

Spatial Analysis of Disaster Risk in Santo Domingo De Heredia, Costa Rica, Central America

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Abstract

This article summarizes the results of an investigation into disaster risk in the *canton* (county) of Santo Domingo de Heredia, Costa Rica. This *canton* is exposed to several natural hazards as well as technological risks. While the Costa Rican national law related to management of risks and emergency confers the responsibility for managing risks on municipal authorities, they are unprepared for this task. As such, we conducted this analysis to facilitate the tasks assigned by law and accelerate the process of informed disaster risk management in Santo Domingo. Threats and vulnerabilities were mapped in each of the 140 Minimum Geostatistical Units (MGU) of the *canton* and then a disaster risk index combining both was estimated and mapped. The main threats in Santo Domingo are floods, volcanic eruptions, earthquakes, landslides and incidents associated with a pipeline that crosses the *canton*. The main social vulnerabilities are physical and economic. In most of the *canton*, disaster risk is relatively low but it is quite high in the southern reaches of the *canton*, in the districts Santa Rosa, Santo Tomas and San Miguel.

Keywords: risk, disaster, hazards, vulnerability, index

1. Introduction

Disasters cause pain and death, substantial economic losses and delays in social, education and health programs. As such, disaster risk reduction must be a national and local priority for action (ISDR, 2005). Therefore, it is imperative to identify, assess and monitor disaster risks and enhance early warning systems. The risk managers must then use this new knowledge and innovation to create a culture of safety and resilience (i.e., the ability to confront hazards) at all levels. Risk factors (threats and vulnerability) must be reduced and disaster preparedness should be strengthened in order to ensure an effective response. National law in Costa Rica charges local governments with the onus of managing and responding to risks within their jurisdiction. Specifically subsection h of Article 14 of the National Law of Emergencies and Prevention of Risk, N° 8488, states that local governments are the entities that are primarily responsible for managing risks in their territories. According to Agreement No. 0443-2011 of the National Commission of Risk Management and Care of Emergencies (CNE in Spanish), all mayors should evict occupants in recognized risk and danger areas, implement the recommendations from CNE technicians and academic institutions, and take concrete and timely actions to safeguard human life in areas of known risk and danger.

Within this backdrop of local responsibility for risk management, this research was carried out in partnership with the local government of Santo Domingo in the difficult task of managing the risks of disasters of the county. Santo Domingo has areas of high risk (Reyes et al., 2014a) and therefore, it is imperative that the local government ensure the safety of people living there. But beyond the support provided to the municipality of Santo Domingo, this study seeks to promote risk management in all municipalities of the country by serving as a model for how to inform local authorities to initiate such management. What was done in Santo Domingo can be done in any other *canton* and if this is done in all *cantons*, Costa Rica will have started a new era in the

management of risk in the country, which would put us on the right path towards the culture of disaster prevention.

The objectives of this paper are to identify and map threats and vulnerabilities in the *canton*, and then to combine them to determine the spatial distribution of a disaster risk index for the 140 census units (i.e., Minimum Geostatistical Units or MGUs) of the *canton*. The MGUs are shown in Figure 1.

