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EVALUATION OF THE TSUNAMI VULNERABILITY IN THE COASTAL ECUADORIAN TOURIST CENTERS OF THE PENINSULAS OF BAHIA DE CARÁQUEZ AND SALINAS

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ABSTRACT

Potential occurrences of tsunamis are the main coastal hazards for the highly touristic peninsulas of Bahía de Caráquez and Salinas in Ecuador. Their hotel infrastructure is of top quality, in addition to having a significant population density at the natonal level. The current study aims to identify the vulnerabilities of the population in order to reduce the tsunami hazard level, and to protect the physical integrity of the present population. Thus, in both cities we have obtained results about the vulnerabilities of basic services, socioeconomic, structural characteristics, community organization and communal services, risk perception as well as communication channels with their respective maps that allow their spatial location. The overall vulnerability results of the conducted analysis demonstrated that there is a medium to high vulnerability for the population of Salinas while Bahía de Caráquez the vulnerability is medium to low. Vulnerability for basic services has a high value of about 80%, while the socioeconomic vulnerability is of about 60%, in both cities. The structural characteristics of the two cities are quite different. Salinas is considered an area of higher surplus value with earthquake-resistant buildings and quality construction materials, a fact almost absent in Bahía de Caráquez, in their respective piers. While within the study areas the predominant structural characteristics are of a modest nature, both from the point of view of movable property and as construction materials. Therefore, the vulnerability for the two cities based on infrastructure is medium to high (60-80%). The community organization and communal services in both cities have a low vulnerability value (40%). The vulnerability of risk perception in Salinas is low (40%) while in Bahía de Caráquez it has a very high vulnerability (100%). Vulnerability by means of communication in the two cities reaches a very low value (20%), due to the fact that the road network is in optimal conditions.

Keywords: Tsunami, Vulnerability, Risk assessment, Evacuation plans, Ecuador

1. INTRODUCTION

Vulnerability studies within the context of natural hazards demonstrate the state or grade of preparedness or response towards an unfortunate situation due to internal or external forces. As a disaster is defined to be the sum of vulnerability plus the hazard(s), then studies or research of vulnerabilities need to be elaborated in the same detailed way as we analyze hazards (Cannon, 2000). The growing awareness of the research of a variety of vulnerabilities of different hydrometeorologic or geologic hazards strengthen the evaluation of the grade preparedness of an exposed public or their infrastructure (Varley, 1994; Cannon, 1994; Cutter, 1996; Morrow, 1999; Cannon, 2000; Paton & Johnston, 2001; Alcantara-Ayala, 2002; Turner et al., 2003: Pelling, 2003; Thomalla et al., 2006; Adger, 2006; Blaikie et al., 2014; Pararas-Carayannis, 2018). Vulnerability studies or assessments about tsunami hazards are scarce but not rare, where such methods have been applied considering the past and potential future tsunami impacts with the worse-case scenario (Papathoma & Dominey-Howes, 2003; Papathoma et al., 2003; Birkmann, & Fernando, 2008; Cochard et al., 2008; Calgaro, Lloyd, 2008; Khasalamwa, 2009; Wood et al., 2010; Omira et al., 2010; Leone et al., 2011; Shimozono, & Sato, 2016; Madani et al., 2017).

Due to the tsunami disasters in recent times in Chile (2010) and Japan (2011), which both attract a high concern of potential impacts and the corresponding vulnerability in the coastal area on Ecuador (Fritz et al., 2011; Vargas et al., 2011; Mori et al., 2011; Muhari et al., 2011; Brizuela et al., 2014). Therefore, as the Ecuadorian government has been recently aware of potential damages from regional and local tsunamis, Ecuador opted to evaluate the associated risks of any tsunami impacts in touristic centers. These particular touristic sites have been easily identified to be represented by the highly-visited peninsulas of Bahia de Caráquez and Salinas in the coastal provinces of Manabí and Santa Elena, respectively. Its hotel infrastructure is of first quality, besides having a significant population density at the cantonal level. The occurrence of a tsunamigenic event in these cities would cause great affection because most of its inhabitants are settled in areas of high risk of flooding by tsunami and the times of evacuation of the population are greater than those of arrival of the first wave (Matheus et al., 2016).

Therefore, the main aim of this study has been to identify the areas of influence for tsunami events and the areas of greater and lesser vulnerability in Bahia de Caráquez and Salinas. The development of this research is aimed at identifying the vulnerabilities of the population in order to revert the level of risk to which they are subjected, and to safeguard the physical integrity of the population immediately, at the first tsunami alert on the coasts of the selected cities. The final result of the study will provide very high-value information that will feed back to the municipalities and the population in potential danger.

2. GEODYNAMIC SETTING

In Ecuador appear the northern Andes, which are part of the 7000 km long classical example of an active continental margin along the South American continent with several volcanic sequences of Mesozoic and Cenozoic ages (De Mets et al., 1989; Trenkamp et al., 2002; Toulkeridis, 2013; Toulkeridis and Zach, 2017). Variations of the volcanic sequences are displayed within the observed geotectonic structures and have evolved due to different subduction geometries along the margin as well as the subduction angle of the subducting plate underneath Southern and Central America (Kellogg and Vega, 1995). In the north, the Cocos plate is subducted underneath the Central American plate, while further to the south the Nazca Pazific plate, is subducted with an angle slightly oblique to the southern American continent producing an overall active tectonic regime with transpression due to its convergence (Fig. 1; Shumway, 1954; Daly, 1989; Gutscher et al., 1999). This Nazca Plate incorporates the aseismic Carnegie Ridge, which was produced by the passage of the ESE moving Nazca Plate over the Galapagos hot spot (Shumway, 1954; Lonsdale, 1978; Freymuller et al., 1993; Jaillard et al., 1995; Toulkeridis, 2011).

The propagation of deformation towards the continent seems to be influenced also by the collision (and mechanical coupling) of the Carnegie Ridge below the South American continent (Gutscher et al., 1999; Dumont et al., 2014). Deformation is partitioned in a NNE-SSW trending strike-slip and reverse faults (Hughes and Pilatasig, 2002). The South American continent itself is composed of two different continental plates, the Caribbean and South American continental plates, of which contact is represented by a transformal or strike-slip fault named Guayaquil-Caracas Mega-Fault or Shear, which extends from the Gulf of Guayaquil in Ecuador until Venezuela (Kellogg and Vega, 1995; Dumont et al., 2005).

As result of both, the collision and subsequent subduction between the Nazca oceanic and the Caribbean with the South American continental plates as well as the movement of the referred Mega-Fault, extreme destruction by a variety of landslides, earthquakes and tsunamis have been manifested in past along the subduction trench and along and aside the fault with high losses of both, life and infrastructure (Barazangi and Isacks 1976; Mendoza and Dewey, 1984; Atakan, 1995; Tibaldi et al., 1995; Pararas-Carayannis, 2012; Chunga, and Toulkeridis, 2014; Parra et al, 2016; Toulkeridis et al., 2018). Therefore, strong earthquakes with catastrophic results for life and infrastructure occur in regular form in the Ecuadorian territory. In a time period of almost five centuries since 1587 until recent times more than 140 earthquakes destructed parts of cities and urban areas, with a total fatality sum of more than 80,000 deaths (Fig. 2; Kahn, 2005; Toulkeridis et al., 2017a).

