EVALUATING RISK FROM A HOLISTIC PERSPECTIVE TO IMPROVE RESILIENCE: A SUBNATIONAL LEVEL EVALUATION IN COLOMBIA[1]

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ABSTRACT: Disaster risk is not only associated with the occurrence of intense hazard events but also with the vulnerability conditions that favour or facilitate disasters when such events occur. Vulnerability is closely linked to social processes and governance weaknesses in disaster-prone areas and is usually related to a set of factors of fragility, susceptibility, and lack of resilience of the exposed human settlements. The holistic risk assessment aims to reflect risk from a comprehensive perspective by using, in one hand, the physical risk or potential physical damage directly linked to the occurrence of hazard events and, on the other hand by capturing how underlying risk drivers or amplifiers –social, economic, environmental factors, non-hazard dependent elements, may worsen the current existing physical risk conditions in terms of lack of capacity to anticipate or resist, or to respond and recover from adverse impacts. This article presents the results of the holistic evaluation obtained at subnational level in Colombia in the framework of the Risk Atlas of Colombia of the National Unit for Disaster Risk Management, UNGRD. The evaluation was performed using the probabilistic physical risk results obtained in the multi-hazard risk assessment and 16 socio-economic indicators available for 1,123 municipalities of Colombia. These results are useful to identify risk drivers that are associated not only to the physical vulnerability of the buildings and infrastructure but also to social issues that should be examined and tackled in a comprehensive way.

Keywords: holistic approach, indicators, lack of resilience, probabilistic risk assessment, socio-economic fragility

EVALUANDO EL RIESGO DESDE UNA PERSPECTIVA HOLÍSTICA PARA MEJORAR LA RESILIENCIA: EVALUACIÓN A NIVEL SUBNACIONAL EN COLOMBIA

RESUMEN: El riesgo de desastres no está asociado únicamente a la ocurrencia de eventos intensos de amenaza sino también a las condiciones de vulnerabilidad que favorecen la ocurrencia de desastres como resultado de dichos eventos. La vulnerabilidad está estrechamente ligada a procesos sociales y a una gobernanza débil en zonas propensas a desastres, y generalmente está relacionada con un conjunto de factores de fragilidad y susceptibilidad y falta de resiliencia de los asentamientos humanos expuestos. La evaluación holística del riesgo busca reflejar el riesgo desde una perspectiva integral utilizando, por un lado, el riesgo físico, o daño físico potencial, directamente relacionado con la ocurrencia de eventos y, por otro lado, capturando como los impulsores subyacentes o amplificadores del riesgo – factores sociales, económicos y ambientales – no dependientes de la amenaza, pueden incidir sobre las condiciones de riesgo físico actuales en términos de incapacidad para anticiparse o resistir, o responder y recuperarse de impactos adversos. Este artículo presenta los resultados de la evaluación holística realizada a nivel subnacional en Colombia en el marco del Altas de Riesgo de Colombia de la Unidad Nacional para la Gestión del Riesgo de Desastres, UNGRD. Para esta evaluación se utilizaron los resultados de riesgo físico obtenidos en la evaluación probabilista de riesgo multi-amenaza y 16 indicadores socioeconómicos disponibles para los 1,123 municipios de Colombia. Los resultados de la evaluación son de gran utilidad para identificar impulsores de riesgo asociados no solo a la vulnerabilidad física de los edificios e infraestructura sino también a asuntos sociales que deben ser considerados y abordados de una manera integral para lograr reducir el riesgo.

Palabras clave: enfoque holístico, indicadores, falta de resiliencia, evaluación probabilista del riesgo, fragilidad socioeconómica

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INTRODUCTION

Nowadays it is accepted that disaster risk is the result of the combination of the potential occurrence of events and the fragility of the elements susceptible to be damaged, which consequently will result on direct and indirect damages and consequential losses for the exposed communities. It is also accepted that there is currently a lot of knowledge and a clear understanding in terms of building codes to ensure resilient infrastructure. Therefore, it can be said that natural events are "destructive because man has made them so, by investing his wealth with a disregard for the hazards that nature may have in store for him" (Ambraseys, 2010).

