ISSN 8755-6839

SCIENCE OF TSUNAMI HAZARDS

Journal of Tsunami Society International

Volume 37 Number 3 2018

VULNERABILITY ANALYSIS BASED ON TSUNAMI HAZARDS IN CRUCITA, CENTRAL COASTAL OF ECUADOR

Julio Cesar Celorio-Saltos[1], Jhonny Marcelo García-Arias[1], Alfredo Bienvenido Guerra-Luque[1] Grey Barragan-Aroca[1] and Theofilos Toulkeridis[2]*

[1]Escuela de Gestión de Riesgo, Facultad de Ciencias de la Salud y del Ser Humano, Universidad Estatal de Bolívar, Guaranda, Ecuador
[2]Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador

*Corresponding author: ttoulkeridis@espe.edu.ec

ABSTRACT

In the coastal center of Ecuador is situated the touristic village of Crucita, which has 13 km large, very flat beach extension, being potentially extremely vulnerable by a future tsunami impact. Therefore, an extensive study has been performed about the vulnerability of the population, of the response authorities and of the infrastructure for tsunami hazards. Once the different variables were analyzed, the different levels of vulnerability in the population of the Crucita parish have been evidenced. In this framework, among the main findings have been the general low knowledge of the population about tsunamis and their hazards, the absence of evacuation plans, the high level of exposure of the physical infrastructure (housing, basic services and telecommunications), and the absence of institutional capacities to respond to a situation of emergencies and / or disasters in general, and of tsunamis in particular.

Keywords: population vulnerability, economic vulnerability, physical structural vulnerability, institutional capacity, degree of exposure

1. INTRODUCTION

Ecuador is one of the few countries on the planet, where all types of plate boundaries are present, represented by the East Pacific Rise, the Galápagos Spreading Center, the Hess Rift, the Ecuadorian trench and the Guayaquil-Caracas Mega Fault (Fig. 1; Gutscher et al., 1999; 2000; Dumont et al., 2005; Toulkeridis, 2011; 2013; Dumont et al., 2014). Based on these plate tectonic movements and being located in a tropical area, which has been frequently exposed to a variety of climatic processes, this small Andean country has been targeted to a high amount of natural disasters such as landslides, flooding, drought, volcanism, earthquakes and tsunamis (Schuster et al., 1996; Harden, 2001; Massonne and Toulkeridis, 2012; Toulkeridis, 2013; Chunga and Toulkeridis, 2014; Toulkeridis et al., 2015; Toulkeridis et al., 2017; Mato and Toulkeridis, 2017; Toulkeridis and Zach, 2017; Pararas-Carayannis and Zoll, 2017; Jaramillo Castelo et al., 2018; Zafrir Vallejo et al., 2018). Therefore, Ecuador has been considered to be a mega vulnerable country, due to exposure to various hazards throughout the national territory, many of which have caused material losses and unfortunately also disproportionally many human lives (Toulkeridis, 2016; Rodriguez et al., 2017; Navas et al., 2018).

Among the natural disasters are various origins of tsunamis, such as severe local tsunamis which hit Ecuador on several occasions, of which the last occurred more than three decades ago, in 1979 (Pararas-Carayannis, 1980; Herd et al., 1981; Mendoza and Dewey, 1984; Beck and Ruff, 1984; Pararas-Carayannis, 2018). Many citizens in Ecuador didn't realize that with the most current strong earthquake in 2016 in the coastal region, also a local tsunami has been generated, with minor damages (Ye et al., 2016; Toulkeridis et al., 2017). Nonetheless, as regional and far-reaching tsunamis have impacted in different, but less severe forms the coasts of Ecuador a great concern has been generated in the population that is settled in such vulnerable sites. The shocking images in the news media of the tsunamis generated in Chile in 2010, Japan in 2011 or in Mexico in 2017 (Delouis et al., 2010; Pararas-Carayannis, G., 2010; Simons et al., 2011; Pararas-Carayannis, G., 2014; Okuwaki and Yagi, 2017), have created a general fear in the Ecuadorian population, which is expecting sooner or later a similar disaster on their own settlements. Thus, it has been considered fundamental to carry out an investigation to determine the level of vulnerability towards tsunami hazards for the population, authorities and their infrastructure (Pararas-Carayannis, 1983; 1988).

Based on the aforementioned, the main objective of this research work has been to identify the vulnerability level of tsunami hazards in the Crucita parish, a typical touristic site in central coastal Ecuador. In this sense, the main objective has been to contribute to the generation of knowledge about the factors that contribute to the increase or decrease of vulnerability towards tsunamis, while some of these may have been directly intervened.

