



Implementation Case Study

Update to the Map of Areas Prone to Mass Movement Phenomena in the City of Ocaña, Norte de Santander, Colombia

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Received: 15/03/2025 / Accepted: 06/07/2026 / Published online: 24/09/2026

Abstract Mass movement phenomena (MMP) are movements of material on slopes that can cause disasters. In Colombia, according to data from the National Planning Department, 66% of disaster-related deaths are attributed to these phenomena, which threaten nearly 11.7 million hectares. Understanding their occurrence is key to risk management. In mountainous regions such as Colombia, MMP are frequent due to topographic, climatic, and seismic conditions. In Norte de Santander, one of the country's most exposed departments, the Geotechnical and Environmental Research Group (GIGMA) updated the map of areas prone to these phenomena in the city of Ocaña using geographic information systems. A total of 581 sites in 46 neighborhoods were evaluated, characterizing the failure mechanisms and identifying vulnerable elements. Compared to previous maps, new affected areas were identified, some of which had been classified as stable in earlier studies. The results reveal that 78% of the evaluated sites present active MMP, primarily landslides and rockfalls. The most common triggering factors are inadequate slope cuts and improper stormwater management. The Simón Bolívar neighborhood is the most affected, with 65 areas with active MMP. This updated map provides an essential tool for risk management in Ocaña, allowing for the prioritization of prevention and mitigation actions. In addition, community awareness efforts are crucial for promoting safe practices in these vulnerable areas.

Keywords: mass movements, predisposing and triggering factors, vulnerable elements, community awareness

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1. INTRODUCTION

Many cities around the world—and especially those in Latin American countries—are experiencing rapid growth, particularly because Latin America is one of the most urbanized regions in the world and its urban population rose rapidly from about 40% in the 1950s to nearly 80% in 2014 (Anza-Ramirez et al., 2022). In most cases, this growth is not supported by adequate land-use planning, which allows urbanized areas to develop in sectors with high geomorphological susceptibility (Cuanalo Campos et al., 2011). These areas are characterized by rugged topography, highly weathered rock massifs, and adverse seismic and rainfall conditions (Gallardo, 2019; Gallardo-Amaya et al., 2022; Alcántara-Ayala & Sassa, 2023; Ferrer et al., 2025; Zhao et al., 2024).

Mass Movement Phenomena (MMP) are processes involving the displacement of materials (soil and rock) that can occur slowly or rapidly, are essentially controlled by gravity, and are triggered by a variety of factors (Cruden & Varnes, 1996; Gallardo, 2019; Casagli et al., 2023; Feng et al., 2025).

The factors influencing the occurrence of mass movement phenomena are divided into predisposing and triggering factors (Cuanalo Campos et al., 2011; Gallardo, 2019). The former depend on intrinsic variables of the slopes, such as the lithological characteristics of the study area—notably the presence of highly weathered materials, the alternation of strata, and low soil cohesion. Similarly, structural conditions result from the presence of stratification planes (joint families), which in many cases intersect along the slope's direction or the direction of the created cut slope. In addition, climatic conditions play a role, particularly the constant changes that occur between winter and summer—cycles of wetting and drying—due to the unimodal or bimodal rainfall patterns to which some territories are subject, especially those located in the equatorial zone. Likewise, hydrological conditions resulting from greater or lesser infiltration and changes in the water table cause variations in effective stress conditions (Cuanalo Campos et al., 2011; Gallardo, 2019; Mondini et al., 2023; Zhao et al., 2023). This is reflected in a reduction in shear stress. Finally, it is important to consider topographic and vegetation conditions, where steep slopes, the absence of protective vegetation, or—in its absence—the presence of vegetation associated with food crops or shallow-rooted plants can lead to instability due to the saturation of surface layers. (Chen & Fan, 2025; Meena et al., 2022; Wang et al., 2023; Yu et al., 2023).

In the case of triggering factors, which are considered to be due to external causes, the first category consists of induced factors, such as surcharge—earth movements resulting from slope construction and, in other cases, changes in land use; it is worth noting that the location of the surcharge is often overlooked, even though it is a significant factor contributing to instability. Second, there are natural triggers, including seismic and volcanic activity and torrential rains (Fang et al., 2025; Mondini et al., 2023; Zhao et al., 2023).

The combined effect of many of the factors mentioned has led the city of Ocaña to experience active MMP problems in some sectors of the urban area of the municipality. For this reason, a proposal has been made to update the map of areas prone to mass movement phenomena in the

city of Ocaña, Norte de Santander, Colombia. (Gallardo, 2019; Macgregor-Torrado et al., 2022).

2. METHODOLOGY

To carry out the project and meet the stated objectives, four (4) stages were necessary, as described below.

2.1 Compilation of Historical Information

The process of compiling historical information involved searching primary and secondary sources, such as various research projects on topics related to slope stability studies in the municipality of Ocaña conducted by members of the Construction, Geotechnical Engineering, and Environment Research Group (GIGMA), as well as reviewing logs and records from each of the institutions responsible for risk management in the municipality. Working groups were organized and assigned to each of the sectors established for the study, namely the Northern Zone, Western Zone, Eastern Zone, Southern Zone, and Central Zone of the urban area of the municipality of Ocaña, Norte de Santander, Colombia. (Gallardo, 2019; Dornik et al., 2022; Huang et al., 2024; Hussain et al., 2023).

Figure 1 shows the location of the study area, which corresponds to the urban center of the municipality of Ocaña.

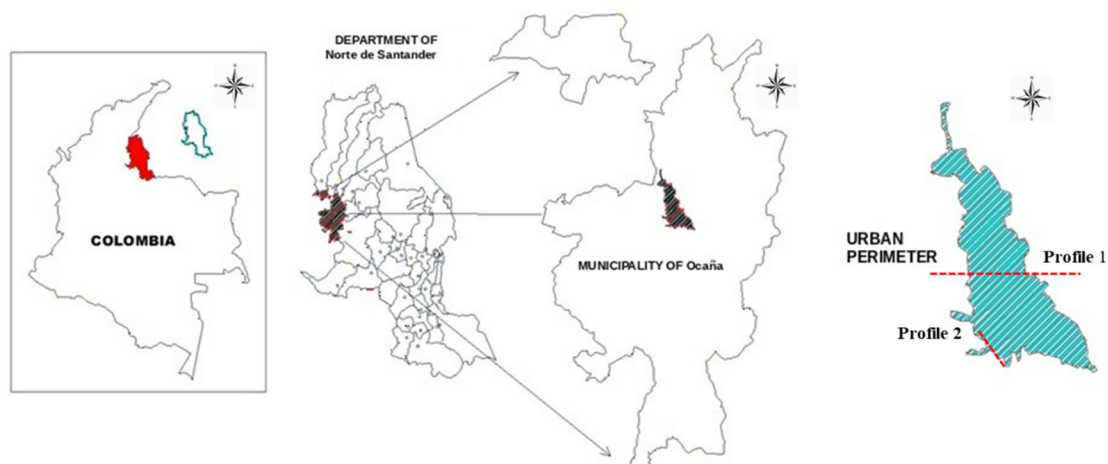


Figure 1. Location of the study area
Source: GIGMA, 2026

Figure 2 shows the topographic conditions of some of the areas where neighborhoods are located in the municipality of Ocaña, where steep slopes ranging from 20% to 30% are evident—a determining factor that contributes to the vulnerability of these study areas.