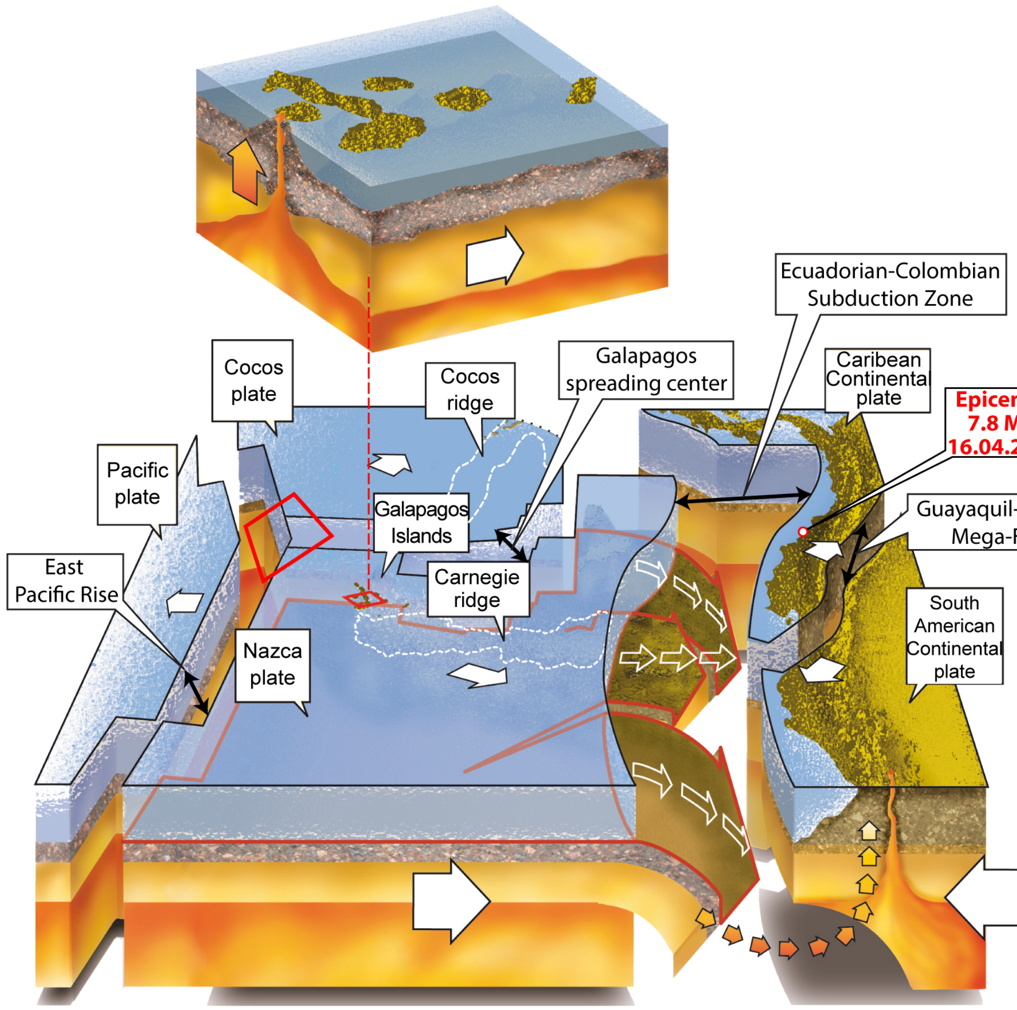

Figure 1: Geodynamic setting and associated continental and oceanic plates as well as plate boundaries of the surrounding of Ecuador, the Galapagos Islands and the Carnegie Ridge. In red has been indicated the most recent epicenter. Adapted from Toulkeridis, 2013 and Rodriguez et al., 2016.

Of these telluric movements, more than 96 (+X) earthquakes had an intensity of VI to VII, another 25 (+X) earthquakes had an intensity of VIII while some 12 (+X) had an intensity equal or higher IX on the international Mercalli Scale. Remarkable of these seismic events have been those at 1797 (XI), 1868 (X) and that of 1949 (X) (Engdahl and Villasenor, 2002; Beauval et al., 2010; USGS/NEIC, 2017). From 1900 until 2017, some 65 seismic events occurred in the area of Ecuador surpassing 6,0 and reaching up to 8,8 in 1906 on the Richter Scale (USGS/NEIC, 2017). The three last earthquakes with a high number of fatalities have been a 6.8 Mw in 1949 with 6,000 deadly victims (Ganse, and Nelson, 1982; Housner, 1984;), a 6.9 Mw in 1987 with more than 1100 deaths (Berz, 1988; Tibaldi et al., 1995; Schuster et al., 1996), and a 7.8 Mw in 2016 with 663 fatalities (Ye et al., 2016; Toulkeridis et al., 2017a; b; Navas et al., 2018).

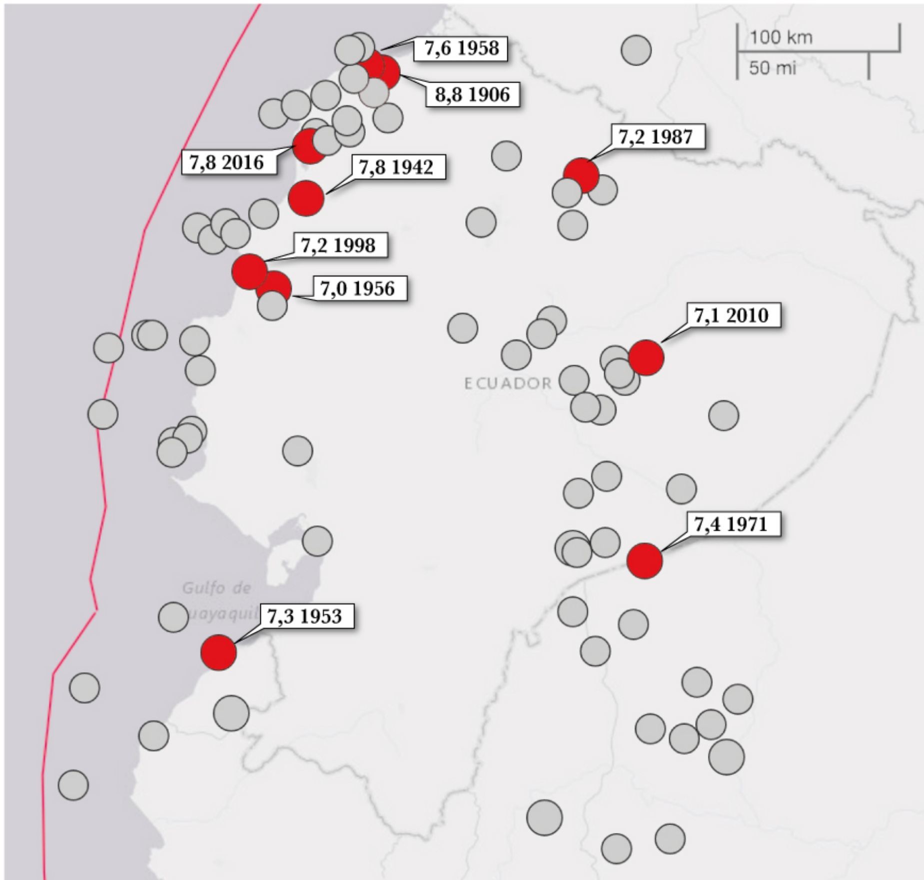

Figure 2: Seismicity of Ecuador from 1900-2017, with epicenters superior 6,0 on the Richter Scale based on the archive and catalogue of the United States Geological Survey (USGS/NEIC, 2017).

3. LOCATION OF THE STUDIED SITES

The coastal territory constitutes a great resource of tourist exploitation since it counts on attractive spas and beaches for the national and international tourists. The most visited coastal sites in Ecuador are Bahía de Caráquez and Salinas, which have a very advanced infrastructure and tourist services. Hereby, the westernmost peninsula of Ecuador constitutes the Santa Elena province, of which canton Salinas is made up of six parishes (Carlos Larrea, Alberto Gallo, Vicente Rocafuerte, Santa Rosa, José Luis Tamayo and Anconcito). This canton has a population of 68,675 inhabitants and a population density of 1007.40 persons per km^2, and is characterized by having a young population as 48.8% of the population comprises people younger than twenty years. For the present study, we used data of urban population of the canton that corresponds to 29,294 inhabitants. (Population Census 2010, GAD Salinas, 2011).

The city of Salinas has two coastal fronts, being South and North. The southern coast (Mar Bravo) does not yet have a high population density and land use is predominantly for the production of salt, (Fig. 3), which constitutes an important economic activity of the canton.

The elevated western coast is occupied by the military bases of the Air Force and Navy, respectively. In the northern coast the main economic activity of the city is carried out, being the tourist sector, since in the area are the main hotel complexes with buildings up to 20 floors. The hotel zone is where the level of the tide reaches the highest level, so the seawall has been protected with walls of cast iron (Fig. 4)

Figure 3: Aerial view of the beach, hotel and commercial area of northern Salinas as well as uninhabited southern area of the peninsula. Courtesy by Marco Villavicencio.

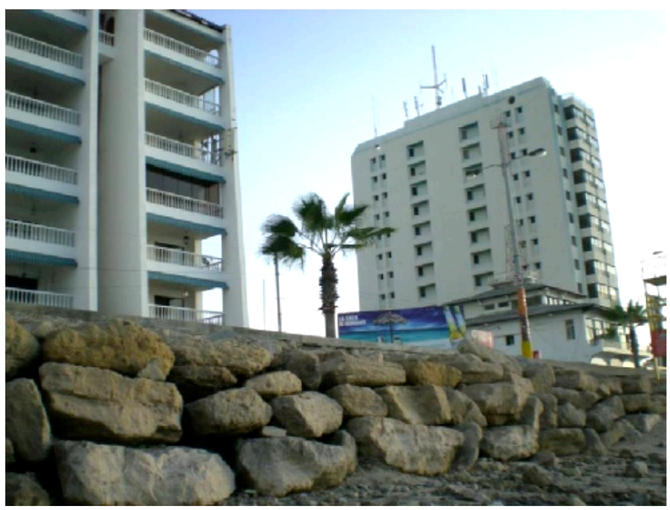

Figure 4: Cast rock-wall around the boardwalk of Salinas

Bahía de Caráquez is located in the northern side of the province of Manabí, forming part of the canton Sucre, that counts on a population of 57,159, a population density of 143,55 persons per km^2, that in the majority is considered young since 46.4% are younger than twenty years of age. For the present study, we have used data of the City of Bahía de Caráquez, which counts on a population of 24,963 inhabitants. At the western edge of Bahía de Caráquez is located the pier Virgilio Ratti in which are several buildings with departments of six to ten floors, while in the center-south zone occur many particular buildings with five floors of average height (Fig. 5).

