Methodology for evaluating implemented measures impacts for risk mitigation by mass movements.

Adriel Augusto Rodríguez Villalba1, Lina Ospina-Ostios2, Jackeline Murillo Hoyos2

1Civil Engineering student at Universidad del Valle

2Assistant Professor at School of Civil Engineering and Geomatics, Universidad del Valle

adriel.rodriguez@correounivalle.edu.co

Abstract

The territorial management plan of Santiago de Cali from year 2014 indicates that due to its geographical location and the geological and seismic conditions of the region, the slopes of the city are highly susceptible to mass removal phenomena (MRF). The Commune 20 is located in the southwestern part of the city of Cali. Has an approximate area of 243 ha, from which 155 ha are located in the hillside zone and 32 ha are in high-risk condition or in a non-mitigable risk zone. The Commune 20 has some basic conditions that affect its stability. At the geological level, the area is characterized by strata in structural slope, of which 60% are highly fractured sedimentary rocks, including coal mantles with relatively high stability, where in the past there was mining activity. The remaining 40% are fresh or partially weathered diabase ("blue rock") whose stability in general terms is high for rocks that are not fractured and not transformed into soils, up to 1m deep. Additionally, Commune 20 has the second highest population density in the city (284.2 Hab/ha), with the lowest level of socioeconomic stratification prevailing. Although, the coverage level of utilities is approximately 88%, there is a high number of illegal that are characterized by a lack of maintenance.

In order to determine the scope of the RISK management process by MRF, a walk-in study is developed to qualitatively evaluate the mitigation measures executed, considering historical records, bibliographic consultation of the entities responsible for the risk management process. Citizen participation is also considered as a fundamental tool and finally an inspection process in the affected areas. The process followed for evaluation begins with the collection and compilation of relevant information and thus determines the scope of the 3 phases of the study. In the first phase, MRF are characterized based on the historicality of reports found in different sources and the geoenvironmental conditions of the study area are identified. The second phase identifies the general framework of mitigation measures by classifying the most frequently used measures in risk management. For the third phase the study of the mitigation measures implemented is carried out, for the specific case of Commune 20 it was determined with the information collected that most of the interventions that are executed are structural in nature (containment structures), it is for this reason that the non-structural measures will not be contemplated in the evaluation. Finally, with the help of the inhabitants of the affected areas, and by inspection of the areas of interest, the status and operating conditions of the areas are recognized.

1. INTRODUCTION

This study develops the necessary activities to achieve the impact of the measures implemented for risk mitigation by Mass Removal Phenomena (MRF) in the 20th commune of Cali. The National Risk Management Policy established in Law 1523 of 2012 identifies three components to achieve the approach of risk management: knowledge, reduction, and disaster management. There is currently a strong trend towards studies and work on risk awareness to establish risk reduction measures and mechanisms for disaster care, but little is said about the evaluation and monitoring of implemented measures. The history of mass movements in Colombia has shown that in most cases where interventions are made to mitigate the risk per MRF, it is maintained and in some cases increases, this is why it is questioned whether those interventions are having the desired impact. To carry out an assessment that shows the actual effect of the mitigation measures executed, it is necessary to characterize the mass movements that occurred in the study area by identifying the most relevant aspects of these. It is also necessary to identify the types of interventions carried out to establish the variables and aspects to be inspected and evaluated.

The evaluation carried out in this study is the first approach to a more detailed assessment to learn more about the behavior and influence of mitigation measures on MRF risk reduction. Knowing the effect that the mitigation measures implemented have on the affected sites, allows us to reflect and analyze more clearly on the critical aspects in the risk mitigation process, to be able to determine whether the process that has been implemented is adequate. This is a great help in establishing what changes or aspects should be reinforced in the risk management process that has been implemented in areas affected by mass removal phenomena.

2. CONCEPTUAL FRAMEWORK

2.1. Mass movement phenomenon

Mass movements or hillside movements are defined as "the movement of a mass of rock, debris, or downhill soil" (Cruden, 1991). According to Cruden & Varnes (1996, cited by Lara & Sepúlveda 2008), its classification is based on the type of movement and the material involved. Regarding the type of movement, five basic cases are considered: fall, overturn, sliding, flow, and lateral propagation. Regarding the material, two types are considered: rocks and soils, the latter subdivided into debris and earth, according to thicker materials, or finer than sand size, respectively.