Physical vulnerability of the exposed elements is the result of inadequate practices and activities in a community as part of unplanned development processes that lead to the construction of susceptible elements and, in several cases to the generation of new hazards (anthropogenic hazards). In this sense, vulnerability can be understood as the lack of capacity to resist and adapt, which is the base of the generation of unfavorable conditions that lead up to the construction of risk that materializes in disaster when an event occurs. Hence, current physical vulnerability of exposed elements is the result of past decisions driven by social, cultural, economic, institutional, and environmental factors. In the last few decades, public concern and understanding that impacts and losses resulting from hazard events are avoidable up to some degree of human control has been increasing, and nowadays it is widely accepted that actions can be and should be taken to prevent and reduce risk.

Although in many countries actions and policies have been implemented for the sake of risk reduction, it is very difficult, if not impossible to lessen current physical risk in the short term and it implies a steady long-term process for which results will only be reflected over time. This situation will inevitably result on a yet greater number of damages and losses in the next several decades.

On the other hand, current intrinsic characteristics of society define either worse or better conditions that amplify or reduce the impact and the ability to recover from adverse events and create an either stronger or weaker new build environment. By improving socio-economic conditions of the society, two issues can be addressed: *(i)* a higher capacity to recover from the impact of the events and *(ii)* the capacity to "build back better" to avoid future disasters.

Risk management decision-making to improve resilience and safety, means to address integrated actions to reduce not only the physical vulnerability (hard) but to enhance social, economic, environmental and governance aspects (soft), contributing to sustainability and development processes. Consequently, a comprehensive risk management strategy must be based on a multidisciplinary approach that considers not only the physical damage and the direct impact but also a set of socioeconomic factors that favour second order effects and consider the intangible impact in case an event occurs: (Cardona and Hurtado, 2000); (Benson, 2003); (Cannon, 2003); (Cutter et al., 2003); (Davis, 2003); (Carreño et al., 2007; 2012, 2014); (Barbat et al., 2010); (Khazai et al., 2014).

Risk evaluations and highly technical risk assessments fill a gap on the understanding of risk and they have been used for years within specific sectors, such as the insurance market. However, it has not been widely used at government level and other sectors involved in development, therefore in many cases, risk management decisions are based primarily on common sense, ordinary knowledge, trial and error, or non-scientific knowledge and beliefs. There is still incipient understanding of what the results of risk assessments are, and how to use them for decision making purposes.

One of the main challenges related with risk assessments is to find the right ways to communicate complex issues from science to policy or public. Thus, in order to achieve effective communication, integrating physical risk results and a set of socio-economic indicators, and considering the usefulness of indicators to describe a problem of a complex system in simple terms a holistic approach evaluation was carried out at subnational level in Colombia for 1123 municipalities and the results are presented herein.

It is worth noting that indicators in general, are not aimed at identifying risk management measures, which must be identified using integrated models and comprehensive analysis. Indicators are big pictures that allow easier interpretation of multi-dimensional issues instead of trying to find a trend in many separate indicators, and they mainly serve to highlight some aspects of risk. Therefore, in order to draw specific conclusions and define courses of actions it is necessary to have more detailed information, that is, disaggregated values. Despite the shortfalls indicators may have, they are useful to attract public interest and raise awareness towards risk, as well as to compare and prioritize areas for action and to promote the improvement of risk management capabilities.

The holistic risk assessment approach aims to reflect risk from a comprehensive perspective by using both, physical risk, and underlying risk drivers. The physical risk or potential physical damage is directly linked to the occurrence of hazard events and, the underlying risk drivers or amplifiers –social, economic, environmental factors– (integrated in the so-called aggravating factor, F), are non-hazard dependent. The holistic risk evaluation reflects how underlying risk drivers worsen the current physical risk conditions in terms of lack of capacity to anticipate or resist, or to respond and recover from adverse impacts.

Holistic evaluations of seismic risk at urban level have been performed in recent years for different cities worldwide (Birkman et al., 2013); (Carreño et al., 2007); (Jaramillo, 2014); (Marulanda et al., 2013), (Salgado-Gálvez et al., 2016) as well as at country level (Daniell et al., 2010); (Burton and Silva, 2014), and multi-hazard at global level (UNISDR, 2017), proving to be a useful way to evaluate, compare and communicate risk while promoting effective actions toward the intervention of vulnerability conditions measured at its different dimensions. This approach has also been integrated in toolkits, guidebooks and databases for earthquake risk assessment (Khazai et al*.*, 2014; 2015); (Burton et al., 2014).