Figure 5: Aerial panoramic view of the city of Bahía de Caráquez. In the center of the image is the bridge, which connects Bahía with the city of San Vicente. In the lower left part of the picture is situated the pier Virgilio Ratti. Taken from the west. Courtesy by Galahar

Horizontal evacuation is not possible in the pier Virgilio Ratti. In the southeastern zone is the so - called Port Amistad in which tourists sail boats from different areas and the Bahía - San Vicente bridge joins these two localities. In this area, there are private houses with two to three floors on average (Fig. 5). To the southwest is the area called "Mirador La Cruz" where there are modest single or double-storey houses of mixed materials (block, wood, zinc) in usually poor condition. Although this area is an elevated zone, and might be used as safe against flooding, it is still a zone of high risk for landslides and therefore not recommended to be used as zone of security towards incoming tsunamis (Fig. 6).

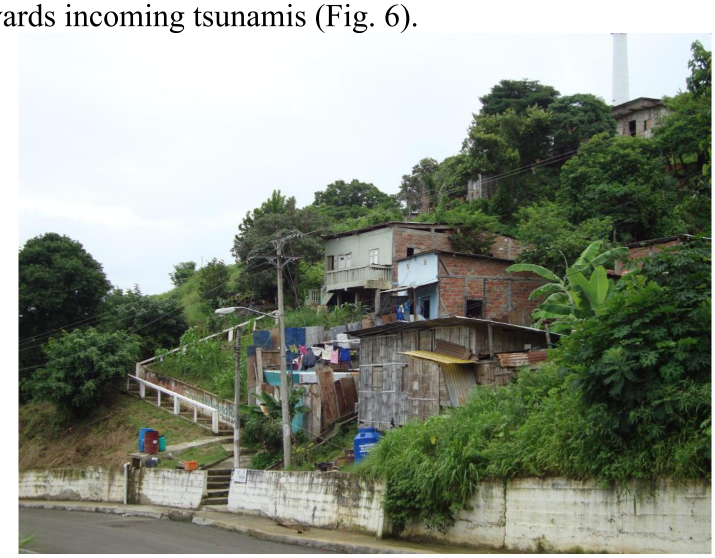

Figure 6: Type of housing in the suburb “La Cruz”.

4. METHODOLOGY

a) Definition

Vulnerability is defined as the weakness or susceptibility of a population, building or infrastructure to suffer damage of such magnitude that it changes its life condition in the case of a population or that it exceeds the capacity of resistance for which it has been designed in case of a building or other structure, due to an adverse event of natural or anthropic origin. There are detailed studies that also address vulnerabilities of natural, physical, economic, social, technical, structural, basic or community services, risk perception and communication pathways (Wilchez-Chaux, 1993). However, the most important vulnerability modifiers are highlighted, such as physical, economic and social (Anderson, 1995; Levine, 2004; Adger, 2006; Birkmann, 2006; Blaikie et al., 2014).

Physical factors refer to the geographical location of human settlements, in areas at risk, such as settlements near the riverbed, which tend to be more vulnerable to flooding than those located in more distant places, as well as a population seated on the slopes of a volcano, will be more vulnerable of being affected by an eruption than one that is far from the volcano. The economic factor has a direct influence on the risk management process, as the lack of sufficient financial resources would not allow to perform plans or projects, which need to deal with a possible disaster, so infrastructure may not be constructed seismic resistant. All these shortcomings lead to a greater level of vulnerability to the possible occurrence of a destructive event. Finally, the social factors refer to the culture of a population, its ideology and education, the same ones that are conjugated when reacting to a situation of a threat. In the same way, it influences the acceptance and reception of the management plans after a destructive phenomenon has arisen (Gestión Comunitaria de Riesgos - Community Risk Management, 2008).

The vulnerability study is an important factor in determining risk, knowing its variables and indicators, which subsequently allows the understanding of a variety of risk scenarios (in this case of natural origin). Often the exposed elements may present threats of low intensity, therefore, a vulnerability analysis may be a platform for (a) Understanding the usefulness of information generated by different institutional sources and their application to vulnerabilities; (B) Building information based on variables and indicators needed to understand vulnerabilities and easily replicated for local authorities; (C) Interinstitutional and multidisciplinary work of actors responsible for information, land use management and development at national and cantonal level (PNUD, 2011).

The analysis of vulnerability is decisive when preparing the community to support, manage and recover from a destructive event, as this delimits zones according to the value of susceptibility for the considered threat. The types of vulnerability considered are: socioeconomic, physical infrastructure, basic services, community services and organization, communication channels and risk perception. These types are in the current study not understood as knowledge of the environment and adverse events that threaten it, but rather as the greater or lesser capacity of reaction or response of the community to a tsunami, due to the limited time that exists before the arrival of destructing waves to the coast. In order to carry out a correct vulnerability analysis, it has been essential to make field visits, with the objective of obtaining necessary information from the primary source, that is, directly from the inhabitants of the area and also to verify and validate the results.

1. GENERAL DATA

Location

East ☐ Neighborhood ☐
North ☐ Address ☐

2. INFRASTRUCTURE IN YOUR NEIGHBORHOOD

Does the neighborhood have a communal house? Yes ☐ No ☐

Where does the community meet to address important issues? ______

What is the best time to bring the community or neighborhood together?

Day ______ Time ______ Place ______

Are there local or communal leaders or presidents? Yes ☐ No ☐

Indicate the names, addresses, telephone numbers: ______

Are there green areas and parks in your neighborhood? Yes ☐ No ☐

Wide ______ Flat ______ Sanitary ______

Which days per week are the most visited by the habitants in these areas?

Monday-Friday ☐ Weekends ☐ Holidays ☐

What number of people approximately visit these areas a week?

0-50 people ☐ 50-100 people ☐ 100-200 people ☐ >200 people ☐

Do people with special abilities / disabilities attend these areas? Yes ☐ No ☐

The house where you and your family live is?

Leased ☐ Own ☐ Borrowed ☐ Antichresis ☐ Other ☐

Do you have basic services in your home?

	Frecuency				Condition		
Service	Yes	No	Occasional	Always	Bad	Regular	Good
Electric power	☐	☐	☐	☐	☐	☐	☐
Street lighting	☐	☐	☐	☐	☐	☐	☐
Landline	☐	☐	☐	☐	☐	☐	☐
Cellular coverage	☐	☐	☐	☐	☐	☐	☐
Drinking water	☐	☐	☐	☐	☐	☐	☐
Other Drinking Water System	☐	☐	☐	☐	Water well ☐ Tank ☐		Piped water ☐ Slope ☐
Wastewater treatment	Septic		☐	Latrine ☐ Public sewer ☐			

How is garbage eliminated in your neighborhood?

Municipal ☐ Burned ☐ Buried ☐ Recycle ☐

3. ROAD AND TRANSPORTATION IN YOUR NEIGHBORHOOD

Of which material are the main access roads to your neighborhood made of?

Flooring ☐ Cobble ☐ Stone ☐ Ballast ☐ Earth ☐ Other ☐

In what state are the roads in your neighborhood?

Great ☐ Bad ☐ Regular ☐

What type of public transportation do you have in your neighborhood?

Buses ☐ Vans ☐ Metro ☐ Taxis ☐ Other ☐

How many public transport lines serve your neighborhood? ______

What time until what time is there a shuttle service in your neighborhood? ______

Figure 7: Fragment of the information capture sheet.

b) Information capture sheet

In order to obtain, homogenize and systematize the field data in a fast way, it has been necessary to design an information capture sheet, with closed questions to facilitate the interaction between interviewers and respondents and the subsequent processing of the data (Fig. 7). Each sheet or card has an identification code and geographic coordinates for its georeferencing, capturing information that has been required for the calculation of partial and total vulnerabilities for each sheet. With the obtained vulnerability values, it has been possible to map the partial and total vulnerabilities in six thematic maps for each city.

SOCIOECONOMIC						
Weighing	**Sheet-code**	**1A**	**2A**	**3A**	**4A**	**5A**
	Does the neighborhood have a communal house?					
4	No	0	1	1	1	1
2	Yes	1	0	0	0	0
Vulnerability by question		2	4	4	4	4
	Are there local or communal leaders or presidents?					
4	No	0	1	1	1	1
2	Yes	1	0	0	0	0
Vulnerability by question		2	4	4	4	4
	Are there green areas and parks in your neighborhood?					
0	No	1	1	1	0	1
0	Yes broad and adequate	0	0	0	1	0
Vulnerability by question		0	0	0	0	0
	Which days in the week are the busiest in the tourist area of the city?					
2	Monday-Friday	0	0	0	0	0
4	Weekend	1	1	1	1	1
5	Holiday	0	0	0	0	0
Vulnerability by question		2	4	4	4	4
	Approximately, how many people visit these areas in the week?					
1	0-50 people	1	1	1	1	0
2	50-100 people	0	0	0	0	1
3	100-200 people	0	0	0	0	0
4	> 200 people	0	0	0	0	0
Vulnerability by question		1	1	1	1	2

Figure 8: Fragment of the vulnerability matrix. A: Type of vulnerability to the tsunami hazard. B: Identification code of the sheet. C: Weighting assigned to each response. D: Indicators of vulnerability. E: Multiple choice responses. F: Weighted value of vulnerability indicator.

c) Design of the vulnerability matrix

After obtaining the data through the data capture sheets, a vulnerability matrix has been created in a spreadsheet, to tabulate the responses and to assign weights according to the response obtained. We present a fragment of the vulnerability matrix created for the two cities, which includes all the data obtained from the community and the weights assigned to each response. (Fig. 8).

d) Data processing

Each response option has been assigned to a weight according to the degree of influence it may has on the tsunami hazard. Considering the scale of the study, the qualitative vulnerability has been classified into five categories, each of which has its respective percentage quantitative correspondence, as illustrated in Figure 9.

