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HOLISTIC SEISMIC RISK ASSESSMENT OF PORT OF SPAIN: AN INTEGRATED EVALUATION AND TOOL IN THE FRAMEWORK OF CAPRA

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ABSTRACT

A holistic evaluation of the seismic risk is conducted for the city of Port of Spain, Trinidad and Tobago. The presented methodology evaluates the seismic risk from a holistic perspective, that is, it takes into account the expected physical damage and also the conditions related to social fragility and lack of resilience, which favour the second order effects when a hazard event strikes an urban centre. Indicators are used in order to capture favourable conditions for direct physical impacts, as well as indirect and, at times, intangible impacts of hazard events. This evaluation is performed on the base of a probabilistic risk evaluation of the city using the CAPRA platform. The holistic methodology has been implemented as a post-processing tool of the platform.

INTRODUCTION

In recent years disaster risk has been defined, for management purposes, as the potential economic, social and environmental consequences of hazardous events that may occur in a given period of time. However, the concept of risk has been defined in a fragmentary way in many cases, according to each scientific discipline involved in its estimation. In order to evaluate risk according to the above stated definition, a multidisciplinary evaluation is necessary. This evaluation should take into account not only the expected physical damage, the number and type of casualties or economic losses, but also the conditions related to social fragility and lack of resilience which favor the second order effects (indirect effects) when a hazardous event strikes an urban centre.

The holistic risk evaluation is based on urban risk indicators. According to this procedure, a physical risk index is obtained for each unit of analysis (communities, in the case of Port of Spain) from physical loss scenarios, whereas the total risk index is obtained by multiplying the physical risk by an aggravating coefficient, based on variables associated with the socio-economic conditions of each community.

Although social circumstances may be associated with vulnerability to disasters, they should not be considered solely as the vulnerability. Vulnerability of human settlements is intrinsically tied to social processes, but is also related to the fragility, the susceptibility and the lack of resilience of the exposed assets. Moreover, it is also closely tied to natural and built environmental degradation at urban and rural levels. Thus, degradation, poverty and disasters are all expressions of environmental problems and their materialization is a result of the social construction of risk, through the

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construction of vulnerability or hazard, or both simultaneously (Carreño et al 2012, Birkmann et al 2013).

CONCEPTUAL FRAMEWORK OF THE HOLISTIC APPROACH

Figure 1 shows the conceptual framework of the holistic approach for risk assessment. From this comprehensive perspective it can be seen that risk is a function of the physical vulnerability –or the potential physical damage– and a set of vulnerability factors ε_i that configure the vulnerability conditions of the context under analysis. The physical vulnerability is obtained from the susceptibility of the exposed elements to hazards, considering the potential intensities, *I*, of the hazardous events in a period of time *t*. On the other hand, the vulnerability of the context depends on the social fragilities and issues related to lack of resilience of the disaster prone socio-technical system (or context). Using the meta-concepts of the control theory and complex system dynamics to reduce risk, it is necessary to intervene through corrective and prospective actions the vulnerability factors ε_i. Consequently, disaster risk management requires a control system (institutional structure) and an actuation system (public policies and actions) to implement the changes needed on the exposed elements to reduce risk.

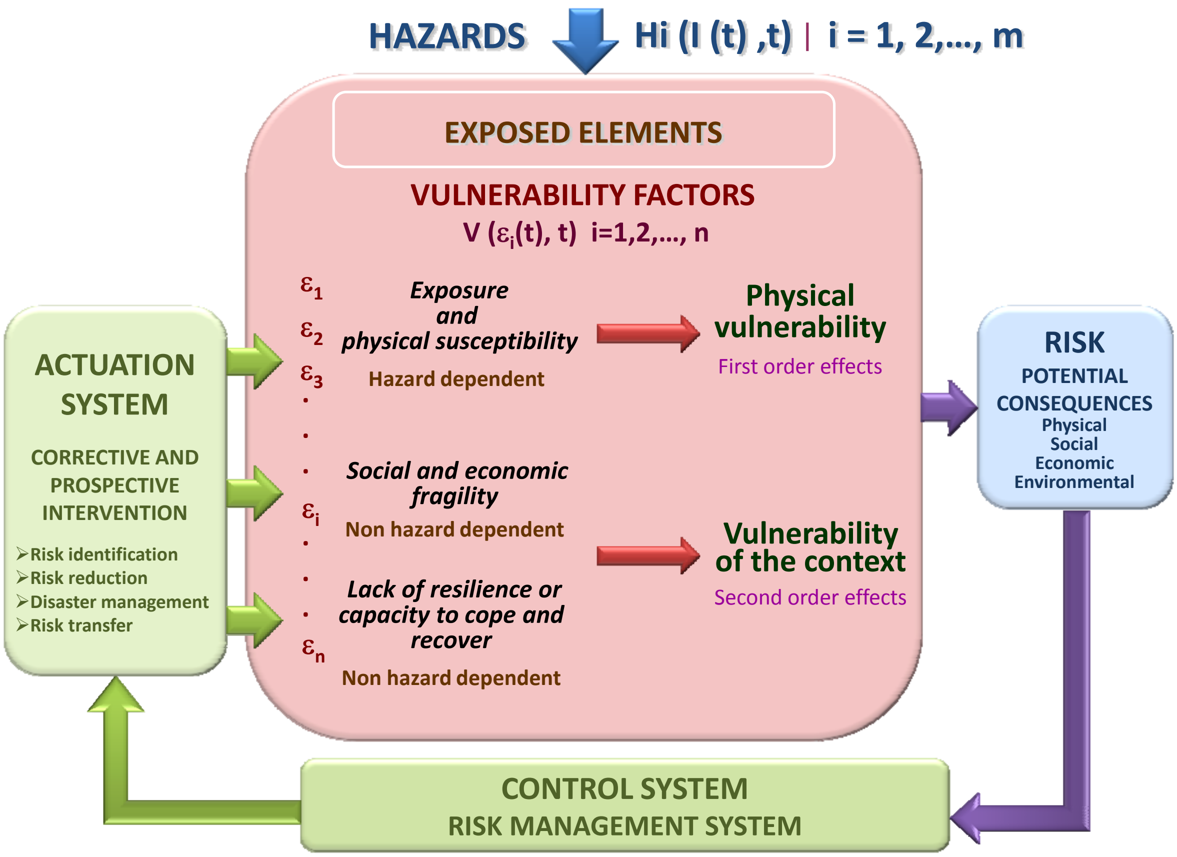

Figure 1. Conceptual framework and model for the holistic approach of the disaster risk evaluation and management (Carreño et. al 2007a,b; Barbat et al 2011)

