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Disaster Risk Assessment of Informal Settlements in the Global South

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Abstract: More than a billion people live in informal settlements worldwide. Their high exposure and vulnerability increase the risk of disaster in their lives. Global changes challenge the capacity to seek practical and quick solutions for the most disadvantaged groups. Most people in Costa Rica reside in the Greater Metropolitan Area (GAM, or Gran Área Metropolitana in Spanish), and nearly half of the informal settlements of the country are also located there. This paper aims to determine the disaster risk of every informal settlement of the GAM in Costa Rica. The study merges the official information that is available to calculate the hazard, exposure, vulnerability, and the risk levels of every informal settlement in the GAM. Moreover, a risk index for informal settlements in the GAM was created using a Pearson correlation technique, normalizing, and spatially distributing the results in three groups (high, medium, and low). The study outputs indicate that municipalities with a greater number of informal settlements also concentrate the higher risk unit's percentage. Moreover, a direct statistical relationship is present between the historical number of disaster events in the municipalities with more informal settlements. The urban context proves useful to apply a methodology that could determine the disaster risk level of informal settlements in less-developed countries where baseline information for hazard, exposure, and vulnerability calculation is usually scarce, limited, or low in quality. This research shows the conditions of dozens of countries belonging to the Global South and constitutes a useful example for all of the stakeholders of disaster risk reduction worldwide.

Keywords: physical geography; urban geography; developing countries; Global South; disaster risk reduction

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1. Introduction

The growth of urban populations worldwide is incessant, with approximately four billion people living in urban contexts [1]. Over 1.6 billion people (~25% of the world's urban population) live in deprived neighborhoods or informal settlements that are commonly known as slums [2,3]. Informal settlements or slums are areas where clusters of dwellings have been built on land that the occupants do not legally claim or that they occupy illegally and lack adequate basic services [4–6]. Informal settlements in urban areas of developing countries are generally characterized by a crowded, small-grain, and erratic urban morphology [7]. People living in slums are projected to increase exponentially in the next decades if no action is taken [8–10]. In this context, Latin America and Costa Rica's urban areas commonly present many informal settlements surrounding the cities or are in natural-risky areas [11–16].

Floods and landslides, especially in developing and tropical countries, are among the most frequent disasters in the world [17–20]. Informal settlements do not escape this trend and are normally affected by hydrometeorological/climatic hazards (floods, landslides, droughts) and eventually to fires [21–25]. Dozens of countries have limited or scarce data to estimate differentiated risk levels at the informal settlement scale. This condition intrinsically underestimates the disaster risk in these urban units. Remote sensing and geographic information systems can be very useful characterizing and analyzing informal settlements and their environmental impacts (such as natural risks) [26].

Nearly half of informal settlements are in the GAM, where almost three fourths of Costa Rica's population reside [27–29]. Moreover, this region gathers the greatest number of municipalities with a higher record of disaster events during the last few decades. Furthermore, there is a research gap in the Global South to identify practical approaches to determine disaster risk levels of informal settlements to take actions from national, regional, and local decision-makers scales. This study hypothesizes that the municipalities with numerous riskier informal settlements are also the political-administrative units with the most documented disaster events throughout the historical record in Costa Rica. Hence, the aim of this research is to design and apply a disaster risk index for informal settlements under limited-data conditions for developing countries using the GAM in Costa Rica as a pilot study for the developing countries of the Global South.

2. Materials and Methods

2.1. Costa Rica and the GAM's Geographical Setting

Between Panama in the south-east and Nicaragua at the north-west, Costa Rica lies in southern Central America at the coordinates of 8–11.2° North and 82.5–86° West. The country is located among four tectonic plates (Cocos, Caribbean, Nazca, and Panama) along with their seismic and volcanic implications [30]. Due to its isthmic position bordered by the Pacific Ocean and Caribbean Sea, as well as its latitudinal location, the country is controlled by the Intertropical Convergence Zone, El Niño Southern Oscillation (ENSO), cold fronts, trade winds, and the indirect/direct effect of tropical cyclones. The coupled dynamics among tectonics, vulcanism, tropical precipitation, and a varied topography provide a suitable combination for different disasters occurrence such as earthquakes, volcanic hazards, landslides, and floods [31]. Nonetheless, roughly ninety percent of the recorded disasters in Costa Rica are hydrometeorological in nature (mostly floods and landslides) [32].