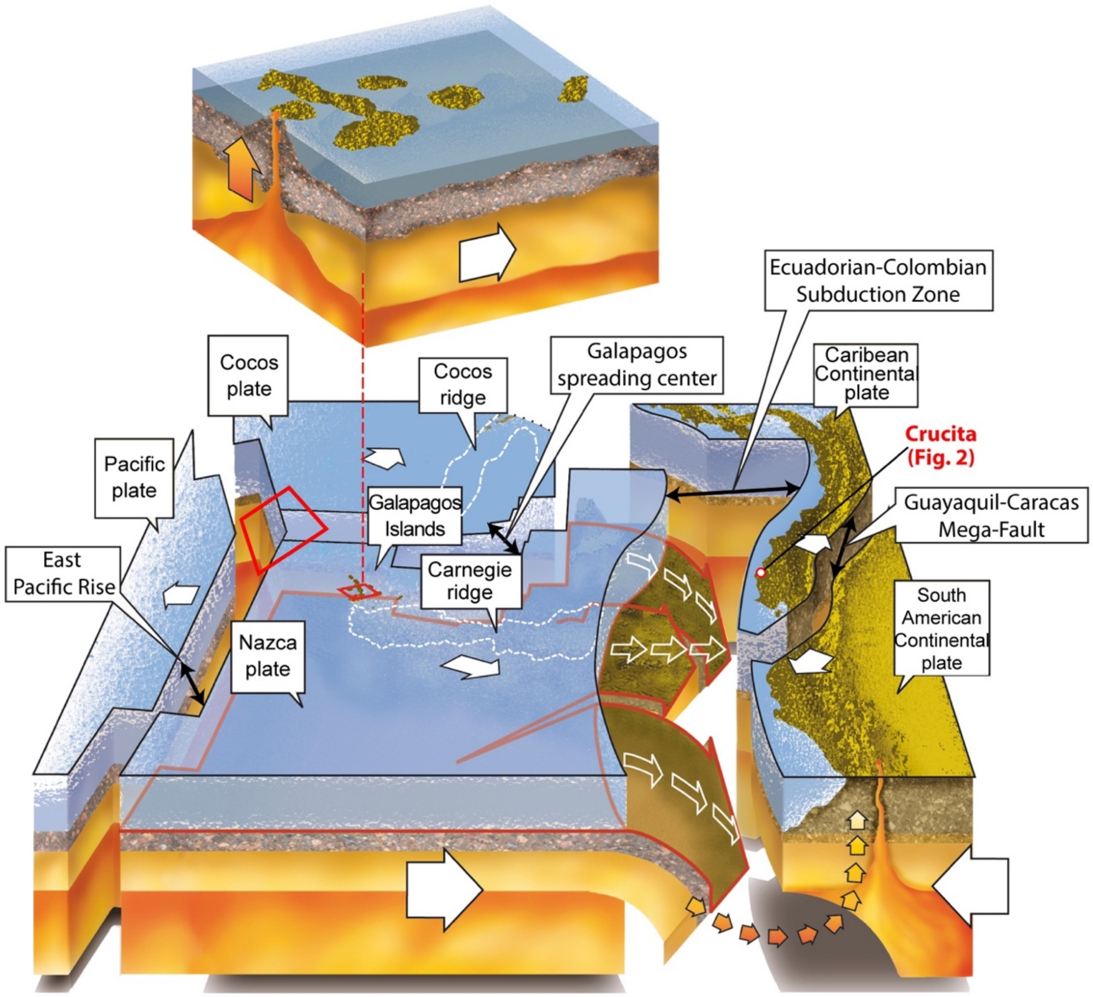


Fig. 1: Geodynamic setting of Ecuador with associated oceanic and continental plates and a variety of plate boundaries, such as the divergent plate boundaries named East Pacific Rise and Galapagos Spreading Center, the convergent plate boundary represented by the Ecuadorian-Colombian Subduction zone, as well as the transcurrent plate boundary represented by the Guayaquil-Caracas Maga-Fault. Also shown the Galapagos Islands and the Carnegie Ridge. Adapted from Toulkeridis, 2013, modified of Toulkeridis et al., 2017a.

2. STUDY AREA AND POTENTIAL TSUANAMI HAZARDS

Crucita is one of the seven rural parishes of the Portoviejo canton with urban characteristics for being a tourist attraction, having 13 km of beach extension (Fig. 2). Although the village is located at an altitude of up to 200 meters above sea level, its average height for the area with the highest people concentration and urban settings is of about 2.5 m.a.s.l. (Fig. 3). The relief of the parish is composed of a fairly regular flat area that is part of the Portoviejo River valley and a high area covered by a dry forest. Crucita is located on a alluvial plain composed of silty sediments with loose conglomerates that give shape to a flat, undulating surface, which rises towards the southeast in a high-pitched sector, composed of white to reddish shales and thin sandstone layers. Crucita extends from the so-called Punta de Charapotó to the North to the Punta de Jaramijó to the South, in an open bay where the beach is composed of thin sandy bars near the shore. In this section of the coastal profile the bottom is sandy and the depths are regular, with shafts (slope of the oceanic shelf) of 10 and 20 m, that cross at a distance of 0.50 and 1.50 miles from the coast. Furthermore, the contours in this area are very pronounced, being up to 10 m, with an average slope of 2% from which it gradually softens until it reaches 0.8% in the 20 m depths. Due to the bathymetric profile and the shape of the bay, the height of the waves are able to increase slightly, and then burst forcefully up to 1 km onshore, destroying weak constructions (wood, cane, block) in the flat area.

Fig. 2: Overview of Crucita from the southern hillside of the parrish.

Due to its geographical location, the Crucita parish is potentially exposed to tsunami hazards, as it has been documented several times after the occurrence of local earthquakes, such as January 31, 1906 (8.8 Mw), October 2, 1933 (6.9 Mw), of December 12, 1953 (7.3 Mw) of January 19, 1958 (7.8 Mw), December 12, 1979 (8.2 Mw) and April 16, 2016 (7.8 Mw) (Berninghausen, 1962; Kanamori and McNally, 1982; Pararas-Carayannis, 2012; Toulkeridis et al., 2017a; 2017b; 2018). However, the earthquake with a distant origin tsunami, which occurred on March 11, 2011 in Japan with a magnitude of 8.9 on the Richter scale (Simons et al., 2011; Norio et al., 2011), have generated a considerable run-up that reached an altitude of 3.24 m during the high tide, causing effects on greater and lesser degree in populations that are located on the coastline, including the village itself (Rentería et al., 2012; Lynett et al., 2013). Due to this facts, it has been evidenced, that the population of Crucita does not have tools for organization and preparation towards tsunami hazards being of local, regional or distant origin, which causes its inhabitants to present conditions of vulnerability in their response capabilities.

Of the twelve documented earthquakes that have occurred nearby during the last 130 years, with intensities greater than 6.0 degrees on the Richter scale, five have been related to local geological faults and the remaining seven with the subduction zone (Fig. 1; Table 1). Crucita is situated just 75 east of the suture zone, between the Nazca plate with the Caribbean and South American continental plates, lying in a strong and active seismic zone, as evidenced also by the map for Seismic Design of the Ecuadorian Construction Standard (NEC, 2014), where the soil may receive accelerations equal to or greater than 0.50 g. Furthermore, the deformations generated by subduction trigger the formation of active fault systems that have been the source of earthquakes on the continental shelf. In the case of Manabí, the surface is affected by the Jama, Bahia de Caráquez, Calceta, Jipijapa and Julcuy geological faults among several minor ones (Egüez et al., 2003).

Table 1: Earthquakes occurred during the last 130 years in Manabí. Data from Lopez (2013) and USGS (2016).

Year	Lat.	Long.	Depth	Magnitude	Intensity	Distance Epicenter to Crucita in km
1896	-0.51	-80.45		7.0	IX	33 Km
1937	-0.50	-80.00		6.5	VIII	68 Km
1942	-0.01	-80.12	50 Km	7.8	IX	110 Km
1956	-0.50	-80.50		6.9		34 Km
1958	-0.50	-81.00		6.2		65 Km
1959	-1.00	-80.50		6.4		16 Km
1961	-0.40	-80.40	56 Km	6.3	VIII	52 Km
1962	-1.30	-80.40	75 Km	6.3	VIII	50 Km
1964	-0.84	-80.29	34 Km	6.0	VIII	25 Km
1990	-0.13	-80.28	53 Km	6.1	VIII	84 Km
1998	-0.55	-80.53	39 Km	7.1	VIII	33 Km
2016	-0.35	-79.92	21 Km	7.8	IX	110 Km

Based on the aforementioned recurrence of earthquake hazards, the following effects are able to coccur in the area of Crucita: (a) partial and complete destruction of houses and buildings; (b) Affectation of the population due to the loss of homes, livelihoods and relatives as well as injuries and alteration of the emotional state; (c) Affectation and destruction of the basic service networks and with it the suspension of the corresponding services; (d) Destruction of the roads by subsidence and liquefaction; (e) Fire, tsunami flooding, when magnitude overcomes 7.5 on the Richter scale.