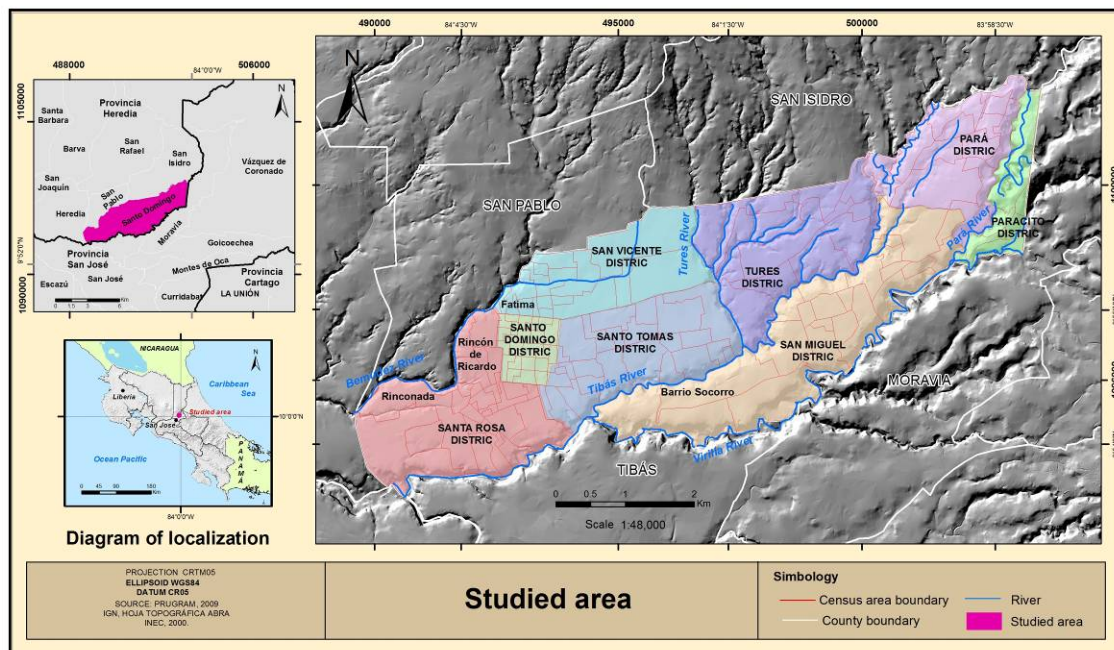


Figure 1. The territory of Santo Domingo and its districts. The smaller areas within the districts are the Minimum Geostatistical Units (MGU)

2. Antecedents

Previous studies have provided evidence for the presence of natural and anthropogenic hazards in Santo Domingo. One of the first works on the subject is that of Paniagua and Soto (1988) who studied the volcanic hazard of volcanoes from Central Costa Rica and showed that fall of ash from them is one of the main potential volcanic impacts for communities of Central Costa Rica. Fernández and Rojas (2000) analyzed the faulting, shallow seismicity (0-30 km), and seismic hazard of the Costa Rican Central Valley. Pérez et al. (2004) recognized an explosive event that left significant deposits in the territory of Santo Domingo 322 K year ago. The canton is exposed to the potential for seismic intensity of VIII and IX degrees on the Modified Mercalli Scale (Reyes et al., 2014b). Those intensities include the following effects: general panic, destruction of medium and low quality construction, general damage to the foundations and the frameworks of buildings, serious damage to dams, rupture of underground pipes and visible cracks in the ground. Moderate and large magnitude earthquakes associated with seismic areas close to Santo Domingo have caused significant structural damage throughout the territory in the past.

Linkimer (2008) examined the correlation between the intensity of the earthquakes and the maximum acceleration generated by them. Benito et al. (2012) analyzed the maximum accelerations produced by Costa Rican earthquakes, which includes those that may cause damage to the structures of the studied area. Fernández et al. (2012) investigated the floods of Santo Domingo finding that the most important events have been those of 1999 and 2010 which severely affected the communities Fatima, Rincón de Ricardo and La Rinconada and left dozens of homes uninhabitable.

In 2012, we began the project “Determination of the risk of disaster in Santo Domingo de Heredia”. As part of this, we have investigated the threats and vulnerabilities present in the canton and we have verified the existence of threats both technological and natural. Fernandez (2013a) evaluated the seismotectonics of the central part of

Costa Rica, which includes Santo Domingo, and analyzed a hypothetical strike-slip fault system that is supposed to pass through it.

Reyes and Fernández (2013b) studied the technological hazards of Santo Domingo and found that the incidents in industrial plants, gas stations and a pipeline are the main anthropogenic hazards of the canton. The main technological hazard may be the potential for accidents associated with the pipeline that transports oil derivatives from the refinery in the Caribbean side of Costa Rica to the storage tanks located in the central side of the country and that passes through the districts of Santa Rosa, Santo Tomas and San Miguel in the south of the canton; so far there have been no accidents, but it cannot be dismissed that there is a strong likelihood for one in the future. Small accidents have occurred in the industrial areas of Santo Domingo during the handling of dangerous substances, for example, there was an explosion caused by the accidental contact of lithium hydride with water in May 2007 that caused injury to an employee of the chemical company (Coto, 2007).