The GAM is in the Central Tectonic Depression of Costa Rica [33], which is surrounded by the Central Volcanic Range at the NE to the NW (e.g., Turrialba, Irazú, Barva, Poás, and Platanar volcanoes), and the Talamanca Range at the SE to the SW (Cerros de la Carpintera, Escazú, and Montes del Aguacate). Costa Rica's population reached 5 million in 2018, and approximately 70% of its inhabitants and the highest population densities are settled in the GAM, which only covers 14% of the national surface [34–36]. The GAM's geomorphology determines the land uses and therefore the urban expansion and subsequent environmental impacts during the urbanization process of the last century [37–39].

2.2. Informal Settlements Risk Determination

The Ministry of Housing and Human Settlements (MIVAH) of Costa Rica has identified 296 informal settlements in the GAM (more than 40% of the national total) with approximately 132.000 inhabitants [40]. To perform a risk index for informal settlements in the GAM, it was necessary to use the best-scale data provided by the MIVAH and additional topographic and socioeconomic parameters (Table 1). The hazard index (Hi) was performed employing the mean slope (SLP) and distance to rivers (RIV) values of every informal settlement. The exposure index (Ei) was calculated using the population density (PD), total population by informal settlement (POP), the number of houses (HOU), and the constructed area (AREA) by informal settlements. To calculate the vulnerability index (Vi), the social development index (SDI) was used (MIDEPLAN-Ministry of National Planning and Economic Policy) [41]. The index merges and assesses educational, civic participation and economic, security, and public health parameters of the districts in the GAM. This index was successfully applied in vulnerability indexes for Costa Rica in the recent past [42–44]. To eliminate the parameters within high collinearity, a Pearson correlation technique [45] was employed to select every parameter weight for each index (Supplementary Material).

The parameters were normalized and distributed in three groups, applying a quantile classification procedure [46]. Therefore, the study calculation is defined as follows:

$$Hi = (SLP * 0.55) * (RIV * 0.45)$$

While,

$$Ei = (PD * 0.35) * (POP * 0.35) * (HOU * 0.3)$$

Ultimately,

$$Ri = (Hi * 0.5) * (Ei * 0.2) * (Vi * 0.3)$$

Table 1. Parameters used to determine disaster risk values for informal settlements.

Risk Parameter	Adjusted Parameters at the Informal Settlement Level	Units	Abbreviation
Hazard	Slope	Mean informal settlement slope degree	SLP
	Distance to rivers	Mean distance in meters to rivers	RIV
Exposure	Total population	Population per informal settlement	POP
	Houses	Number of houses per informal settlement	HOU
	Informal settlements area	Informal settlements areas in m^2	AREA
Vulnerability	Social development index	Average municipal records	SDI

3. Results and Discussion

3.1. Risk of the GAM's Informal Settlements

From the total informal settlements in the GAM (296 units; Figure 1), 13.51% belong to the provinces of Alajuela (40 units), 17.22% are part of Cartago (51 units), 8.1% belong to Heredia (24 units), and a prominent 61.14% is part of San José (181 units). This clear majority of informal settlements in San José province also condition this province's higher numbers and percentages in all of the variables (hazard, exposure, vulnerability, and risk) and in all of the degrees (high, medium, and low; Table 2).

Table 2. Number and percentage of informal settlements according to their province, variable, and degree.