3. METHODOLOGY

The study of vulnerability about tsunami hazards in Crucita, has been developed on a simple random sample of ten public institutions and 389 inhabitants being located in the center, north and northeast side of the Crucita parish. The study area extends along 13 km of beach on an area of around 63.26 km^2, of which only 8.77 km^2 (13.86%) is currently destined for housing occupation, tourism services such as accommodation and food, development of commercial activities, operation of the public administration, networks of basic services, education and health facilities.

For the development of the research the type of descriptive, qualitative and quantitative study has been used, as such is based on an analysis of the physical characteristics of the structures and networks of services, the social, economic, educational, cultural, institutional policies as well as the institutional and community capacities. This allows an alphanumeric evaluation of the obtained results in order to estimate the vulnerability level from the specific to the general, depending on the independent and dependent variables. This may explains in a descriptive way the results of the current research for a subsequent adequate decision making process.

Based on the analysis of methodologies used for the analysis and evaluation of vulnerability factors such as the Methodology for Vulnerability Analysis at the Municipal Level proposed by the United Nations Development Programme and the National Secretary of Risk assessment (UNDP-SNGR, 2011), Methodology for Vulnerability Assessment proposed by the Disaster Prevention in the Andean Community (PREDECAN, 2009) and the Basic Manual for the Estimation of Risk developed by the National Institute of Civil Defense, the National Directorate of Prevention and the Unit for Studies and Risk Assessment (INDECI- DINAPRE- UEER, 2006). An alpha numerical methodology has been defined for estimating vulnerability to the threat of tsunamis, which includes indicators and evaluation parameters related to four aspects of analysis, namely structural, social, institutional and community. Therefore, the present methodology contemplates the following criteria for its application: a) selection of indicators and evaluation parameters; b) qualitative and quantitative analysis of indicators. c) weighting of indicators; d) estimation of the level of vulnerability; e) survey by sampling.

a) Selection of indicators and evaluation parameters

The selection of the type and number of indicators and evaluation parameters have been dependent on the independent and dependent variables of the present study. The same ones that have been organized for their application in ten matrix fields that allowed the verification of elements in the field. The first matrix field allows for an appreciation of the level of structural physical vulnerability of the household, according to the resistance they may have to the occurrence of tsunamis, in relation to the distance of the houses from the shore of the high tide (Table 2).

The second matrix field determines the level of vulnerability of service networks in relation to the access and functionality of systems for the provision of basic services, by checking co-verage, redundancy of systems and dependence on other levels (cantonal, provincial, national) for its respective operation (Table 3).

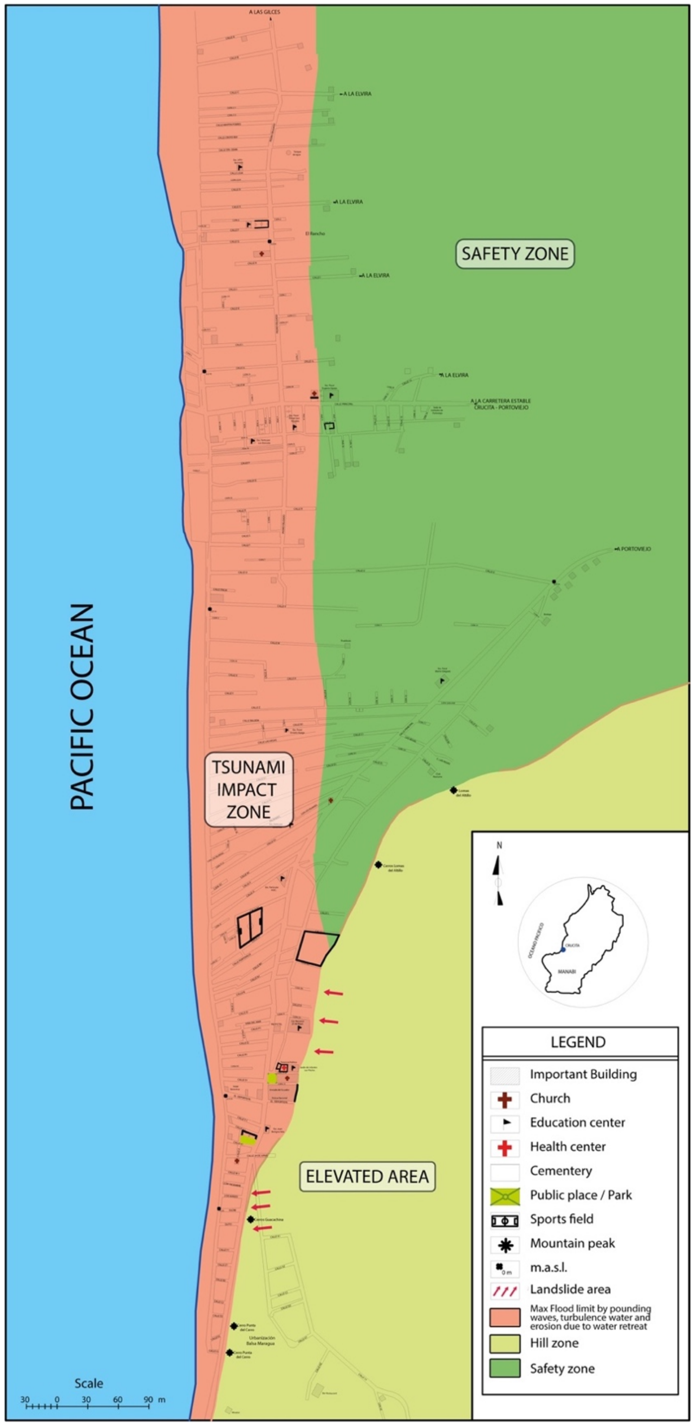


Fig. 2: Tsunami impact area and safety zone of Crucita. Based on Cruz and Vasquez (2010).

Fig. 4: a) Indication to avoid parking in order to be able to evacuate in one of the main roads perpendicular to the ocean´s shore line; b) Typical warning sign and indication of evacuation direction for incoming tsunamis; c) Coastal barrier, more likely for high tides; d) sign for tsunamis above barrier, being less visible from the beach; e) Sign of safety zone from tsunamis; f) Abandoned outlook point for rescue stuff, at priod of storming sea (red flagg) and evacuation sign of tsunamis. All photos taken in Crucita.

The third matrix field, defines the level of social vulnerability in relation to the existing social organization for the sustainability of processes, citizen participation in activities of coexistence and development, as well as the access of families to basic services and social order (Table 4).

The fourth matrix field determines the level of economic vulnerability of the family core according to the total income per family, the type of housing and the number of people that make up the family nucleus (Table 5).

The fifth matrix field, allows to define the level of educational vulnerability, in relation to the level of formal education reached by family members, as well as training on tsunami preparedness that they may have received (Table 6).