2.2. The risk equation in mass movement phenomenon

The first step in landslide risk assessment is understanding land sliding. However, risk concerns establishing the likelihood and extend future slope failures that could adversely affect society (Lee & Jones, 2004). The purpose of this section is to provide the framework for landslide risk.

- Hazard: threat to humans, that a physical event of natural origin, or caused, or induced by human action accidental, is present with adverse consequences to cause loss of life, well-being, material goods as well environment.
- Vulnerability: susceptibility or physical, economic, social, environmental, or institutional fragility that a community has to be affected or suffer adverse effects if a dangerous physical event occurs. It can be defined as the potential to suffer harm, loss, or detriment from a human perspective. (Law 1523 of 2012, modified).
- Exposure (exposed items): total value of all threatened items valued by humans and including population, artifacts, infrastructure, economic activity, service, amenity, etc., (Lee and Jones, 2004, modified) within an area where hazard occurs.
- Disaster risk reduction: these are all potential disaster losses that depend on the type of threat, exposure, and type of vulnerability of a community or system (UNGRD, 2017; modified).

2.3. Risk mitigation

Mitigation is understood as the selective application of appropriate measures and management principles to reduce an event's occurrence possibility or its unfavorable consequences.

The mitigation risk process is composed of all the intervention measures that modify the characteristics of the phenomenon,

reducing the threat or vulnerability of the exposed elements. The interventions can be prospective or corrective.

Additionally, mitigation measures can be structural or non-structural. In the first case, all physical constructions are considered to reduce or avoid the possible impacts of threats, or the application of engineering techniques aimed at increasing the resilience of structures or systems against threats. In the second case, any measure that does not involve physical construction and uses existing knowledge, practices, or agreements to reduce the risk and its impacts are considered; especially through policies and laws, greater public awareness, training, and education (UNISDR, 2017).

3. METHODOLOGY

The activities required to evaluate the mitigation measures executed are grouped into three phases. Before the development of each of the phases there is a fundamental activity that is the collection, debugging and compilation of information, to understand the evolution of the mass movement risk scenario in Commune 20, a thorough search is carried out on all records of mass movements within the study period for Commune 20, the collection of relevant information is also carried out to identify the geoenvironmental characteristics of the study area covering the conditioning, triggering and socio-economic factors, in the same way, the literature on interventions to mitigate the risk of mass movements is reviewed. The first phase is focused on determining the attributes of the mass movements of the study area. The second phase encompasses the search and ordering of interventions used for risk mitigation, both at the general and local level by mass movements. Finally, the activities aimed at understanding, identifying, the characteristics of the measures implemented for risk mitigation by mass movements in the study area are carried out in phase three. Figure 1 presents the methodological outline of the evaluation phases.

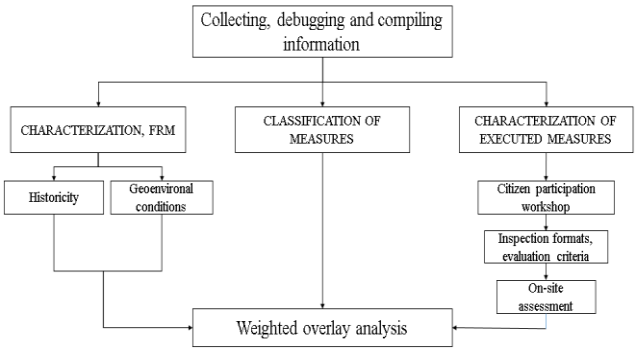

Figure 1. Evaluation phases.

3.1. Mass motion characterization

3.1.1 Historicity

For the development of the historicity of mass movements, the main entities responsible for risk awareness are consulted; the existing literature on the subject (previous studies, thesis, reports, etc.) is also reviewed. The sources and documents consulted are described below:

Open-nature databases: As a tool in the risk management process, disaster inventories have been built at global, local, and regional levels that give important information on historical events. These databases are mostly open to the public for consultation.

Files: In the archives of entities that record or attend emergencies or make technical visits associated with hillside instability are located a series of unreleased documents, evidence of actions performed, and events that occurred.

Hemerography: In this category, bibliographic sources and periodic publication documents that record events and events at the local and regional level are consulted.

3.1.2 Geoenvironal conditions

To define the main geoenvironmental aspects of the study area, information consisting of historical records of the CVC, DAGMA, EMCALI, SGC, and cartographic plans obtained from the

Secretary of Municipal Planning was used; information is also complemented by inputs made by the inhabitants of the study area.