Disaster risk from a holistic perspective means economic, social and environmental consequences of the physical phenomena. These potential consequences are the result of the convolution of hazardous events and the physical vulnerability. For disaster risk management, it is desired to have a control and an actuation system that represent the risk management institutional organization and the corrective and prospective intervention measures.

Carreño et al (2007a, 2012) developed two alternative versions of the model in which the evaluation of risk is achieved by affecting the physical risk with an impact factor obtained from contextual conditions, such as the socio-economic fragilities and the lack of resilience, given that both conditions aggravate the physical loss scenarios.

In order to reduce risk, it is necessary to intervene in corrective and prospective ways the vulnerability factors and, when possible, the hazards directly. Then risk management requires a control system (institutional structure) and an actuation system (public policies and actions) to implement the changes needed on the exposed elements or complex system where risk is a social process. Public policies of risk management include decision-making about risk identification and reduction, disaster management, and risk transfer. Risk identification entails the representation and objective assessment of risk, individual perceptions, and how those perceptions are understood by society as a whole. Risk reduction involves prevention and mitigation measures. Disaster management involves emergency response, recovery and reconstruction. Finally, risk transfer is related financial protection mechanisms and schemes.

CAPRA is a techno-scientific methodology and information platform, composed of tools for the evaluation and communication of risk at various territorial levels. This model allows the evaluation of probabilistic losses on exposed elements using probabilistic metrics, such as the exceedance probability curve, expected annual loss and probable maximum loss, useful for multi-hazard/risk analyses. The platform is conceptually oriented to facilitate decision making (Marulanda et al., 2013; Velásquez et al., 2014). This holistic evaluation method has been implemented as a post-processing tool of the CAPRA platform (see Figure 2).

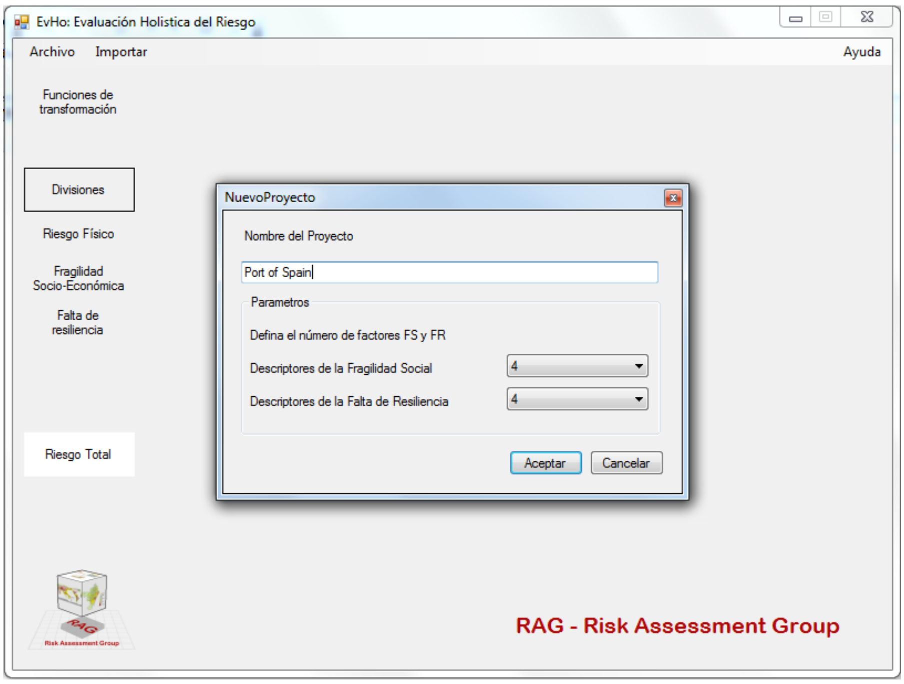

Figure 2. EvHo, a post-processing tool of the CAPRA platform

EVALUATION EQUATIONS

In this methodology, risk requires a multidisciplinary evaluation that takes into account not only the expected physical damage, the number and type of casualties or economic losses (first order impact), but also the conditions related to social fragility and lack of resilience, which favor the second order effects (indirect impact) when a seismic hazard event strikes an urban center (Carreño et al 2007a, Carreño et al 2012).

In the holistic evaluation of risk using indexes, risk results are obtained by aggravating the physical risk by means of the contextual conditions related to the socio-economic fragility and the lack of resilience. Input data about these conditions at urban level are necessary to apply the methodology.

This approach contributes to the effectiveness of risk management, inviting to the action through the identification of weaknesses and problems at the urban centre level.

The socio-economic fragility and the lack of resilience are described by a set of indicators (related to indirect or intangible effects) that aggravate the physical risk. Thus, the total risk depends on the direct effect, or physical risk, and the indirect effects expressed as a factor of the direct effects. Therefore, the total risk is expressed as follows:

$$R_T = R_F\left(1+F\right) \tag{1}$$

This equation is known as the Moncho's Equation[3] in the field of disaster risk indicators, where R_T is the total risk index, R_F is the physical risk index and F is the aggravating coefficient. The coefficient depends on the socio-economic fragility, FS, and the lack of resilience of the exposed context, FR. Figure 3 shows the process of calculation of the total risk index for the units of analysis, which could be districts, municipalities, communities or neighborhoods; the Figure suggests some of the indicators that can be used.