Reyes et al. (2014) described the natural hazards of the canton and determined that floods, landslides, volcanic eruptions and earthquakes are present in Santo Domingo. The seismic hazard for Santo Domingo has been briefly described in Reyes et al. (2014b). Reyes and Fernández (2014a) assessed the potential of landslide for Santo Domingo and found that although that territory is relatively flat, the potential for landslides exists and deadly landslides have occurred there (e.g., the 2008 landslide in Barrio Socorro, San Miguel District, see Figure 2). Reyes and Fernández (2014b) investigated the maximum human vulnerability of Santo Domingo and found that the critical areas of vulnerability overlap with flooding zones where the human settlements have significant physical exposure and are inhabited by people with low economic resources.

3. Methodology

To estimate the disaster risk for Santo Domingo, hazards and vulnerabilities were identified and the resulting spatial information was combined to obtain a disaster risk index following Collins et al. (2009). Data came from the Instituto Nacional de Estadística y Censo (INEC), consultations at the headquarters of the institutions of the canton, Compañía Nacional de Fuerza y Luz, and field work. The analysis was done using the ArcGIS 10.x Model Builder.

Technological (Reyes & Fernández, 2013) and natural (Reyes et al., 2014a) hazards were identified through bibliographical consultations and field reconnaissance. The maps of technological hazards (i.e., pipeline, industrial areas, and gas stations) were created with information collected in the field and through the use of other data from the PRUGAM (Planificación Regional y Urbana de la Gran Area Metropolitana) project. Geomorphological maps, derived from air photos, were used to evaluate areas at risk to landslides and flooding (Reyes et al., 2014a). These maps involved information about slopes, lithology and rain pattern. Volcanic and earthquake risk maps for Santo Domingo were downscaled from national-level sources for integration in this analysis (Pérez et al., 2004; Paniagua & Soto, 1988; Benito et al., 2012; Fernández et al., 2013; Reyes et al., 2014b).

To create the hazard density index, a score between 0 and 1 was assigned to each hazard in each MGU according to the number of events (landslides, floods) or geographical coverage of the hazard (e.g., a MGU with 100% coverage for volcanic products would receive the score of 1 for volcanic eruptions). The hazard density index method was used to calculate each hazard index (Bolin et al., 2002). This method gives each MGU an estimate based on the density of each hazard in them. The hazard measures for each MGU were then summed by adding the indexes calculated for each individual hazard together (Reyes et al., 2014). The resulting index was then standardized by dividing the cumulative hazard density score of each MGU by the maximum, in order to create a unique hazard density index ranging from 0 to 1.00, with higher values indicating greater hazard.

The components of the global vulnerability addressed in this work are physical, social, political, technical, economic, educational and institutional vulnerability (Wilchez, 1993). Each type of vulnerability is comprised of a series of variables that will have equal weight at the time of obtaining comprehensive map of vulnerability. The total population and total housing increase vulnerability as grows the amount. The communal organization increases social cohesion and reduces vulnerability. Physical health increases the resistance to hazards (Pelling, 2004) and therefore, reduces the vulnerability. At local level of organization, women are often best positioned to manage the risk, because of their role as users and administrators of the environmental resources, as a source of economic livelihood, as well as care providers and community workers (Wilchez, 1993). It is therefore necessary to identify and use information differentiated by gender, to ensure that risk reduction strategies are properly directed to the most vulnerable groups (Words into Action, 2007). The elderly, children and disabled can suffer limitations due to their status, which would make difficult their response to a hazard, increasing the vulnerability. The lack of autonomy of the community to manage its risks, inadequate structures, low income by family, lack

of educational programs at risk of disaster and the absence of public institution and leadership (this variable can be measured by identifying organized groups and local actors involved in disaster risk management) also increase the vulnerability.

