

Mudflood risk analysis in San Antonio del Sur, Guantánamo following Hurricane Oscar

Análisis de riesgo por deslaves en San Antonio del Sur, Guantánamo, tras el paso del huracán Oscar

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Abstract: San Antonio del Sur municipality, in Guantánamo province, is an area prone to natural phenomena such as landslides, floods, and hurricanes. The interaction between these natural hazards and climate change poses a growing threat to the safety of the community, its infrastructure, and ecosystems. This article is aimed at assessing mudflow risk in San Antonio, following Hurricane Oscar, in the face of future climatic situations. The study area was evaluated, also, the phenomenon's causes and effects on the population and the environment were interpreted. Accordingly, measures to reduce mudflow risk in the region are proposed.

Keywords: debris flow, mass movements, geological risk

Resumen: El municipio San Antonio del Sur, en la provincia de Guantánamo, es una zona susceptible a fenómenos naturales como deslizamientos de tierra, inundaciones y huracanes. La interacción entre estos riesgos naturales y el cambio climático plantea una amenaza creciente para la seguridad de la comunidad, su infraestructura y sus ecosistemas. El artículo tiene como objetivo evaluar el riesgo de flujo de lodo en San Antonio luego del paso del huracán Oscar, ante situaciones climáticas futuras. Se realizó la evaluación del área de estudio y se interpretaron las causas del fenómeno y efectos

sobre la población y el medio ambiente. Se proponen medidas para reducir el riesgo del flujo de lodo en la región.

Palabras claves: flujo de detritos, movimientos en masa, riesgo geológico

Introduction

The interaction between natural hazards and climate change represents a growing threat to the security of local communities, infrastructure, and ecosystems (Hoffmann, 2020; Portacio Rodríguez, 2023). Bruschi *et al.* (2023) and Chiriboga, Gaibor & Monteros-Pazmiño (2024) highlight the importance of effectively understanding and managing the relationship between environment, society, and geology. Climate change increases the incidence of natural phenomena such as torrential rains associated to flood disasters, both pluvial and fluvial, which trigger mass movements like mud or debris flows (Gabriel-Campos *et al.*, 2025). The impacts of climate change and disasters triggered by natural events are related to a lack of territorial planning, which requires generating adequate risk management to improve land-use planning in municipalities (Vasquez & Delgado, 2021; Menjiva, 2023).

Cuban coastal and rural communities are significantly affected by adverse phenomena stemming from climate change (Hernández, Báez & Carrasco, 2021). In coastal communities, risks are greater for ecosystems and human settlements, increasingly threatened by the progressive rising sea level and the extreme meteorological events occurrence (Ferrera, Pérez & Soler, 2020; García Dueñas *et al.*, 2022; Barreira & García, 2024). The Southeastern region of Cuba requires specific plans and treatments for its management, as indicated by Milanés (2015), who notices increased rainfall following storms and hurricanes on Guantánamo's south coast.

San Antonio del Sur is a territory with coastal and mountainous characteristics located to the southeast of Guantánamo province (Bonilla, 2023). Most of the municipality's soils are part of fragile ecosystems such as mountainous areas and zones with steep slopes, with a high erosion risk, and coastal or adjacent accumulative plains at risk of salinization (Maresma Alba *et al.*, 2021). San Antonio del Sur has been exposed to adverse climatic phenomena such as drought —which significantly affect its communities' essential productive activities (Duran-Díaz & Rodríguez-Montoya, 2022; Muñoz, Maturell &

Duvergel, 2023) —, floods due to intense rains (Clark-Feoktistova *et al.*, 2021), and downbursts as a manifestation of severe local storms (Rojas-Díaz, 2022).

Debris flows occur during or immediately after a period of exceptional rainfall (Páez *et al.*, 2013) and are a frequent cause of disasters worldwide (Aristizábal, Martínez & Vélez, 2010). Mud flows originate from the mixture of water with sediments carried by landslides. There is usually a predominance of sediments from soils with silt and clay particles, but also large blocks or fragments of rock are transported (Insuasty, 2012).

Hurricane Oscar hit directly eastern Cuba between October 20th and 21st, 2024, causing severe damage in several Guantánamo's municipalities, with San Antonio del Sur reported among the most affected ones. It was a Category 1 hurricane, characterized by a prominent precipitation volume and extensive flooding in the province's intramontane plains (Ramos, 2025).

Oscar brought to light the urgency of addressing the risks existing in the municipality, highlighting the need to assess physical-geographical and geological conditions contributing to this vulnerability. Each rainfall-related event generates significant impacts both spatially and temporally. It is necessary to understand its dynamics and interaction processes, as they are associated with mass removal or mass movement processes, such as landslides, mudflows, floods, and intense rains (Cartagena Cutipa *et al.*, 2023).