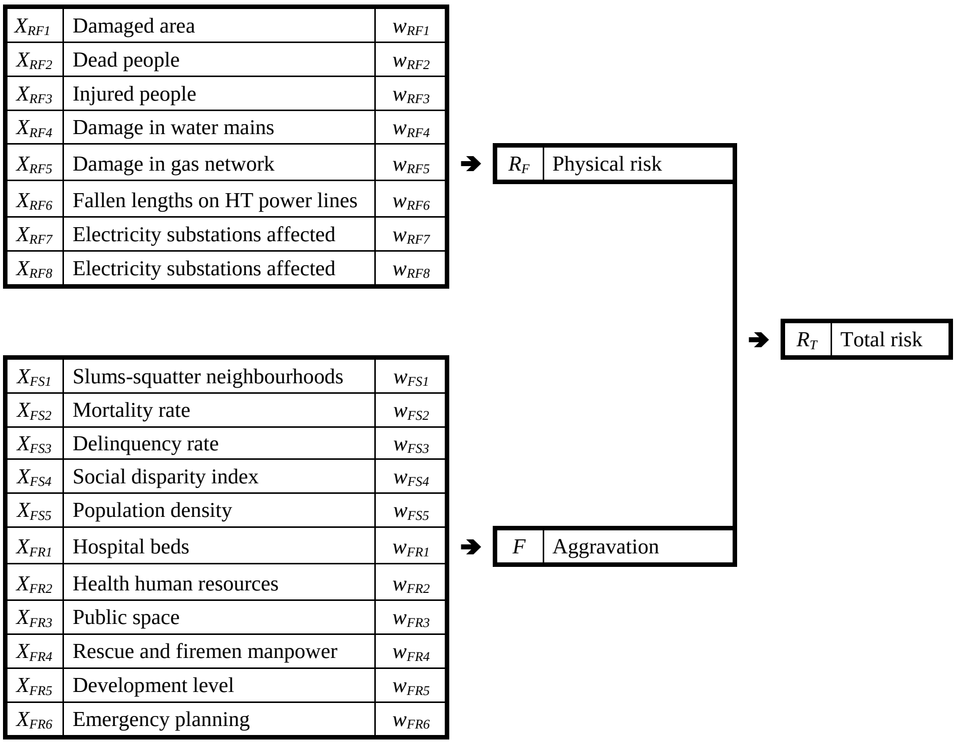

Figure 3. Factors of physical risk, social fragility and lank of resilience and their weights

The physical risk, R_F, is evaluated in the same way, by using the Equation 2.

$$R_F = \sum_{i=1}^{p} F_{RFi} . w_{RFi} \tag{2}$$

where p is the total number of descriptors of physical risk index, F_{RFi} are the component factors and w_{RFi} are their weights respectively. The physical risk factors, F_{RFi}, are calculated using the net values of physical risk descriptors; they can be results from a deterministic or a probabilistic risk assessment, such as the number of casualties, the destroyed area, and the pure risk premium and so on. The weights are defined by means of the Analytic Hierarchy Process (AHP) which is used to derive ratio scales from both discrete and continuous paired comparisons (Saaty 1991; Carreño et al. 2007a).

[3] This equation was named by an experts group during a workshop of the IADB-IDEA Project about risk indicators in Barcelona, in November 2003.

The descriptors used in this evaluation have different characteristics and units, and the transformation functions standardize the gross values of each descriptor, transforming them into commensurable factors. By using the gross value of each variable, which represents the physical risk (casualties, injured, etc.), the transformation function gives the value of each physical risk factor, which can take a value between 0 and 1. These functions are explained in the following section.

Similar functions are used in the case of the descriptors for social fragility and lack of resilience. In the case of the descriptors of lack of resilience, the function has an inverse shape; higher values of the indicator result in lower values of aggravation. The aggravating coefficient is calculated in a way that is similar to computing the weighted sum of the aggravating factors

$$F = \sum_{i=1}^{m} F_{FSi} \cdot w_{FSi} + \sum_{j=1}^{n} F_{FRj} \cdot w_{FRj} \tag{3}$$

were F_{FSi} are factors related to the socio-economic fragility, and F_{FRj} factors related to the lack of resilience of the exposed context, the weights w_{FSi} and w_{FRj} represent the relative importance of each factor and are calculated by means of the AHP.

TRANSFORMATION FUNCTIONS

Figure 4 shows a model for the transformation functions used by the methodology in order to calculate the risk factors. They represent membership functions for high level of risk for each descriptor. In Figure 3 the *x*-axis represents values of the descriptors, while the value of the factor (physical risk) is in the *y*-axis, taking values between 0 and 1. A value of 0 represents the non-membership and 1 corresponds to total membership. The limit values, Xmin and Xmax, are defined taking into account expert opinions and information about previous disasters. Similar functions are used in the case of social fragility and lack of resilience variables.