The sixth matrix field, allows to define the level of cultural vulnerability of the population towards tsunami hazards, through the verification of prescriptive elements such as the knowledge and occurrence of the aforementioned hazards, as well as the attitude of the people facing a possible occurrence of tsunamis in the Ecuadorian coasts (Table 7).

The seventh matrix field is aimed to identify the political and institutional elements that guarantee the reduction of disaster risk in the parish, and allows determining the level of institutional political vulnerability through state and local policies, budgetary availability to promote processes of disaster risk reduction, the existence of control and planning mechanisms, as well as the development of actions to reduce disaster risk and staff training (Table 8).

The eighth matrix field allows to determine the level of vulnerability of the essential elements existing in the parish, by verifying the location of the same in relation to the high tide and its functional condition (Table 9).

The ninth matrix field is related to the identification of the capacity level of the parish institutions for the management of the response to emergency and or disaster situations (Table 10).

1. Variable about physical structure		
1) With which type of material has been constructed your living place?		
a) Reinforced concrete ☐	b) Metallic structure ☐	c) Wooden structure ☐
d) Structure of cane (light) ☐	e) Supporting wall structure ☐	f) Supporting wall structure ☐
	g) Mixed wood / concrete ☐	
2) What type of housing cover has been used?		
a) Metal cover ☐	b) Reinforced concret slab ☐	c) Wood and zinc beams ☐
d) Cane and zinc ☐		e) Wood and tile beams ☐

Fig. 5: Example of a field record (matrix) format.

Finally, the tenth matrix field is related to the identification of the level of community capacity to reduce risks and act in case of emergency and or disaster, through the verification of existence or not of Risk Management Committees, Emergency Community Brigades, knowledge about the location of meeting points and marked evacuation routes, a tsunami warning system, temporary accommodation and emergency plan, the availability of emergency family plans, as well as the participation in simulation drills or exercises (Fig. 4a-f; Table 11). The final result has been a set of 55 indicators with their respective evaluation parameters, which for their verification have been organized in field matrices (Fig. 5).

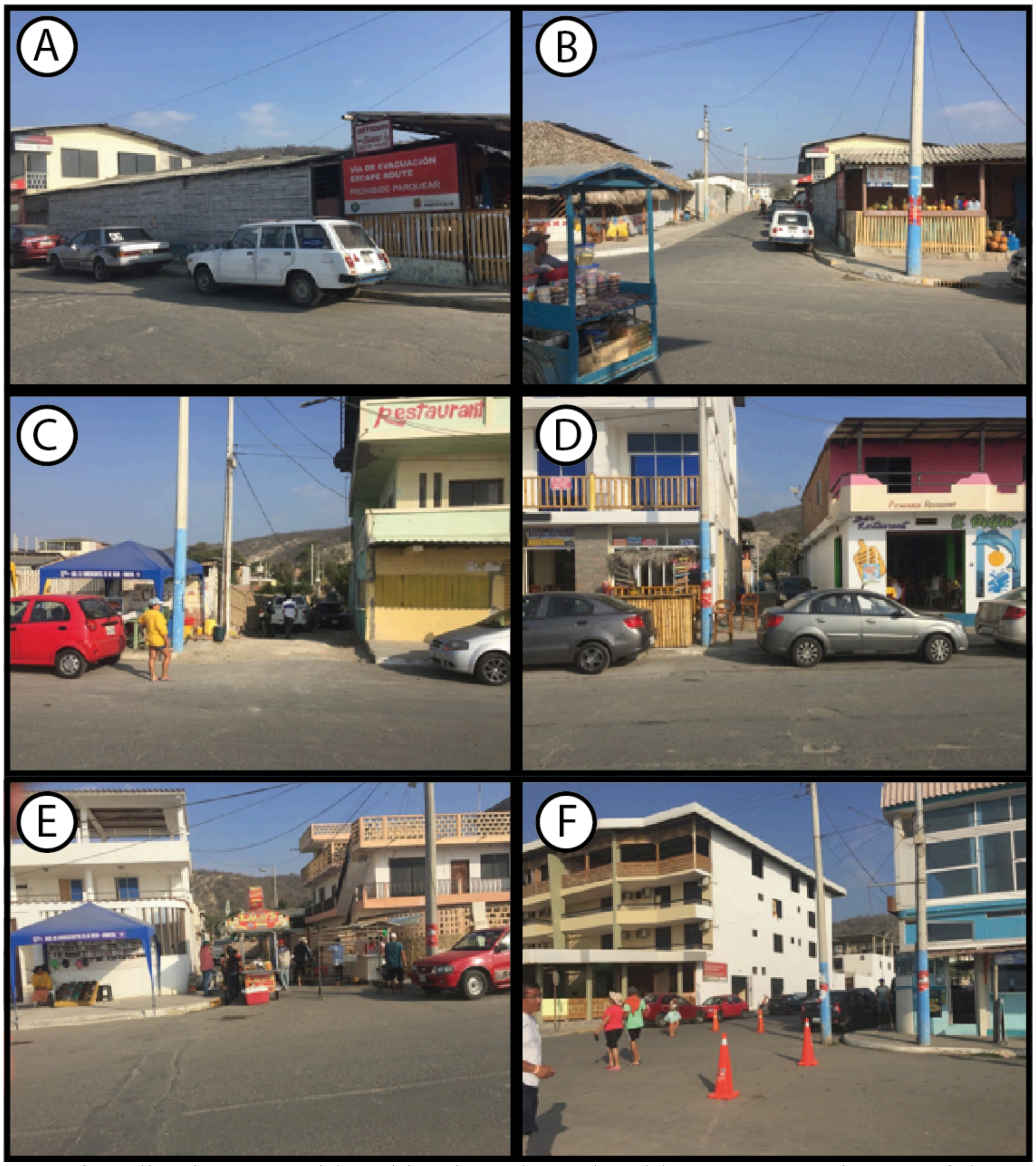


Fig. 5: a-f) Indication to avoid parking in order to be able to evacuate in one of the main roads perpendicular to the ocean´s shore line and the lack of doing so. All photos taken in Crucita.

b) Qualitative and quantitative analysis of indicators

The qualitative and quantitative analysis of the variables has been carried out based on the rating of the indicators, based on a numerical scale of 0.50 to 2, which assigns a level of importance to each of the indicators. Where for the case of independent variables: 2.00 is very important, 1.50 is important, 1.00 is moderately important, 0.50 is unimportant. The result has been the distribution of numerical values for the qualification of each of the indicators, according to their classification as indicated in Tables 2-11.

Table 2: Parameters for the qualification of indicators of the vulnerability of the physical structure. Based on PNUD-SNGR (2011).

