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Update of Geological Risk Mapping of the Mutange District in the Municipality of Maceió - AL, Brazil

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Resumen: *ACTUALIZACIÓN DEL MAPEO DE RIESGOS GEOLÓGICOS DEL DISTRITO DE MUTANGE EN EL MUNICIPIO DE MACEIÓ - AL, BRASIL.* El municipio de Maceió - AL, Brasil realizó, en el año 2007, el Plano Municipal de Reducción de Riesgos (PMRR) con el objetivo de identificar áreas susceptibles a erosión y a deslizamientos, gracias al incentivo del Ministerio de las Ciudades, que desde el 2003 viene implementando una política nacional de reducción de riesgos en asentamientos informales. La población se establece en cortes realizados en pendientes de alta declividad, con suelos formados a partir de rocas sedimentares. Susceptibles a sufrir erosión acelerada y deslizamientos, durante las lluvias. Estos elementos potencializaron el interés en escoger el barrio Mutange para este trabajo. Por lo tanto, monitorar la ocupación poblacional en esas áreas es un elemento importante para prevenir riesgos así como también, para evaluar la vulnerabilidad de casas que se encuentran en la cima o base de laderas y en pendientes cortadas. De esa forma, este trabajo presenta un proyecto piloto de actualización del mapeamiento de riesgo geológico del área conocida como Grota da Borracheira en el Barrio Mutange en Maceió/Alagoas. En la metodología de trabajo fueron utilizados, una ficha catastral para recoger informaciones sobre las familias y también, sobre las condiciones de las casas; el Modelo Digital del Terreno (MDT) y el catastro territorial con el código de cada domicílio y familia que reside en esa área. Con toda la información catastral levantada fué creado un Sistema de Informaciones Geográficas. La actualización de este catastro permitió identificar, de forma más precisa, el número de casas en el barrio, pues el cálculo realizado anteriormente por el PMRR fué a partir del número de tejados vistos en las fotografías aéreas. Los resultados permitieron diseñar un nuevo zoneamiento de las categorías de riesgo en el área catastrada. La identificación de los domicilios más afectados y de las habitaciones que ya se derrumbaron. Los mapas que fueron generados y las informaciones vinculadas a estos, constituyen herramientas de gestión esenciales para la Defensa Civil de Maceió, para la identificación y prevención de riesgos, así como también para posteriores estudios direccionados a identificar soluciones para la contención de las laderas que presentan un riesgo más alto.

Abstract: The city of Maceió - AL, Brazil, performed in 2007, the Municipal Plan for Risk Reduction (MPRR) in order to identify areas susceptible to erosion and landslides in the city, owing to incentives of the Cities Ministry, which has been implementing since 2003 a risk reduction national policy in precarious settlements. The occupation is associated to hillside with high slope in developed soils from sedimentary rocks, susceptible to accelerated erosion and landslide in the rainy season. These elements potentiated the choice of the Mutange neighborhood for this research. The monitoring of the occupation of those areas is a substantial factor in the prevention of risks as well as in the analysis of the vulnerability of dwellings that are in tops or bases of hillside and slopes. Thus, this work presents a pilot project to update the geological risk mapping of the area known as Grota da Borracheira in the Mutange neighborhood in Maceió / Alagoas. In the methodological sketch were used residences and family records, Digital Terrain Model (DTM) and the territorial registration with the

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codification of all the households and the families residing in that area. Thus, a geographic information system was created with all the cadastral information. The cadastral Update allowed a more precise identification of the dwelling numbers, since the count carried out by the PMRR was done through roofs restored from the aerial photographs. The results brought a new zoning of the risk categories in the registered area. Besides, the Identification of the most affected households and dwellings that have already collapsed. The maps generated and the information related to them constitute essential management tools for the Maceió Civil Defense in the identification and prevention of risks as well as for further studies that identify solutions to contain the slopes that present the greatest risk.

Palabras clave: Riesgo Geológico. Mapeamiento. Catastro Territorial. Gestión del Territorio.

Key words: Geological risk. Mapping. Territorial Cadaster. Territorial Administration.

Introduction

From 1950 on, it is verified in Brazil an accelerated growth in urban areas, causing a disorderly urbanization process and numerous socio-environmental problems for the resident population in those places. With that, the socio-spatial segregation on cities was accentuated (IBGE 2000; Reckiegel and Robaina, 2005). This process entailed problems due to the cities lack of infrastructure by receiving a large number of people and new social demands (Sánchez, 2010).

The population growth acceleration in urban areas associated with a lack of planning causes social and environmental problems (Novack and Kux, 2010). These stand out: traffic congestion, garbage accumulation, air pollution, floods (Amaral and Ribeiro, 2009), accelerated erosion and sliding (Tominaga *et al.*, 2015), lack of water or space and irregular occupations that are the subnormal settlements. These are usually occupied by the low-income population and proliferate in areas frequently of environmental protection (Gonçalves *et al.*, 2013) or, subject to geological risk (Reckiegel and Robaina, 2005). Multiplying this way, neighborhoods with deficient infrastructure, housing located in areas of risk and in natural systems (Bandeira and Coutinho, 2008).