Figure 1 presents the conceptual framework of the holistic risk approach, where it is shown that risk is a function of hazard and vulnerability (physical vulnerability and socioeconomic factors). The holistic evaluation approach states that to reduce existing risk or to prevent the generation of new risk it is required a comprehensive risk management system, based on an institutional structure accompanied by the implementation of policies and strategies to intervene not only susceptible elements but also diverse factors of the society that may create or increase risk, as well as to intervene, when possible, created hazards (anthropogenic, technological, etc.). In the same way, in the case a hazard event is materialized resulting in a disaster, emergency response and recovery actions should be conducted as part of the risk management framework.

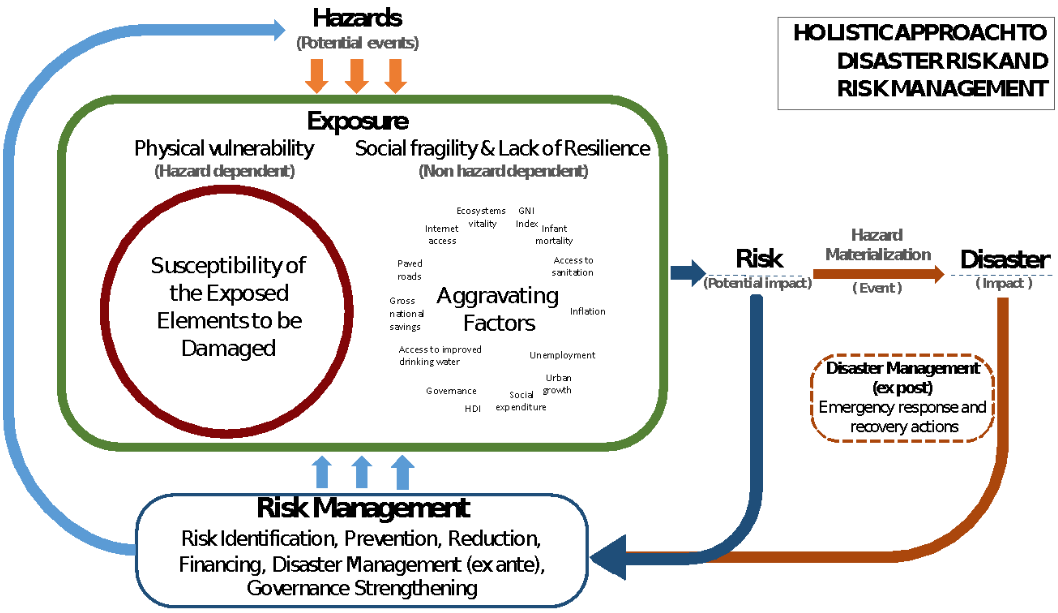

Figure 1: **Conceptual framework of the holistic approach to disaster risk.**

This methodology is a simplified yet comprehensive representation of risk, based on an interdisciplinary approach, which allows to account not only for the potential physical damage (using a probabilistic model) but also the socioeconomic factors that may worsen the direct effects of hazard events.

For this evaluation, physical risk values were obtained from the normalization of the Average Annual Loss, AAL, values resulted from the multi-hazard probabilistic risk assessment performed for Colombia by Cardona et al. (2018). The AAL is a metric that indicates the amount of funds the government or responsible entity would have to set aside, annually, to cover all the potential future losses. This metric attempt to compress risk in a single number and it is the most convenient metric for comparison purposes.

For the socioeconomic factors 16 variables were chosen considering not only that they capture important aspects of the society, but also the coverage of municipalities and the source of the information. Indicators were available in national databases for the 1123 municipalities. As with physical risk values, the factors were obtained using transformation functions for their standardization.

This is the first time that a study following the abovementioned methodology is conducted considering hazard, exposure, and socio-economic descriptors at subnational level for a whole country. The results are useful to identify risk drivers that are not only associated to the physical risk of buildings and infrastructure but also to social issues that should be examined and tackled in a comprehensive way.