Indicators	**Evaluation parameters**	**Qualification**
Structural system	Reinforced concrete	0,5
	Metallic structure	1
	Wooden structure	2
	Structure of cane (light)	2
	Mixed (wood, concrete, metallic)	1,5
Type of housing	Reinforced concrete slab	0,5
	Metal cover	1
	Beams made of wood and zinc	1,5
	Beams of cane and zinc	2
	Wood and tile beams	1,5
Number of floors	1 floor	2
	2 floors	1,5
	3 floors	1
	4 floors	0,5
	More than 4 floors	0,5
Construction age	Between 1950 and 1980	2
	Between 1980 and 2000	1
	After 2000	0,5
Closeness to the sea	Less than 500 meters from the beach	2
	Between 501 to 1000 meters from the beach	1,5
	Between 1001 and 1500 meters from the beach	1
	More than 1500 meters from the beach	0,5
Site topography	Flat	2
	Below the level of the road	1,5
	On the level of the road	1
	On the escarpment	0,5
Relative state	Good	0,5
	Acceptable	1
	Regular	1,5
	Bad	2

Table 3: Parameters for the qualification of indicators of the vulnerability of basic service networks. Based on PREDECAN (2009).

Indicators	Evaluation parameters	Qualification
Access to drinking water	Yes	0,5
	No	2
Reliance of the potable water system	More than one	0,5
	One	1
	None	2
Drinking water system dependence	With reliance	2
	Without reliance	0,5
Access to sewage	Yes	0,5
	No	2
Reliance to the sewer system	More than one	0,5
	One	1
	None	2
Reliance to the sewage system	With reliance	2
	Without reliance	0,5
Access to electric energy	Yes	0,5
	No	2
Redundancy of the electric power system	More than one	0,5
	One	1
	None	2
Reliance to the electric power system	With reliance	2
	Without reliance	0,5
Access to communication	Yes	0,5
	No	2
Redundancy of the communication system	More than one	0,5
	One	1
Reliance to the communication system	With reliance	2
	Without reliance	0,5

Table 4: Parameters for the rating of social vulnerability indicators. Based on PREDECAN (2009).

Indicators	Evaluation parameters	Qualification
Organization level	Acceptable	0,5
	Insufficient	1,5
	Any	2
Participation	Frequent	0,5
	Infrequent	1,5
	Any	2
Age and dependency condition	Less than 15 years	2
	More than 65 years	2
	Equal to one and more than two people with disabilities	2
Access to health services, education, employment, potable water, sewerage, electric power, communication	Yes	0,5
	No	2
Access to education	Yes	0,5
	No	2
Access to employement	Yes	0,5
	No	2
Access to potable water	Yes	0,5
	No	2
Access a sewerage	Yes	0,5
	No	2
Access to electric power	Yes	0,5
	No	2
Access to communication	Yes	0,5
	No	2

Table 5: Parameters for the rating of indicators of economic vulnerability. Based on PREDECAN (2009).

Indicators	Evaluation parameters	Qualification
Unsatisfied basic needs	Less than a minimum wage	2
	Between 1 and 3 minimum wages	1
	More than 3 minimum wages	0,5
Type of housing	Department	0,5
	House or villa	1
	Hut	1,5
	Farm, hoval o shack	2
Overcrowding	Less than 5 people	0,5
	Between 6 and 7 people	1,5
	More than 8 people	2

Table 6: Parameters for the qualification of indicators of educational vulnerability. Based on INDECI- DINAPRE- UEER (2006).

Indicators	**Evaluation parameters**	**Qualification**
Education level	None	2
	Primary	1,5
	High school	1
	Higher education	0,5
Tsunami education programs	Permanent	0,5
	Intermittent	1,5
	Sporadic	1
	Does not exist	2
Training programs on tsunamis	Permanent	0,5
	Intermittent	1,5
	Sporadic	1
	Does not exist	2
Broadcast campaigns	Permanent	0,5
	Intermittent	1,5
	Sporadic	1
	Does not exist	2

Table 7: Parameters for the qualification of indicators of cultural vulnerability.

Indicators	**Evaluation parameters**	**Qualification**
Knowledge about tsunami hazards	Enough	2
	Insufficient	1,5
	None	0,5
Knowledge about the occurrence of tsunamis	Knows	0,5
	Does not know	2
Behavior towards the occurrence of tsunamis	Acceptance	0,5
	Indifferent	1,5
	Denial	2

Table 8: Parameters for the qualification of indicators of the vulnerability of institutional policy. Based on PNUD-SNGR (2011).

Indicators	Evaluation parameters	Qualification
Local risk management policies	Yes	0,5
	No	2
	Does not apply	2
Institutional risk management plan	Yes	0,5
	No	2
	Does not apply	2
Governamental risk management policy	Yes	0,5
	No	2
Budget established for risk management	Yes	0,5
	No	2
Mechanisms for the application of policies	Yes	0,5
	No	2
Disaster risk reduction activities	Yes	0,5
	No	2
Staff training	Yes	0,5
	No	2

Table 9: Parameters for the qualification of indicators of the vulnerability of essential elements. Based on PNUD-SNGR (2011)

Indicators	Evaluation parameters	Qualification
Exposure level	Less than 500 meters from the beach	2
	Between 501 to 1000 meters from the beach	1,5
	Between 1001 and 1500 meters from the beach	1
	More than 1500 meters from the beach	0,5
Structural vulnerability	high	2
	Medium	1,5
	Low	0,5
Accessibility	Accessible	0,5
	Less accessible	1,5
	Inaccessible	2
Redundancy systems	More than one	0,5
	One	1
	None	2
Reliance	With reliance	2
	Without reliance	0,5

Table 10: Parameters for the qualification of indicators of the institutional capacity of response.

Indicators	**Evaluation parameters**	**Qualification**
Committee of Emerging Operations (CEO) of the parrish	Yes	0,5
	No	2
	It does not work	2
Response institutions	Yes	0,5
	No	2
	Doesn´t know	2
Signposted meeting points	Yes	0,5
	No	2
	Doesn´t know	2
Signposted evacuation routes	Yes	0,5
	No	2
	Doesn´t know	2
Alarm system for tsunamis	Yes	0,5
	No	2
	Doesn´t know	2
Temporary shelters	Yes	0,5
	No	2
	Doesn´t know	2
Risk maps	Yes	0,5
	No	2
	Doesn´t know	2
Emergency plan	Yes	0,5
	No	2
	Does not apply	2
Drills	Once	1
	Twice	0,5
	Never	2

Table 11. Parameters for the qualification of community capacity indicators.

Indicators	Evaluation parameters	Qualification
Risk management committees	They do Exist	0,5
	Do not exist	2
	Exist, but they do not work	2
Emergency brigades	They do Exist	0,5
	Do not exist	2
	Exist, but they do not work	2
Meeting points	They do Exist	0,5
	Do not exist	2
	Unknown	2
Evacuation routes	Known	0,5
	Unknown	2
Alarm for tsunamis	Known	0,5
	Unknown	2
Temporary shelters	Known	0,5
	Unknown	2
Tsunami contingency plan	Known	0,5
	Unknown	2
Family emergency plan	Known	0,5
	Unknown	2
Participation in drills	Known	0,5
	Unknown	2

c) Weighting of indicators

Once each of the indicators has been qualified, the results of each of the indicators have been weighted by assigning comparative importance by pairs of indicators, for which the Analytical Hierarchical Process (AHP) has been used as a method. For example, the exposure level of the Crucita Health Center (C1) is as important as the level of structural vulnerability of the Center (C2), but both are three times more important than access to the Health Center (C3). In terms of percentage distribution it means that C1 reaches 34.08%, C2 some 16.06% and C3 some 19.02% of the real value, as demonstrated in tables 12 and 13.