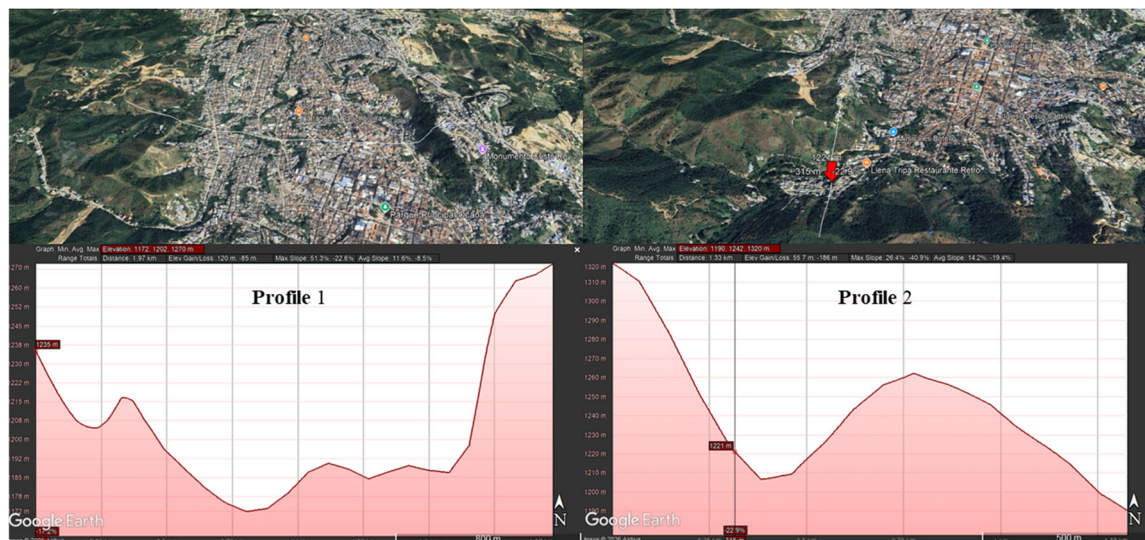


Figure 2. Characteristic topographic profiles 1 and 2 in the municipality of Ocaña
Source: GOOGLE EARTH, 2026

Figure 3 shows one of the work teams formed to carry out the process of compiling historical information; the main objective of these visits was to gather information for subsequent organization and validation.



Figure 3. Fieldwork – Compilation of historical information
Source: GIGMA, 2020

2.2 Characterization of Failure Mechanisms in Areas with Active Mass Movement Phenomena and Identification of Vulnerable Elements

To carry out this activity, a tool titled “Characterization Form for Slopes with Mass Movement Phenomena or Prone to Them” was developed, which enabled the systematic collection of data from the various analysis points. (Gallardo, 2019; Macgregor-Torrado et al., 2022; Alcántara-Ayala & Sassa, 2023).

Figure 4 shows the structure of the identification form for sites susceptible to MMP, which was divided into the following sections to facilitate completion and understanding:

a. Identification: Coordinates, type of movement, and Observations. In this section, the location coordinates of the property were recorded, as well as the number and type of past movements or those likely to occur in the area under analysis.

b. Stabilization works: In this section, the stabilization works existing at the study site were documented as mitigation measures against the risk to vulnerable elements located in the area.

c. Photographic record: This section included part of the photographic record to support the information provided in the two previous items.

UNIVERSIDAD FRANCISCO DE PAULA SANTANDER OCAÑA				GIGMA	
IDENTIFICATION					
NEIGHBORHOOD		DATE		ADDRESS	
Colinas de la Esperanza		7/24/2019		KDX 985-100	
COORDENADAS					
NORTH	1407266.426	EAST	1078276.322	ELEVATION	
LATITUDE	8.2782089	LONGITUDE	-73.36745466	1188.00	
TIPO DE MOVIMIENTO (ACTUAL "A", PROBABLE "P")					
SOIL OR ROCK	ROTATIONAL LANDSLIDE	TRANSLATIONAL LANDSLIDE	FLOWS		
AP		AP			
OBSERVACIONES					
In the central part of the neighborhood, 6 dwellings are located on the same slope, being simultaneously situated from the crown to the middle part of the slope; these are settled on the Algodonal Formation, having weathered rock as the conforming material. The landslides in these dwellings occur during rainfall periods, causing material detachments and flooding that affect them. Added to this is the fact that due to the poor condition of the access roads, the rainwater allows a high degree of infiltration into the slope, generating oversaturation and thus diminishing the load-bearing capacity of the terrain.					
STABILIZATION WORKS: YES NO X					
DRAINAGE ELEMENTS	RETAINING WALLS	SURFACE PROTECTION	OTHERS		
OBSERVATIONS					

PHOTOGRAPHIC RECORD



Figure 4. “Characterization of slopes with MMP” worksheet
Source: GIGMA, 2020

2.3 Updating the Map of Areas Susceptible to MMP Using ArcGIS® Software

Once the field data had been fully validated, flight paths were plotted to acquire aerial imagery of the study areas using a Phantom 3 Advanced drone owned by the GIGMA group. The use of unmanned aerial vehicles has proven to be a valuable tool for the detailed reconnaissance of unstable areas, the generation of photogrammetric data, and the monitoring of processes associated with mass movements (Casagli et al., 2023; Bhuyan et al., 2023; Jakopiec et al., 2023).

Flight planning was carried out using the DroneDeploy app, which was used to configure the polygons corresponding to each previously established work area. On average, 220 photographs were obtained per analysis zone, providing a sufficient visual basis for interpreting the morphological conditions and susceptibility of the terrain (Macgregor-Torrado et al., 2022; Jakopiec et al., 2023).

The photographic data obtained was subsequently processed using the free version of Pix4D Mapper software, which allowed for data processing during the 15-business-day license period,

following the necessary guidelines to ensure the quality of the generated photogrammetric products. This type of processing yields orthomosaics and spatial products useful for identifying, delineating, and analyzing areas with slope instability processes (Casagli et al., 2023; Wu et al., 2024).

In each photogrammetric survey, in addition to flight time, characteristics such as longitudinal overlap, lateral overlap, flight direction, and flight speed were also established—parameters that are important for ensuring the quality of the data obtained by the drone’s sensor and the final result of the photogrammetric processing (Bhuyan et al., 2023; Jakopec et al., 2023). Table 1 shows the drone specifications, as well as the planning criteria defined for each flight.

Table 1. Sample of scheduled flights

SPECIFICATION	FEATURE
WEIGHT (BATTERIES AND PROPELLERS)	1280 Gr
DIAGONAL SIZE	350 mm
AVERAGE SPEED	7m/s
TILT ANGLE	35°
SATELLITE POSITIONING SYSTEM	Differential GPS
CAMERA	sensor ½.3” CMOS
EFFECTIVE PIXELS	12.4 m (total pixels: 12.76M)
ELECTRONIC SHUTTER SPEED	8-1/8000s
FRONT OVERLAP	75%
SIDE OVERLAP	65%
FLIGHT DIRECTION	-3°
MAPPING FLIGHT SPEED	9 m/s

Source: Authors

Table 2 shows information on 10 of the 37 scheduled flights. The flight duration for each project ranged from 6 to 14 minutes, depending on the study area to be covered by each pre-planned flight path. In total, a cumulative flight time of 5 hours, 27 minutes, and 24 seconds was required to collect all the field data for the project.

Table 2. Sample of scheduled flights

N°	DATE			FLIGHT LOCATION	FLIGHT TYPE	FLIGHT DURATION		
	DD	MM	YYYY			HH	MM	SS
1	03	09	2019	Colinas de la Esperanza	Autonomous	00	06	33
2	03	09	2019	Colinas de la Provincia	Autonomous	00	08	29
3	04	09	2019	Libano	Autonomous	00	08	14
4	04	09	2019	Altos del Norte	Autonomous	00	06	09
5	10	09	2019	Asovigiron	Autonomous	00	07	55
6	11	09	2019	José Antonio Galán	Autonomous	00	08	26
7	12	09	2019	El Carmen	Autonomous	00	07	02
8	24	09	2019	Fundadores	Autonomous	00	07	02
9	01	10	2019	Cristo Rey	Autonomous	00	09	27
10	01	10	2019	Travesías	Autonomous	00	09	36

Source: Authors

Once all the data collected by the drone had been processed, the map was updated using ArcGIS® software, into which the baseline data from the basic land-use plan for the municipality of Ocaña—such as the urban perimeter and block divisions—was loaded, along with all the orthomosaics obtained from drone flights. (Dashbold et al., 2023; Rossi et al., 2022; Xing et al., 2023).