HOLISTIC RISK ASSESSMENT METHODOLOGY

The holistic risk evaluation or Total Risk, R_T, is defined as a combination of a physical risk index, R_F, and an aggravating coefficient, F, in the following way:

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

known in the literature as Moncho's equation (Carreño et al., 2007), where R_F and F are composite indicators (Cardona, 2001); (Carreño, 2006); (Carreño et al., 2007). R_F is obtained from the probabilistic risk results, while F, which accounts for the socioeconomic fragility and lack of resilience of the area under analysis, is obtained from available data regarding political, institutional and community organization aspects. Descriptors are selected according to availability and relevance of indicators for the area under study. Socio-economic descriptors seek to reflect weak emergency response, lack of compliance of existing codes, economic and political instability and other factors that contribute to the risk creation process and to the incapacity to cope or recover (Carreño et al., 2007); (Renn, 2008). In the evaluation, potential physical damages are affected or aggravated by a set of socio-economic conditions that may worsen the negative effects when an event occurs. Detailed information about this methodology can be found in Carreño (2006), Carreño et al. (2007) and Barbat et al. (2011).

It is assumed that Total Risk, R_T, can be maximum two times the physical risk of the affected area. It means that, if in a hypothetic case where socio-economic characteristics are perfect and there is neither fragility nor lack of resilience, the aggravating factor would be zero and then, the total risk would have the same value of physical risk. While if society characteristics are as bad as to obtain the maximum value of the aggravating coefficient 1.0, total risk would be twice the physical risk value. This assumption is made with the aim to reflect that socio-economic characteristics can influence the magnitude of a disaster, whether it is twice, three, four or more times higher than the physical damages is not defined here but, the objective in the context of the holistic evaluation is to make the impact of these characteristics manifested and show that they can really influence the most direct effects of a disaster (physical damage).

Risk addressed from a physical point of view is the starting point to start analysing the subsequent impacts of a disaster. Disasters resulting from natural and anthropogenic events are the damages on the built environment or on the physical means affecting people and their activities in different ways.

The physical risk index, R_F, is calculated based on the results of the probabilistic multi-hazard risk assessment made for the Risk Atlas of Colombia (UNGRD, 2018). For Colombia, R_F was calculated considering the Average Annual Economic Loss, AAL of each hazard considered (earthquake, tsunami, tropical cyclones – wind and storm surge, and floods). Physical risk only considers the Average Annual Loss related to economic losses and does not consider any other direct physical impacts such as death or injured people. The AAL is transformed to values between 0.0 and 1.0; the maximum value corresponds to those AAL greater than 10‰, means a loss of USD 10 per thousand (USD 1.000) (i.e. 1%). The calculation of R_F was made following the equation:

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

where F_{RFi} is the transformed AAL per hazard and w_{RFi} their corresponding weights which in this evaluation were equal for each hazard.

The aggravating coefficient, F, is calculated as follows:

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

where F_{FSi} and F_{FRj} are the aggravating factors, w_{FSi} and w_{FRj} are the associated weights of each i and j factor, here again, it is assumed that the weight of each factor is the same; m and n are the total number of factors for social fragility and lack of resilience, respectively. For this case, 8 descriptors were used to capture the social fragility conditions and other 8 to capture the lack of resilience. The descriptors were obtained using data from national databases (i.e. "Departamento Administrativo Nacional de Estadística (DANE), Departamento Nacional de Planeación (DNP), Ministerio de trabajo, Ministerio de salud"). Figure 2 shows the summary of the descriptors used in this analysis where the ones denoted as F_{RFi} are related to the physical risk index, the ones denoted as F_{SFi} are related to the social fragility and the ones denoted as F_{FR1} are related to the lack of resilience. Each of the factors used in the calculation of the Total Risk, R_T, captures different aspects of the society and is quantified in different units. For this reason, normalizing procedures are needed to standardize the values of each descriptor and convert them into commensurable factors. In this case, transformation functions were used to standardize social fragility and lack of resilience factors selected. Some of them are shown in Figure 3. The factors and their units, as well as the [min, max] values are shown on the abscissa. Depending on the nature of the descriptor, the shape and characteristics of the functions vary. It means that functions related to descriptors of social fragility have an increasing shape while those related to resilience have a decreasing one. Thus, in the first case, a high value of an indicator means greater contribution to aggravation (i.e. corruption indicator, if this value is high, it will contribute more to aggravate or worsen conditions to cope or respond in an adverse situation). In the second case, a high value of the indicator means a lower negative influence on the aggravation (i.e. access to education, a high value is a positive characteristic for more resilient societies, therefore, it will contribute less to aggravating an adverse situation).