Variable	Degree	Province			
		San José	Alajuela	Cartago	Heredia
Hazard	High	55 (18.58%)	20 (6.75%)	13 (4.39%)	10 (3.37%)
	Medium	63 (21.28%)	13 (4.39%)	15 (5.06%)	8 (2.75%)
	Low	63 (21.28%)	7 (2.36%)	23 (7.77%)	6 (2.02%)
Exposure	High	50 (16.89%)	11 (3.71%)	22 (7.43%)	2 (0.67%)
	Medium	54 (18.24%)	13 (4.39%)	10 (3.37%)	10 (3.37%)
	Low	77 (26.01%)	16 (5.46%)	19 (6.41%)	12 (4.05%)
Vulnerability	High	49 (16.55%)	18 (6.08%)	12 (4.05%)	7 (2.36%)
	Medium	66 (22.29%)	13 (4.39%)	19 (6.41%)	8 (2.75%)
	Low	66 (22.29%)	9 (3.04%)	20 (6.75%)	9 (3.04%)
Risk	High	37 (12.52%)	8 (2.72%)	16 (5.4%)	2 (0.67%)
	Medium	37 (12.52%)	11 (3.71%)	6 (2.02%)	10 (3.37%)
	Low	107 (36.14%)	21 (7.09%)	29 (9.79%)	12 (4.05%)

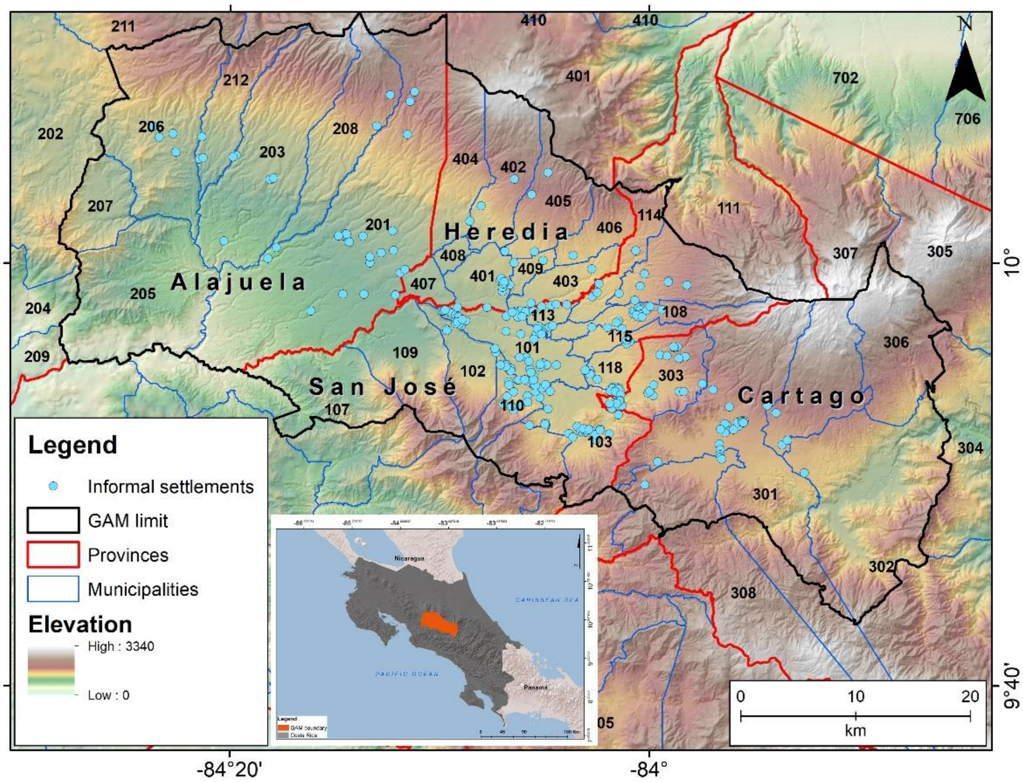

Figure 1. Informal settlements, municipalities, and provinces of the GAM in Costa Rica.

Due to its mountainous location inside a tectonic depression with volcanic deposits of a recent geological past, the natural hazards in the GAM are related to the rapid transition among the volcanic summits, their piedmonts, and the lowlands where the population is concentrated [47]. This means that the interaction of slope and distance to rivers clearly define higher hazard degrees depending on the location of informal settlements [48,49]. Many informal settlements originated from informal appropriation or illegal squatters who settled in private or even in public properties relegated to risky areas near the slopes of the valley or nearby alluvial plains [50,51]. San José province led the high, medium, and low hazard results or index, followed by Cartago, Alajuela, and Heredia (Table 2).