Table 1. Indicators of vulnerability. ↓ reduce the index ↑ increase the index

Risk factor	Indicador	Direction of Influence	Source of information
Natural Hazards	Floods	↑	RET
	Earthquakes	↑	RET
	Volcanic eruptions	↑	RET
	Landslides	↑	RET
Technological Hazards	Incidents in pipeline	↑	RF
	Incidents in gas stations	↑	RF
	Incidents in factories	↑	RF
Physical Vulnerability	Human settlements located in high risk areas	↑	Field research
Social vulnerability: population and structures	Total population	↑	INEC 2000
	Total number of houses	↑	INEC 2000
	Number of organized groups (Local organization)	↓	Field research
	Location and type of health services	↓	INEC 2000
	Female population	↑	INEC 2000
	Participation of women in risk management	↓	
	Number of persons under 18 years of age	↑	INEC 2000
	Number of persons over 64 years of age	↑	INEC 2000
	Disabled population	↑	INEC 2000
	Community participation in decision-making	↓	Field work
Political Vulnerability	Leadership	↓	Field work
	Government support to community management of disaster risk	↓	Local government
	Mitigation resources	↓	Local government
Technical Vulnerability	Construction techniques.	↓	INEC 2000
	Structural resistance	↓	INEC 2000
	People with no health insurance	↑	INEC 2000
Economic Vulnerability	Condition of housing stock	↑	INEC 2000
	Electrical consumption	↓	CNFL
	Households that rent	↑	INEC 2000
	Average level of education (weighted average of the level of instruction)	↓	INEC 2000
Educational Vulnerability	Training courses in disaster risk management	↓	Field research
	Disaster risk management plans	↓	Field research
	Education in disaster risk management	↓	Field research
	Institutions involve in disaster risk management.	↓	Field research

Note: RET: Reyes et al. (2014a), RF: Reyes & Fernández (2013).

To determine human vulnerability index, 25 indicators were re-scaled and summed (see Table 1). Using a similar approach to the hazard indicators, we re-scaled each indicator to range between 0 and 1, with 1 corresponding to maximum vulnerability. A comprehensive map of human vulnerability, with corresponding measurements for each MGU, was created by adding all variables of individual vulnerability scores together. As with hazard variables, each variable of vulnerability was standardized by dividing its MGU value between the maximum in all the MGU (maximum MGU value), to create an index that varies between 0 and 1.00, with a higher value indicating greatest vulnerability. Once the values for each indicator were summed, they were re-scaled on a new scale from 0 to 1.00. These indexes were imported into the GIS as a data layer and deployed on maps.

The spatial overlap of the cumulative hazard and vulnerability indexes generates a disaster risk index. To obtain the final index, the scores of hazard and vulnerability were summed in each MGU and standardized by dividing between the maximum value across all the MGUs, to create an index that varies from 0 to 1.00, with 1.00 the maximum risk.

4. Results

4.1 Hazards

According to the investigation, in Santo Domingo there is geographical variability in the technological and natural hazards. The county is exposed to the potential for seismic intensity of VIII and IX degrees on the Modified Mercalli Scale (Reyes et al., 2014b).

The areas close to the river canyons present higher hazards, while low-hazards places are found in the central area of the *canton*. Even in some places that are relatively flat, a high level of biophysical hazard may exist due to inefficient water transport systems for rain and domestic uses, which led to inundations during maximum precipitation events.

Figure 2 shows the distribution of the hazards density index for Santo Domingo. Santo Domingo, Santo Tomás, Tures and Pará districts have low density of hazards. This is because there are only two important hazards in those districts: the potential for volcanic events and earthquakes. The remaining districts, namely San Vicente, Santa Rosa, San Miguel and Paracito, have the highest density of hazards. Of these, San Vicente has had the most serious incidents to date.