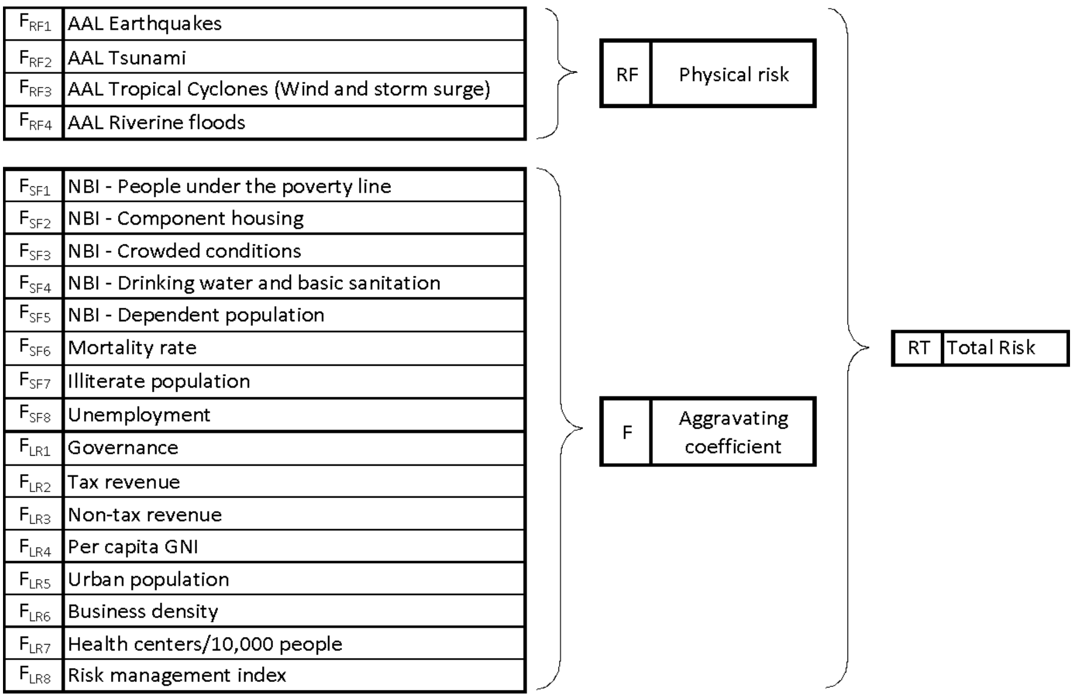

Figure 2: Summary of the descriptors used in this evaluation.

The transformation functions can be understood as risk and aggravating probability distribution functions or as the membership functions of the linguistic benchmarking of high risk or high aggravation.