Qualitative vulnerability	**Quantitative vulnerability** (%)
Very high	**100**
High	**80**
Medium	**60**
Low	**40**
Very low	**20**

Figure 9: Assigned categories of qualitative and quantitative vulnerabilities.

Weighted values of each indicator have been obtained from all the tabs obtained in the field, then these values were ordered in a new matrix to obtain a total value for each type of vulnerability. In the vertical sense, the partial vulnerability value has been obtained by applying descriptive statistics, in this case we have used the Mode function, which uses the frequency of weighted values. Below, we present a fragment of the matrix of weighted values of one type of vulnerability (Fig. 10).

Having partial vulnerability values for each type of vulnerability, the mode function has been applied again horizontally to obtain the total vulnerability value by type of vulnerability for the entire study area (Fig. 11).

Finally, in order to obtain total vulnerability values for each sheet, a new matrix has been generated, where the values of partial vulnerability per sheet of all types of vulnerability are recorded. In this case, as there have been scattered values, we applied the statistical function of the arithmetic mean to better adjust to the reality of each city (Fig. 12).

PHYSICAL INFRASTRUCTURE	1A	2A	3A	4A	5A
What is the structural system of your home?	1	1	1	1	1
What is the type of wall-materials of your home?	2	3	2	2	3
What is the type of roof of your home?	4	1	3	3	3
What is the type of the mezzanine system?	1	1	1	1	1
Number of floors of your home?	3	1	4	4	2
Year of construction of your home?	3	2	4	3	2
What is the state of conservation of your home?	2	2	2	3	3
Characteristics of the soil on which your home is located?	5	1	1	1	1
What is the topography of the site?	4	4	4	4	4
What is the type of construction of your home?	1	1	1	1	1
PARTIAL VULNERABILITY BY SHEET	3	1	3	3	3

Figure 10: Fragment of the matrix of weighted values. A: Partial vulnerability per sheet, concerning the physical infrastructure. B: Weighted values of each indicator.

VULNERABILITY SERVICES ORG COMMUNITY	7B	8B	9B	10B	11B	VULNERABILITY SERVICES ORG COMMUNITY
What health unit exists in your neighborhood?	2	2	2	2	2	
What schedule does it accomplish?	1	4	4	4	4	
Who uses frequently health centers in your neighborhood?	3	3	3	3	3	
What types of schools exist in your neighborhood?	6	4	4	6	2	
Does the educational center have large spaces, classrooms in good condition and sanitary batteries?	2	5	5	2	5	
What level of education does the educational institution have?	3	2	2	2	4	
What working days does the educational institution have?	3	3	3	3	3	
In what state is the educational building?	1	1	1	3	1	
Does the neighborhood have cultural or tourist centers?	1	2	2	2	2	
Does the municipality have programs to support ecotourism?	1	1	1	1	1	
Are there libraries in your neighborhood?	2	2	2	1	2	
Is there a community alarm system in your neighborhood?	1	2	2	1	2	
Are there surveillance units or police checkpoints in your neighborhood?	5	5	5	5	5	
Does the neighborhood have a monitoring and surveillance system?	3	3	3	5	5	
Does the neighborhood has hydrants?	1	1	1	1	1	
Does the neighborhood count with a system of shelters in case of emergency?	2	2	2	2	2	
Does the neighborhood have a communal house?	0	0	0	0	0	
Does the neighborhood have leaders or presidents of the neighborhood?	2	5	5	5	5	
PARTIAL VULNERABILITY BY SHEET	2	2	2	2	2	2

Figure 11: Fragment of the matrix of partial vulnerability values. A: Total vulnerability by type for the entire study area.

PARTIAL VULNERABILITY VALUES	1A	2A	3A	4A	5A
Socioeconomic	3	3	3	3	3
Infrastructure	3	1	3	3	3
Basic services	4	4	4	4	4
Community services and organization	2	2	2	2	2
Risk perception	5	5	5	5	5
Communication routes	1	1	1	1	1
TOTAL VULNERABILITIES FOR EACH FILE	3	3	3	3	3

A B

Figure 12: Fragment of the total vulnerability matrix per sheet. A: Total vulnerability for each file for the entire study area. B: Values of partial vulnerability for each type of vulnerability.

5. RESULTS AND DISCUSSION

The vulnerability matrix is the instrument that allows the analysis of vulnerability and is the basis for obtaining all further results. The standardized matrix contains six different types of vulnerabilities considered for this study, vulnerability indicators, weights, weighted values, partial vulnerabilities per file, total vulnerabilities by type of vulnerability and total vulnerability values per block in the study. For each city, the respective standardized vulnerability analysis has been performed. Based on the information obtained from the matrix of each city, the following thematic cartography has been generated, which contained six different maps (socioeconomic, physical infrastructure, basic services, community organization, risk perception (reaction capacity) and communication abilities) representing the partial quantitative vulnerabilities. In addition, a total vulnerability map has been obtained for each city (Figs. 14a-f and 21a-f). Subsequently, the star of the total vulnerability has been generated for the study area of each city, which graphically illustrates the percentage values of the six indicated vulnerabilities (Figs. 34 and 35).

5a) Vulnerability in Salinas

The city of Salinas presented vulnerability values in the range of 60% to 80%, corresponding to medium vulnerability (in yellow color) and high (in orange color), respectively (Fig. 13).

Medium Vulnerability Zone of Salinas:

The medium vulnerability zone (Fig. 13, in yellow tonality) occupies an area of 1,047km^2 corresponding to 93% of the urban area. The average total vulnerability value has been assigned for this zone based on a variety of factors, which are described in detail in the following analysis. Along the Salinas boardwalk there are numerous multi-floor, high-rise buildings (usually ten floors), with private apartments of which many of them are luxury, for holiday or rest, being preferably occupied on weekends and holidays. The rest of the year they remain uninhabited. Considering this circumstance, the qualitative vulnerability, from the point of view of movable and immovable property, should be high, due to the degree of affectation that would cause the tsunami in the departments and communal services (Fig. 15).

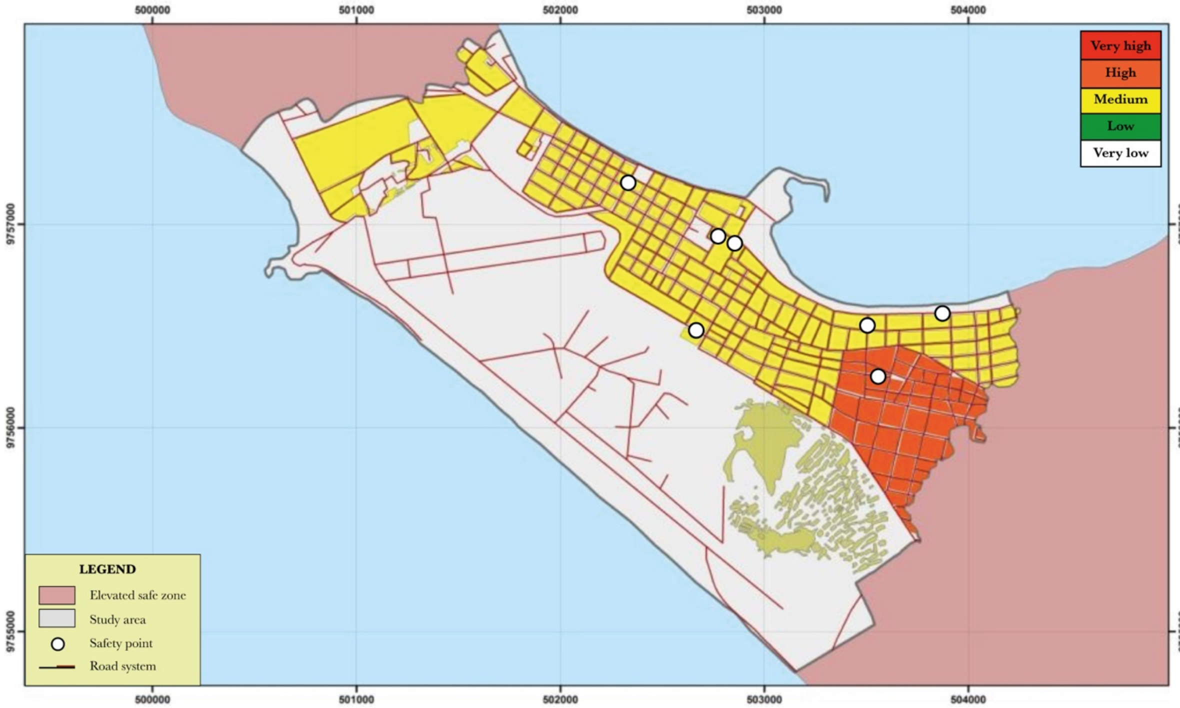

Figure 13: Map of total vulnerability of Salinas.