Condition factors: Factors are conditioned to the basic conditions that a determining

the zone has and that makes it susceptible to the occurrence of mass movements (GSC, 2017). Among the most representative factors used in this project are: geology (geological formations and surface formations), geomorphology (predominant morphological and slope units), hydrology, coverage and land use

Triggering factors: In this category are the factors that trigger mass movements by altering the equilibrium state in which the slopes /slopes (natural or anthropic) are located. The climate (precipitation, temperature) and the seismicity of the area (SGC, 2017)are triggering factors. Anthropic factors despite being considered as trigger factors will be treated in a different "Socio-economic" section due to their level of influence in the study area.

Socio-Economic Factors: Disorganized urbanization, generates occupation of areas susceptible to mass movements, destabilizing slopes/slopes (SNGRD. 2017, modified). The main socio-economic aspects studied in this project are social stratification, population and housing growth, occupation of unstable areas, urbanization processes, and coverage of public services.

3.2. Classification of measure for risk mitigation from mass movements

To cover all measures being implemented to mitigate risk, measures that have been universally accepted as effective actions are studied. These measures are contextualized at the national level by consulting references in the risk management process that, in recent years, have tried to propose and implement a more comprehensive risk management policy than was once developed (only oriented to the control of phenomena that occurred with works of stability and environmental recovery), among the entities consulted are the Regional Autonomous Corporation of Caldas – CORPOCALDAS - the National Unit for Disaster Risk Management – UNGRD - the District Institute of Risk Management and Climate Change – IDIGER – and the administrative department of disaster risk management MEDELLÍN.

Based on the general framework of mitigation measures, they are classified into a clear format and can be applied not only at the national level, but also at the regional level, it is important to clarify that this classification is based on the information consulted in text and secondary information, i.e. this classification includes the classification processes planned by the responsible entities, not executed processes that may differ from planned.

3.3. Characterization of measures implemented for mass movement risk mitigation

- Citizen participation workshop: the first thing to do in this process is to define what you want to map. The mapping section aims to identify areas that are susceptible to mass movements and interventions that have been performed to mitigate MRF risk. It also seeks to obtain a first description of the type of intervention executed and the perceived impact. This information is of great help in the elaboration of the formats to be used in the inspection process. For the inspection of the measures executed is based on the results obtained from the citizen participation workshop to identify the points to be inspected (intervened areas), these points are corroborated with the information obtained from the numerals 3.1, 3.2 and 3.3.
- Inspection formats and evaluation criteria: for the preparation of the formats, studies were consulted where evaluation processes were carried out, mainly of containment structure that is the most recurrent in Comuna 20, and this information becomes the basis for the design of the formats considering the

characteristics of mass movements and the measures executed in the study area. For the determination of the evaluation criteria, refer to the literature on the subject. For this project, the model used for the Prioritization of Geotechnical Works for the Intervention and Maintenance of Road Infrastructure Works of the National Road Council (CONAVI, 2013) of Costa Rica is based. With the inspection formats and evaluation criteria established, the on-site evaluation is carried out. Also, the inspector has the compendium of information on the study area that has been built in the course of the project that is a great help when carrying out the inspection.

- Analysis by weighted overlay: as a final result, the purpose is to develop the influence map of mitigation measures on risk reduction, this is the effect that the measures executed on risk from mass movements have had. For the elaboration and analysis of this map the weighted overlay was used, in this type of analysis, you must divide the model into submodels and identify the input layers. Each layer of the weighted overlay analysis is assigned a weight, based on the level of importance in reducing risk.

4. STUDY AREA

Commune 20 is located in the southwestern part of Santiago de Cali city, covering a hillside and piedmont area, where are settled a population in eight neighborhoods and three urbanizations. In this commune, approximately 3.2% of the total population of the city is concentrated in an area that corresponds to 2%, reflecting a high population density (284.2 habs/ha). The commune has around 9,198 constructions that makeup around 15,828 houses, the vast majority lack of technical construction standards. The number of homes is 64.9/ha where the most common socioeconomic stratum is one (DAPM, 2017). Concerning land use, residential use is predominant, generally human settlements of incomplete development, constructions in waste materials (cans, boards, and cartons) and/or guadua or mud, houses partially finished in durable material, some located in sectors with severe topographic and geological restrictions in precarious socioeconomic conditions.