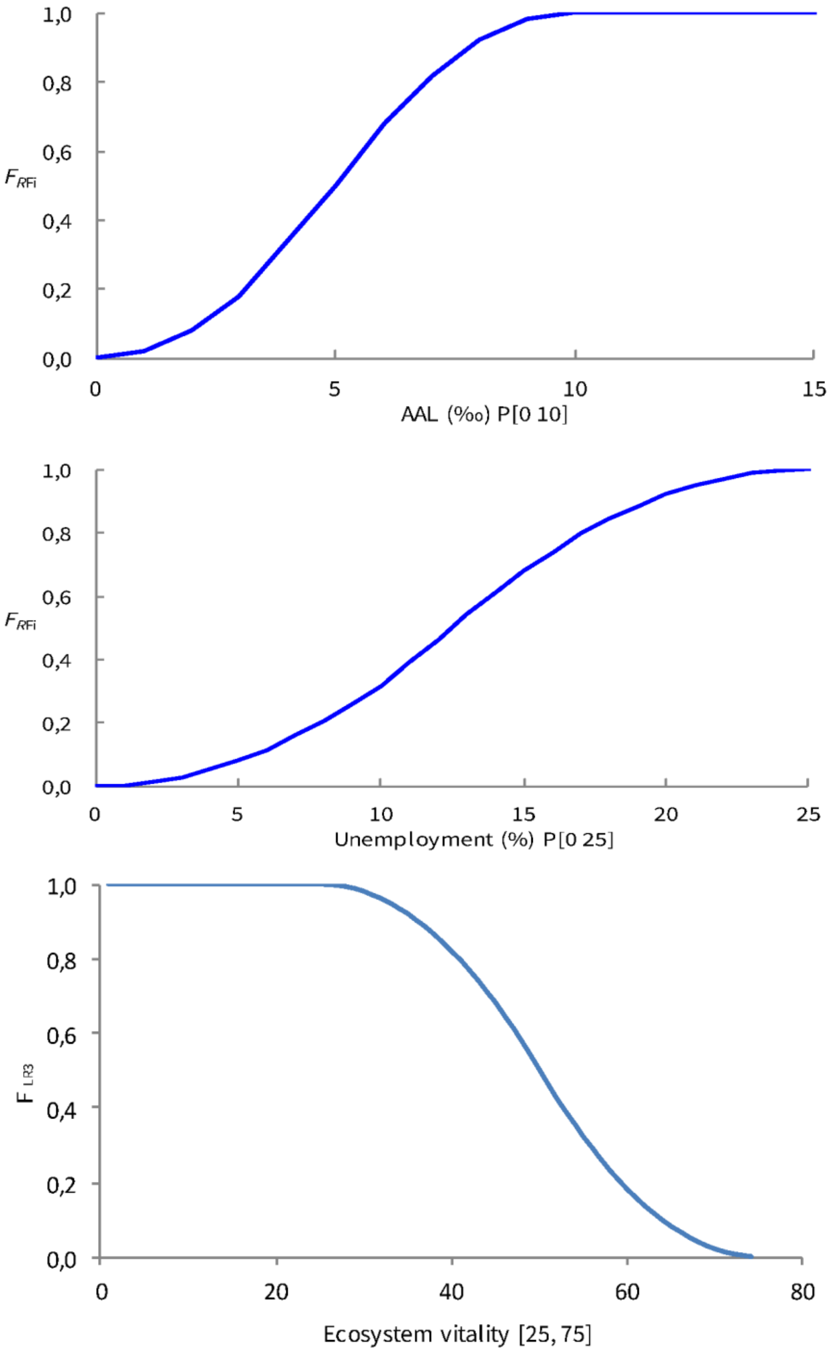

Figure 3: Examples of transformation functions.

The values on the abscissa of the transformation functions correspond to the values of the descriptors or raw indicators (as found in the international databases) while the ordinate corresponds to the final value of each factor, either related to the physical risk or to the aggravating factor. In all cases, values of the factor lie between 0.0 and 1.0. Since the transformation functions are membership functions, for high risk and aggravating coefficient levels, 0 corresponds to non-membership (or zero contribution to risk and aggravating coefficient) while 1 means full membership (or full contribution to risk and aggravating coefficient). Limit values denoted as X_{min} and X_{max} are defined by using expert criteria and information about previous disasters in the region. Relative weights w_{FSi} and w_{FRj} that associate the importance of each of the factors on the index calculation are defined in this specific evaluation as equal, that is, it is assigned the same importance or contribution to each of the indicators that intend to characterize the socio-economic dynamics of the society.

SELECTION OF THE AGGRAVATING FACTORS

For the selection of the aggravating factors, besides considering the availability of data and coverage, an effort was made to specify relevant issues that reflect social fragility and lack of resilience. Indicators representing social fragility such as: illiterate people, access to sanitation, and access to improved drinking water, are function of economic development as living standards rise along with disposable income levels. High values of these indicators reflect a comparatively unfavorable situation that reflect a notion of susceptibility of a community when faced with hazardous events, whichever its nature or severity. The distribution of population, and the trend towards greater concentration in the cities is portrayed by the urban population indicator, which reflects the exposure of population as a condition of susceptibility whenever the growth of this population has been disorderly, lacking land use regulations that result not only in fragile constructions but also in serious impacts on the environment. Differences in vulnerability of social and physical context, determines the selective nature of the severity of the effects of the natural phenomenon (Cardona, 2001).

Other indicators of social fragility are poverty, crowded conditions, housing, and unemployment, which in general represent income inequality. Poverty constrains the capacity of the society to cope with disasters, rendering its functioning particularly fragile. It is a vulnerability condition that reflects, in general, an adverse and intrinsic predisposition to be affected when faced with a hazardous event.

Indicators representing lack of resilience capture, at a macro level, the capacity to recover from or absorb the impact of hazardous events. When these indicators are low, means that necessities of the society are not being covered, accounting for a deficit in the quality of life, thus reflecting a notion of susceptibility and an incapacity to adequately face disasters.

RESULTS OF THE HOLISTIC MULTI-HAZARD PROBABILISTIC RISK ASSESSMENT FOR COLOMBIA

This section presents the results obtained using the methodology in terms of R_F, F and R_T. Detailed information about the results can be found in (UNGRD, 2018).