Figure 15: Communal services of the Riviera del Mar building (Salinas).

However, there are several modifying factors of the such as (a) they are uninhabited most of the year; (b) the impact of the tsunami does not involve 100% of the building, but at worse the first four floors, (c) the economic capacity of their owners is generally high; (d) owners are subject to credit (they are able to obtain timely financing for repairs and replacement of their assets). Therefore, due to these factors, the overall qualitative vulnerability has been assigned to be medium.

The city of Salinas extends itself from the second avenue parallel to the seawall to the salt pits and the runway. Taking into account that the central sector is relatively distant from the beach and the direct impact of the waves, in the event of a tsunami the affect would be caused by permanent secondary flooding due to the morphology of the terrain, with a potential high environmental impact due to contamination and interruption of the basic services. Due to these circumstances, this zone had been initially assigned with a high total vulnerability value. However, after analyzing the responses recorded in the data capture sheets, other vulnerability modifiers have been identified, according to criteria discussed below.

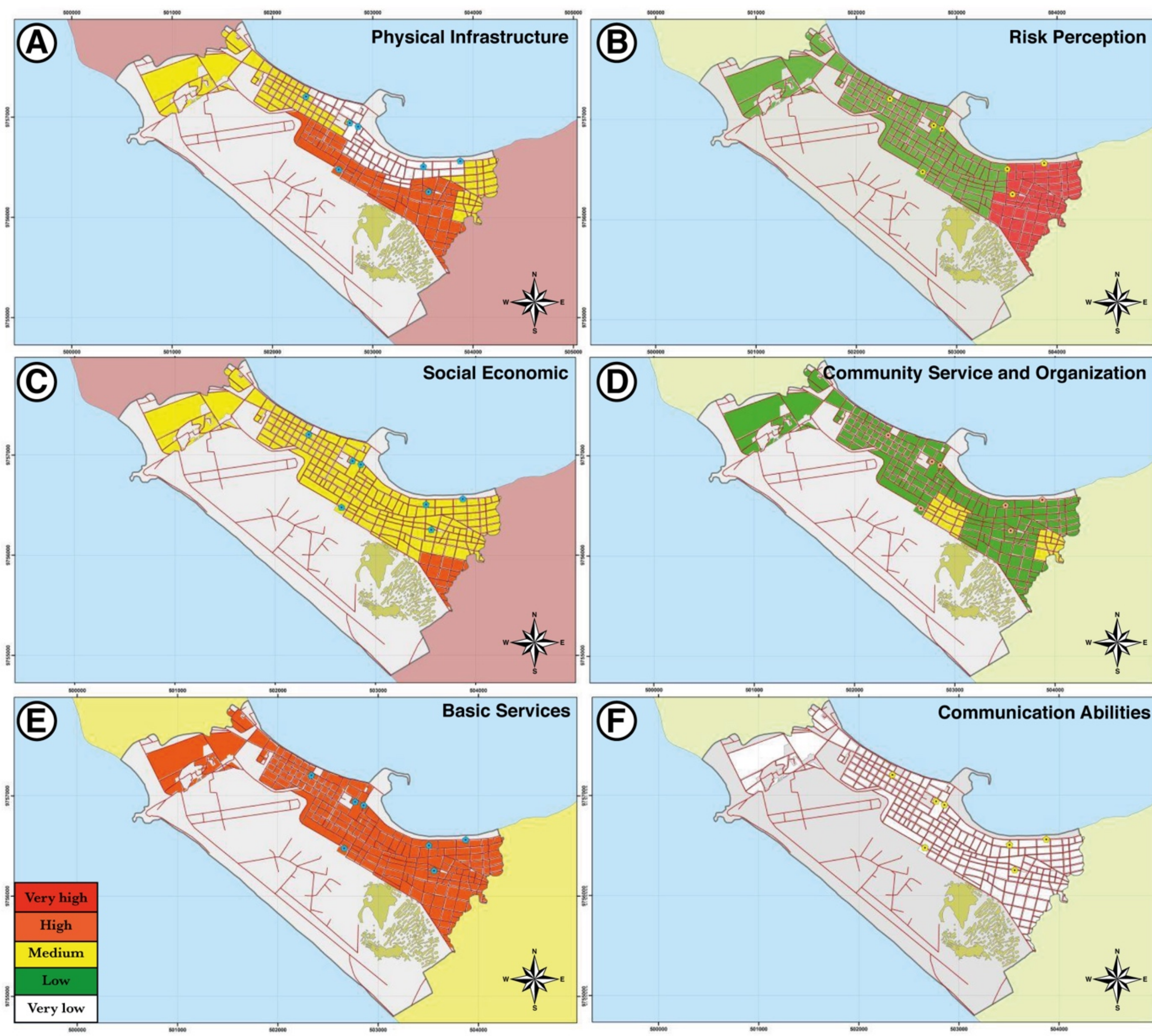

Figure 14 a-f: Specific vulnerability maps of Salinas

Physical infrastructure: In the central area of the city, corresponding to the middle-income class, (Fig. 16), there are constructions that present a maximum of three floors in height with resistant construction materials, in good condition, covered with asbestos cement or reinforced concrete slab. Many are new or in good condition. Therefore, in case of a potential tsunami flood occurrence, they would not suffer major damage to their structural systems. Therefore, they have been assigned to a medium vulnerability value (Fig. 14a).

Figure 16: Type of housing in the central area of Salinas.

Social and economic: The population is markedly stratified according to their economic income, which are directly related to their economic activity. The general public is represented by being public employees, private sector workers, small and micro entrepreneurs, military, among others, whose homes occupy the central area of Salinas (Fig. 13) and constitute the denominated "middle class". Their income ranges from 300 to 600 dollars per month. In terms of the aspects of formal education, most have achieved third-level degrees. This social stratum is moderately vulnerable to any negative events due to their indebtedness capacity, which, although limited, credited as creditors to financial institutions.

On the other hand, informal workers (fishermen, small traders, artisans, domestic workers) constitute the most vulnerable social class because of their low economic resources (low daily income or, at best, the basic monthly wage) and their limited access to health and education services (incomplete basic level). They inhabit the urban - marginal sectors of the city (area near the salt pits, around the cemetery and via Mar Bravo), where, in general, there are no complete basic services because they are settlements, which still seek to be legalized (Fig. 14c).

Basic services: Most of the inhabitants of the central area have complete vital networks, with good functionality and maintenance. In case of tsunami earthquake or tsunami, it is very probable that the service networks are not completely affected, leading to an assignment of these services to be of medium vulnerability (Fig. 14e).

Community services: The presence of the public hospital "Dr. José Garcés Rodríguez" has been evidenced, being located in the area, which is considered to a safe zone (between Quito Avenue and Juan Vargas Street). In the central area of Salinas there are no libraries or cultural development centers, but close to the Salinas market there is an amusement park "Salinas Aqua Club" (Fig. 17), which brings together residents on public holidays. Due to the location, the quality and quantity of such services, a low vulnerability value has been assigned (Fig. 14d).

Figure 17: “Salinas Aqua Club”.

Road network: The existing road network in the central area is composed of wide, well-maintained streets and paved avenues (Fig. 18), which would allow a rapid evacuation to the nearby buildings considered to be safety zones. Additionally, due to their characteristics, they would not necessarily be destroyed with a potential flood, leading to a low vulnerability value (Fig. 14f).

Figure 18: State of Salinas roads.

Therefore, by all the factors described above, the total qualitative vulnerability of the analyzed area corresponds to an average value (Fig. 13).

High Vulnerability Zone of Salinas:

The high vulnerability zone (Fig. 13) occupies an area of about 0.299km^2, which corresponds to 7% of the urban area. Although most of the area is far from the beach and consequently free of the direct impact of the waves in the event of a potential tsunami, a high value of vulnerability has been attributed to it, because after the analysis of the responses of the population, we encountered a variety of modifiers of this vulnerability, which will be described detailed below.

Infrastructure: The houses are mostly of one or two floors, of mixed materials (wood and cane), with structural system of roofs of beams of wood or cane and zinc cover and system of mezzanine with timber and cane. The average age of the buildings is of about 30 years. The houses are built at ground level and are in a regular state of conservation. It is therefore clear that at the time of an earthquake that may generates a potential tsunami, these houses have a high probability of being seriously affected, (Fig. 14a), leaving their owners as refugees (Fig. 19).

Figure 19: Mixed constructions in the high vulnerability zone.

Economic and social: The main economic activity of the inhabitants of this area focuses on informal work (small traders, fishermen, artisans, land transport drivers, domestic workers, among others), which make up the low class and the lower middle class. Due to their low economic incomes, they are not considered as creditors by the financial institutions, therefore, they have a reduced capacity of indebtedness and response to face the possible damages caused by tsunami, for which they constitute the most vulnerable population segment in front of a disaster. Socially, high levels of consumption of alcohol, drugs and sale of articles of dubious origin have been evidenced, reason why the zone is considered violent and dangerous, factor that would affect the immediate answer the moment of requiring an evacuation since the individuals may be under the effects of alcohol and hallucinogenic and psychotropic substances, which would alter potentially better behavior.