Due to the population dynamics and the constant changes in the subnormal settlements, it is essential to update the mapping of these areas to quantify the population growth and to evaluate the progress of the degradation of the physical environment. Therefore, the mapping of risk areas is an important aid tool in urban planning (Teixeira and Heller, 2005). By locating inadequate points for residency, with evidence of destructive soil processes such as erosion and landslides, and suggesting their environmental recovery (Hapke and Plant, 2010). Additionally, the mapping allows to estimate the geological risk of the area from the product between the danger (destructive process, in this case) and the vulnerability (degree of exposure to the destructive process) that is calculated from damage to people and buildings due to exposure to danger (Dias, 2010).

Some literatures use the concepts of risk and geological risk with the same definition, but in this research will be approached the definition presented by Carvalho (2004) and Parizzi (2014), being defined the risk as any form of threat (= danger) to which people and properties may be exposed. In return, geological risks are those that involve events or geological processes, natural or induced by anthropic action. According to Cerri and Amaral (1998), geological risk may or may not generate losses and damages. When there are losses and damages it is called an accident. In return, when there are not, it is considered an event.

In the last decades Brazil has experienced significant advances in relation to the management of environmental risks. This is due to the mass movements that happen in almost all the large Brazilian metropolis and involve losses of assets, infrastructure and fatal victims (Bandeira *et al.*, 2009). At the beginning of the 21st century, the management of risk development in Brazil began with the creation of the Ministry of Cities in the National Secretary of Urban Programs, which support and subsidize the municipal programs of Risk Reduction and Eradication (Nogueira *et al.*, 2013). The municipalities must use the subsidies for training and elaboration of the PMRR, execution of works and contention of hillside. Especially those with exposed soil, affected by sliding on urban slopes (Cerri and Nogueira, 2012). These are due to population growth and disordered occupation (Schuster and Highland, 2007).

To monitor erosive processes and mass movements three aspects are indispensable: their spatial location and area of coverage, and the identification of the type of geological process that has occurred. Only from this information on it will be possible to implement preventive and rectifying measures to mitigate damages, or avoid disasters. In the location and dimensioning of these processes, the use of geoprocessing methodologies and the spatial modeling of these data, associated, for example, to population register, incorporated into Geographic Information Systems - GIS, has been contributed significantly, anticipating the decision making of territorial management bodies, such as Civil Defense.

GIS is intrinsically related to spatially referenced databases. These, in turn, become responsible for storing large amounts of information, both alphanumeric and vector. In this sense, Lima and Brandalize (2015) indicate that the integration of the GIS platform with the Multipurpose Territorial Cadastre - MTC generates a fundamental tool for the management of decisions regarding the socioeconomic planning and development of cities. Its peculiarities make it indispensable for the quantification, qualification and localization of environmental problems of a given region.

In 2009, the Ministry of Cities published Regulation 511, which provides guidelines for the creation, institution and updating of Multipurpose Territorial Cadastre (MTC) in Brazil. Normatizing the urban and rural cadastral surveys in the country as a base tool for land use and occupation planning in the municipalities. By effectively guiding the management of the city halls public administration.

Unlike its initial use in Brazil, only for tax purposes, omitting the territorial cadastre as a whole by excluding peripheral areas and irregular occupation; The current cadastre in Brazil considers economic, physical, legal, environmental and social aspects per land division (Santos, 2013). Linking also the people who inhabit it. Hence its importance in the identification of geological risk areas. The MTC allows to identify areas with desirable occupation of urban land, as well as areas with irregular occupation. Given this potential, it was chosen as the base methodology of this study (Águila and Erba, 2007; Cunha and Erba, 2010).

The object of this survey is located in Maceió, more precisely in the Mutange neighborhood. This choice is justified because the neighborhood is in a peripheral area of irregular occupation. In this way, it has a strong occupation dynamics, characterized by great concentration of housing, high slope and irregularities in buildings. These factors prevent the use of orthorectification of aerial photographs and / or images captured by orbital sensors to be effective in accurately identifying the number of dwellings in each area, making not possible to use them for the needs of the study. It is worth mentioning that in its scope there is the presence of known grottoes, deep gullies or gullies - high declivity slopes with soil exposed to strong erosion processes during rains. Lack of planning becomes more visible. Therefore, the environmentally unstable areas are reserved for the needy Maceioense population.

Material and methods

The registration information collected in the first part of the Mutange neighborhood

(1/3 of the pilot study area) was organized and recovered. And high resolution satellite images were added. Maps of location, cadastral, sectoral and MDT for better interpretation of the study area were built.

In a first step, the bibliographic data of the Mundaú Lagoon risk complex (Mundaú River hydrographic basin), where the study area was inserted, was obtained from the PMRR (2007). Next, the cadastral bulletin was drawn up and data collection activities were started in the field, which were essential for the division of the area into subareas. Finally the data for the preparation of the maps were organized.

Following are details of the study area and materials and methods used.

General aspects of the study area

The city of Maceió is the capital of the State of Alagoas, Brazil and extends between the parallels 09°21'31 ¨and 09°42'49¨ south latitude and the meridians 35°33'56 ¨and 35° 38'36¨ west longitude. It presents a tropical-humid climate with an average annual precipitation of 2,167.7mm, with approximately 60% of the precipitation of the whole year being concentrated between the months of April to July.