Through an approach that integrates the characterization of the study area's geographical and geological conditions, the aim is to establish a diagnosis of existing hazards and the community's response capacity. The hypothesis guiding this research claims the evaluation of risk and vulnerability indices allows for the development of concrete strategies that strengthen local resilience and promote greater community awareness about risk management. This contributes to the generation of proposals that not only mitigate the damage caused by natural phenomena but also foster the active participation of the population in comprehensive risk management, in accordance with Fong & Vega (2023) criterion, who state that disaster risk management seeks to reduce the possibility of negative impacts from a hazardous event.

In this context, this paper is aimed at analyzing the mudflow risk in San Antonio del Sur following Hurricane Oscar. Essential aspects related to geological and hydrometeorological risks are addressed, as well as the vulnerabilities inherent to the territory in the face of similar events, in order to develop effective strategies that minimize the impacts of future disasters.

Materials and Methods

San Antonio del Sur municipality comprises six people's councils. It is located in the southeastern part of Guantánamo province with a territorial extension of 584.94 km². It is bordered to the north by Yateras municipality, to the south by the Caribbean Sea, to the west by Caimanera and Manuel Tames municipalities, and to the east by Imías and Baracoa (Francisco-Pedro, 2020).

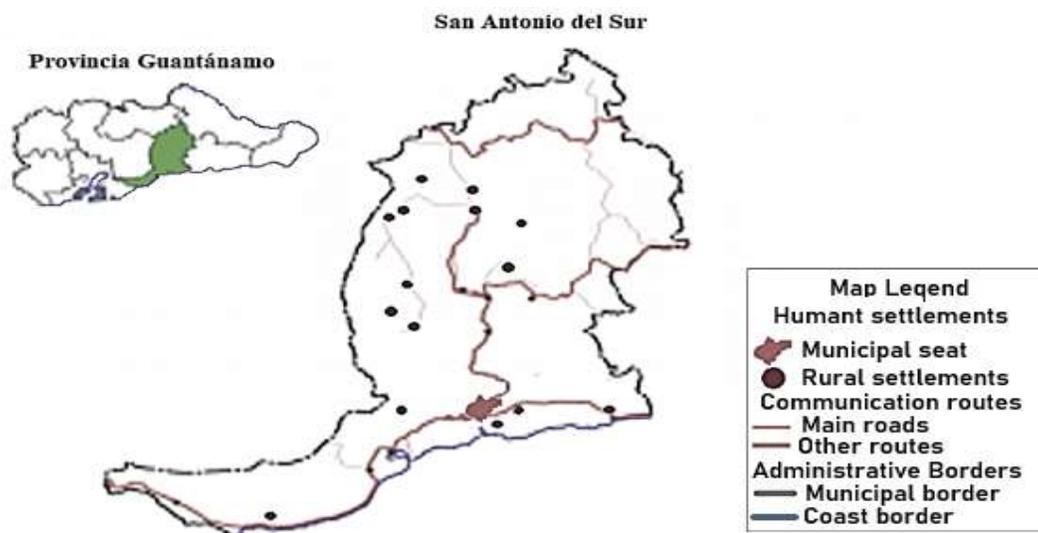


Figure 1. Location of the study area, San Antonio del Sur Municipality (Francisco Pedro, 2020).

First Stage. Bibliographic Review: In this stage, information was collected for get to know and understand the conditions of the study area.

Second Stage. Information Processing: In this stage, data from previous research were processed. Identification and evaluation of the area was achieved.

Third Stage. Information Interpretation: Based on the collected and processed information, the phenomenon, its causes and effects were interpreted, and measures are proposed to reduce mudflow risk in San Antonio del Sur.

Research Results

Conditions that Generated Mudflow in San Antonio del Sur Following Hurricane Oscar

1. Intense rains generated by Hurricane Oscar.
2. The geomorphological conditions that determined the accumulation of friable material, the morphology of its slopes, the structure of the basin and the valley which have coastal terraces at the end.
3. The geological conditions that determined the accumulation of friable material from the basin, the evolution of different geological processes, weathering, erosion, and gravitational processes, as well as tectonic dislocations.
4. Anthropogenic activities that caused the alteration of the environment in the catchment basin.

Vulnerabilities in the Study Area

Physical

The climatological event was exceptional as the precipitation levels exceeded recorded historical values and, undoubtedly, those considered by planners to determine maximum flood levels in the area. Therefore, it cannot be assured that all the damage was due to design or construction errors.