The interaction between population, number of houses, and area of the informal settlements have drawn the exposure of these communities in the GAM. Hence, some communities are more crowded and exposed to landslides and floods (Figure 2). The exposure to disasters of these crammed settlements has historical reasons, but in the last decades they have grown along due to the limited action of the local governments and the absence of enough initiatives of public institutions which can improve the living conditions to these populations [52]. Exposure to disasters is higher in the provinces of San José, Cartago, Alajuela, and Heredia, respectively (Table 2).

These communities require a differentiated approach from the government, which is normally absent in their territorial and disaster risk management [53]. For example, the highest vulnerability is often associated with insecurity conditions due to the higher criminality numbers, and infrequent police actions [54]. The surrounding areas of the informal settlements show intense pollution due to clandestine dumps or water contamination due to the absence of treatment [55–57]. The quality of public education has decreased in the last decades and informal settlements do not escape from this reality [58,59]. Therefore, the lack of quality employment options pushes the young population into delinquency or informal economic activities that do not ensure their livelihood [60].

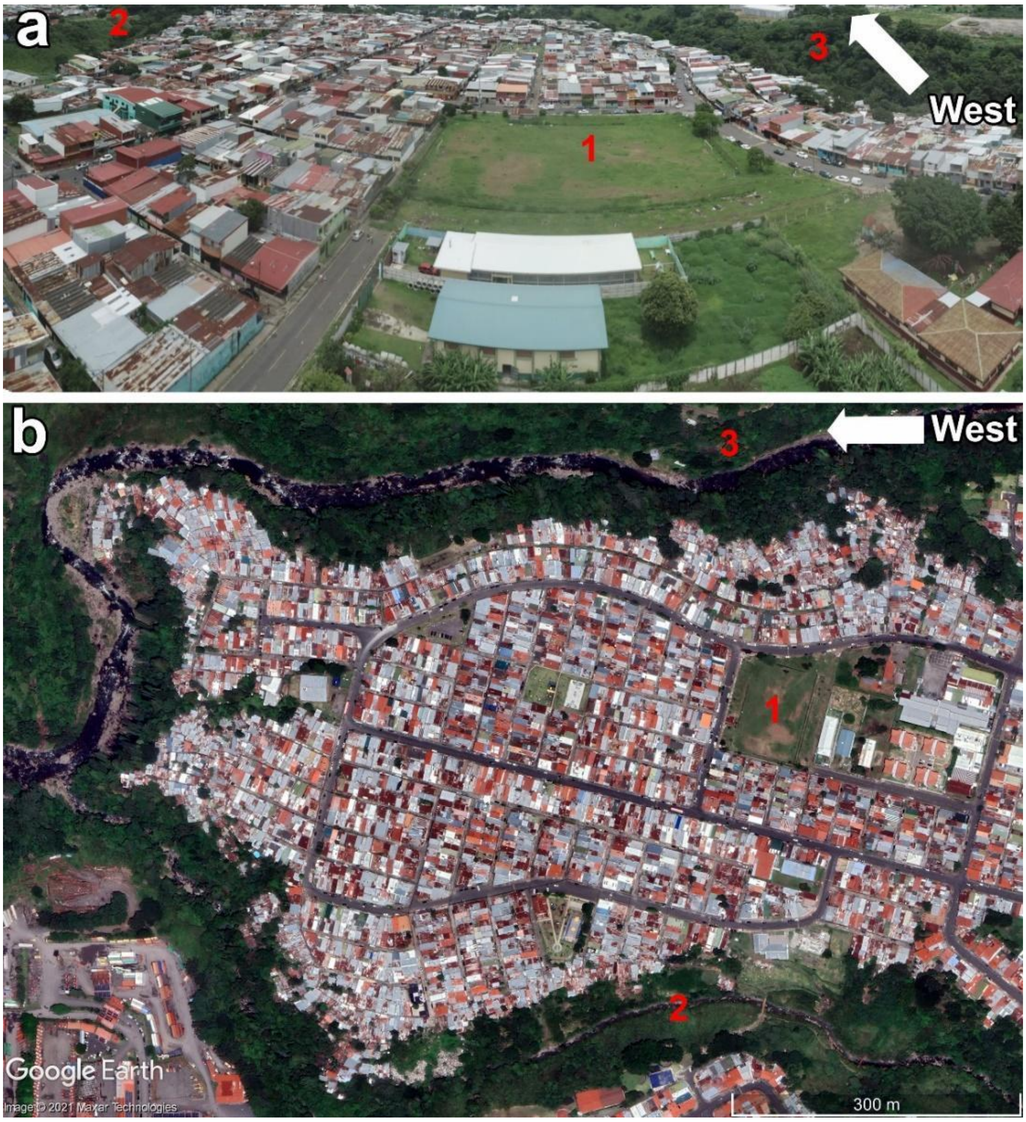

Figure 2. León XIII's informal settlement in San José, Costa Rica. (**a**) Drone flight (image taken by Dennis Chavarría); (**b**) Google Earth satellite image. Red numbers: (1) football pitch (coordinates: 9°57′37.6″ N–84°06′00.8″ W), (2–3) river canyon sections.

According to the interaction between hazard, exposure, and vulnerability, the risk values were calculated for each informal settlement of the GAM (Figure 3). Most of the slum units are in San José province (61.18%), followed by Cartago (17.21%), Alajuela (13.52%), and Heredia (8.09%). A total of 63 out of 296 informal settlements of the GAM were determined to be high risk, with a clear majority located in San José (37 units; Table 2). The municipalities with higher numbers of informal settlements indicating a high risk are indicated in Figure 4. Interestingly, these municipalities also report the numbers above the average in the country (over 200 cases over the last five decades) [31,32]. Consequently, the highest number of disastrous events in the GAM and Costa Rica (∼50%) are reported in Desamparados, San José, Alajuela, Cartago, Aserrí, and La Unión's municipalities [50]. Research in the past years has determined similar results in the mentioned municipalities such as Alajuela [61], Desamparados [62], and La Unión [63].