2.4 Raising Awareness among Communities Located in Areas Prone to MMP

For this activity, field visits were conducted to each of the communities identified as having active problems or being prone to MMP impacts. These activities were carried out individually or collectively, depending on the number of susceptible sites in the community, as well as variables such as the history of past events and the receptiveness of the residents.

To address this, a workshop titled “First Training Workshop for Vulnerable Communities” was organized in collaboration with the Regional Observatory for the Construction Sector and the Municipal Council for Disaster Risk Management (CMGRD), with the Colinas de La Esperanza and La Santa Cruz neighborhoods selected as participants.

Figure 5 shows the brochure that was distributed during the training session as a resource for the communities; it concisely presents relevant information on how to respond to a potential landslide event.

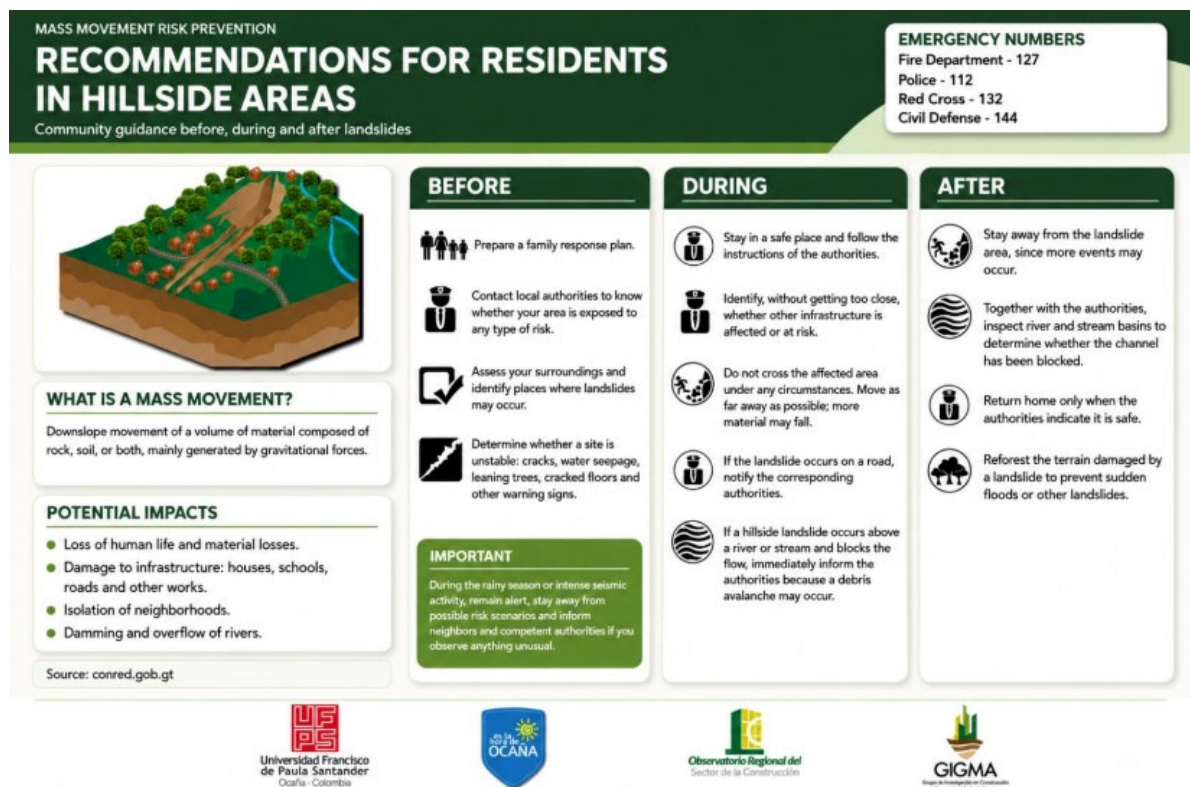


Figure 5. Brochure used in awareness-raising activities

Source: GIGMA, 2020

3. RESULTS

3.1 Historical Information

Once the validation process for the information collected from primary and secondary sources was completed, the information was organized based on a delineation by zones and neighborhoods where problems associated with mass movement phenomena have occurred. Table 3 shows the delineation based on the collected and validated information.

Table 3. Delimitation by zones of neighborhoods exhibiting mass movement phenomena in the city of Ocaña

NORTHERN ZONE	WESTERN ZONE	CENTRAL ZONE	EASTERN ZONE	SOUTHERN ZONE
Altos del Norte, Asovigiron, Colinas de la Esperanza, Colinas de la Provincia, El Líbano, José Antonio Galán, La Perla II, Los Sauces	Juan XXIII, San Fermín, La Santa Cruz, La Torcoroma, Landia, Las Delicias, Marabelito, Nueva España	Betania, Bruselas, Hacaritama, Las Cajas, Santa Ana	9 de Octubre, Belén, Camino Real, Cañaveral, Comuneros, Cristo Rey, Cuesta Blanca, El Carmen, Fundadores, La Colina, La Paz, Libardo Alonso, Nuevo Horizonte, Promesa de Dios, Santa Lucía, Sesquicentenario, Simón Bolívar, Tacaloe, Travesías	12 de Octubre, 3 de Abril, El Bambo, El Bosque, Gustavo Alayón, La Esperanza, La Palmita, Las Mercedes, Los Almendros, Olaya Herrera, EL Carbón

Source: Authors

3.1.1 Information from Previous Studies

Zone 1: This information is based on a detailed analysis of research conducted by the GIGMA research group from 2010 to 2015, which identified sites that exhibit or are prone to MMP in the northeastern and northwestern zones of the municipality of Ocaña.

Figure 6 provides a concise overview of the information for the northeastern and northwestern zones. Regarding the areas with landslide-prone sites, it is clear that only 5% of the territory exhibits this condition. Currently, the primary types of landslides—accounting for 84%—are translational landslides, followed by translational landslides with rockfalls. Similarly, it was determined that the types of landslides most likely to occur in these areas are translational landslides and rockfalls, accounting for 89%, while rotational landslides and debris flows account for a low percentage of 11%.

Zone 2: This information is based on a detailed analysis of the research conducted by the GIGMA research group from 2010 to 2015, which identified sites that exhibit or are prone to MMP in the southeastern and southwestern zones of the municipality of Ocaña.

Figure 7 provides a concise overview of the information for the southeastern and southwestern zones. Regarding the areas with landslide-prone sites, it is clear that only 6% of

the territory exhibits this condition. Currently, the primary types of landslides—accounting for 79%—are translational landslides, followed by translational landslides with rockfalls. Similarly, it was determined that the types of landslides most likely to occur in these areas are translational landslides and rockfalls, accounting for 93% of the total, while rotational landslides and debris flows account for a low percentage of 7%.