As the second determining social factor in this area, we identified that the majority of people leave their children in the care of third parties (neighbors and friends), during work hours and therefore in case of an immediate evacuation the first response of these people would not be to evacuate to safety zones, but to return to their place of habitation to reunite with their children and other relatives, a factor that certainly complicate the displacement of the population towards safe areas.

Community services: The sector lacks of a communal house and the neighborhood president could not be identified in the course of this study, so it has been presumed that there is no regular community organization. The nearby educational centers are fiscal and in regular state of maintenance. The existence of relief agencies close to the sector could not be evidenced (Fig. 14d).

Basic services: There are generally no comprehensive basic services because they are de facto settlements, which seek to be legalized (Fig. 14e).

Risk perception: In this context, the scenario is even more critical because according to the obtained answers, there is evidence of a total lack of awareness of the tsunami phenomenon, its effects on the environment and self-protection of the population. In addition to the absence of a contingency plan, there has also been no training at all in risk management (Fig. 14b).
By the factors described above the total qualitative vulnerability of this area has been modified to the category of high vulnerability (Fig. 13)

5b) Vulnerability in Bahía de Caráquez

In the studied area, despite the existence of high quality physical infrastructure, constituting the sector of the highest surplus value as well as having the highest tourist and economic interest, predominates a medium level vulnerability (Fig. 20).

High Vulnerability Zone:

The area of high vulnerability (Figure 20, in orange tonality) occupies an area of 0.132km^2, which corresponds to 92% of the total area of study. An average total vulnerability value has been assigned for this zone based on the analysis detailed further on. Along the pier "Virgilio Ratti", there are buildings of several floors of height (generally nine floors), with predominately particular apartments, many of them of luxury. Among the buildings there are also private houses of one and two floors high (Fig. 22), which would be flooded by a potential tsunami. From the point of view of material goods furniture and estate property, the value of qualitative vulnerability should be high because of the impact degree that a potential tsunami may have on such infrastructure. However, from the analysis of the responses obtained from the data capture sheets, several factors that modify this vulnerability have been identified. Of these are (a) the apartments are for holidays or for rest, therefore, they are preferably used on weekends and holidays; (b) the impact of an expected tsunami would not involve 100% of the building, but the lower floors; (c) the economic capacity and quality of life of their owners is generally high; (d) owners are subject to credit, as they are able to obtain timely financing for repairs and replacement of their assets. Therefore, the vulnerability of the area is modified from high to medium.

Towards the interior of the city, specifically from the second avenue parallel to the pier, is located the central zone of the study area (Fig. 23), in which different indicators have been identified that catalog such as a zone of medium vulnerability. These will be discussed further below.

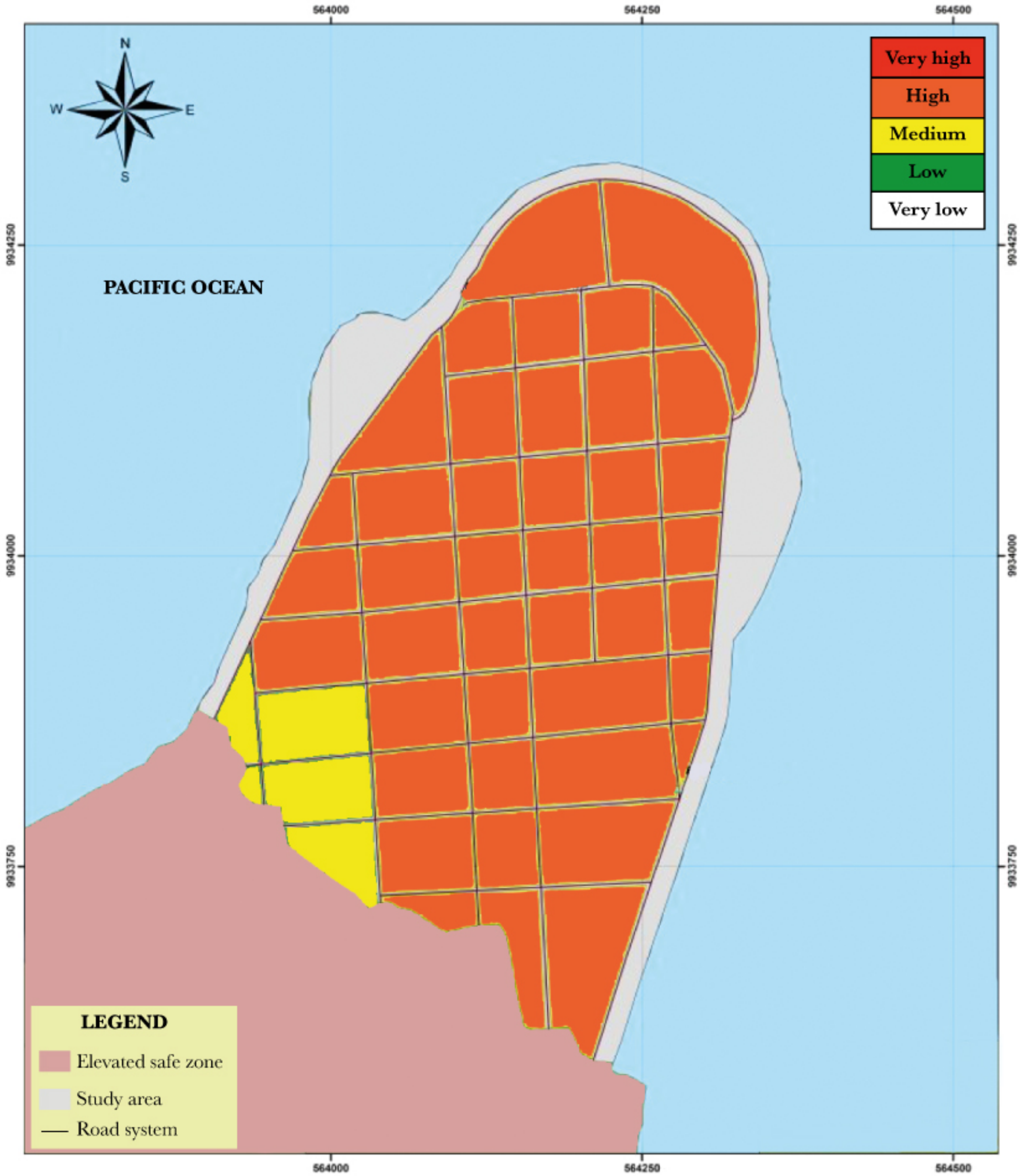

Figure 20: Total vulnerability of Bahía de Caráquez.

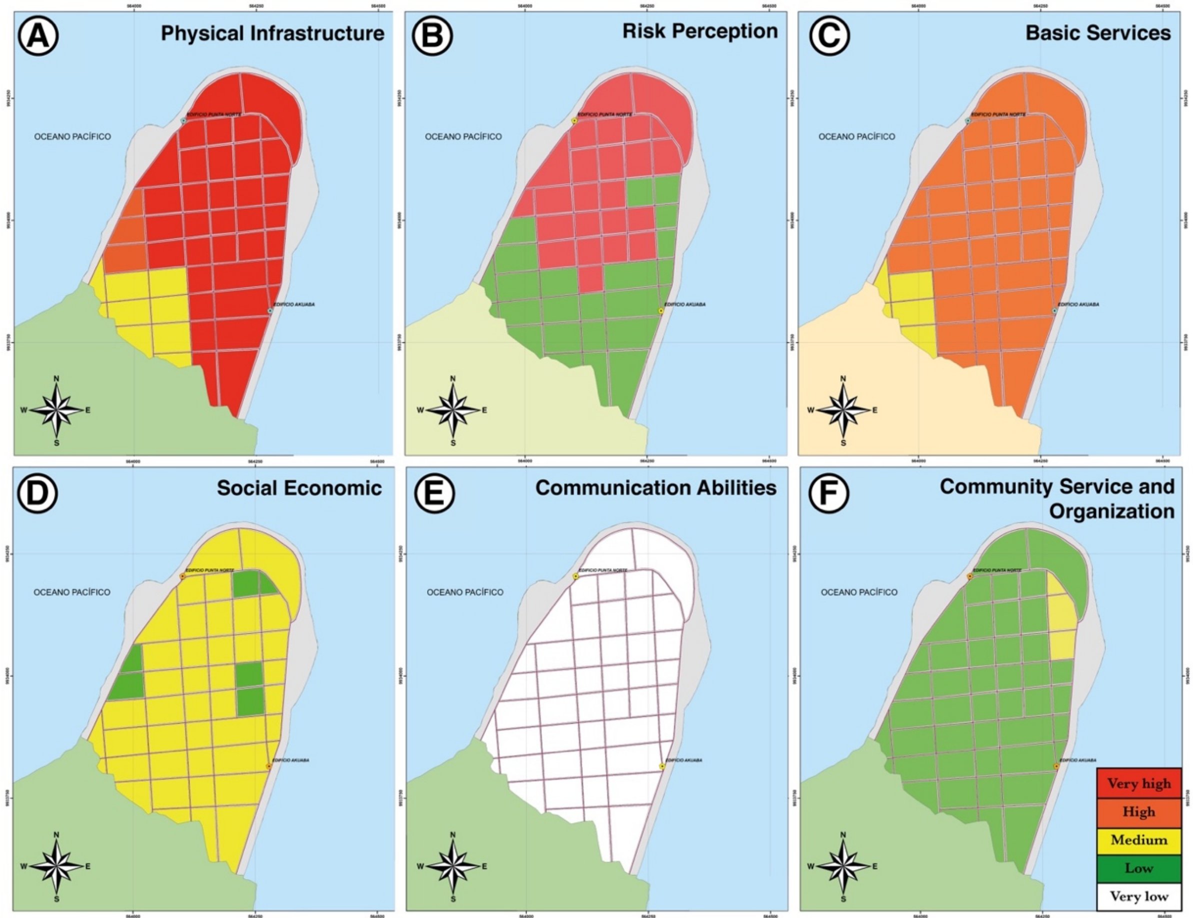

Figure 21 a-f: Specific vulnerability maps of Bahía de Caráquez

Figure 22: Homes located between buildings on the pier "Virgilio Ratti".