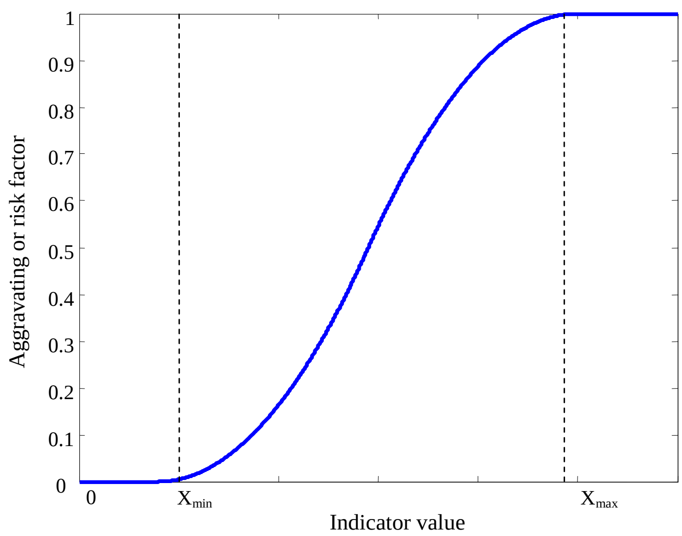

Figure 4. Model for the transformation functions applied

In order to develop the transformation functions, sigmoid functions were used in most of the cases. Once the shape of the functions is determined, all their maximum and minimum values (corresponding to the values of 1 or 0 of each factor) were fixed using existing information about previous disasters as well as expert opinion.

HOLISTIC SEISMIC EVALUATION OF RISK FOR PORT OF SPAIN

Trinidad and Tobago is located in the southern Caribbean, in the northeast of Venezuela. The country is exposed to a range of natural hazards due to its location, climate and geology. In addition, the nation displays an increasing high exposure of its physical infrastructure (much of the country's social and economic infrastructure is concentrated within active earthquake zones), social fragility and lack of resilience.

Port of Spain is the capital city of Trinidad and Tobago, and it is the administrative, political and commercial centre of the country. It is located in the north-western part of the island of Trinidad. The Port of Spain Municipality has one of the smallest land areas, only 12.8km^2 approximately, and a population of 37889 inhabitants according to the 2011 census, which makes it the most densely populated municipality with 2946 persons per square kilometre (CSO, 2012).

The holistic evaluation of risk for the city of Port of Spain is based on the physical risk results included in the report "Country risk evaluation" developed in the framework of the Inter-American Development Bank Operation ATN/OC-12349-TT. These results were used to calculate the physical risk index. In order to calculate the Aggravating Coefficients, information collected from the Central Statistical Office of Trinidad and Tobago (2012) was used. The city of Port of Spain is comprised by 15 communities; the physical risk index and the aggravating coefficient were calculated for this level of resolution.

PHYSICAL RISK INDEX

Table 1 shows the selected indicators for this evaluation. Table 2 shows the obtained factors, their weights and the physical risk index.

Table 1. Physical risk descriptors for Port of Spain

Descriptor		Units
X_{RF1} to X_{RF4}	Losses for the commercial, industrial, institutional and residential sectors	Pure risk premium [‰]
X_{RF5}	Injured people	Number of injured people each 1,000 inhabitants
X_{RF6}	Casualties	Number of casualties each 1,000 inhabitants
X_{RF7}	Homeless people	Percentage of population
X_{RF8}	Jobless people	Percentage of population

Table 2. Physical risk factors and Physical risk index for the communities of Port of Spain

Community	F_{RF1}	F_{RF2}	F_{RF3}	F_{RF4}	F_{RF5}	F_{RF6}	F_{RF7}	F_{RF8}	R_F
Belmont	0.12	0.00	0.00	0.25	0.09	0.08	0,00	0,00	0,07
Cocorite	0.00	0.00	0.00	0.09	0.04	0.03	0,59	0,00	0,08
Ellerslie Park	0.08	0.00	0.00	0.20	0.13	0.13	0,01	0,00	0,07
Federation Park	0.50	0.00	0.00	0.23	0.12	0.11	0,00	0,00	0,13
Gonzales	0.28	0.00	0.00	0.23	0.11	0.10	0,00	0,00	0,10
Long Circular	0.08	0.00	0.00	0.03	0.03	0.04	0,00	0,01	0,02
Newtown	0.04	0.00	0.27	0.02	0.00	0.00	0,00	0,12	0,06
Northeast Port of Spain proper	0.03	0.00	0.00	0.23	0.04	0.04	0,00	0,00	0,05
Port Area	0.07	0.01	0.00	0.57	0.00	0.00	0,00	0,00	0,10
Port of Spain Proper	0.03	0.03	0.19	0.03	0.00	0.00	0,00	0,16	0,06
Sealots	0.34	0.01	0.00	0.00	0.00	0.00	0,00	0,00	0,05
Southeast Port of Spain Proper	0.06	0.01	0.48	0.03	0.02	0.02	0,00	0,40	0,13
St. Clair	0.02	0.00	0.32	0.13	0.04	0.03	0,00	0,38	0,12
St. James	0.05	0.01	0.31	0.09	0.05	0.04	0,21	0,64	0,16
Woodbrook	0.07	0.00	0.19	0.06	0.04	0.04	0,00	0,20	0,08
Weight	*0.15*	*0.15*	*0.15*	*0.15*	*0.1*	*0.1*	*0.1*	*0.1*	-

Figure 5 shows the obtained results for the physical risk index for Port of Spain, grouped by communities, considering only the seismic hazard.