Table 12: Assignment of comparative importance between criteria

Indicators:		**C1**	**C2**	**C3**	**C4**	**C5**
Exposure level	**C1**	1	1	3	2	2
Vulnerability	**C2**	1	1	1/3	1/2	1/2
Accessibility	**C3**	1/3	1/3	1	2	2
Redundancy system	**C4**	1/2	1/2	2/3	1	2
Reliance	**C5**	1/2	1/2	2/3	1	1
	Total	**3,33**	**3,33**	**5,67**	**6,50**	**7,50**

Table 13: Normalization of results by comparative criteria

	C1	C2	C3	C4	C5	Weight	Weight (%)
C1	0,30	0,30	0,53	0,31	0,27	0,34	34,08
C2	0,30	0,30	0,06	0,08	0,07	0,16	16,06
C3	0,10	0,10	0,18	0,31	0,27	0,19	19,02
C4	0,15	0,15	0,12	0,15	0,27	0,17	16,77
C5	0,15	0,15	0,12	0,15	0,13	0,14	14,10
Total	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**100**

The results of the peer-to-peer comparison exercise allowed to assign the weights according to the level of importance to each of the indicators by type of vulnerability, as documented in the tables 14 to 23.

Table 14: Indicators of the structural physical vulnerability

Indicator	Values of the indicator	Weighing
Structural system	0.50, 1, 1.50, 2	26
Type of housing	0.50, 1, 1.50, 2	10
Number of floors	0.50, 1, 1.50, 2	6
Construction age	0.50, 1, 1.50, 2	3
Closeness to the sea	0.50, 1, 1.50, 2	26
Site topography	0.50, 1, 1.50, 2	26
Relative state	0.50, 1, 1.50, 2	3
Total		**100**

Table 15: Vulnerability indicators of basic service networks

Indicator	Values of the indicator	Weighing
Access to drinking water	0.50, 2	20
Reliance of the potable water system	0.50, 1, 2	12
Drinking water system dependence	0.50, 2	12
Access to sewage	0.50, 2	15
Reliance to the sewer system	0.50, 1, 2	7,5
Reliance to the sewage system	0.50, 2	7,5
Access to electric energy	0.50, 2	7
Redundancy of the electric power system	0.50, 1, 2	3
Reliance to the electric power system	0.50, 2	3
Access to communication	0.50, 2	7
Redundancy of the communication system	0.50, 1, 2	3
Reliance to the communication system	0.50, 2	3
Total		**100**

Table 16: Indicators of social vulnerability

Indicator	Values of the indicator	Weighing
Organization level	0.50, 1.50, 2	24,7
Participation	0.50, 1.50, 2	24,7
Age and dependency condition	2	24,7
Access to health services	0.50, 2	4,9
Access to education services	0.50, 2	4,9
Access to employment	0.50, 2	4,9
Access to potable water	0.50, 2	2,7
Access a sewerage	0.50, 2	2,7
Access to electric power	0.50, 2	2,7
Access to communication	0.50, 2	2,7
Total		**100**

Table 17: Economic vulnerability indicators

Indicator	Values of the indicator	Weighing
Unsatisfied basic needs	0.50, 1, 2	48,6
Type of housing	0.50, 1, 1.50, 2	35,2
Overcrowding	0.50, 1, 2	16,2
Total		**100**

Table 18: Educational vulnerability indicators

Indicator	Values of the indicator	Weighing
Education level	0.50, 1, 1.50, 2	42,9
Tsunami education programs	0.50, 1, 1.50, 2	21,4
Training programs on tsunamis	0.50, 1, 1.50, 2	21,4
Broadcast campaigns	0.50, 1, 1.50, 2	14,3
Total		**100**

Table 19: Indicators of cultural vulnerability

Indicator	Values of the indicator	Weighing
Knowledge about tsunami hazards	0.50, 1.50, 2	30
Knowledge about the occurrence of tsunamis	0.50, 2	30
Behavior towards the occurrence of tsunamis	0.50, 1.50, 2	40
Total		**100**

Table 20: Indicators of the institutional policy vulnerability

Indicator	Values of the indicator	Weighing
Local risk management policies	0.50, 2	29,9
Institutional risk management plan	0.50, 2	15,3
Governamental risk management policy	0.50, 2	27
Budget established for risk management	0.50, 2	10
Mechanisms for the application of policies	0.50, 2	6
Disaster risk reduction activities	0.50, 2	6
Staff training	0.50, 2	6
Total		**100**

Table 21: Vulnerability indicators of essential elements

Indicator	Values of the indicator	Weighing
Exposure level	0.50, 1, 1.50, 2	30
Structural vulnerability	0.50, 1.50, 2	26
Accessibility	0.50, 1.50, 2	12
Redundancy systems	0.50, 1.50, 2	16
Reliance	0.50, 2	16
Total		**100**

Table 22: Institutional capacity indicators

Indicator	Values of the indicator	Weighing
CEO of the parrish	0.50, 2	19,1
Response institutions	0.50, 2	17
Signposted meeting points	0.50, 2	5,3
Signposted evacuation routes	0.50, 2	3,8
Alarm system for tsunamis	0.50, 2	6,4
Temporary shelters	0.50, 2	3,8
Risk maps	0.50, 2	19,1
Emergency plan	0.50, 2	6,4
Drills	0.50, 1, 2	19,1
Total		**100**

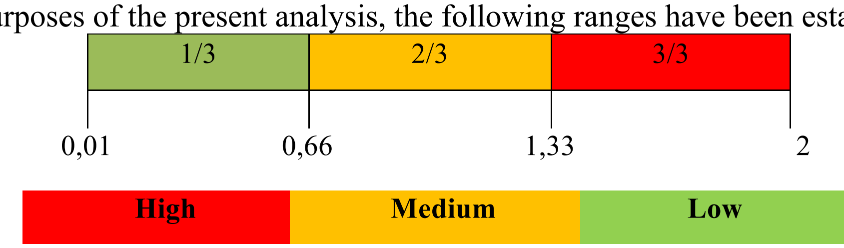
Table 23: Community capacity indicators

Indicator	Values of the indicator	Weighing
Risk management committees	0.50, 2	19,1
Emergency brigades	0.50, 2	17
Meeting points	0.50, 2	5,3
Evacuation routes	0.50, 2	3,8
Alarm for tsunamis	0.50, 2	6,4
Temporary shelters	0.50, 2	3,8
Tsunami contingency plan	0.50, 2	6,4
Family emergency plan	0.50, 2	19,1
Participation in drills	0.50, 2	19,1
Total		**100**

d) Estimation of vulnerability level

We have used as a qualification method to determine the level of vulnerability, the three-thirds criterion (3/3), which consists of assigning ranges to the traditional qualitative scale of high, medium and low by numeric values from 0.01 to 2, where the intermediate values have been taken into account, for example 0.33, 1.35, 189, etc. The qualification method allowed decisions to be made, when it hs been not easy to qualify the variable between high and medium, or between medium and low. Herevy, we avoided any bias of the information when estimating the level of vulnerability of the parish.