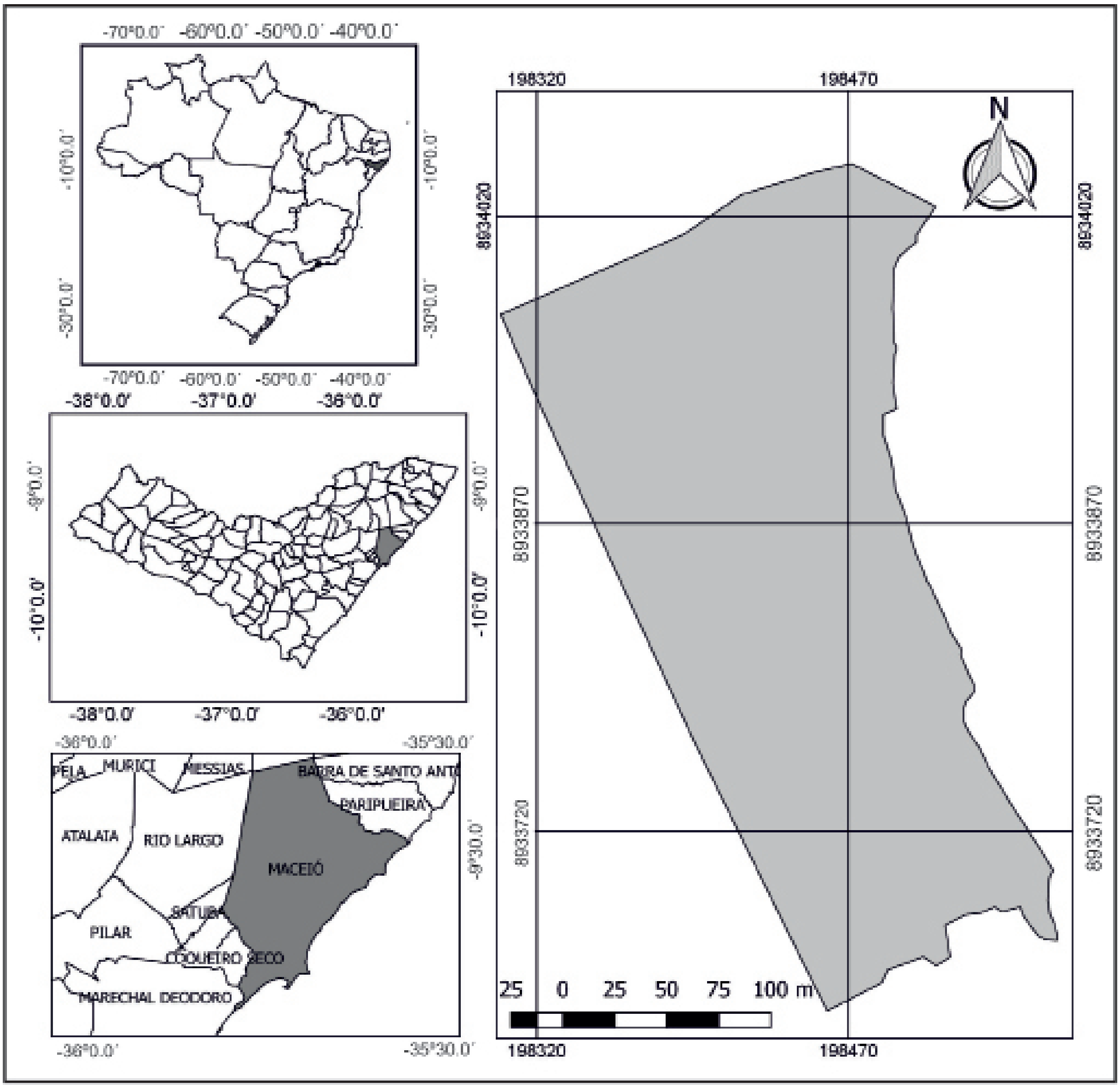

Figure 1. Location of Subarea 01 of the Mutange District, belonging to the municipality of Maceió-AL. / **Figura 1.** *Localización de la Subárea 01 en el barrio Mutange, municipio Maceió-AL.*

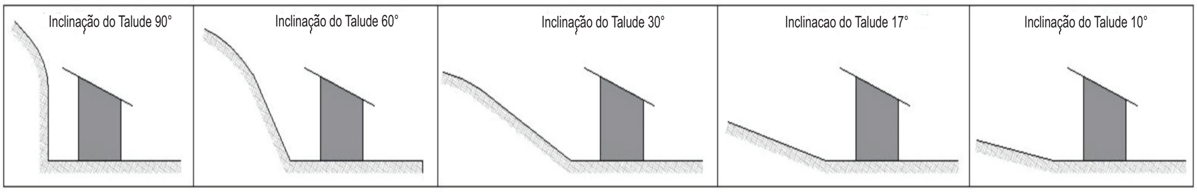

Figure 2. Possible residence relations with the slope and its inclination. Source: TRI. / **Figura 2.** *Posibles relaciones de las casas con la pendiente y su inclinación.*

The geology is marked by the influence of the Barreiras Formation (Tertiary), composed by the alternation of argillites, siltstones and arenites and sandy-clay soils to sandy ones (Araújo *et al.*, 2010; Soares and Toujaguez, 2015).

In view of the points presented, the study area is the Mutange neighborhood located in the urban perimeter of Maceió, defined by municipal law 4953 on January 6, 2000, amending law No. 4,687/98. Being this a recent neighborhood in its definition, but when it comes to occupation the neighborhood is one of the oldest, being located at the banks of Mundaú Lagoon, it has been occupied mainly by fishermen's colony , who extracted from the Lagoon their sustenance. This presents areas of geological risk being one of the most worrying areas for Civil Defense in Maceió - AL. Figure 1 presents a location map of the state of Alagoas in Brazil, the expansion of the state and in particular the study area of the Mutange neighborhood.