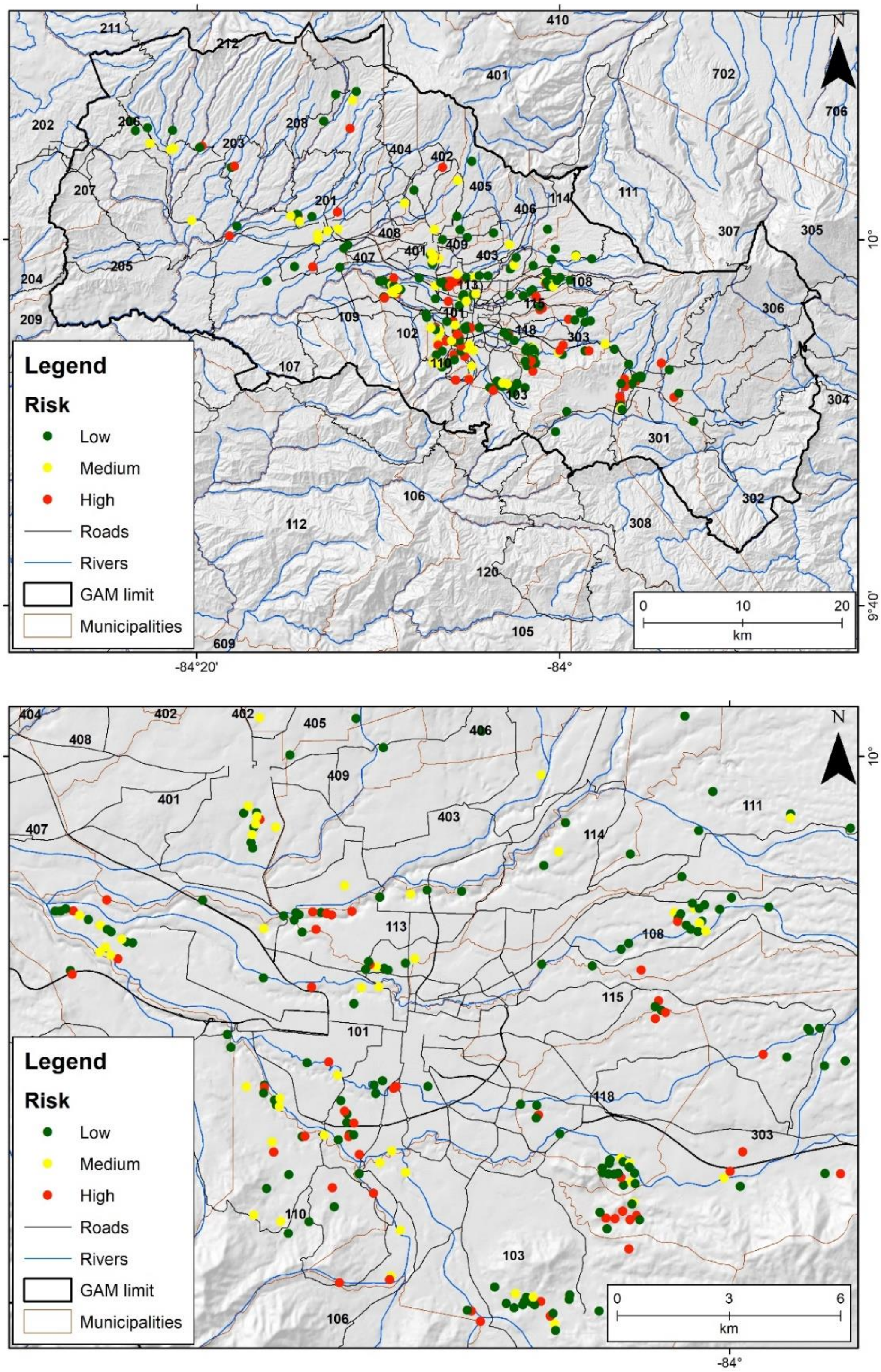

Figure 3. Informal settlements risk classification results. Municipalities codes in the Supplementary material. The upper panel shows all GAM informal settlements. The lower panel shows the denser grid of informal settlements around San José, Tibás, and Desamparados.