According to the results shown in the Map of Figure 4, the highest R_F values are generally found in municipalities located in areas highly prone to floods where in many cases the area affected by an event represents virtually the whole area of the territory. In these cases, exposure plays an important role in risk, given the intensity of the events and the small territories that in relative terms result more affected. Another reason for these high values of potential losses can be given by the disorganized growth and the lack of proper building and land use codes. Usually, the larger the event and the smaller or the weaker the economy, the more significant is the impact.

From the socio-economic perspective, highest values belong to weaker economies, where organizational, institutional, environmental, and social conditions are also weaker, and it is reflected in this evaluation by the high values of susceptibility and lack of resilience indicators (Figure 5).

As it can be seen in the map (Figure 6), Total Risk, R_T, results evidence the important influence that the aggravating factors have on the physical effects after an event. The results depict how most of the municipalities with higher R_T values are lower and weaker economies. These results reflect susceptibility in terms of physical, organizational, and attitudinal factors that may lead to generate or increase vulnerability faced with the occurrence of hazard events.

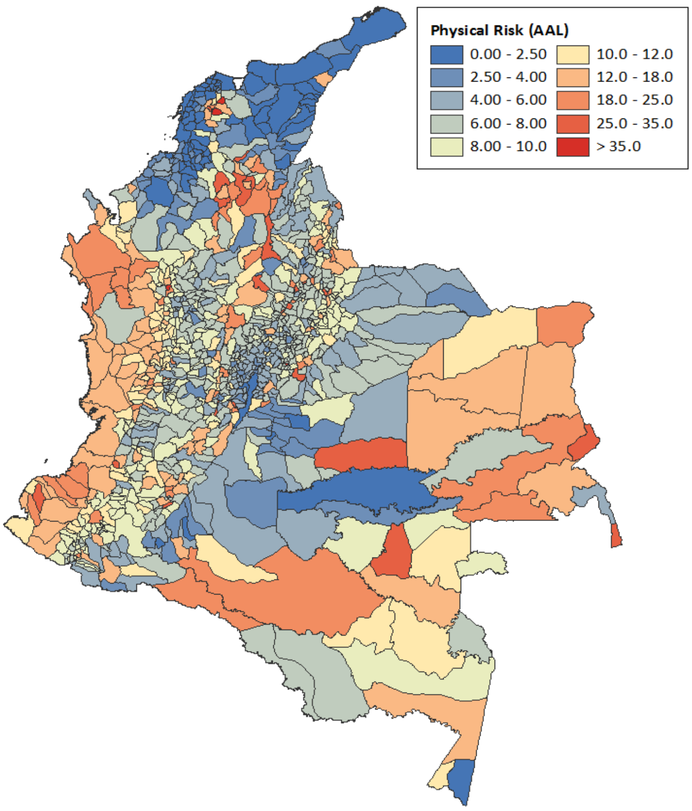

Figure 4: Physical risk, AAL.

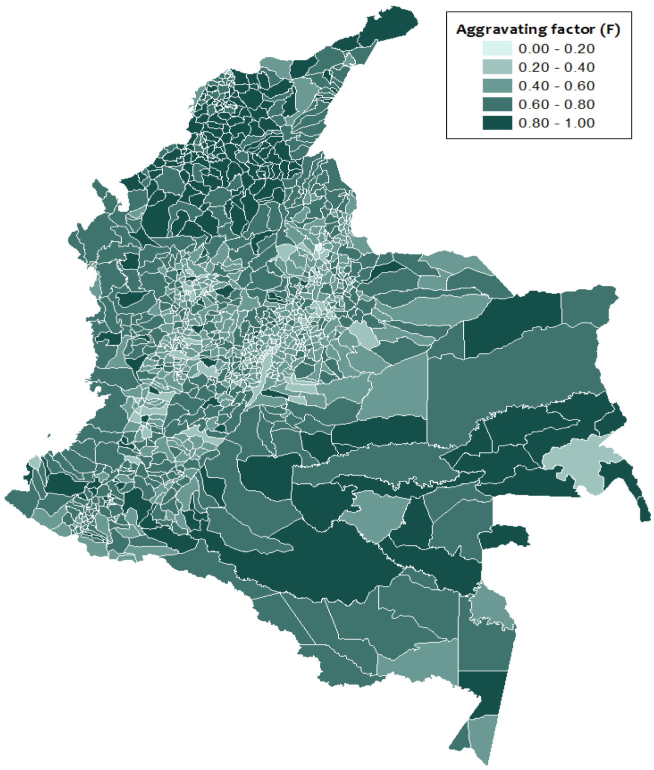

Figure 5: Aggravating factor, *F*.