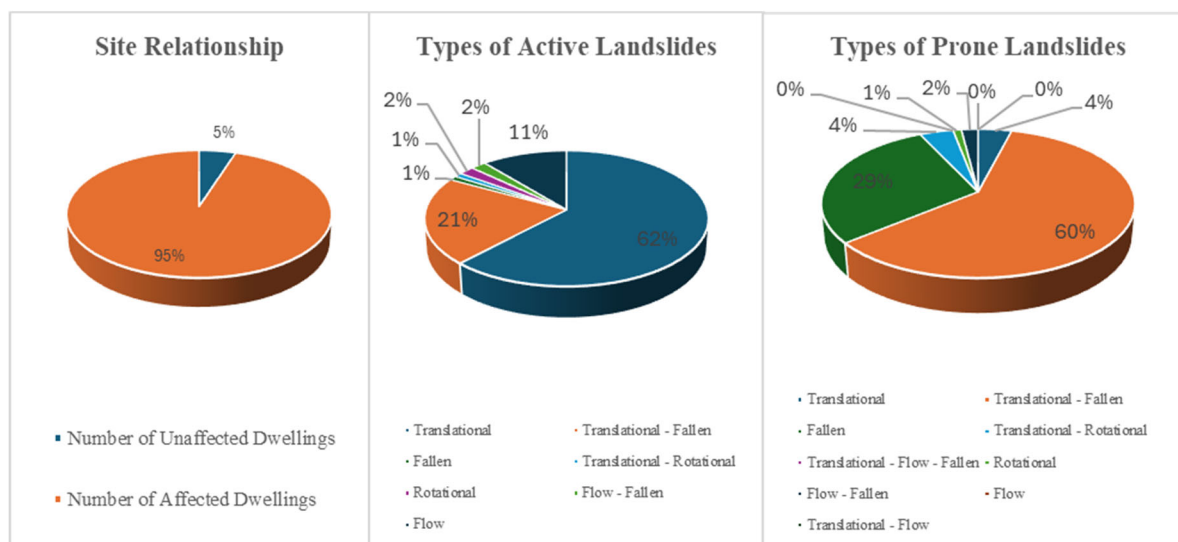


Figure 6. Summary of the northeastern and northwestern zones of Ocaña, Norte de Santander
Source: GIGMA, 2025

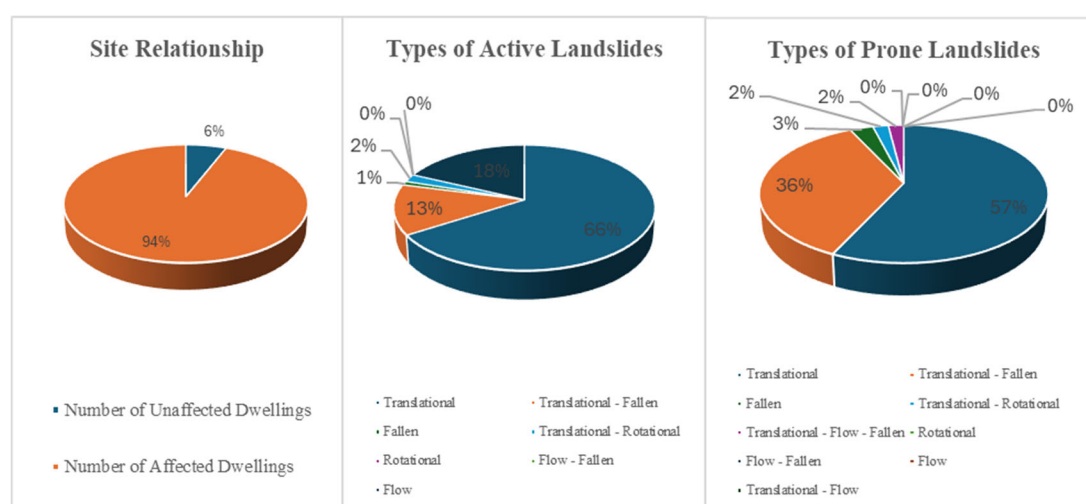


Figure 7. Summary of the southeastern and southwestern zones of Ocaña, Norte de Santander
Source: GIGMA, 2025

3.1.2 Information from Risk-Management Agency Records

This information is based on a detailed analysis of logbooks and other records kept by response teams at various risk management agencies, such as the volunteer fire department and the Municipal Council for Disaster Risk Management (CMGRD) of the municipality of Ocaña. In total, 61 sites with MMP issues were identified in 20 of the neighborhoods that make up the municipality's urban area.

Table 4 provides a summary of 4 of the 20 neighborhoods found to have MMP issues within the study area analyzed.

Table 4. Historical MMP information for four of the twenty neighborhoods studied

Day	Month	Year	Time	Neighborhood	Address	Event	Note
La colina							
10	January	2019		La Colina	Calle 18 a No 22 - 85	Slope landslide	Damage to a dwelling located at a lower level.
Sesquicentenario							
1	April	2019		Sesquicentenario	Calle 12 No 27 a-02	Slope landslide	Damage to the dwelling.
Cañaveral							
19	May	2019	21:35	Cañaveral		Slope landslide	Structural damage to two dwellings in the lower and upper parts of the same building
22	May	2019		Cañaveral		Slope landslide	Damage to the dwelling, which also affected part of the neighboring dwelling.
Colinas de la provincia							
15	May	2018		Colinas de la provincia		Slope landslide	Damage to the dwelling.
30	May	2018	15:43	Frente a alfa transportes	KDX 707-275	Slope landslide	It completely buried a motorcycle repair shop and damaged a nearby restaurant
23	November	2018	09:18	Colinas de la provincia		Slope landslide	A man is completely trapped in the landslide

Source: Authors

3.1.3 Evaluation and Validation of Information

The validation process for the information in sections 3.1.1 and 3.1.2 was carried out through field visits, during which the data presented in Figures 5 and 6 and Table 4 were verified; however, new sites prone to MMP were identified as a result of the ongoing urbanization of the municipality of Ocaña, which is expanding increasingly into hillside areas or through new slope cuts in previously developed areas to enlarge dwellings. (Ferrer et al., 2025; Zhang et al., 2023; Zhao et al., 2024).

In the northern part of Ocaña, there has been a notable increase in active sites exhibiting MMP, as conditions that existed in 2015 have changed, causing sites previously prone to these phenomena to become active and thereby increasing the risk of MMP in the area.

Figure 8 shows that, as of 2015, *the northern zone* had a total of 81 active sites and 30 inactive sites. For the period from 2015 to 2024, there were 80 active sites and 31 inactive sites. It is worth noting that most neighborhoods saw a 45% reduction in susceptible sites; however, the

neighborhoods of Colinas de La Provincia, Altos del Norte, and La Perla II have new sites, representing an increase of between 12% and 15%.

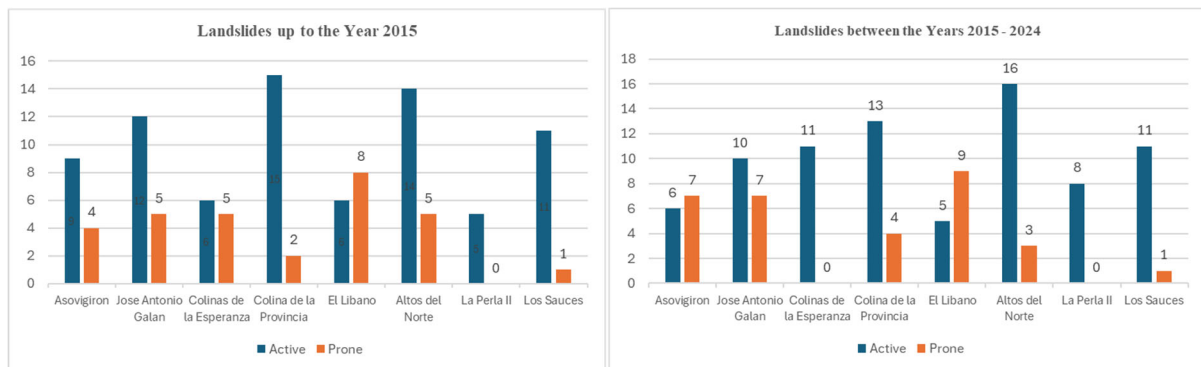


Figure 8. Number of landslides in the northern zone

Source: Authors

In the eastern part of the municipality of Ocaña, a total of 174 active sites and 25 sites at risk were identified through 2024, indicating a change of only one site compared to 2015; however, neighborhoods such as Fundadores and Cristo Rey saw a 12% increase compared to 2015. It is also worth noting that between 2015 and 2024, a new neighborhood—Santa Lucía—emerged with a significant number of susceptible sites, 26 in total; see Figure 9.