5. MASS MOVEMENTS CHARACTERIZATION

5.1. Historicity

Mass movements' historicity constitutes one of the most important pillars in this type of study since it allows results calibration and validation. Although there is no detailed information about events' technical descriptions, it provides valuable historical information for determining areas of influence, type of movements, causes, frequency, possible damages, and affected.

In the period between 1990 - 2018 307 events have been recorded in the municipality of Santiago de Cali (Alcaldia de Santiago de Cali-Univalle, 2018), of which Comuna 20 contributes 20% of these. The largest peaks for Commune 20 are between 1995 – 2001 and 2005 – 2008. It is noted that the first months of the year have the highest number of records. This is consistent with the information provided by the mayor of Santiago de Cali where they point out that February, April, May are the months that present the highest number of events in the city. It also stands out in November coinciding with the rainy seasons of the country that extend from the end of March to the beginning of June and from the end of September to the beginning of December. In the results of the historical stand out the neighborhoods of Siloé, Lleras Camargo, Bethlehem, and Tierra Blanca, such as those with the highest number of records, mass movements.

5.2. Geoenvironmental conditions

The neighborhoods of the upper part of Comuna 20 are characterized by the largest number of areas of incomplete development (they do not present a process of urbanization, lack of public services and basic infrastructure) and difficult topographical conditions (topographical accidents, steep slopes) and are therefore the most affected by mass movements.

Among the most relevant condition factors, we find that the study area is located on two geological formations mainly the Guachinte Formation (TOg) and

the Volcanic Formation (Kv). In the area, there is also the presence of quaternary deposits corresponding to the unconsolidated materials that are covering the rock units among which are alluvial fans (Qab), active alluvial deposits (Qal), colluvial deposits (Qco). In the area are grouped the large geoforms that characterize the terrain on which the City of Santiago de Cali is located and its surroundings. They have high mountain slopes that are characterized by steep to steep mountains, with deep "V"-shaped channels; many of them with long slopes and straight slopes, in general, the study area is located on land with slopes between 30 and 40%. The Commune 20 of Santiago de Cali is part of the Cañaveralejo River basin. This basin has three main ravings: “Isabel Pérez”, “Guarrus” and “El Indio” (CVC, 2018). As a result of the high residential occupancy, the area has low levels of plant cover. The development of infrastructures such as roads and housing gives way to the destruction of vegetation facilitating the colonization of new lands, the predominance of residential use is observed and commercial and institutional activities are scarcely carried out.

The main donor factors are climate, seismicity, and anthropic activity. The maximum multi-year rainfall in Comuna 20 varies between 50 and 150mm. The average annual multi-year temperature is 26.3oC. The minimum is 22.6oC and the maximum is 33.4oC. The annual cycle of regional temperatures is closely linked to variations in precipitation. Maximum rainfall in 24 hours generally does not exceed 100 mm and usually, the heaviest part of the downpour falls in the first 3 hours. The seismicity of the area is defined by the Cali-Patía fault system. This tectonic structure passes eastward at the bottom of the study area and has a predominant N-NE direction with almost vertical dip. This fault mainly affects sedimentary rocks that have a high degree of fracturing due to the intense tectonic forces present in the contact area (Arango Duque & Vallejo, 2011). Commune 20 has an accelerated and uncontrolled growth process, causing a greater number of events recorded; this process is seen to be critical in relatively new neighborhoods that have experienced an accelerated demographic explosion and also see a significant increase in mass movement records.

6. CLASSIFICATION OF MEASURES FOR RISK MITIGATION

In general terms, mitigation measures are classified according to their purpose, i.e. whether they are aimed at reducing the threat or vulnerability of the exposed elements. The timing of the intervention is also considered. Those measures classified as prospective, seek to prevent future risk scenarios; corrective measures are aimed at reducing potential negative impacts. This way of classifying measures applies to both structural and non-structural measures. In the planning of risk management for Commune 20, corrective actions predominate. These are seeking to mitigate existing risks and address specific cases, such as the stabilization of slopes and slopes, protection and adequacy of bodies of water, structural reinforcement of buildings, among others.

7. CHARACTERIZATION OF MEASURES FOR RISK MITIGATION BY MASS MOVEMENTS

As regards the characteristics of mitigation measures, the most common interventions have to be structural measures, mainly we are talking about two measures; containment structures and supplementary works, canals, sinks, bleach, this measure is corrective in nature and seeks to mitigate the threat level, the second kind of measure is the replenishment and crewing of aqueduct and sewerage networks, this measure is corrective in nature and aims to mitigate the vulnerability.