The road crossing the area is constructed, in the most critical sections, more than one meter above the buildings on both sides. This caused the formation of an artificial barrier to water drainage and water damming north of the road, with the consequent accumulation of mud.

The existing dams did not fulfill their regulatory function during the meteorological event, as the basin located downstream has a large area that generated the floods, furthermore, they were already holding large volumes of water.

The area is rich in limestone promontories with karst formations, which favored landslides and landslips. The road and some buildings are located near some of these promontories where high hazard is generated.

In recent years, housing construction has increased in areas highly vulnerable to flooding; these buildings were the most affected by the event.

The floods magnitude carried away large amounts of vegetation and mud, aggravating existing drainage problems at critical points. Several bridges and sewers are, today, partially obstructed.

The main watercourses in the area feature poorly defined channels with numerous curves, which causes large floodwaters in unforeseen areas. On the other hand, the characteristics of the soil, river mouths, and thalwegs favor scour in masonry works.

The area is surrounded by mountains in a low-lying zone that facilitates the accumulation of mud torrents coming from higher areas. Another factor influencing the accumulation of mud torrents in San Antonio del Sur are marine terraces, as they obstruct their rapid drainage.

Socioeconomic

San Antonio del Sur government does not count on a budget for Disaster Risk Reduction, which increases its vulnerability to climatological events.

San Antonio region is a territory vulnerable to frequent internal and external geological and hydrometeorological processes, which generate disaster risks such as earthquakes and intense rains that cause floods, mud flows, and landslides.

Both officials and the population have little information on how to reduce the existing vulnerabilities in their municipality and how to mitigate the effects of any natural disaster that affect the municipality.

Mudflow Risk in San Antonio del Sur Following Hurricane Oscar

The flooding of mountain river channels in San Antonio and the flows of friable, clastic materials (gravel, sand, clay), where the terrain is fine-grained clayey (mud), leads to mud torrents formation. The floods caused by Hurricane Oscar's intense rains generated mud torrents of great proportion and rather high current velocities for several hours (between 3 and 5 hours).

Geomorphological conditions constitute the second factor for mudflows formation in San Antonio del Sur basin, as the terrain inclination enables the transport of materials.

The third element is given by geological conditions, tectonics, and faults and fractures systems that constitute the guide for flows in the basin and sub-basins, the types of soils and rocks, and the weathering effects, as this region is a semi-desert area where rainfall levels are low and phenomena such as landslides contributed to the better development of mud torrents.

It is important to evaluate the basin and its water volume before a storm. Prolonged or intense rains can generate mudflows in this municipality. In addition, human activity in the basins should be assessed. Deforestation combined with the climate and its semi-desert environment contribute to flows. In San Antonio del Sur basins, the concentration of sediments generates debris flooding coming from upstream, which, upon flowing, encounters a sedimentation area where large percentages of solids are retained (Figure 2).

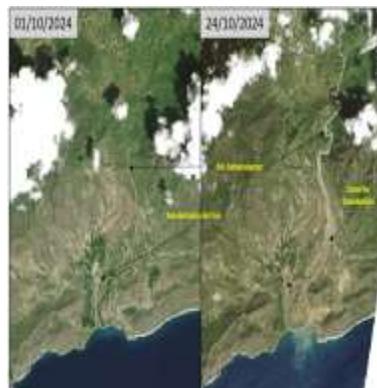


Figure 2. San Antonio del Sur's satellite image shows the difference regarding sediment accumulation in the area before and after Hurricane Oscar.

Protective Measures to Mitigate Mudflow Impact in San Antonio del Sur

It is necessary to take action to mitigate disaster risk and reduce impact through monitoring and an early warning system to protect human lives and infrastructure (Maresma Alba *et al.*, 2021). For this purpose, a series of protective measures are proposed to minimize mudflow impacts in San Antonio del Sur in the face of future climatological events.

- Organization of an observation service for the catchment basin's regime in the hazard zone.
- Execution of reforestation works on slopes with landslide hazards surrounding the community.
- Execution of works to regulate surface drainage on catchment basins' slopes in mudflow zones.
- Construction of regulatory and capturing facilities in streams' channels.
- Construction of protective facilities around family homes and infrastructure to be protected.
- Relocation of homes located in hazard zones.
- Development of an emergency communication and evacuation plan for families living in hazard zones.

Conclusions

The physical-geographical and geological conditions of San Antonio del Sur that represent a mudflow risk were analyzed.

San Antonio del Sur municipality is exposed to the occurrence of mudflows when intense rains occur, a situation demonstrated by the heavy rains caused by Hurricane Oscar.

Landslides pose a high level of risk for San Antonio del Sur's inhabitants, making it necessary to implement measures designed to avoid loss of human lives and reduce the impacts of future disasters.

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