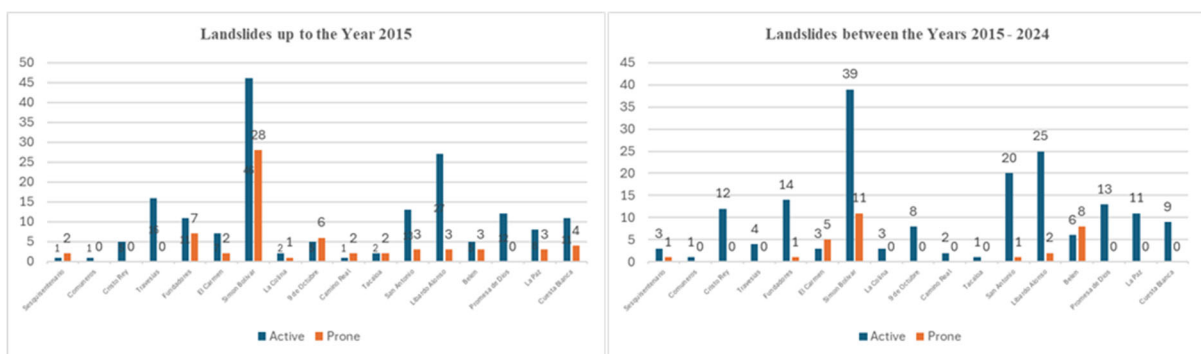


Figure 9. Number of landslides in the eastern zone

Source: Authors

For the western zone of Ocaña the number of active events decreased from 116 to 93 sites, a reduction of 19.82%; and of the 29 points classified as “prone” in 2015, no sites were found in this category in the update conducted for the 2015–2024 period; see Figure 10.

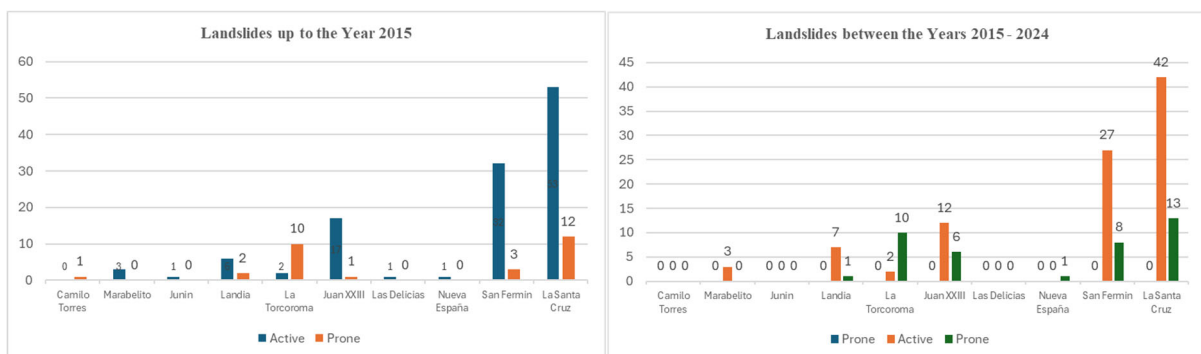


Figure 10. Number of landslides in the western zone

Source: Authors

In the Central zone of the municipality of Ocaña, of the 5 neighborhoods that have historically experienced landslides and accounted for 13 active sites, the neighborhoods of Betania, Las Cajas, and Bruselas saw a reduction of between 83% and 100% in their susceptible sites; the remaining neighborhoods still retain all of their active sites for the period studied; see Figure 11.

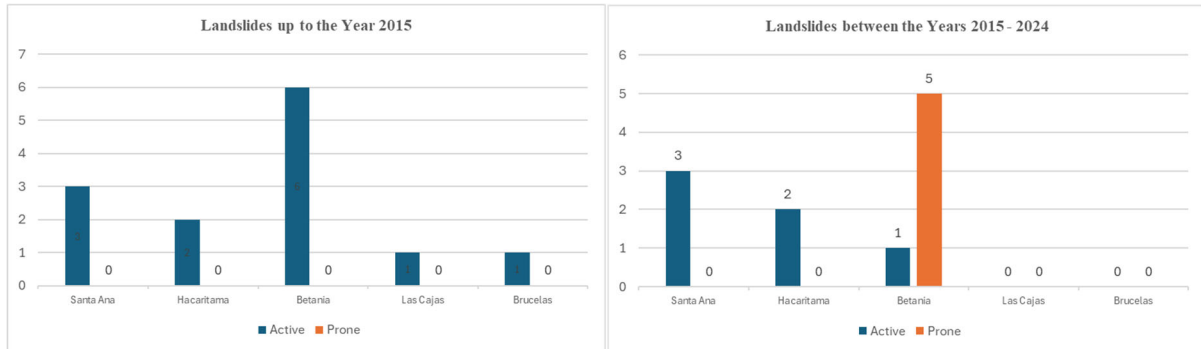


Figure 11. Number of landslides in the central zone through 2024

Source: Authors

For the southern zone of the municipality of Ocaña, which includes neighborhoods that have historically had MMP, one of the ten neighborhoods shows a 75% reduction in active sites by 2024; however, inactive sites increased by 80% in eight of the ten neighborhoods in this sector of the municipality of Ocaña; see Figure 12.

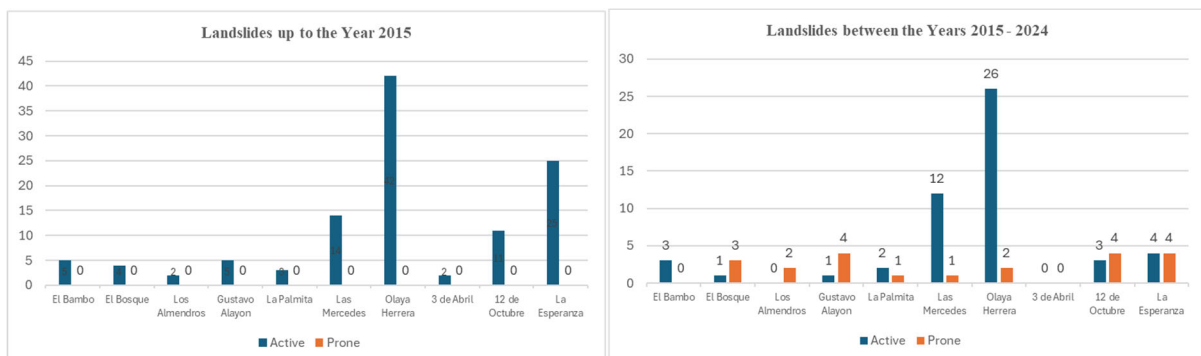


Figure 12. Number of landslides in the southern zone through 2024

Source: Authors

3.2 Characterization of the Study Areas Through the Use of a Study Form

3.2.1 Characterization of the Northern Zone

In the northern zone of the municipality of Ocaña, eight neighborhoods affected by MMP were analyzed: Colinas de la Esperanza, Colinas de la Provincia, Asovigirón, La Perla II, El Líbano, Altos del Norte, José Antonio Galán, and Los Sauces. In this zone, a total of 112 dwellings with problems associated with MMP were identified, of which 78 have been affected by active sites and 34 are susceptible to MMP impacts. Figure 13 shows the number of homes directly affected by active sites as well as those at risk due to inactive sites; it also illustrates the types of MMP present in each neighborhood.