Field cadastral survey

In order to speed up the effectiveness of field registration activities, the risk area of the Mutange neighborhood was divided into four subareas, starting the activities from subarea 01, the target of this research, highlighted in figure 1.

After subdivisions of the area, the registration step was initially with the development of the Cadastral Bulletin. It was developed starting from two models, one from the Technological Research Institute (TRI), which contained specific and detailed data for the cadaster of dwellings near slope, and another one based on the premises of the Multipurpose Territorial. Cadastre of the Municipality of Arapiraca (Santos, 2013).

The Registration Bulletin was prepared to obtain the following information:

• Social: Number of people living in the area, income and age group.

• Housing: Type of occupancy; Structure, housing risk, need for removal etc.

• Infrastructure: Basic sanitation (piped water, sewage collection and treatment), mainly in relation to wastewater.

• Aspect of the slope: as to the height, slope, presence of vegetation or wastewater.

In order to assist the residents in registering the position of the residence with respect to the base or top of the slope (when it is present), a figure was inserted in the bulletin showing the possible proximity and slope relations of the dwelling (figure 2).

The house-to-house registration was carried out, placing in the dwellings an identification code following the precepts of Regulation 511/09, in the card and in the map, so that later it was possible to identify them and to associate the collected information to its geometry through a Geographical Information System (GIS). Figure 3 presents a map of subarea 01 containing the codes of all identified buildings; it is emphasized that this process will be applied to the other subareas.

For a better analysis of the characteristics and vulnerability of the study area, the DTM was generated from the Shuttle Radar Topography Mission (SRTM) with 1 arc second (30 meters), obtained from the USGS page (http: //earthexplorer.usgs .gov/).

Results

By registering the subarea 01, the Risk Map contained in the Municipal Risk Reduction Plan (PMRR) carried out in 2007, was taken as basis, where all existing buildings had been identified. As the dynamics of areas of occupation tend to be accentuated, without effective supervision by the competent tax authorities, then it is common that changes have occurred and only with the identification of all dwellings through a detailed cadastre, these changes can be identified.

The cadastral survey allowed updating the number of dwellings in subarea 1, indicating the total existence of 446 dwellings, of which 71 dwellings were not included in the identification of the PMRR, as shown in figure 4.