For the purposes of the present analysis, the following ranges have been established:



Based on the established ranges and once the field data have been obtained, the assessment parameters and the weighting of each of the indicators using a database have been carried out as the last step in the automated evaluation process. Thus, after crossing the qualifications and indicator weights, the final result of the estimation of the level of vulnerability of the parish have been obtained, as demonstrated in table 24.

e) Survey by sampling

Such survey consisted in applying a series of 55 questions in a random way to 389 people and 10 institutions of the Crucita parish. Therefore, interviews have been conducted for the population and authorities and / or technicians of the different public institutions of

Table 24: Matrix example of the evaluation of cultural vulnerability

LOCATION DATA					Knowledge about tsunami hazards	30%	Knowledge about occurrence of tsunamis	30%	Behavior towards the ocurrence of tsunamis	40%	CRITERION 3/3	
Code	Sector	Closeness to the sea	Longitude	Latitude		Qualification		Qualification		Qualification	Vulnerability assessment	Cultural Vulnerability
AR 01	Arenales	300	551965	9905534	Natural event	0,5	No	2	Denial	2	1,55	High
AR 02	Arenales	30	551744	9905538	Natural event	0,5	No	2	Denial	2	1,55	High
AR 03	Arenales	80	551818	9905534	Natural event	0,5	No	2	Denial	2	1,55	High
AR 04	Arenales	80	551825	9905541	Natural event	0,5	No	2	Denial	2	1,55	High
AR 05	Arenales	20	551722	9905504	Natural event	0,5	No	2	Denial	2	1,55	High

the parish, in order to obtain primary data. The application of the surveys has been based on the use of questionnaires and field registration formats, established from the definition of a set of criteria and evaluation parameters for each type of vulnerability and capacity. The same ones that have been organized for their application in ten matrix fields that allowed the verification of the elements in the field. For the development of the present analysis, a sample of 389 people with a margin of error of 5% has been obtained.

The communities where the surveys have been applied are Crucita Parochial Headquarters (272 surveys), Los Arenales (8), Los Ranchos (49), Las Gilses (26), La Sequita (12), San Silvestre (20), La Boca (2). The distribution of the sample has been performed randomly, taking as reference the level of consolidation of the different communities and the principle of parochial coverage in relation to the location of the communities in the South Center, North Center, Northeast and North Crucita.

4. RESULTS AND DISCUSSION

Vulnerability of physical structures

Seven different questions have been used to encounter the vulnerabilities of the physical structures as listed in table 2 using the indicator values of table 14. Thus, the result has been that the vulnerability level is high with 91% and median with 9%, with an intermediate quantitative value between the lower and upper limit of the high level (1.56).

High 91%	Medium 9%	Low 0%

This result has been obtained by weighing the quantitative values by the weight corresponding to each one of the factors of the physical structure vulnerability, which allowed obtaining partial values, which when added together determined the level of vulnerability, as detailed in the given example from Table 25.

Table 25: Example of the estimation of the physical structure vulnerability

LOCATION DATA		VERIFICATION VARIABLES							CRITERION 3/3	
CODE	SECTOR	STRUCTURAL SYSTE	TYPE OF HOUSIN	NUMBER OF FLOO	CONSTRUCTION AGE	CLOSENESS TO THE SEA	SITE TOPOGRAPHY	RELATIVE STATE	LEVEL OF VULNERABILITY	
		0,26%	0,10%	0,06%	0,03%	0,26%	0,26%	0,03%		
AR 001	ARENALES	1,5	2	2	1	1,5	2	0,5	1,665	High
AR 002	ARENALES	1,5	1,5	2	1	2	2	1,5	1,775	High
AR 003	ARENALES	1,5	1,5	2	0,5	2	2	1,5	1,76	High
AR 004	ARENALES	1,5	1,5	2	1	2	2	1,5	1,775	High
AR 005	ARENALES	1,5	2	2	2	2	2	1,5	1,855	High
AR 006	ARENALES	1,5	1,5	2	1	2	2	1,5	1,775	High
AR 007	ARENALES	1,5	1,5	2	1	2	2	0,5	1,745	High
AR 008	ARENALES	1,5	1,5	2	0,5	1,5	2	2	1,645	High
CR 009	CRUCITA	1,5	2	2	1	2	2	1,5	1,825	High
CR 010	CRUCITA	0,5	1	1,5	2	2	2	0,5	1,435	High

CRITERIA AND RANGES TO DETERMINE VULNERABILITY LEVEL

Valuation criteria		Vulnerability level ranges			
2	Very high	High	1,33 - 2	1,7255	High
1,5	High	Medium	0,67 - 1,32	VULNERABILITY LEVEL OF PHYSICAL STRUCTURE	
1	Medium	Low	0 -0,66		
0,5	Low				