Figure 23: Central zone of the study area in Bahía de Caráquez.

Social and economic: The majority of the inhabitants of this area are formal private sector workers who work under a fixed contract and receive a monthly salary ranging from 600 to 900 dollars. With regard to the formal education aspects, most have achieved third level academic degrees and in some fourth level degrees. They own their home and make up the middle and middle - upper social stratum. This stratum is moderately vulnerable to any negative events due to its indebtedness capacity, which accredits them as creditors to financial institutions and could recover in a short time from the damages and losses caused by a potential tsunami.

Figure 24: Types of housing in the central zone of the study area.

Infrastructure: There are buildings with a height ranging from two to five floors, with a main structural system of reinforced concrete, reinforced concrete mezzanines, ceilings with metallic structure and cover of asbestos-cement plates or reinforced concrete slab, in good conserved condition, with a construction age of about 20 years, being upon dry and apparently firm ground (Fig. 24). Therefore, in case of a tsunami flood occurrence, these sites may not suffer major damage to their structural systems. Nonetheless, history has demonstrated otherwise due to the earthquakes of 1998 and 2016 as illustrated in figures 25 to 27 (Trenkamp, 2003; Toulkeridis et al., 2017a; b).

Figure 25: Collapse of the hotel Calypso due to the earthquake with an epicenter close to Bahía de Caráquez on the August, 4 in 1998.

Figure 26 and 27: Strong damage and collapse due to the earthquake of Muisne in April 16, 2016, close to the entrance to the city of Bahía de Caráquez, as well as in the hotel area.

Basic services: Most of the inhabitants of the central area have the complete vital networks, with good functionality and adequate maintenance. In the event of a tsunami earthquake or a tsunami, it is very likely that these networks will not be fully affected and will partially retain their functionality.

Risk Perception: According to the answers obtained in the field research, a high degree of interest is indicated to participate in risk management activities (simulations, training in self-protection of citizens), and, at the same time, a total lack of knowledge of the consequences that may lead with the occurrence of a potential tsunami, and any other adverse events (Fig. 28).

Figure 28: People having fun during a storm. Courtesy by Eduardo Quijije.

Road networks: There are wide, paved roads, in good condition, with little vehicular traffic (Fig. 29), usually open roads for free pedestrian traffic and a very low level of traffic accidents, characteristics that would allow a rapid evacuation to nearby buildings being considered to be safety zones.

Figure 29: Wide and well preserved avenues in the study area.

With these indicators, and based on the assigned weighting and statistical treatment of the vulnerability matrix, a medium-level vulnerability value has been obtained.

Medium Vulnerability Zone:
The area of medium vulnerability (Fig. 20) occupies an area of $0.013km^2$ corresponding to 8% of the total study area. This area has very similar characteristics in relation to the area classified as an area of high vulnerability in terms of socioeconomic aspects and physical housing infrastructure. Nonetheless, we encountered a few indicators that modify the degree of vulnerability of this area, as discussed below.

Infrastructure: There are constructions with a height ranging from two to five floors, with a main structural system of reinforced concrete, reinforced concrete mezzanines, ceilings with metallic structure and cover of asbestos-cement plates or reinforced concrete slab, in good condition on dry and firm soil. A reinforced concrete wall has been built on the west side of the pier, where it has been sanded to protect that zone from waves (Fig. 30). In this sector, the wall is up to four meters high and the enclosed area is very close to the pier, which represents an additional protection in case of a tsunami occurrence.

Figure 30: Protective wall in the western sector of the pier.

Basic services: In the central area, most inhabitants have all the basic services available, however, this area in particular, presents problems in terms of cellular telephone coverage, as well as intermittent hydric service of potable water, so that many of the houses are supplied by cisterns (Fig. 31) or water wells.

Figure 31: Cisterns in the medium vulnerability zone.

Community services: The analyzed area has a health center (located between Marañón and Cecilio Intriago streets), which serves eight hours a day (Fig. 32). There are private education institutions with a level of education up to high school and according to information provided by the sector´s residents, have ample spaces and sufficient sanitary services to be used as shelters for people when necessary.

Figure 32: Health center in the low vulnerability area of Bahia de Caráquez.

Risk perception: The inhabitants of the area have a clear notion of the scenario that could occur if a destructive tsunami type event occurs. They feel that the event would affect the whole sector and that the best option is to escape towards elevated places to safeguard their life. They are also interested in participating in simulations and training about risk assessment as well as about self-protection.

Road network: The roads are wide, paved, in good condition, having reduced vehicular traffic, wide sidewalks suitable for pedestrian traffic and a very low rate of traffic accidents, (Fig. 33).

Figure 33: Av. Simón Bolívar (central sector of Bahía de Caráquez).

With these indicators, and based on the assigned weighting and statistical treatment of the vulnerability matrix, a medium vulnerability value has been obtained for this zone.

5c) General results

Vulnerability is defined as the degree of susceptibility of a population to be affected by a negative or adverse event. Such vulnerability is able to be measured according to different criteria such as: socioeconomic, physical infrastructure, basic services, community services, risk perception (knowledge of the environment, negative events and responsiveness) and communication channels. Each of these criteria provides a vulnerability value, which must be analyzed independently and in its entirety, in order to identify weaknesses and strengths in order to incorporate them into a contingency plan or risk management, which allows corrective actions and preventive actions of mitigation as well as preparation and that optimizes the response of the population to a negative event of any nature, in order to safeguard their lives, and as much as possible, their assets.

In the studied cities, which are considered to be strategic and of national importance due to the physical and tourist infrastructure that agglutinate, results have been obtained of the six mentioned vulnerabilities, with their respective maps. These maps allow the spatial location, and a model that predicts the results and incidences of a horizontal or vertical evacuation in function of the variables that intervene in the same, considering the particularities of Salinas and Bahía de Caráquez. Therefore, these results constitute the basic inputs for a risk or contingency management plan, which, with the contribution of this study, should be carried out by the public and private relief and response agencies.

Salinas

In Salinas, we considered and subsequently analyzed six different types of vulnerabilities as the most representative of the reality of this city, and also being adequate to characterize the physical environment as a prerequisite to obtaining any (vertical) evacuation model.

The highest vulnerability demonstrates the basic services, which indicates that most of the inhabitants of the city have complete (in situ) basic services, being functional and in good condition. By having more services, they are also more likely to be totally or partially affected by a tsunami-like event. The most appropriate option to reduce this vulnerability value is to encourage citizens to have alternative systems for the provision of services, such as having cisterns to store potable water, to have generators or other devices for the alternative provision of electric energy and lighting, among others.

Second is the socioeconomic vulnerability and physical infrastructure, both with a value of 60%. It is difficult to change the economic and social condition of a whole population, so it is proposed to promote the culture of saving to face situations of any economic emergency. In terms of physical infrastructure, it is vital that there is a correct and proper municipal ordinance stating that all buildings must have earthquake-resistant designs and materials of good quality, in order to reduce the potential damages caused by the generator earthquake of the potential tsunami.

In terms of risk perception and community organization, vulnerability reaches a value of about 40% because the population knows their environment and perceives damages that may be caused by a potential tsunami. They also have notions of how to react to a phenomenon of this type, although it is necessary to reinforce this knowledge through education campaigns to the population. As for community organization and communal assets, neighborhood committees, with their representatives and community services such as health centers, medical clinics, courts and sports clubs, they have been identified with their respective leaders, which indicates a good community organization that would facilitate any training and coordination, and then subsequently for any needed reaction.

The lowest vulnerability (20%) corresponds to the road network since the roads are wide, paved, in good state of conservation and perfectly functional, which would facilitate any type of evacuation and displacement. Besides that, after the tsunami flood has passed, they would continue to function, albeit in a limited way, to the cleaning of mud and debris.