The evaluation of containment structures found that 80% are reinforced concrete retaining walls, and 20% are handcrafted structures, mainly stacking of elements and/or building materials whose operation is that of a gravity wall. Among the reinforced concrete walls it was found that 15% were built by the same community and lack the corresponding technical regulations, Colombian Construction Regulation (NSR-10), Colombian Concrete Technical Standard (NTC-3318). Only 40% of the walls in reinforced concrete have good conditions of stability, the rest have problems of cracks and fissures that in some cases seriously compromise the stability of the structure, also a high degree of deterioration due to the weather, presence of vegetation and humidity. The

handcrafted structures have good stability in general terms, for their construction style, stacking, these allow the natural filter of water, and their degradation by environmental conditions is less. Finally, the occupations of these containment structures for the construction of homes alter the designs and the operation of them, this being the main cause of most of the pathologies appreciated in the inspection.

In assessing the replenishment and endowment of aqueduct and sewerage networks, the Municipal Companies of Cali, EMCALI, in cooperation with the planning committee of Commune 20 have been identifying, since 2013, critical areas where aqueduct networks have a high degree of deterioration, mainly because of their age many of these networks are from the 70s built by the community without any regulations, these networks have been suitable for compliance with the technical regulations of aqueduct and sewer (EMCALI, 2011), as well as improved and repowered drainage structures of access roads, bleachers, platforms, etc. Despite the improvement in utility networks, the level of illegal connections is of concern, by EMCALI regulations the company is responsible for public networks, but connections to these networks are the responsibility of the owners of the premises, making it difficult to standardize and adopt these connections.

8. INFLUENCE OF MITIGATION MEASURES

As a result, the influence map was obtained from interventions for risk mitigation in areas susceptible to mass movements in commune 20. It is clear that, in those areas of high susceptibility to mass movements, interventions have been carried out, of a structural nature mainly, only 24% of the intervened areas have had a positive, high impact, 67% of the susceptible areas have had an average impact on the part of the interventions carried out, and only 9% of the intervened areas have had an impact under (Table 23). In general terms, it is appreciated that the interventions that have been implemented in the commune have had a positive impact on areas susceptible to mass movements, this is largely due to the change in focus in the risk mitigation process. In recent years, measures focused on water treatment and the adequacy of public services have been taking on more and more strength as the inhabitants of the community in the social mapping workshop and as could be seen in field visits. On the other hand, those areas where the impact has been low mainly correspond to specific interventions of type containment structures, many of the old and in poor working order.

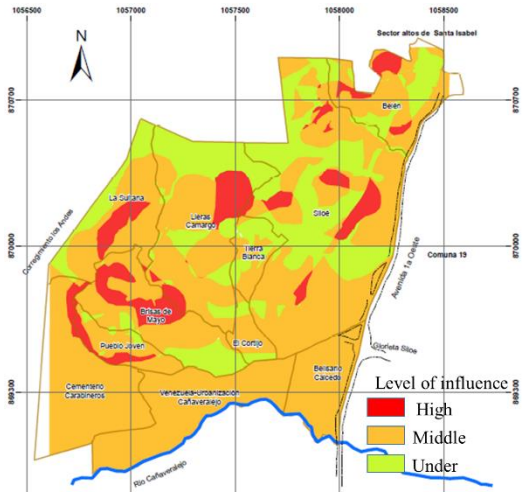

Figure 2. Map of the influence of mitigation measures implemented on risk by MRF.

9. CONCLUSIONS

The characteristic mass movements identified in the area are of the type slippage, volley falls and flows resulting from erosion in the margins of ravings. From the information collected in the section of mass movement characterization, it could be shown that commune 20 has basic conditions (geology, hydrology, seismicity, etc.), but it is the anthropic activities related to urbanization processes that have the most impact on the occurrence of MRF.

Risk management processes in Commune 20 have historically been limited to containment structures, in some cases artisanal (community-built) structures, and by a large percentage are ancient structures that have already served their lifespan. These structures, like most buildings at the national level, lack a maintenance and rehabilitation program, which is why their state of operation is affected by the degradation resulting from the weather and the constructive activities of the community on and/or around the structures, manifesting themselves in the appearance of pathologies such as fissures and cracks.

