (SFB)" is present, corresponding to the Bucaramanga fault. According to [14], the SFB has a straight line with a longitudinal extension of approximately 600 km, if a single line is assumed" and corresponds to a fault of the left lateral displacement heading. According to [15] Ocaña is in an area of intermediate seismic threat, but it is not associated with the occurrence of landslides.

5.2.3. Influencia de la actividad humana. The different hillside zones of the city of Ocaña have undergone accelerated processes of intervention through the realization of cuts or excavations (construction of dirt roads), generating slopes to which crown overloads have been placed due to debris or the construction of buildings and These factors significantly influence the behavior of the slopes and slopes of the city, Figure 7(a). Figure 7(b) shows a hillside sector of the city of Ocaña with high anthropic intervention generating deforestation, this intervention has given rise to problems of erosion and slope instability. In many sectors of the city, with presence of slopes, it has been decided to build a masonry wall bordered with beams and columns. In several sites where these types of walls have been built, collapse and stability problems have occurred, because it has not been designed to withstand the lateral thrusts of the ground, Figure 7(c).

It was also found that many landslides have occurred due to improper handling of wastewater and runoff that are discharged directly onto the slopes, and sometimes due to leaks generated by making illegal connections to the adduction line of one of the treatment plants. potable water of the municipality or by a deficient connection of the household connection that generates permanent dripping saturating the land and propitiating the landslide.



Figure 7. (a) Placement of overloads and construction on slopes and slopes. (b) Deforestation for livestock. (c) Collapse of masonry wall

5.3. Type of landslides

The action of the different conditioning factors and triggers identified leads to the occurrence of landslides of different types: rotational, translational, flows, falls and combinations of them, Figure 8.



(a) (b) (c)

Figure 8. Some typologies of landslides in the city of Ocaña, Colombia.

The fallen landslides are the ones with the highest occurrence with 62.86%, these are characterized by a detachment of blocks of rock or soil or gravel particles (on the slopes with slopes in the formation of sedimentary origin) by free fall, caused in the majority of cases due to rain and inadequate management of cutting slopes, the translational-fall type is presented in 17.71%, the translational type in 16%, the rotational type in 0.95%, flow - fallen at 0.95% and the flow rate at 1.53%.The landslides of greater magnitude presented in the city have been generated by torrential downpours (high rainfall in 2 to 3 hours), those of smaller magnitude type flow or fallen, the trigger is the rains of little intensity but of greater persistence. In the historical records of annual rainfall and landslides in the city of Ocaña, Colombia [16], it can be seen that for the years 2010, 2011 and 2014, which have been relatively rainy, landslides have increased proportionally.

For the cases of historical landslides from 1992 to 2005 their behavior obeys to the gradual and progressive intervention of the hillside areas of the city.

57% of the landslides that have occurred in the city have occurred in the slopes built in the igneous geological formation called Intrusive-Extrusive complex, consisting of granodiorites and quartz monzonites, which have a high degree of fracturing and residual soil profiles of little thickness, facilitating the sliding of type translational and fallen, the remaining 43% are presented in the geological formation of sedimentary type known as “Algodonal Formation”.

6. Conclusions

Within the geological phenomena generating the threat, the most important for the Municipality of Ocaña, Colombia, are the mass removal phenomena, which have brought adverse effects from the social, economic and environmental point of view.

The anthropic intervention of the hillside areas of the city of Ocaña, Colombia, mainly from the 90s, has progressively turned these areas into sectors susceptible to landslides during the rainy season.

The rains that occur in the city of Ocaña, Colombia, have seasons with periods of rainfall of low level of precipitation but with considerable persistence, which facilitates the saturation of superficial layers of residual soils. In the case of seasons with torrential rains (rainfall of high level of precipitation and short duration) there are landslides mainly on the slopes and slopes formed by materials from the sedimentary geological formation.

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