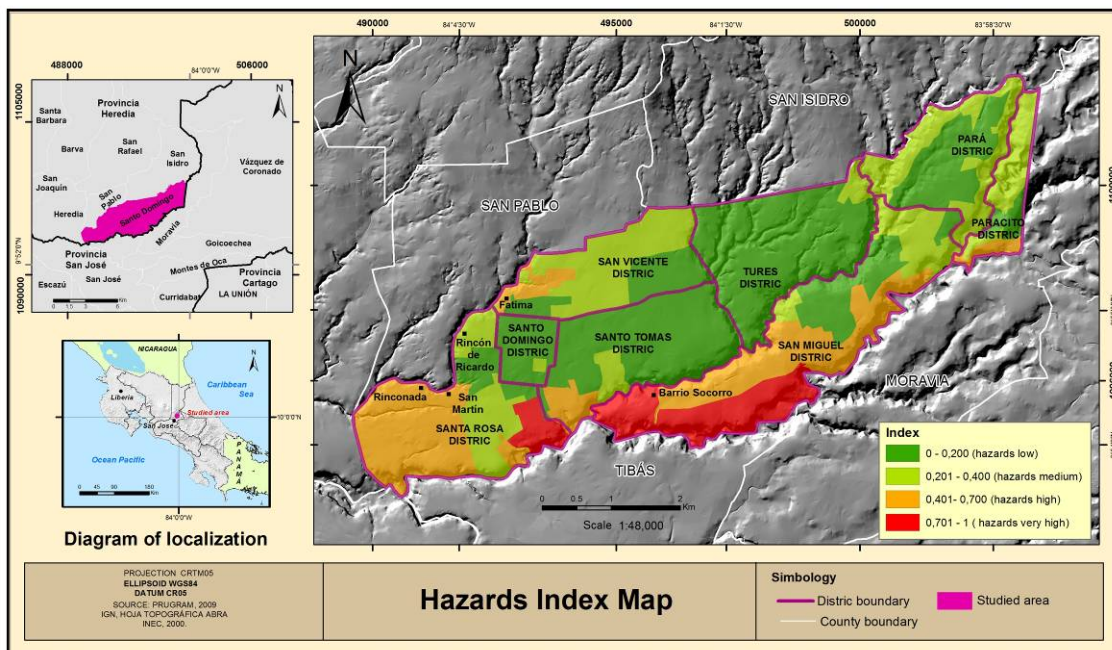


Figure 2. Map of hazards density index in Santo Domingo

San Vicente has suffered from serious flooding in Barrio Fatima (see Figure 3), a settlement located on the slope of the Bermudez river. The overflows are due to insufficient hydraulic capacity in the river. On the slopes, there are also signs of landslides. In San Vicente there is also possibility of industrial incidents like explosions in gas tanks.



Figure 3. Damage in Barrio Fátima caused by the flood of 2010. Courtesy of Oscar Sojo

The value of the hazard index in Santa Rosa is due to the concentration of industrial activity in that district and also to the presence of the oil pipeline. The Bermúdez river also cause problems in neighborhoods of this district including Rincon de Ricardo and Barrio San Martin. The district also has a human-made floods generated by lack of capacity to evacuate the rainwater.

In San Miguel, the hazard index score is relatively high because, in addition to the seismic and volcanic hazards, part of the district is crossed by the oil pipeline and there is possibility of landslides on its north and south boundaries, which correspond to the edge of the rivers Tibás and Virilla. On the northern border, a deadly landslide took place in 2008. A long segment of the pipeline that crosses the canton is also located in this district.

Only a small part of the Paracito district has a high hazard density index, and this is in its southern end. This is explained by the landslide potential, which is at its maximum in this section of the cantón (Reyes y Fernández, 2014).

Based on the above information we conclude that southern and western sectors of Santo Domingo have the highest density of hazards. It is important to note that most of the territory is under relatively low hazard.

4.2 Vulnerability

Figure 4 shows the result of the combination of the 25 indicators of vulnerability in Santo Domingo. The spatial distribution of vulnerability can be grouped into 3 categories: medium-low (0-0.769), high (0.770-0.846) and very high (0.847-1). Approximately 45% of the territory has an index of vulnerability between low and medium. Another 45% can be characterized as having high vulnerability and 10% of the area has very high vulnerability. High vulnerability, especially in the northern areas, is influenced by the lower levels of electrical consumption (which corresponds to higher levels of poverty), lower levels of education, which is more common in rural areas, the fewer numbers of institutions, the lack of disaster preparedness at in the time of the study, low levels of organization and lower levels of social cohesion in the rural areas.

The red areas in Figure 4 have the greatest vulnerability. There are physical and economic aspects within them that greatly contributes to the vulnerability. One of these factors is the location of human settlements in or near areas of high hazard, in which human beings are extremely exposed to the impact of natural and anthropogenic adverse events. Other aspect is the economic factor which is very important in the construction of vulnerability since people in poverty and those with few economic resources often settle in hazardous areas not suitable for living (Figure 5), where land prices are very low or virtually zero. They live at high-risk, even though their lives might be threatened because they have no money to settle in a better place. Therefore, they have reduced capacity to face the danger and in consequence they suffer the most when the threats are manifested.