There is a clear discrepancy between the theoretical (or planned) framework for Commune 20 in terms of risk management and what has actually been implemented, in the classification of planned measures for commune 20, presented in this study, consistent planning can be seen in mitigation measures, integrating corrective and prospective measures, as well as considering structural and non-structural measures that mitigate

both the threat and vulnerability, but the collection of information, the participation workshop, and inspections showed that the interventions implemented are limited to mitigation measures to the type of containment structures and recently to the improvement of the infrastructure of public services and runoff water management.

It should be noted that the commune shows a good picture of the influence of the measures implemented for risk mitigation, this is in large part the change in approach that mitigation measures have had, shifting from focusing only on containment structures to including more and more measures for water control, both runoff and leaks from utility networks, this shows that more holistic solutions have better results. The specific cases of mass movements are a reflection of a more macro scenario, a lack of integrality, deficiencies in the infrastructure of public services, treatment of runoff water, and inadequate earth movements due to the construction activities typical of the area. In order to ensure that measures implemented for mass movement risk mitigation are more far-reaching at the ward level or even the commune itself, they should consider the needs diagnosed in terms of risk management and should be aimed at resolving structuring aspects of territorial order and development of the area, social, political development, cultural and infrastructure since the absence of these aspects in Commune 20 throughout history have been the main cause of specific cases, mass movements.

10. REFERENCES

Arango Duque, D., & Vallejo, A. (13 de Octubre de 2011). bibliotecadigital.univalle. Obtenido de http://bibliotecadigital.univalle.edu.co/handle/10893/1527

Alcaldia de SAntiago de Cali-Univalle. (2018). Historicidad y caracterización del escenario de riesgo por Movimientos en Masa del municipio de Santiago de Cali. Santiago de Cali.

Corporación Autónoma Regional de Caldas, CORPOCALDAS. (2006). Taller internacional sobre gestión de riesgo a nivel local el caso Manizales, Colombia. Manizales, Caldas.

Congreso de la República. (2012). “Ley 1523”. Diario Oficial (48411).

Consejo Nacional de Vialidad, CONAVI. (2013). Modelo de Priorización de Obras Geotécnicas para la Intervención y Mantenimiento de Obras de de Infraestructura Vial . Costa Rica.

Cruden D. M. (1991). “A simple definition of a landslide”. Bull Inter Assoc Engng Geol 43, 27-29.

CVC. (2018). cvc.gov.co. Obtenido de https://www.cvc.gov.co/carousel/3151-cvc-construye-23-obras-en-laderas-de-cali-para-mitigar-riesgos

Departamento administrativo de gestión del riesgo de desastres, MEDELLIN. (2015). Plan municipal de gestión del riesgo de desastres de Medellín 2015-2030. Medellín.

Departamento Administrativo de Gestión de Medio Ambiente DAGMA. (2017). “Consejo ambiental de Cali-Comuna 20”. Alcaldía de Santiago de Cali.

Departamento Administrativo de Planeación Municipal De Cali DAPM. (2017). “Comuna 20”. Alcaldía de Santiago de Cali

Empresas Municipales de Cali EMCALI. (2011). Lineamientos para elaboración y representacion de diseños hidrasanitarios.

Instituto Distrital de Gestión de Riesgos y Cambio climático, IDIGER. (2019). idiger. Obtenido de https://www.idiger.gov.co/rmovmasa

Lara, M. y Sepúlveda, S. (2008). “Remoción en Masa. Apunte del curso GL62C”. Departamento de Geología. Chile.

Lee, EM y Jones, DK. (2004). “Landslide risk assessment” (p. 454). Londres: Thomas Telford.

SGC. (2017). www2.sgc.gov.co. Obtenido de https://www2.sgc.gov.co/Archivos/GM(2017).pdf

SNGRD. (2017). repositorio.gestiondelriesgo.gov.co. Obtenido de https://repositorio.gestiondelriesgo.gov.co/bitstream/handle/20.500.11762/20761/Terminologia-GRD-2017.pdf;jsessionid=4C09CD708172A7F5641A9790E146BA3A?sequence=2

Unidad Nacional para la Gestión del Riesgo de Desastres UNGRD. (2012). “Formulación del Plan Municipal de Gestión del Riesgo”. Sistema Nacional de Gestión de riesgo de desastre.

Unidad Nacional para la Gestión del Riesgo de Desastres UNGRD. (2017). “Terminología sobre Gestión del Riesgo de Desastres y Fenómenos Amenazantes”. Sistema Nacional de Gestión de riesgo de desastre