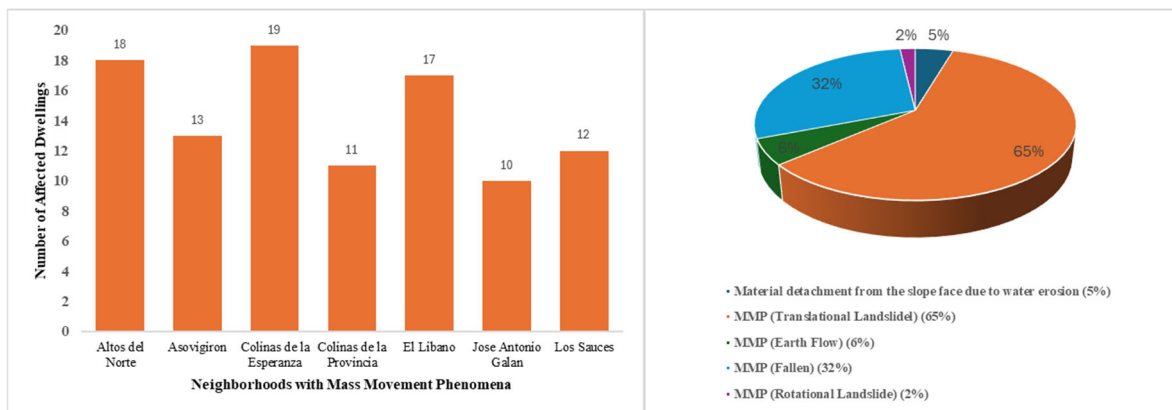


Figure 13. Number of homes affected in the northern area through 2024

Source: Authors

3.2.2 Characterization of the Eastern Zone

The eastern zone is home to the largest number of neighborhoods that have exhibited MMP in the city of Ocaña, for a total of 19 neighborhoods, namely: 9 de Octubre, El Carmen, Simón Bolívar, Sesquicentenario, Comuneros, La Colina, Cristo Rey, Travesías, Camino Real, Tacaloa, Santa Lucía, Nuevo Horizonte, Libardo Alonso, Belén, Promesa de Dios, La Paz, Cuesta Blanca, and Cañaveral.

The eastern zone not only has the largest number of neighborhoods with MMP but is also the area where the most homes have been affected by mass movements, with a total of 240. Figure 14 shows the list of neighborhoods with the corresponding number of affected homes.

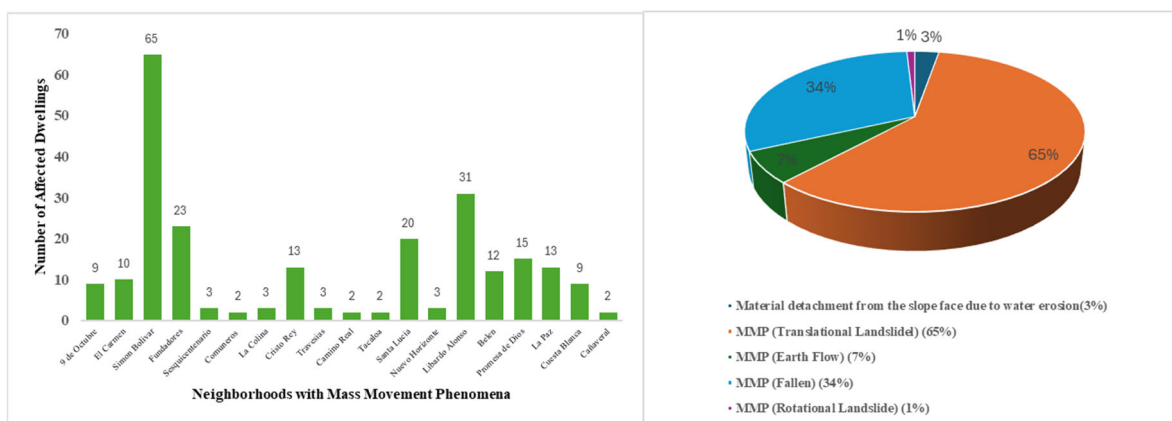


Figure 14. Number of affected homes in the eastern zone through 2024

Source: Authors

3.2.3 Characterization of the Western Zone

In the western zone of the city of Ocaña, eight neighborhoods that have been affected by MMP were studied. These are: San Fermín, Juan XXIII, La Santa Cruz, La Torcoroma, Marabelito, Landia, Nueva España, and Las Delicias. The western zone has the second-highest number of homes that have been adversely affected by MMP. Figure 15 below lists the neighborhoods along with the corresponding number of affected homes; in total, the western zone has 133 affected homes.

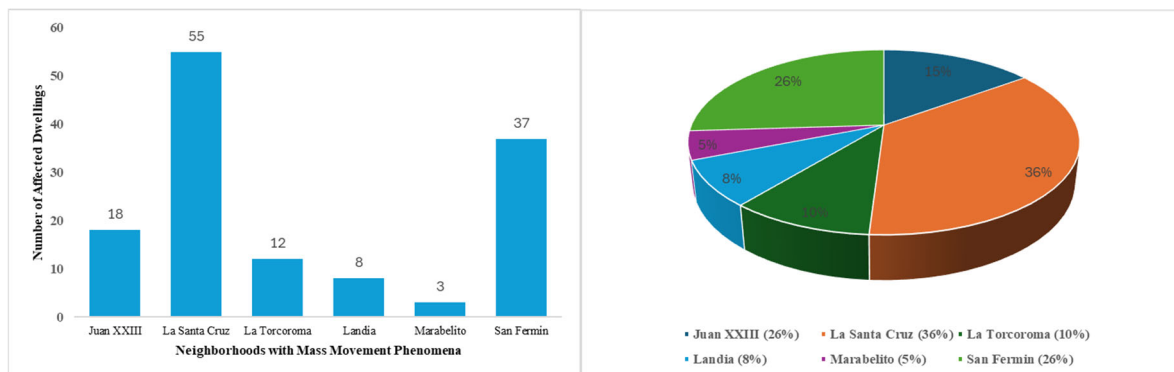


Figure 15. Number of affected homes in the western zone through 2024
Source: Authors

3.2.4 Characterization of the Central Zone

In the downtown area of the municipality of Ocaña, five neighborhoods affected by the MMP were analyzed: Betania, Bruselas, Hacaritama, Las Cajas, and Santa Ana. Of the five areas, the Central Zone has the lowest number of affected homes, with a total of 14. Impact was observed in 3 of the 5 neighborhoods; see Figure 14. Although the Betania neighborhood has historically had the highest number of affected homes, over the past 4 years (2020–2024), 56% of the sites with MMP have shown no activity; see Figure 16.

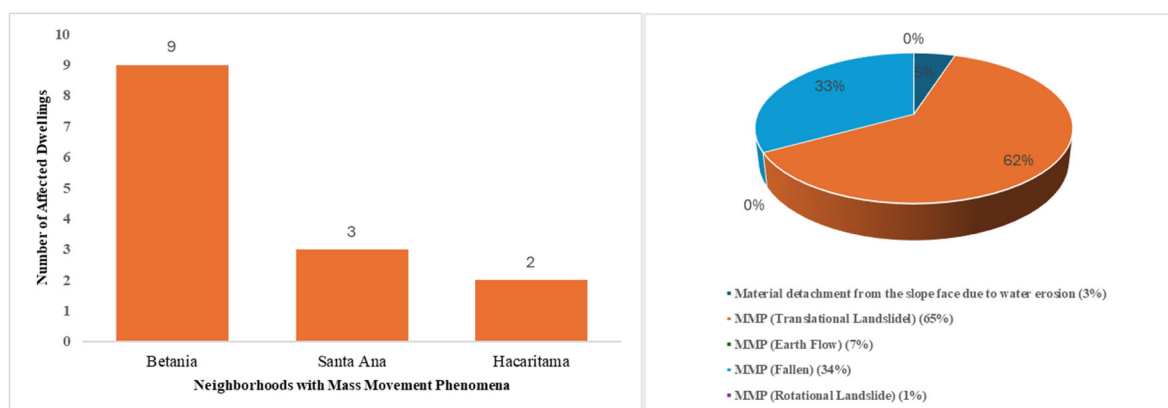


Figure 16. Number of affected homes in the Central Zone through 2024
Source: Authors

3.2.5 Characterization of the Southern Zone

In the southern zone, the following neighborhoods have been affected by MMP: 12 de Octubre, 3 de Abril, El Bambo, El Bosque, Gustavo Alayón, La Esperanza, La Palmita, Las Mercedes, Los Almendros, Olaya Herrera, and El Carbón. The southern zone, after the downtown area, has the lowest number of homes affected by mass movements: 78 homes. Figure 17 shows the homes affected by MMP in this sector of the city and the types of mass movements that have occurred.