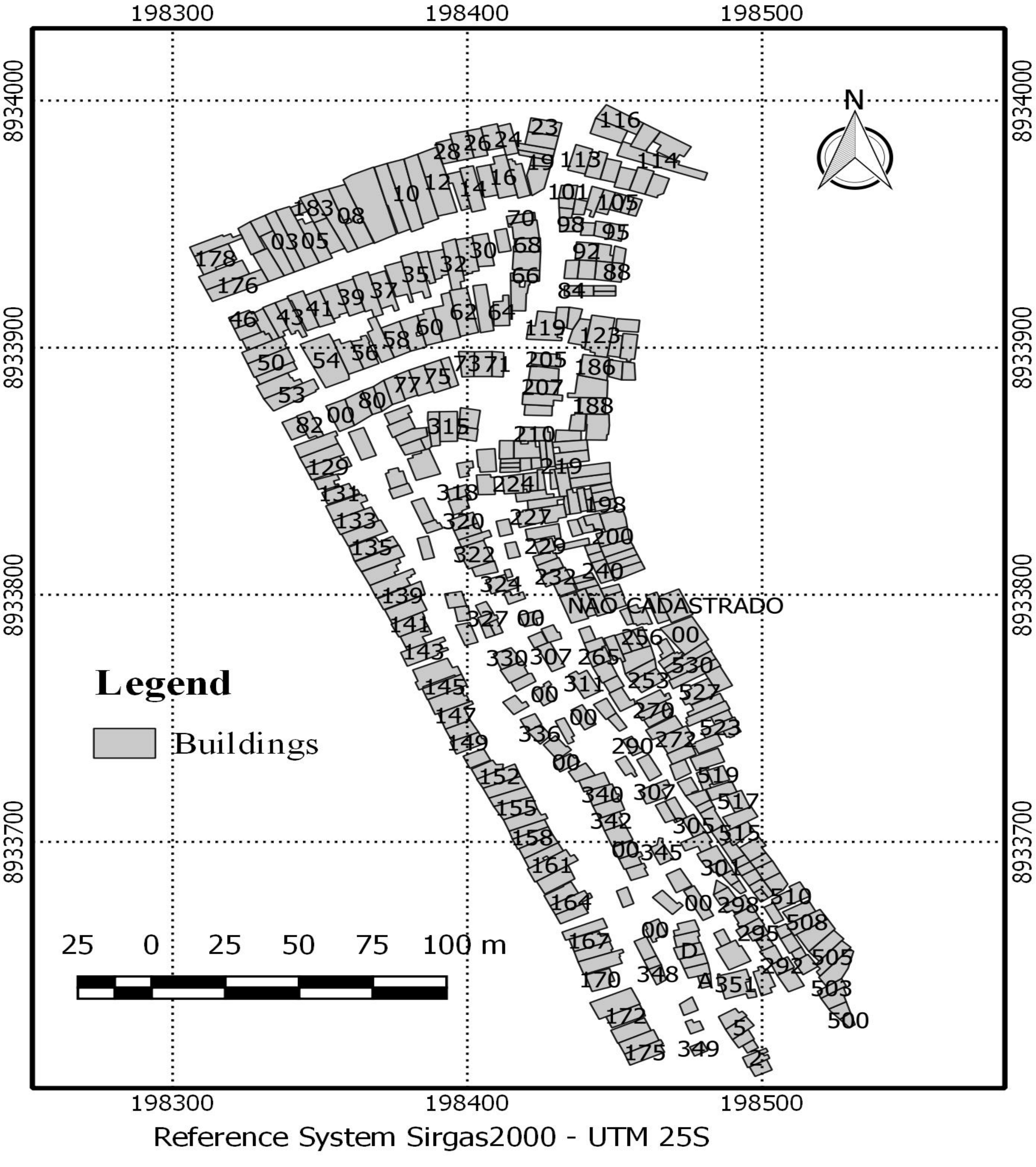

Figure 3. Identification of the dwellings in Subarea 01 of the Mutange District. / **Figura 3.** *Identificación de las casas en la Subárea 01 del barrio Mutange.*

As shown in figure 4, the cadastre made in the area contributed to the PMRR having the database updated in relation to the number of dwellings. This information is of extreme interest to COMDEC managers during the rainy season as emphasized by Lima and Brandalize (2015). With current information on the most vulnerable and, therefore, priority points for the removal of people, it is possible to optimize geological risk management and avoid possible disasters (Bandeira *et al.,* 2009). The study also confirmed in the Mutange, growing disordered occupation between 2007 and 2016 (Novack and Kux, 2010). Which was only speculative in formation, not confirmed. The cadastral survey also allowed us to relate the dynamics of the neighborhood to the processes of accelerated erosion and landslides in subarea 1.

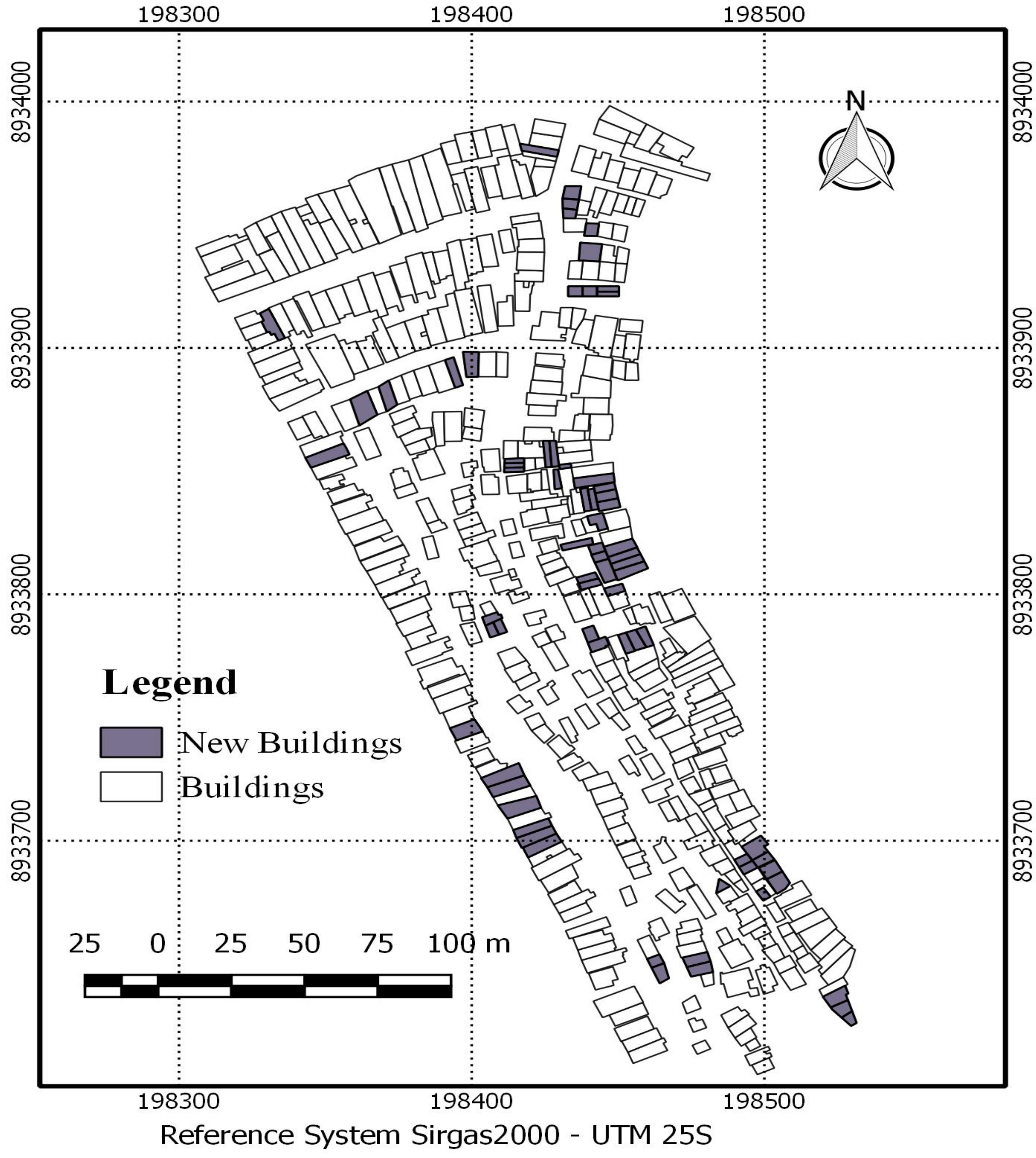

Figure 4. Update of the dwelling numbers in the PMRR database. / **Figura 4.** *Actualización del número de casas en el banco de datos del PMRR.*