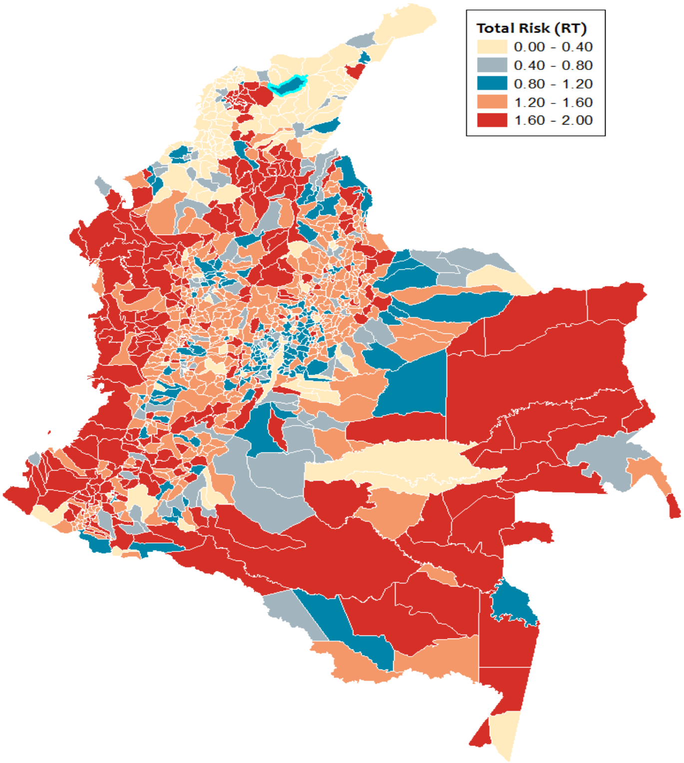

Figure 6: Total risk, R_T.

CONCLUSIONS

This is the first time that a study following the above-mentioned methodology is conducted in all the aspects (hazard, exposure, vulnerability, and socio-economic descriptors) at subnational level for a whole country. It is worth noting that this evaluation does not correspond to a high-resolution risk assessment. However, this approach allows a direct and appropriate comparison of the obtained results and it can help in prioritizing areas for developing higher detail disaster risk analysis. This evaluation also allows the disaggregation of the results to highlight the main risk drivers by identifying the descriptors that are contributing the most in each of the indexes (physical risk, social fragility and lack of resilience). Finally, the results are useful to identify underlying risk drivers that are not only associated to the physical risk of buildings and infrastructure, but also to social factors that should be examined further.

The holistic risk evaluation is based on probabilistic risk assessment methodologies and socio-economic indicators. Probabilistic risk assessments are models that intend to represent a reliable order of magnitude of potential losses, and they do not predict events nor exact amounts of damages and losses. Therefore, these models consider different uncertainties related to the occurrence of natural phenomena and generation of losses.

Socio-economic indicators are also a way to represent and quantify the reality of a region, they are approximations, and many details might be lost in condensing in a single number what wants to be measured. Nevertheless, this number can give a good approximation of reality as well as it allows measuring it with respect to something else and to set a more concrete achievement. Indicators also allow comparison among different periods or among different areas, identifying weaknesses and strengths which serve as a starting point to take concrete actions to improve the socio-economic reality.

Although uncertainties related to the physical risk assessment have been accounted for, research is needed to incorporate the ones existing in the considered socio-economic characteristics Burton and Silva (2014). Those cannot be handled by means of probability distributions. Nevertheless, it is important to highlight that sensitivity tests have been made to demonstrate the robustness of risk rankings and risk level ranges derived from the composite indicator (Marulanda et al., 2009).

Finally, this kind of evaluations can be periodically updated to evaluate the changes in physical risk and in development. The results obtained from this evaluation allow measuring the progress towards the goals established in the Sendai Framework for Disaster Risk Reduction 2015-2030, and the Sustainable Development Goals, SDGs, without waiting for disasters to happen. It is possible to measure progress in reducing future negative effects in the occurrence of events, without having to experience a disaster (Muir-Wood, 2016).

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