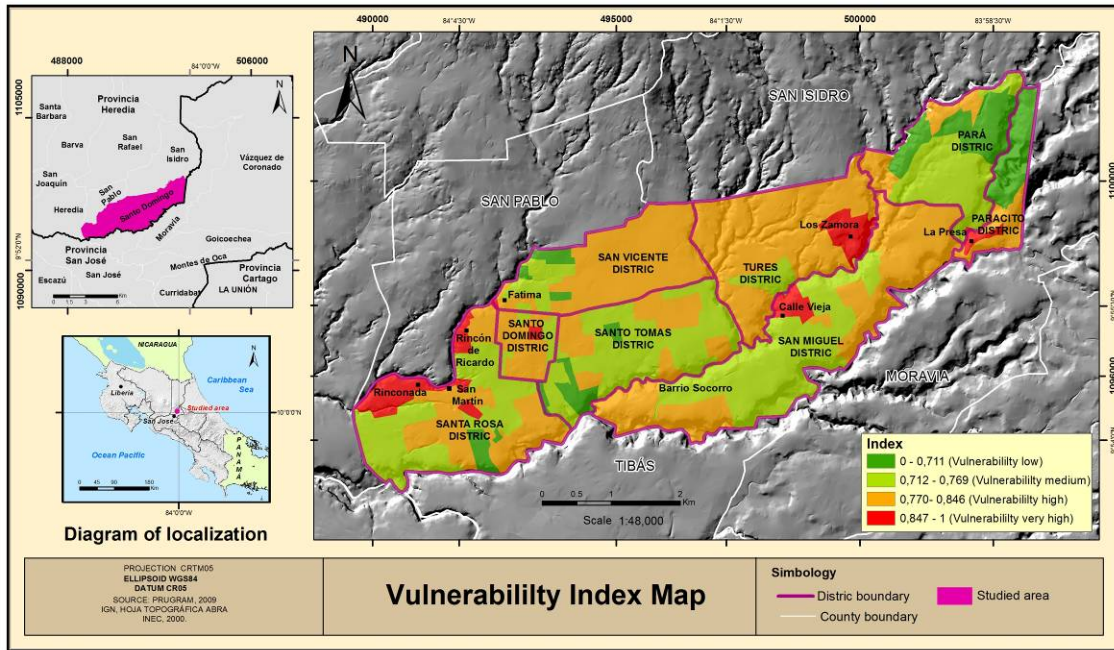


Figure 4. Distribution of the vulnerability index in Santo Domingo de Heredia

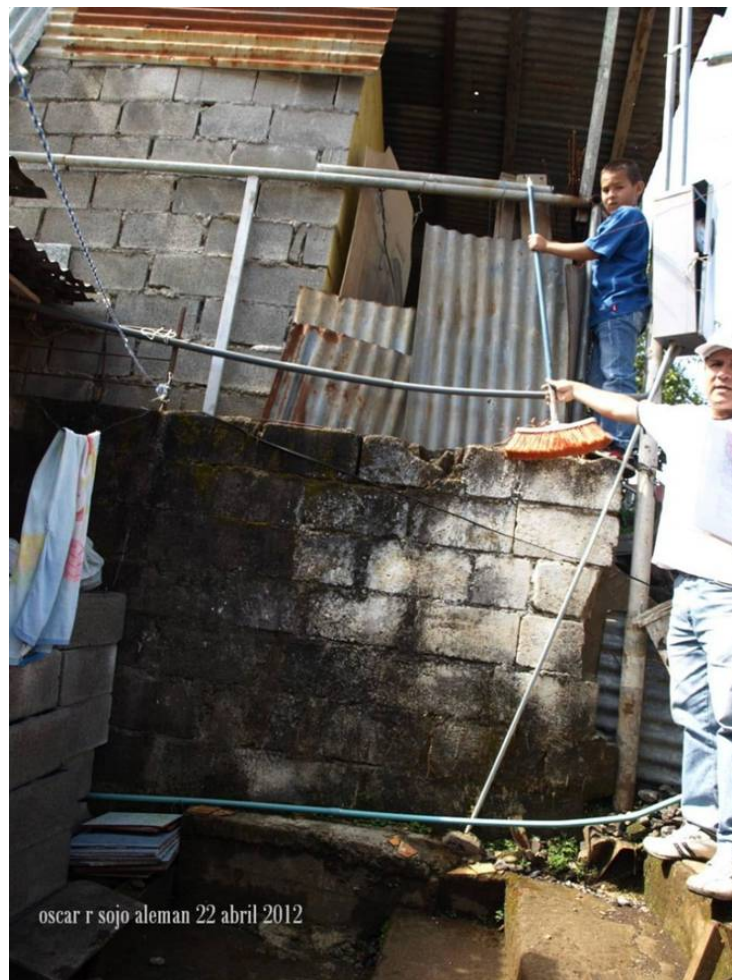


Figure 5. Houses occupied by low-income families near the Bermúdez river in San Martín. The child shows the height (of almost 10 meters) of the inundation in July of 2010. Courtesy of Oscar Sojo

According to the study, the most vulnerable populations of Santo Domingo reside in some areas of the south and west of the *canton*, specifically La Rinconada, San Martín, Rincon de Ricardo, Calle Vieja, La Zamora and a small sector of Paracito. A curious fact is that in the central district, in the city center of Santo Domingo, there is a small area of high vulnerability which is due to the concentration of older aged residents there, which increases vulnerability due to a reduced capacity to respond in a disaster and hence, lower resistance to confront the threats. The study found general overlap between populations of lower incomes and high levels of hazard.

4.3 Disaster Risk Zonation

After combining the information about hazards and vulnerabilities of Santo Domingo we obtained the map of disaster risk shown in Figure 6. Such map shows that around 80% of the territory is under the category of low to medium risk. A little more than 10% of the total area is at high risk and less than 10% in very high risk. The districts having higher levels of risk are Santa Rosa, San Vicente and San Miguel. Santo Tomás and Paracito have small areas of high risk.

The high risk of the Santa Rosa district is mainly due to the concentration of industry and a low income population on one hand and the presence of natural and technological hazards on the other. Santa Rosa is one of the most populous districts of Santo Domingo. In the south it is threatened by a pipeline and in the north by the floods of the Bermudez river. Its critical points, according to estimates, are la Rinconada and sector bordering Santo Tomás. Both sites are densely populated and in the case of the border sector mentioned, risk is increased by the presence of a gas station.

The critical area of San Vicente is Barrio Fatima, a settlement occupied by poor families who for many years have lived in an area of high risk that becomes increasingly risky as time pass. The only alternative to reduce the risk of this community is to relocate the population, which is already being done by the local government.

San Miguel yields a high risk basically due to the presence of important hazards as the landslide potential and incidents in the pipeline and the presence of people who live close to those threats.