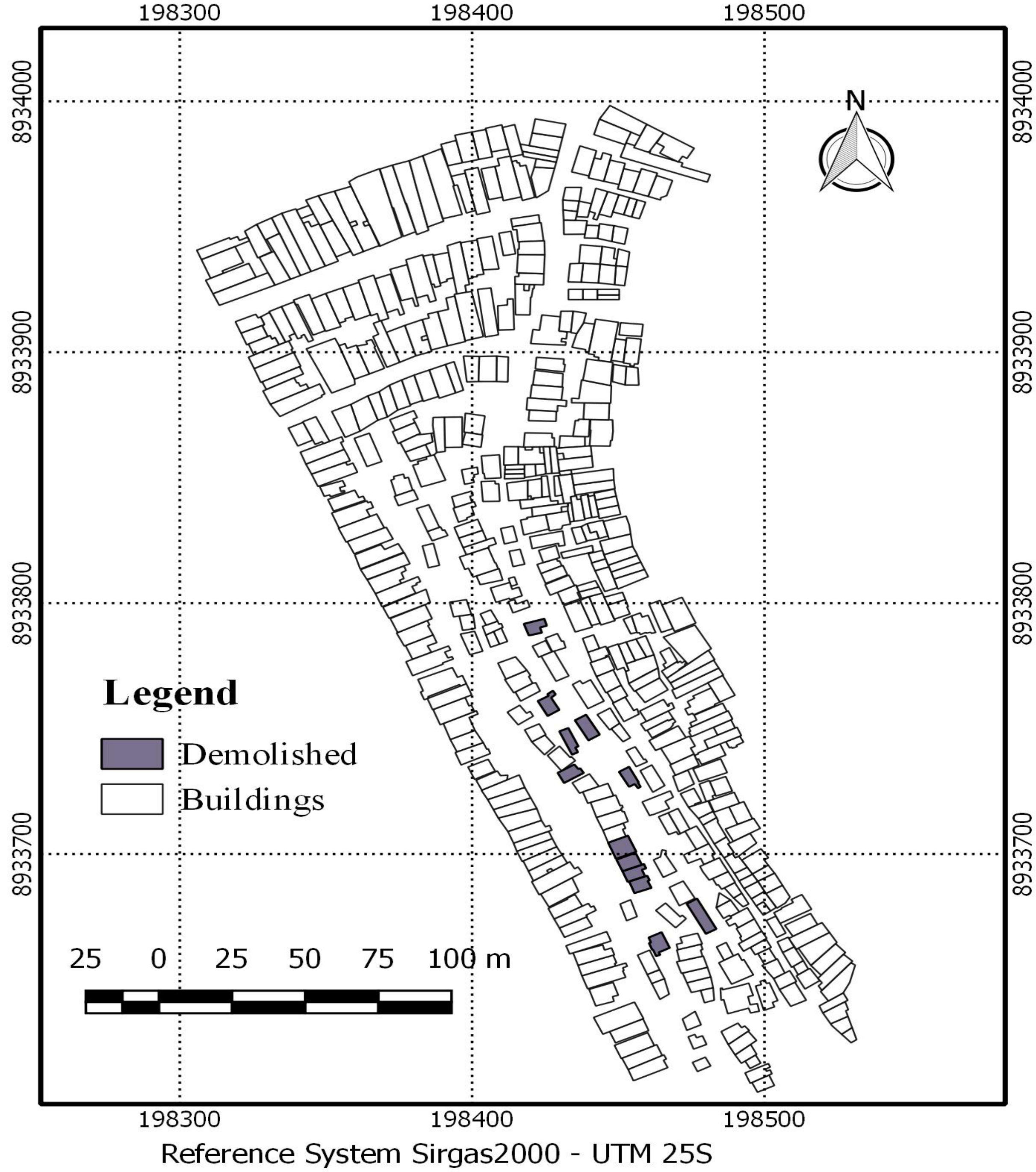

Figure 5. Updating of building conditions. / **Figura 5.** *Actualización del censo sobre condiciones de las casas.*

At the bottom of buildings with numbers 167 to 170 (figure 3), a cut slope with exposed soil, identified as slope 1 in previous studies (Soares and Toujaguez, 2015) is found. Being the erosive feature of larger dimension in subarea 1, with height of 10 m and width of 9.70 m, with soil characterized as clayey sand. Above this feature, from the figures 4 and 5 it is observed that there were demolitions, but also, new buildings were built. These works may have contributed to the sum of the stresses exerted on the soil at the top of the slope (in addition to slope and rainwater discharge directly on the slope), facilitating the loss of cohesion between the sandy soil particles at the top of the slope 1. Even during the dry season, however, facilitating the