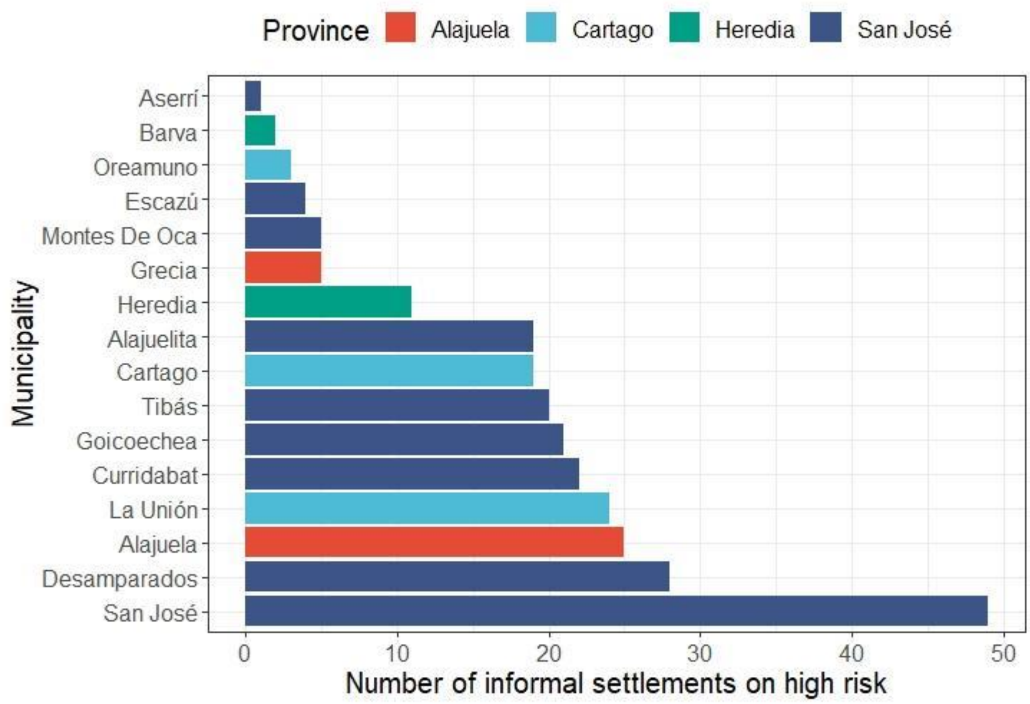

Figure 4. Number of informal settlements showing high risk according to their municipality and province.

The top ten municipalities with higher numbers of informal settlements also concentrate a high percentage of higher risk units (Table 3; Figure 4). One of the main factors for this phenomenon is related to the population density where most of these municipalities have more than 2000 inh/km^2 (Desamparados, La Unión, and Escazú), 4000 inh/km^2 (Montes de Oca, Goicoechea, Alajuelita, and Curridabat), and 7000 inh/km^2 (San José and Tibás). Moreover, many of the mentioned municipalities have a lower average value in their social development index compared to their surrounding neighbors (75 out of 100). A clear, positive statistical relationship between the number of disaster events by municipality between 1970 and 2020 [32,50], and the number of informal settlements by municipality and province is shown in Figure 5. There is a strong, positive correlation between historical disaster events and the municipalities where riskier, informal settlements are in Alajuela province, followed by strong, positive relationships in Heredia, Cartago, and San José, respectively.

Table 3. Top ten municipalities with higher number of informal settlements and their percentage in high risk.

Municipality	Total Units	High Risk Percentage
San José	49	22.45
Desamparados	28	21.43
Alajuela	25	24.00
La Unión	24	37.50
Curridabat	22	18.18
Goicoechea	21	9.52
Tibás	20	30.00
Cartago	19	31.58
Alajuelita	19	26.32
Heredia	11	9.09