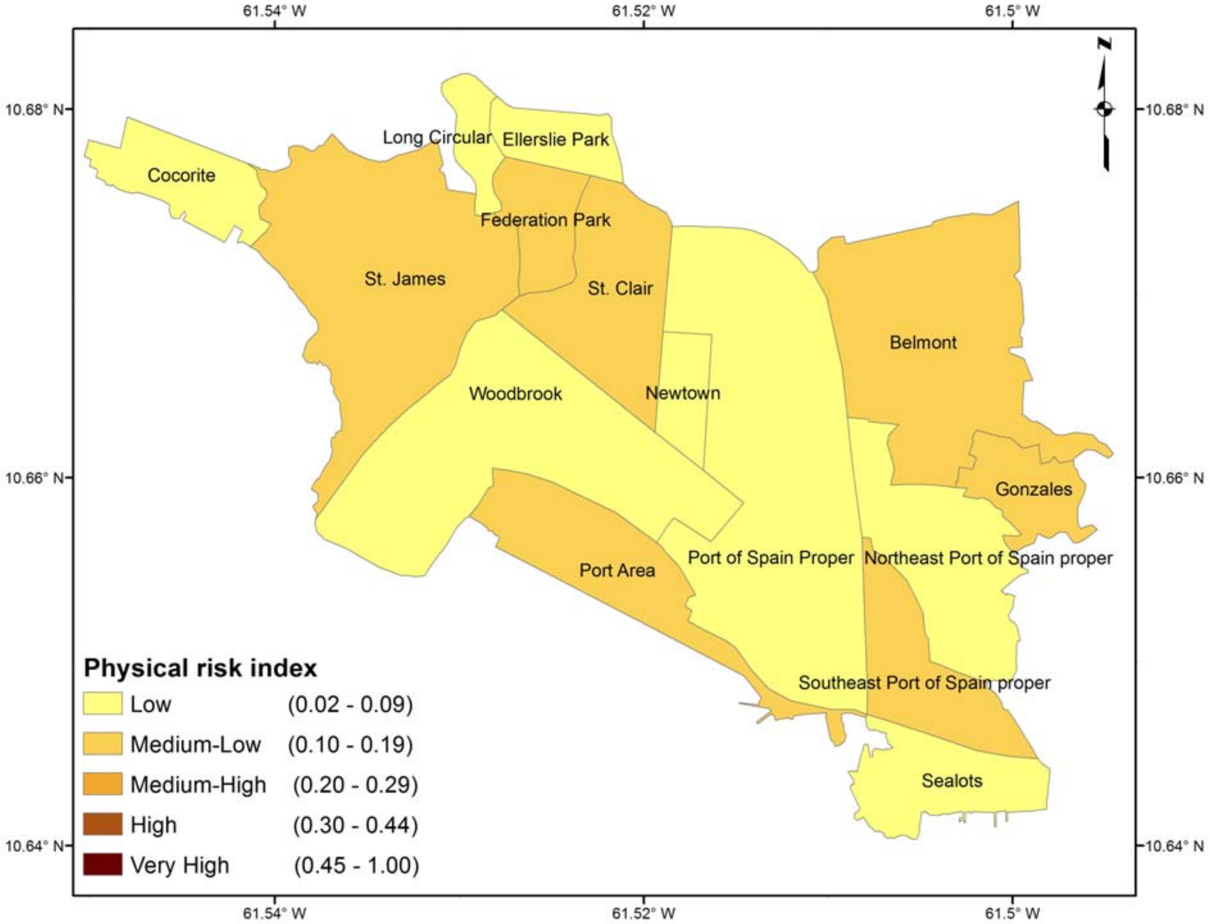

Figure 5. Physical risk index, R_F, for the communities of Port of Spain

AGGRAVATING COEFFICIENT

Existent indicators related to the social fragility and the lack of resilience were identified to be suitable for the evaluation of the aggravating conditions at community level. These indicators reflect the absences, weaknesses and susceptibilities that should be addressed by the processes of economic and social development. The information available from the Central Statistical Office of Trinidad and Tobago (2012) for Port of Spain was used.

Table 3 shows the indicators related to the social fragility, *FS*, and the lack of resilience, *FR*, selected for the holistic evaluation according to the available information for the fifteen communities. Table 4 shows the values of the obtained for the aggravating factors.

Table 3. Indicators for the aggravating conditions for the communities of Port of Spain

	Indicator	Units
X_{FS1}	Population older than 14 years with primary or less education level	% of population
X_{FS2}	Population density	Inhabitants / Km^2 of constructed area
X_{FS3}	"Low-income population (Monthly income under $TT500 or $US 78)	% of population
X_{FR1}	Parks' area/Community area	% of the community area
X_{FR2}	Distance between the community centroid and the hospitals' center of gravity	m

Table 4. Factors of aggravating conditions for the communities of Port of Spain

Community	F_{FS1}	F_{FS2}	F_{FS3}	F_{FR1}	F_{FR2}	F
Belmont	0.03	0.35	1.00	1.00	0.56	0.59
Cocorite	0.05	0.19	1.00	1.00	0.90	0.63
Ellerslie Park	0.00	0.00	1.00	1.00	0.39	0.48
Federation Park	0.00	0.00	0.00	0.99	0.23	0.24
Gonzales	0.06	0.96	1.00	1.00	0.78	0.76
Long Circular	0.00	0.00	0.01	1.00	0.46	0.30
Newtown	0.00	0.00	0.00	1.00	0.00	0.20
Northeast Port of Spain proper	0.09	0.05	0.97	1.00	0.67	0.56
Port Area	0.16	0.00	0.00	1.00	0.29	0.29
Port of Spain Proper	0.09	0.00	0.00	0.00	0.25	0.07
Sealots	0.21	0.13	0.00	1.00	1.00	0.47
Southeast Port of Spain Proper	0.09	0.05	0.33	1.00	0.80	0.45
St. Clair	0.00	0.00	0.00	0.06	0.02	0.01
St. James	0.07	0.00	0.43	1.00	0.41	0.38
Woodbrook	0.00	0.00	0.23	0.98	0.14	0.27
Weight	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	-

Figure 6 shows the obtained results for the aggravating coefficient for the fifteen communities in Port of Spain.