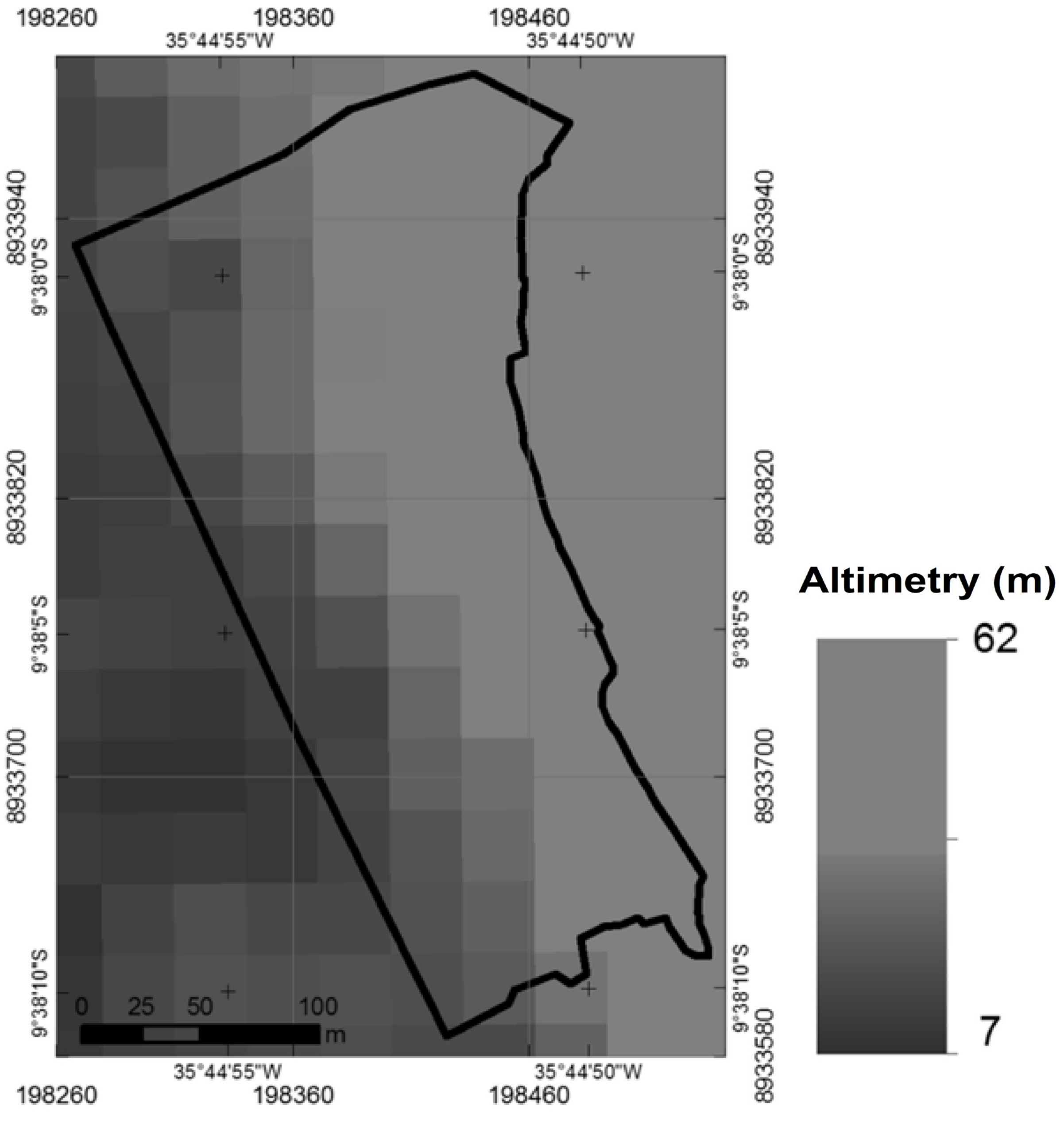

Figure 6. DTM from subarea 01 of the Mutange District. / **Figura 6.** *MDT de la Subárea 01 en el Barrio Mutange.*

erosive action of rain during the winter.

When there is the largest record of landslides in the area and, therefore, the period of greatest geological risk (Parizzi, 2014).

The identification of abandoned buildings, ruining or that already collapsed was also carried out. In some situations it was still possible to see traces of building materials in the place where buildings existed and reports of residents confirming the situation, 13 houses were identified in this state, as shown in figure 5.

It is observed in figure 5 that due to the lack of infrastructure in the area some residents had to move to other locations. Due to the occurrence of adverse events and/or suggestion of COMDEC due to the destruction of the residences. Mainly due to slides after accelerated erosion generated by heavy rains as happened in 2010. Although, from the cadastre data, it was observed that during visits that the population prefers to remain in the place, tied to their roots, even knowing that exposure to danger may bring