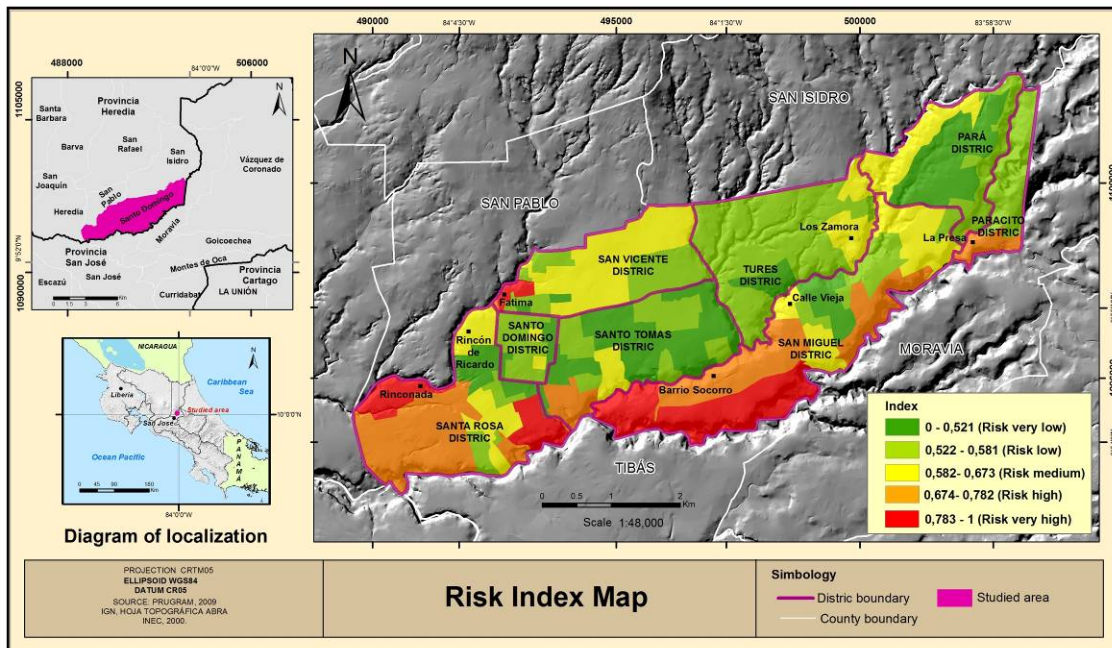


Figure 6. The resulting map of Risk Index

5. Limitations

The MGU is the smallest territorial unit of Costa Rica and although this allows us to capture maximum spatial variability in this estimation of risk, the big size may affect the accuracy of the results as error would be maximized at lower spatial resolution. Another factor that affects the quality of the results is the age of the social data; population census data from 2000 were used in this study because the most recent census was not yet available. For the assessment of social vulnerability, it was sometimes necessary to use proxy variables (e.g.,

energy consumption for economic status) given data limitations. Finally, within each index, we assigned equal importance (weighting) to all layers of information, as did Collins et al. (2009). If we gave different weights to the layers (e.g., based on severity or potential for harm), the end result may be more accurate. We hope to do that in future research. Also, in future studies, it would be advisable to study the stability of the slopes on which Barrio Fátima, Monte Carmelo and Calle Vieja are located.

6. Application of the Results

The results of this research are part of a project called the National Information Infrastructure for Disaster Risk Management. This project will be a catalyst for disaster risk management at the local level (Municipalities). The municipality of Santo Domingo will have a local platform with the disaster risk information of its territory. The information presented here will be given to local risk managers who are charged with implementing efficient and sustainable risk management at the local level. It is our hope that the members of the municipal and district emergency committees will study, analyze and improve the information about hazards, vulnerability and risk presented here.

In Costa Rica, the local organization for disaster risk management consists of a municipal committee and a committee for each district. In Santo Domingo, for example, there is municipal committee and eight district committees for emergencies. The staff of each district committee consists of 15 members, which include a coordinating group, and ten more members that have responsibility for the following aspects: shelters, volunteering, information management, evacuation and rescue, risk assessment, storage, management of supplies, health, security and education and divulgation.

Then, Santo Domingo has a contingent of at least 120 risk managers that will use this information to reduce disaster risk and better manage emergencies or disasters that occur. As these people know better the territory than external specialists, they could contribute much to improving of the estimates presented in this study and with the reduction of vulnerability and therefore risk.

7. Conclusions

Santo Domingo is a canton of low to medium index of risk of disaster; 80% of its territory is under this condition. The districts of San Vicente, Santa Rosa, San Miguel and Paracito have the highest density of hazards. The most vulnerable populations of Santo Domingo reside in the south and west of the canton, specifically in the district of Santa Rosa, San Miguel and Paracito. The most vulnerable communities are La Rinconada, San Martín, Rincón de Ricardo in Santa Rosa, Barrio Fátima in San Vicente, Calle Vieja in San Miguel, La Zamora in Turés and a small sector of Paracito. The districts having more disaster risk (i.e., the sum of hazard and vulnerability) are Santa Rosa, San Vicente and San Miguel. Santo Tomás and Paracito have small areas of high risk. Indicators that have more influence on the vulnerability of the *canton* are exposed settlements and poverty.

The results could improve if the new census data is used and if we give different weights to the variables.

If this spatial analysis of disaster risk is replicated in all cantons of Costa Rica, the country will become one of the best prepared in disaster risk management and therefore, emergencies and disaster management will be easier and more effective. With the new approach, the risk management will be local and participatory instead of national and centralized as it is today.

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