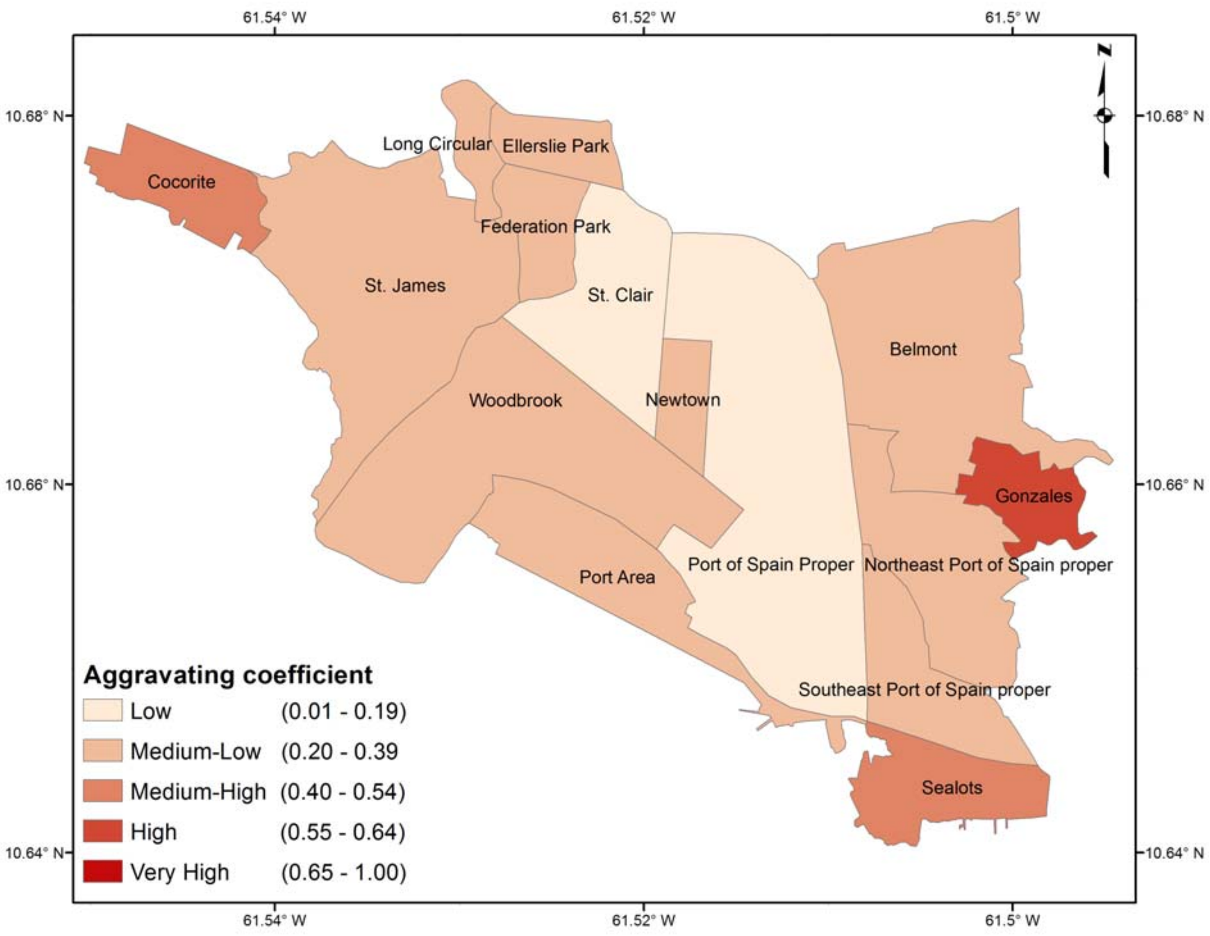

Figure 6. Aggravating coefficient for the communities of Port of Spain

TOTAL RISK, R_T

Finally, the total risk index is calculated based on the component indexes presented before. Table 5 and Figure 7 show the obtained results for the fifteen communities.

Table 5. Total risk index for the communities of Port of Spain

Community	R_F	F	R_T
Belmont	0.07	0.59	0.11
Cocorite	0.08	0.63	0.13
Ellerslie Park	0.07	0.48	0.10
Federation Park	0.13	0.24	0.17
Gonzales	0.10	0.76	0.17
Long Circular	0.02	0.30	0.03
Newtown	0.06	0.20	0.08
Northeast Port of Spain proper	0.05	0.56	0.07
Port Area	0.10	0.29	0.13
Port of Spain Proper	0.06	0.07	0.06
Sealots	0.05	0.47	0.08
Southeast Port of Spain Proper	0.13	0.45	0.19
St. Clair	0.12	0.01	0.12
St. James	0.16	0.38	0.22
Woodbrook	0.08	0.27	0.10