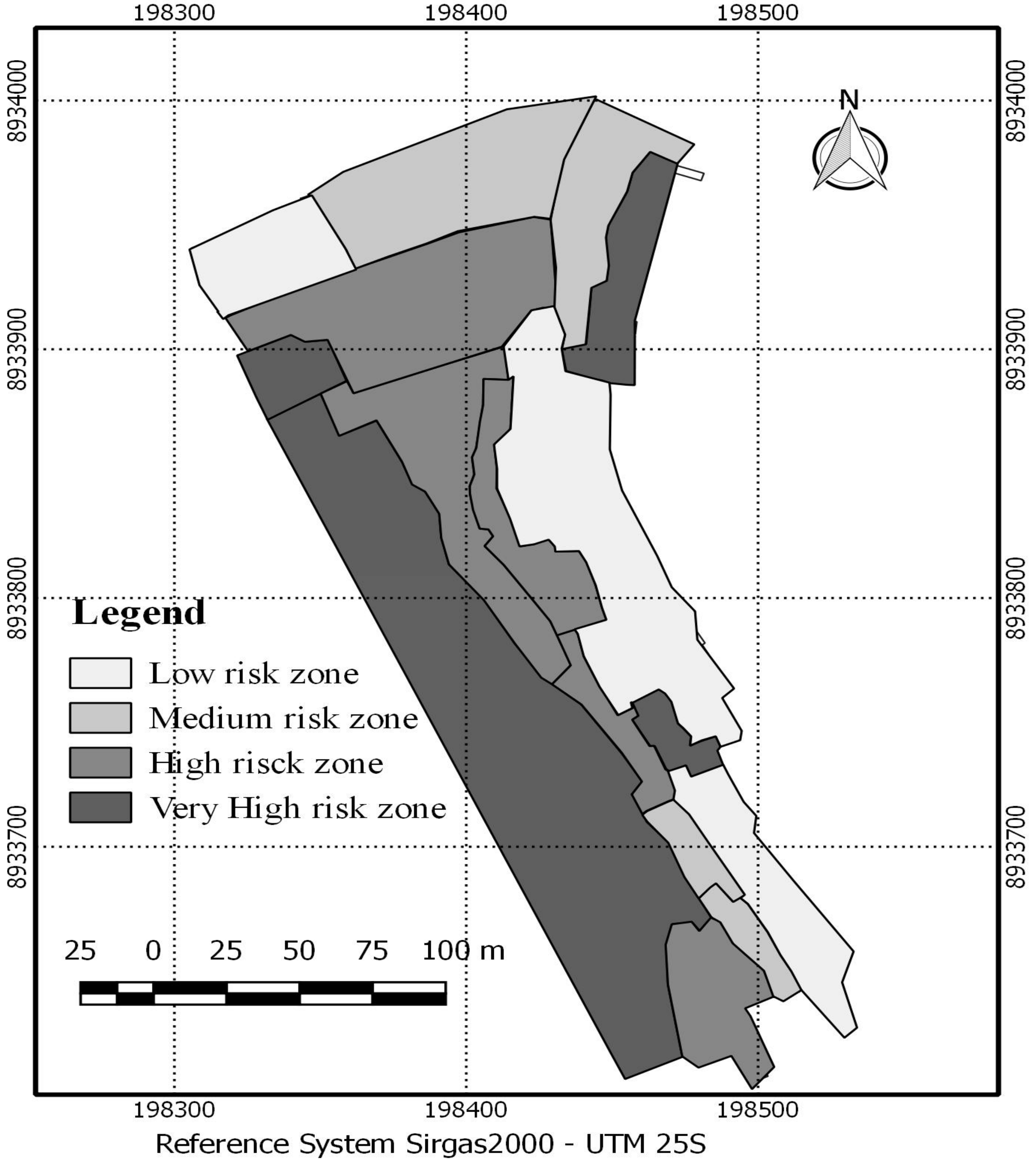

Figure 7. Risk zoning area of subarea 01 of Mutange district. / **Figura 7.** *Actual Zoneamiento de riesgos en la Subárea 01 del Barrio Mutange.*

damage to health and material losses (Cerri and Amaral, 1998).

Another way to analyze the subarea 1 behavior was by the DTM creation. It was fundamental to represent the altimetry variability as shown in figure 6.

Based on the data collected from the cadaster and the generation of the MDT, as well as the database update, it was possible to produce a proposal for a new risk zoning of subarea 01, which was divided into 4 zones, as shown in figure 7.

It is observed in figure 7, 4 zone classifications: very high risk, high risk, medium risk and low risk. For the classification of the area the following criteria were observed:

Very high risk zone - Areas near water

bodies, very inhabited, with demolished houses, dwellings at the top or base of slopes, hill with inclination angle equal or greater than 90º, areas susceptible to many mass gravitational movements and floods.

High risk zone - areas slightly distant from water bodies, inhabited, areas slightly distant from the top and base of slopes, hill with inclination angle between 59º and 90º, areas susceptible to mass gravitational movements and floods.

Medium risk zone - areas away from water bodies, ordered dwellings, areas slightly distant from the top and base of slopes, hill with inclination angle between 29º and 60º, areas susceptible to few mass gravitational movements and floods.

Low risk area – areas distant from water bodies, orderly dwellings, areas well-spaced from top and bottom slopes, hill with inclination angle less than 30º, areas that are not susceptible to mass gravitational movements and floods.

Additionally, from figure 7 it was observed that occupation monitoring of these areas is important for risk prevention, as well as geological risk. Another important factor is the analysis of the vulnerability of dwellings that are in topo or base of slopes and cut embankments.

Conclusions

The Multipurpose Territorial Cadaster (MTC) used in geological risk mapping (Águila and Erba, 2007; Cunha and Erba, 2010) was shown to be effective for surveying cadastral data and generating DTM. It made possible the analysis of the risks that the inhabitants in the area find, as well as the geological risk that the area presents. It is worth noting that this methodology can be applied in the other sub-areas of the Mutange district, since the risk zoning was initially applied only to subarea 01, as it can be used in other areas that present the characteristics identified in the zoning map of risk.

The maps generated in this work can be used to update the geological risk mapping with the PMRR, allowing better monitoring of the area, as well as other areas that present risks.

From the results generated it is possible to update the data of dwellings, numbers of people, infrastructure, among others. In addition, it is possible to evaluate the susceptibility of the area with the field data of the surveyed cadaster and with the maps generated.

For future work it is recommended the development of geotechnical charts and erosion susceptibility charts, mass gravitational movements and floods, the continuation of this methodology throughout the area of the Mutange. It emphasizes the need for urgent intervention in slope 1 with vegetation cover and discipline of the storm drains around and at the base of the slope.

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