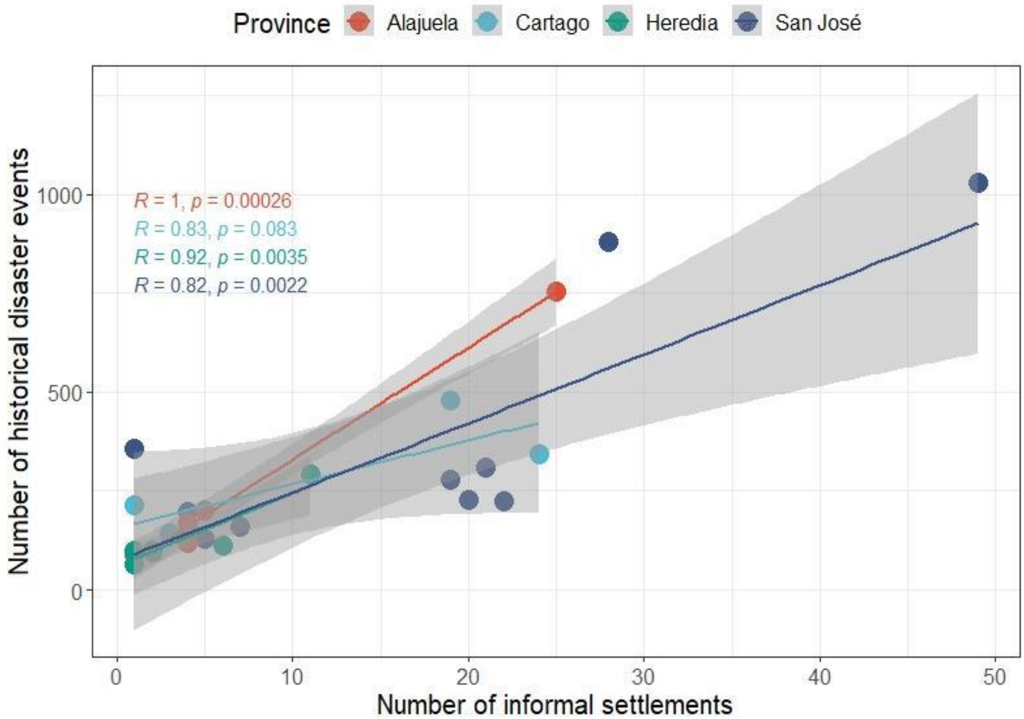

Figure 5. High and very high positive relationship among the number of informal settlements by municipality and province with the historical number of disaster events during the last five decades.

3.2. Policy Implications

The main reasons for the uncontrolled GAM urban expansion are related to territorial management policies deficiency that (in)directly favored the construction sector dispositions. Costa Rica must enhance its reference line and natural hazards mapping. Better characterizations of urban contexts, their geomorphology, and dynamics must be developed. Low-cost and fast implementation technologies (e.g., RPAS, high resolution satellite images) can expand reference data to generate high resolution risk maps for informal settlements. Still, the research on exposure and vulnerability studies' parameters need to increase to reduce disasters [64].

In the 20th century, the four provinces of the GAM have slowly formed a central urban nucleus which concentrates most of the population and its related economic activities [65–67]. A large portion of the population of rural areas of Costa Rica move to the GAM due to better study and work options. Therefore, the uncontrolled GAM growth with the increase of housing, offices, and industry construction has provoked a pattern of housing overcrowding for low-income families. The built area of the GAM has grown 600% since 1990 [68–70]. Horizontal urban development remains the main model for a large amount of the population. Nonetheless, vertical housing has started to be a considerable option for certain economic groups of the population since the 21st century [71]. An inter-municipal cross-institutional cooperation and the identification of external trigger events are keys to promote a sustainable urban transition including solutions based on nature in the GAM [72–74].

The cooperation of environmental governance at the regional scale (such as GAM) precludes the incorporation of decision makers into organizational networks, the insertion of citizens, and the expansion of social responsibility for private and public stakeholders [75–77]. There is no tool or routine impeccably adjustable to all contexts; the success of the interventions targeted at a sustainable use of land alters the differed interaction of the type of instruments and territories, and of the implementation scale [78]. Territorial planning actions accompanied with engineering plans are needed to avert the effects of disasters in the future at a municipal and local scale [79]. Moreover, it is key to unravel country level hierarchy in disaster risk assessment planning and decisions [80].

Disaster risk management decentralization might expand disaster governance in municipalities and closing distance between citizens and their local governments [81,82]. To develop successful disaster risk local plans, national social and disaster in-charge institutions efforts must be implemented with community-driven approaches to reduce disaster risk in informal settlements in developing countries [83]. At some point, radical change in informal settlements must be enforced to increase access to good urban conditions in a changing world [84]. Community and city-government-led measures must be implemented to improve settlement conditions and increase resilience to climate-change risks in the next decades [83].

4. Conclusions

The disasters that impact the GAM's informal settlements are mostly hydrometeorological. Most of the disasters are linked to localized events induced by the rainy period and eventual events such as tropical cyclones or ENSO (excessive rains or droughts). The risk accumulation over time can provoke large-scale cascading disasters. Unplanned urban expansion favors most of the registered landslides and floods as a result of inefficient sewerage and stormwater management. The enactment of a land use planning law is paramount for the country. Moreover, it must incorporate the municipalities' planning aspects at national, regional, and local levels within climate change scenarios in the urban planning processes. Eventually, more municipalities will have the obligation to create their own territorial regulatory plans. Costa Rica is an example of disaster risk and urban planning issues in the Global South. Hence, this approach and method can be employed in countries where baseline information lacks.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su141610261/s1, Figure S1: Pearson correlation matrix for Hazard index (Hi); Figure S2: Pearson correlation matrix for Exposure index (Ei); Figure S3: Pearson correlation matrix for Risk index (Ri).

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