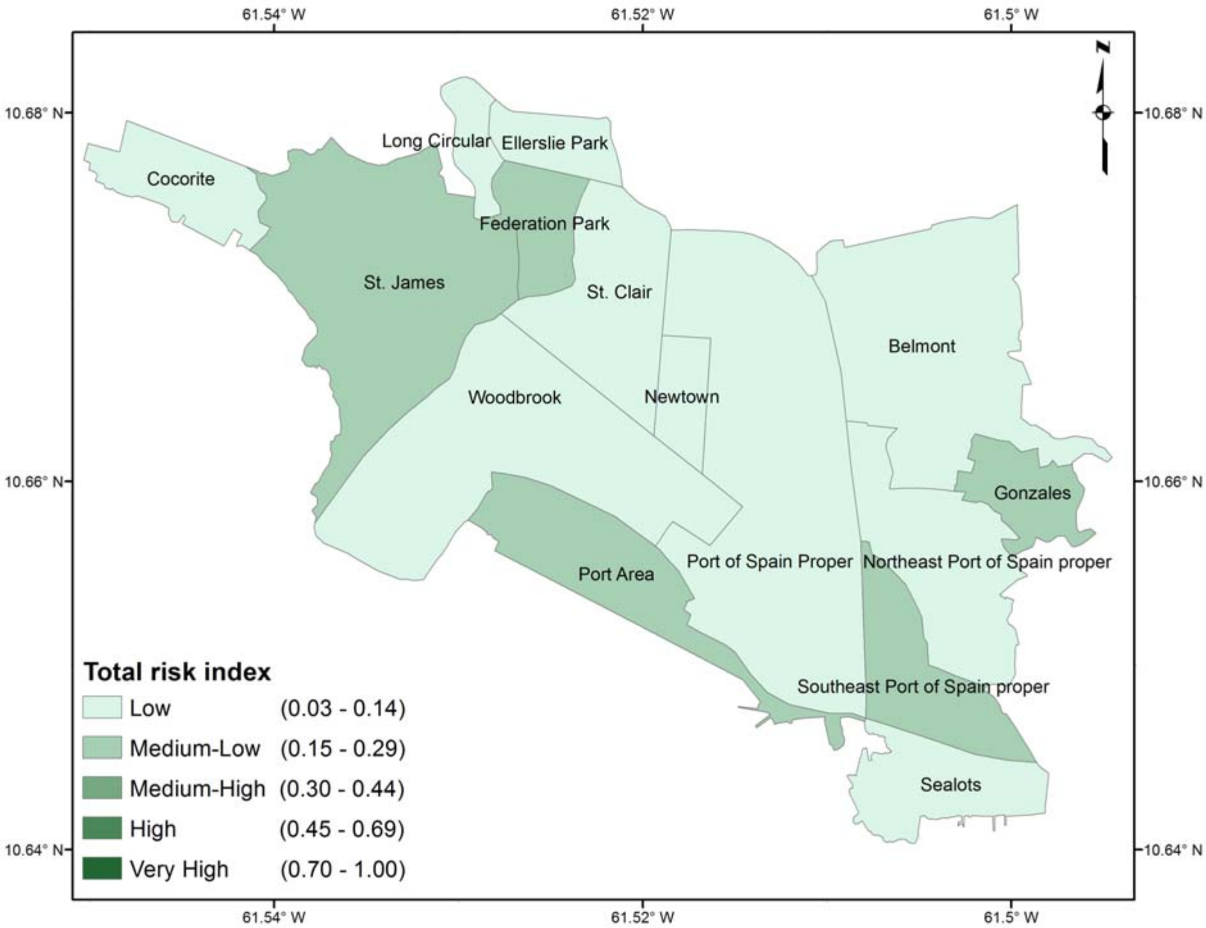

Figure 7. Total risk index for the communities of Port of Spain

DISCUSSION OF THE RESULTS AND CONCLUSIONS

This holistic evaluation of risk facilitates the integrated risk management by the different stakeholders involved in risk reduction decision-making. It permits the follow-up of the risk situation and the effectiveness of the prevention and mitigation measures can be easily achieved. Results can be verified and the mitigation priorities can be established as regards the prevention and planning actions to modify those conditions having a greater influence on risk in the city.

The holistic evaluation was done with the basis of a probabilistic analysis of the physical seismic risk. Probabilistic techniques are used to calculate the Probable Maximum Loss (PML) for different return periods and the Average Annual Loss (AAL) also known as technical risk premium. The CAPRA platform was used to calculate the mentioned metrics for the city of Port of Spain, Trinidad and Tobago, to estimate scenarios of damages and losses.

Risk analysis from a holistic perspective allows for a classification or ranking of the territorial units in terms of the relative risk levels. This enables the identification of the areas with the greatest physical risk, as well as those that have social, economic or environmental conditions that can worsen the consequences in the case of a seismic event. Figures 8, 9 and 10 show these rankings for the communities of Port of Spain in terms of physical risk, aggravating coefficient and total risk.

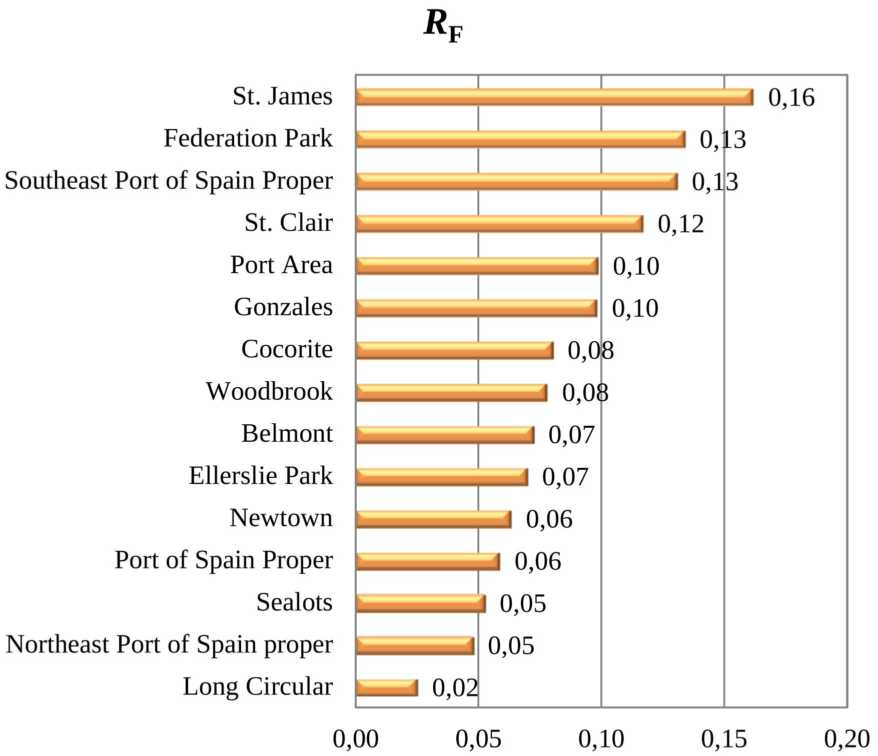

Figure 9. Ranking for the physical risk index of the communities of Port of Spain