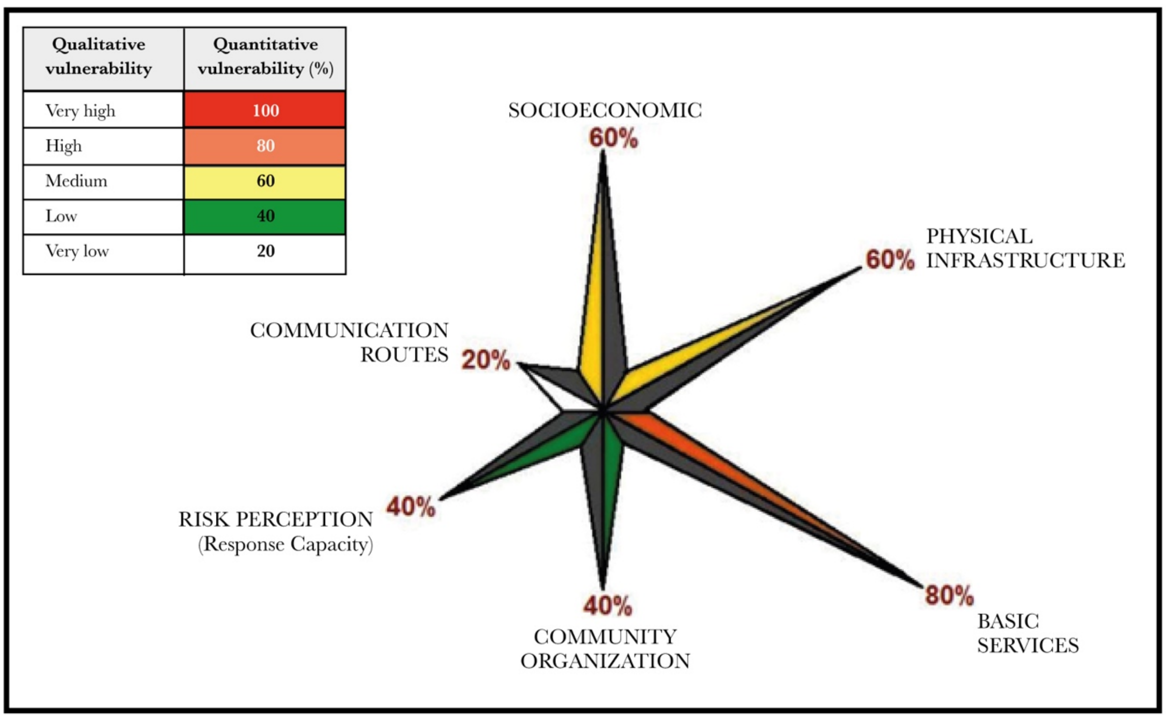

Figure 34: For Salinas, the Vulnerability Star illustrates the different types of vulnerabilities and their level, expressed as a percentage, in respect to a tsunami hazard.

Bahia de Caráquez

Like for Salinas, in Bahía de Caráquez, the same six types of vulnerabilities have been considered and analyzed. The highest vulnerability (100%) is the risk perception, focused from the point of view of ignorance and lack of knowledge about the environment, the capacity of reaction or response of the population and the impact that could cause the potential tsunami phenomenon. This result, apparently, could appear to be a contradiction in a city whose population experienced very insidious negative events in 1998, with the phenomenon El Niño and a severe earthquake (Rodbell et al., 1999; Trenkamp, 2003; Mato and Toulkeridis, 2017), events that certainly have left lessons learned in the population, especially being of scarce resources.

These results may be explained by the analysis and treatment of the information obtained in the field, since it has been evidenced that the population that occupies the study area, in the great majority, is wandering, meaning that they are tourists and people of good economic condition that occupy villas and buildings only during vacation periods and holidays. Consequently, since they do not belong to the environment, they do not know (or have no idea) of what may happen to them if a tsunami event occurs. For this reason, they have not participated (and are not interested) in training workshops, drills and other events to improve their ability to respond. Awareness and training in this high-risk sector should be a priority task of the Relief Organizations and the National Risk Management Secretariat, given that this is the tourist and hotel area of the city, and agglutinates, at the time tourism and a high population density, both of visitors and of those who offers their services to the tourism.

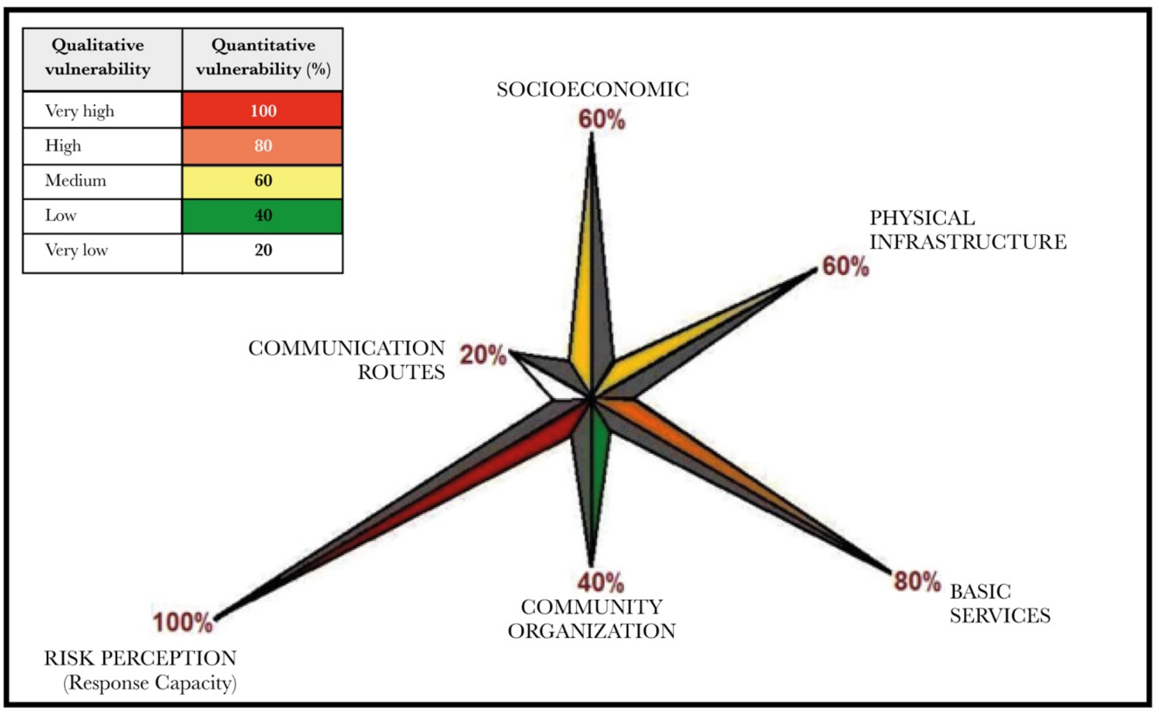

Figure 35: For Bahía de Caráquez, the Vulnerability Star illustrates the different types of vulnerabilities and their level, expressed as a percentage, in respect to a tsunami hazard.

The second highest vulnerability with about 80% is basic services, demonstrating similar benefit-need affection as discussed for the city of Salinas. The third highest vulnerability however, is the socioeconomic vulnerability as well as the physical infrastructure, both with a value of 60%. This value is explained by the fact that the area with the highest surplus value is circumscribed to the seawall. The central zone is occupied by an economically active population made up of public employees and private permanent residents of Bahia, with monthly economic income fluctuating between 400 and 800 dollars. This segment of the population constitutes the middle class of the city and its houses, although comfortable, are modest in their majority, both from the point of view of material goods and as construction materials, indicators that explain the level of obtained vulnerability.

In the community organization and the communal assets, the vulnerability is with 40% low, as there we identified neighborhood committees with their representatives and community services as well as a health center, parks and squares for community recreation, which demonstrates a good community organization that would facilitate any task of training and coordination and, subsequently, reaction.

The lowest vulnerability with 20% refers to the road network since, as previously described, the study area has wide, paved, well-maintained, perfectly functional roads with little vehicular traffic, which would facilitate any type of evacuation and displacement. Besides that, after the flood has passed, this could continue to function, albeit in a limited way until the cleaning of mud and debris.

6. CONCLUSIONS

For the purposes of this investigation, we considered the worst scenario to occur, in order to incorporate variables that include the most unfavorable conditions that may arise, in order to have a greater safety margin to save the highest number of human lives. The information obtained from the data base of the vulnerability matrix allowed the identification of susceptibilities in the study area, through the various values of specific and total vulnerabilities.

The vulnerability analysis towards tsunami hazards carried out in the study areas corresponding to both cities, resulted in a medium to high vulnerability for the population of Salinas and low to medium vulnerability for Bahía de Caráquez, respectively. Both cities have a high vulnerability (80%) for basic services, a medium vulnerability (60%) in social economic issues as well as in physical infrastructure, a low vulnerability (40%) in community organization and the lowest vulnerability (20%) by means of communication.

The great difference between Salinas and Bahía de Caráquez yielded the value of vulnerability due to risk perception. Salinas has a low vulnerability (40%) as its population knows the environment and perceives the damages that could be caused by a potential tsunami. In contrast, Bahía de Caráquez has a high vulnerability (100%), because the population in its great majority that occupies the study area, is wandering and therefore, as they do not belong to the environment, they lack of knowledge or have no notion of potential adverse event with the occurrence of tsunami hazard.

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