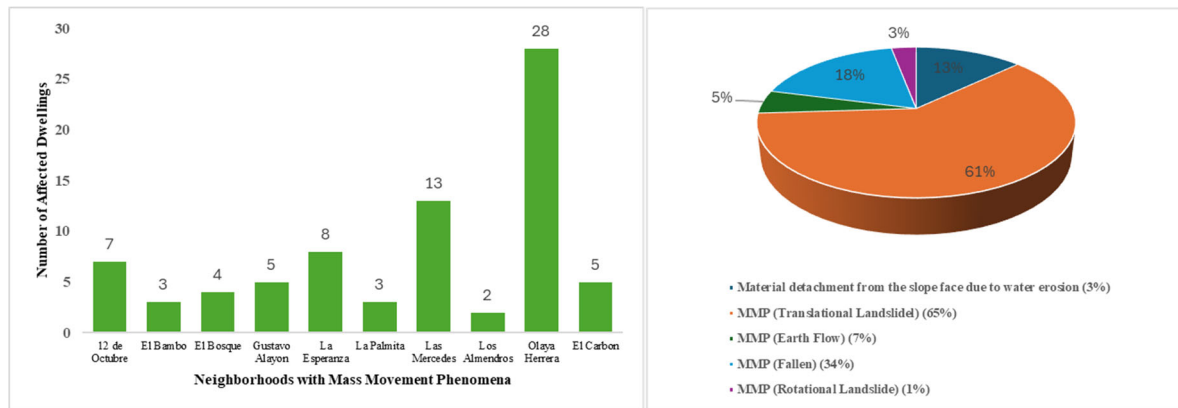


Figure 17. Number of homes affected in the southern zone through 2024

Source: Authors

3.3 Comparative Analysis of Sites with Active and Inactive MMP Between 2015 and 2024

Based on the field data compiled in the characterization sheets for the four zones (North, East, West, and Central), Table 5 presents a comparative analysis for the periods 2015 (baseline) and 2024 using the chi-square statistical test. (Huang et al., 2022a; Huang et al., 2022b; Huang et al., 2024; Xing et al., 2023).

Table 5. Comparative analysis between the periods 2015 and 2024 using the chi-square statistical test

Zone	Act. 2015	Pro. 2015	Act. 2024	Pro. 2024	Δ Active (%)	χ^2 (df=1)	p- value
North	78	30	80	31	+2 (+2.6%)	0.001	0.980 (ns)
East	173	66	174	29	+1 (+0.6%)	11.558	0.001 (***)
West	116	29	93	39	-23 (-19.8%)	3.399	0.065 (ns)
Central	13	0	6	5	-7 (-53.8%)	7.464	0.006 (**)
South	113	0*	52	21	-61 (-54.0%)	36.644	<0.001 (***)
TOTAL (5 zones)	493	125	405	125	-27 (-7.1%)	1.889	0.169 (ns)

Note: Act. = active sites; Pro. = prone sites. Chi-square calculated from the contingency table [Active, Prone] $\times$ [2015, 2024]. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns = not significant

The results in Table 5 allow the following conclusions:

- Eastern Zone (statistically significant change, $p = 0.0007$): This is the zone with the greatest dynamics. Although the total number of active sites remained stable (173 $\rightarrow$ 174), the active-to-prone ratio changed dramatically: the number of prone sites fell from 66 to 29 (-56.1%), indicating that 37 sites classified as “prone” in 2015 escalated to “active” status by 2024. This phenomenon is particularly pronounced in Cristo Rey (+140%, from 5 to 12 active sites) and San Antonio (+54%, from 13 to 20 active sites), and is directly linked to unplanned urban expansion. (Ferrer et al., 2025; Zhao et al., 2024).
- Central Zone ($p = 0.006$, significant): Shows the largest proportional reduction in active sites (-53.8%). The Betania neighborhood went from 6 active sites to 1, with the emergence of 5 prone sites, suggesting a transition toward a stable zone.

- Western Zone ($p = 0.065$, marginal): A 19.8% decrease in active sites ($116 \rightarrow 93$), with an increase in sites likely to be active ($29 \rightarrow 39$). La Santa Cruz has the highest number of active sites in the zone in 2024 (42 out of 93, or 45.2%), although it saw a decrease from 53 to 42 active sites (-20.8%); it is followed by San Fermín ($32 \rightarrow 27$ active sites, -15.6%). Finally, Juan XXIII shows a significant individual change ($\chi^2=4.43$, $p=0.035^*$); that is, in the Juan XXIII neighborhood there was a redistribution of risk status: some sites that were active were reclassified as “prone” (possible partial informal stabilization), and/or new “prone” sites emerged that did not previously exist. It is not that the overall situation improved; rather, the risk simply changed in nature.
- Northern Zone ($p = 0.98$, no significant change): The distribution of active and prone sites did not change significantly. However, Colinas de la Esperanza had 5 prone sites in 2015, which decreased to 0 in 2024, while the number of active sites increased from 6 to 11 ($+83.3\%$).
- Southern Zone (highly significant change, $p < 0.001$, $\chi^2 = 36.64$): This is the zone that has undergone the greatest transformation. The baseline studies (2015) did not distinguish between prone sites; all 113 recorded sites were classified as active. In 2024, only 52 of those 113 sites remain active (-54.0%), while 21 new prone sites have emerged.

3.4 Cartographic Update of Sites Prone to Mass Movement Phenomena in the Municipality of Ocaña

The update of the cartography of sites where mass movement phenomena have occurred or are susceptible to them resulted in the development of two maps. The first map depicts the different types of mass movement phenomena, and the second identifies areas prone to being affected by these same events. Each mass movement was classified using the nomenclature from the Methodological Guide for Mass Movement Hazard Zoning at a scale of 1:25000, (Servicio Geológico Colombiano, 2017), which defines types and subtypes of mass movements (landslides, rockfalls, debris flows, creep, and avalanches), as well as their current activity status (active or inactive) and the affected study area. The attributes were assigned and verified during each field visit and were, in turn, cross-checked against the orthophotos generated by drone flights. The type of movement was validated by comparing the records with historical events documented by the GIGMA group, the logs of the Volunteer Fire Department, and the Ocaña CMGRD office for the period 2010–2024. (Fang et al., 2024; Qi et al., 2024; Rossi et al., 2022; Yu et al., 2025).

To create these two maps within the ArcMap application of the ArcGIS® software, two polygon-type data layers (shapefiles) were created. The first was used to identify existing landslides and record data for each event, such as type, subtype, activity, part of the landslide, field verification, and identifying nomenclature. The second layer was used to delineate the areas that could be affected in the event of new mass movement events.

Figure 18 shows the two maps that were generated. The map on the left lists the areas that are susceptible to MMP or prone to being affected by them, while the map on the right shows the specific location of each site with MMP issues, in this case in the Simón Bolívar

neighborhood, highlighting that this neighborhood has the highest number of sites prone to MMP in the municipality of Ocaña, Norte de Santander.