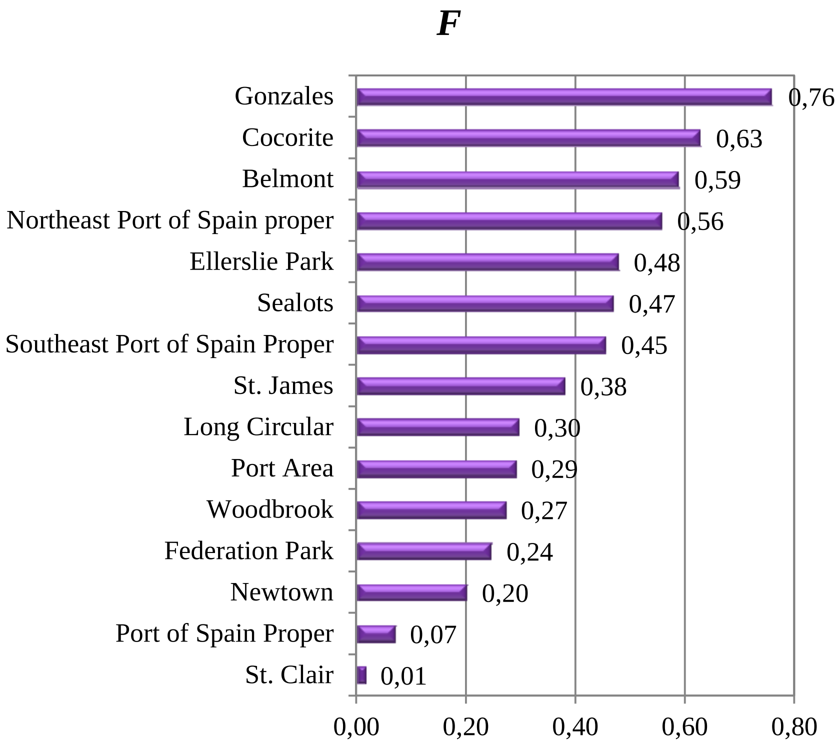

Figure 10. Ranking for the aggravating coefficient of the communities of Port of Spain

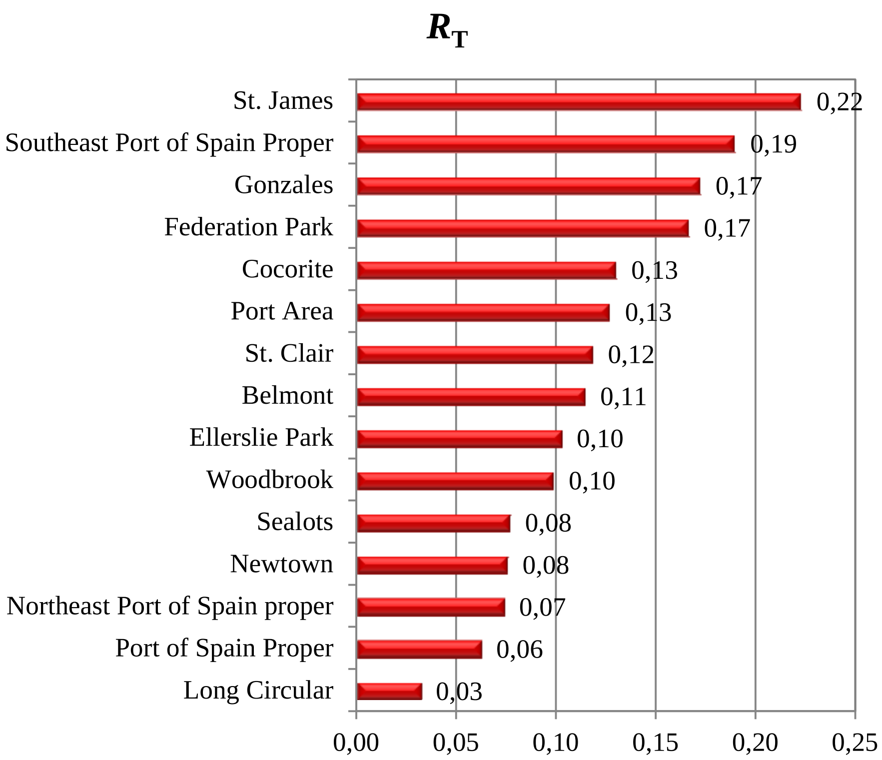

Figure 11. Ranking for total risk index of the communities of Port of Spain

According to the obtained results, the community of Sant James has the highest physical risk index in the city. The smaller physical risk index is for the communities of Long Circular, Northeast Port of Sapain proper and Sealots in the southeastern area of the city. However, in terms of the aggravating coefficient the situation is very different; the community of Gonzales has the highest value and this corresponds to a high level of aggravating conditions. The communities of Saint Clair and Port of Spain Proper have a low level of aggravation.

Finally, the total risk index shows that the community of Sant James has the highest level in the city (same as in the case of the physical risk index). This community as well as Southeast Port of Spain Proper, Gonzales and Federation Park have a medium-low level of total risk. The other communities have a low level of total risk.

It is important to highlight the case of Saint Clair. This community presents almost the same value for physical and total risk; this may be due to the very low value of the aggravating coefficient (0.01). Moreover, this reflects the very good social and resilience conditions of the area. A similar situation can be seen in the community of Port of Spain Proper. Another interesting example is Gonzales, which has the highest value of aggravation which creates an important increase in the total risk.

In general, the indicators of park-area and distance between the community centroid and the hospitals have the highest contributions to the aggravating coefficient. The relevance of these indicators is evident we consider the importance of such spaces after the occurrence of a disaster.

Periodic evaluations can help identify the influences and changes in risk, aggravating variables and the rest of the results that can be derived. It is possible to identify the benefit of prospective and corrective interventions that involve changes as a result of development and prevention efforts. In other words, the value of variables can be updated easily, which favors the sensitivity analysis and model calibration. Finally, it is possible to identify the most relevant aspects of risk without conducting major efforts of analysis and interpretation of results.

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