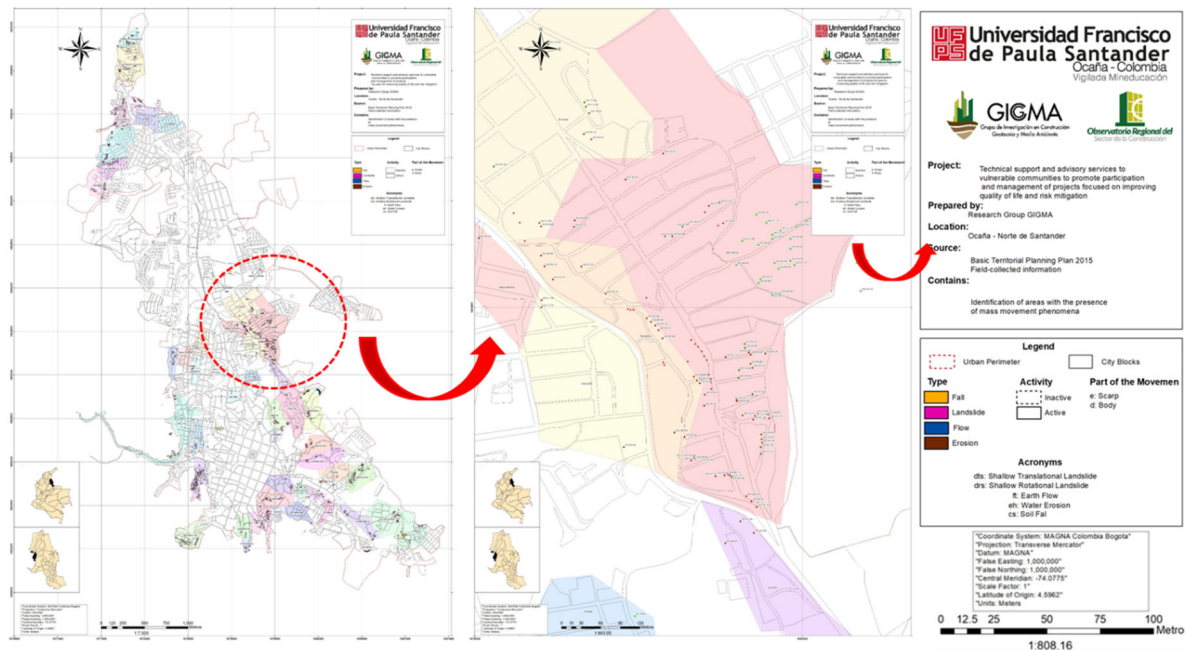


Figure 18. Types of maps produced as a result of the research
Source: Authors

3.5 Awareness-Raising Among Vulnerable Communities

The awareness-raising process for the community in the La Santa Cruz neighborhood was carried out as follows:

- Presentation of the factors that cause landslides in the area, explaining their significance and detailing the causes of specific landslide events that have occurred in the neighborhood, including the contributing and triggering factors—among which human intervention is one of the most significant in this sector.
- Identification of critical zones and their respective types of landslides using maps generated from aerial photographs.
- Screening of a video titled “Key Concepts in Disaster Risk Management.”
- As a final activity, participants were given a brochure containing recommendations on how to respond before, during, and after a disaster occurs. (Alcántara-Ayala & Sassa, 2023; Kang et al., 2024; Mondini et al., 2023).

Figure 19 shows the participation of the communities in the Colinas de la Provincia and Santa Cruz neighborhoods in awareness-raising activities.

Figure 20 shows the locations of vulnerable sites in the La Santa Cruz neighborhood; this information was presented to the community in both print and digital formats



Figure 19. Community Awareness-Raising in the Colinas de la Provincia and Santa Cruz Neighborhoods

Source: GIGMA, 2024



Figure 20. Map of vulnerable areas in the La Santa Cruz neighborhood, Ocaña, Norte de Santander

Source: GIGMA, 2024

The training sessions for families living in the most critical vulnerable areas were held collectively in the evenings to ensure higher attendance. The participants in the awareness-raising sessions are listed in Table 6.

Table 6. List of community participation in the awareness-raising sessions

Training Session for Families Living in Vulnerable Areas		
Neighborhood	Attendance	
	Adults	Minors
Colinas de la Esperanza	25	18
Colinas de la Provincia	21	14
San Fermín	34	17
La Santa Cruz	37	22
Libardo Alonso	14	11
Simón Bolívar	48	15
La Esperanza	12	8
La Paz	14	13
La Palmita	25	16
Las Mercedes	22	11

Source: GIGMA, 2024

4. CONCLUSIONS

Through the course of the project, areas prone to MMP were identified in 46 neighborhoods in the municipality of Ocaña, Colombia, totaling 581 sites susceptible to these phenomena. This made it possible to determine that, of the 51 neighborhoods that historically had problems of this nature, 43 continue to experience active MMP. Furthermore, it was found that there are three new neighborhoods with areas highly prone to these phenomena; this is a consequence of urban expansion on hillsides through inappropriate construction practices. Thus, it was determined that the Simón Bolívar neighborhood has the highest frequency of problems associated with MMP, with an affected area of 3,500 m², representing 11.71% of the neighborhood's total area.

A chi-square (χ^2) analysis of the data collected through 2015 on sites susceptible to MMP and the data defined for 2024 revealed distinct patterns by region. In the Eastern Zone, the distribution between active and susceptible sites changed in a statistically significant manner ($\chi^2=11.56$, $df=1$, $p=0.0007$); although the total number of active sites remained virtually stable (173 in 2015 vs. 174 in 2024), the number of susceptible sites decreased from 66 to 29 (−56.1%), indicating that at least 37 sites previously classified as prone escalated to active status, with the most notable cases in Cristo Rey (from 5 to 12 active sites, +140%) and San Antonio (from 13 to 20 active sites, +54%), both areas experiencing rapid informal urbanization. In the Central Zone, the chi-square test also detected a significant change ($\chi^2=7.46$, $p=0.006$), with a 53.8% reduction in active sites (from 13 to 6), indicating relative stabilization in the sector. The Northern and Western Zones showed no significant changes in distribution ($p = 0.98$ and $p = 0.065$, respectively), although in the Northern Zone, the Colinas de la Esperanza neighborhood showed a variation of 83.3%, increasing from 6 to 11 active sites.

In the Southern Zone, where the 2015 studies recorded 113 exclusively active sites without distinguishing between likely and non-likely sites, the present study found only 52 active sites and 21 new sites at risk ($\chi^2 = 36.64$, $p < 0.001$), with reductions of up to 84% in neighborhoods such as La Esperanza. Taken together, these results demonstrate that the novelty of this study lies not only in extending the inventory to neighborhoods without a prior baseline, but also in documenting the diachronic transformation of risk status: progressive urbanization systematically converts prone sites into active ones and generates new susceptible areas.

The Northern and Western Zones showed no significant changes in distribution ($p = 0.98$ and $p = 0.065$, respectively); however, in the Northern Zone, the Colinas de la Esperanza neighborhood showed an 83.3% increase in active sites, rising from 6 to 11 sites. Taken together, these results highlight the importance of continuously updating this type of study, which makes it possible to identify areas where human activity has created new zones of instability—whether by cutting new slopes or expanding previously developed areas to enlarge homes—thereby transforming a prone site into an active one.

It was found that, of the 46 communities in landslide-prone areas, 95.65% of their residents have not received any training or awareness-raising on the issue from the agencies responsible for risk management. This highlights the urgent need for risk management agencies in the

municipality of Ocaña, especially considering that this study was only able to cover 4.35% of all vulnerable communities. The awareness-raising sessions revealed that the communities are aware of two key issues: that they are located on slopes susceptible to MMP, and that they themselves have exacerbated the problem through poor construction practices, expanding the cut area year after year, which has led to an increase in the height of the slope and, consequently, its degree of instability.

The communities where vulnerable sites were identified share a common characteristic: their residents have limited financial resources, and most are people displaced by violence. This situation leads to the informal construction of their homes—without the necessary technical guidance—in areas with high geomorphological susceptibility to MMP. The study's findings were presented and submitted to the coordinator of the Risk Management Office of the Ocaña Municipal Government so that the information could be incorporated into the update of the local Land Use Plan (POT).

The development of a 1:5000-scale map, on which the 581 sites identified as having MMP issues in the city of Ocaña have been marked, will provide local risk management agencies with a vital tool for targeting mitigation measures at the most critical points identified. In general terms, this map serves as a technical resource that can be directly integrated with the instruments provided by Law 1523 of 2012 (National Disaster Risk Management System, SNGRD); in particular, with the Municipal Disaster Risk Management Plan (PMGRD) and the Land Use Plan (POT) of the municipality of Ocaña, which must incorporate the prioritized zones as areas for intervention with their respective structural and non-structural measures. At the departmental and national levels, the methodology applied can be replicated in other municipalities in Norte de Santander with high susceptibility to MMP, provided that access to unmanned aerial vehicles and trained personnel is guaranteed, which suggests the need for institutional strengthening programs within the framework of the SNGRD.

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