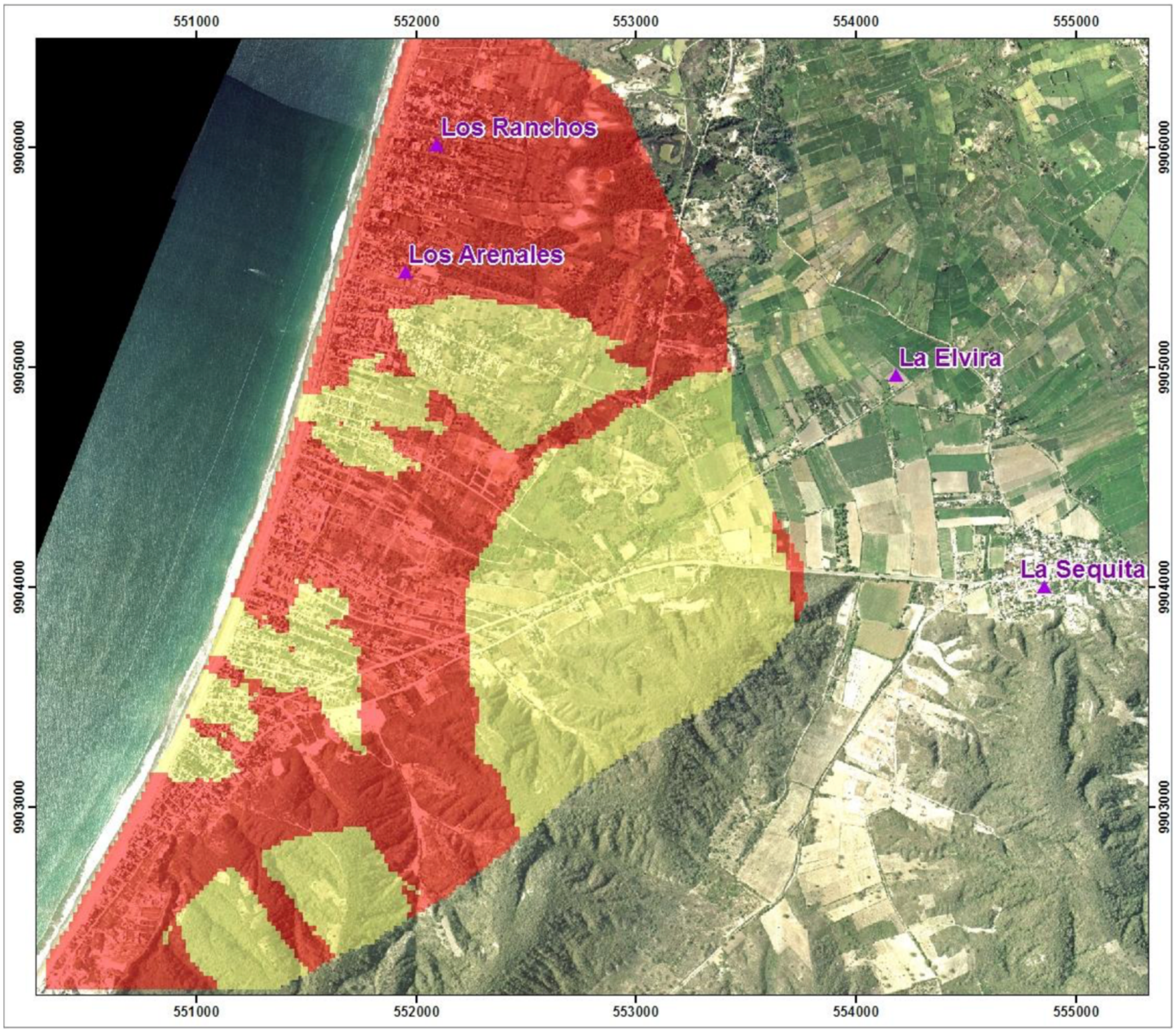


Fig. 6: Map of Crucita indicating the vulnerability of physical structures, based on the present survey.

Fig. 7: Typical vulnerable buildings in the beach area of Crucita.

Vulnerability of Basic Services Networks

Three different questions have been used to encounter the vulnerabilities of the basic service networks, as listed in table 3 using the indicator values in table 15. Thus, the result has been that the level of vulnerability is high (100%), with a quantitative value close to the upper limit of the high level (1.72%).

High 100%	**Medium 0%**	**Low 0%**

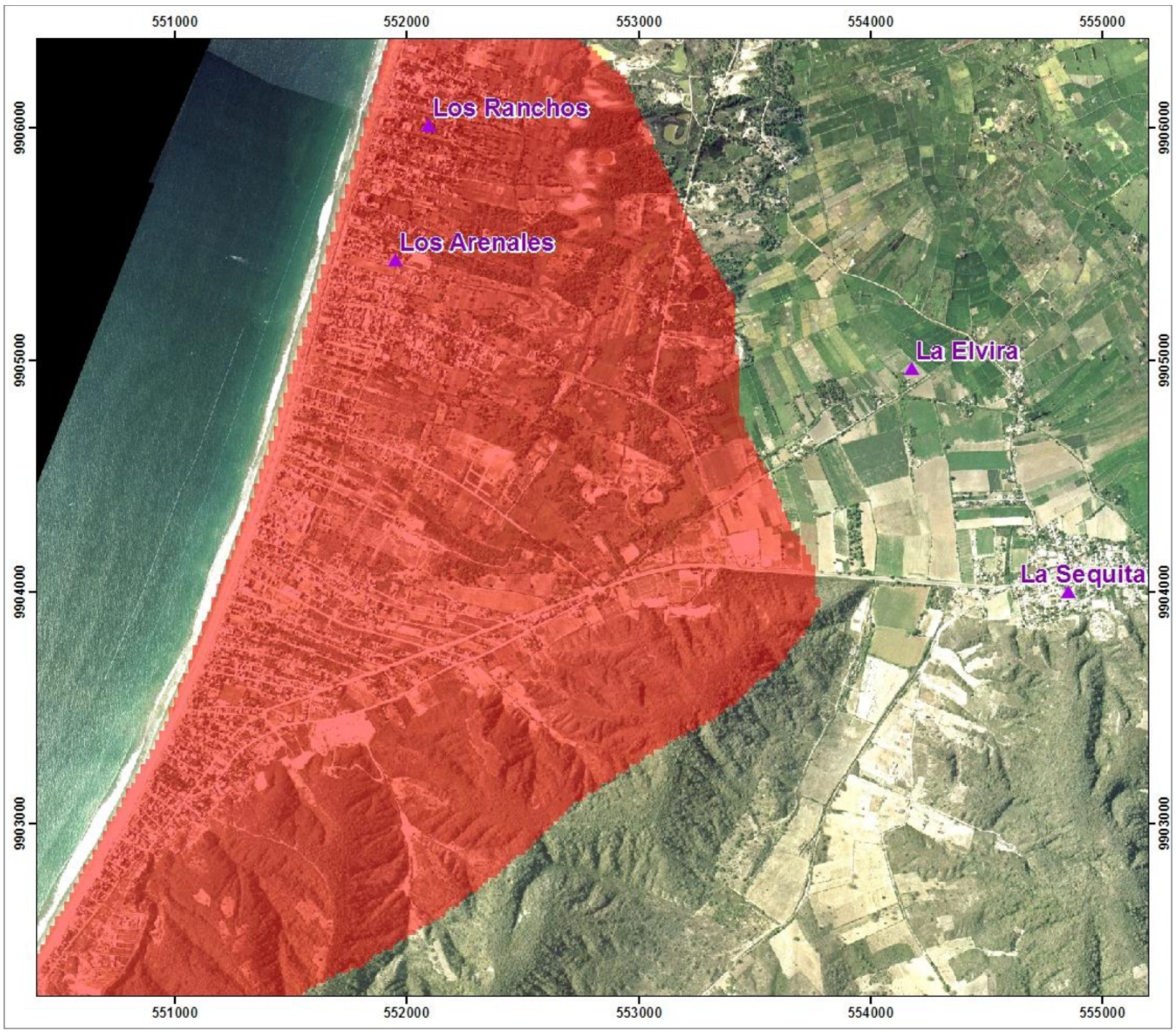


Fig. 8: Map of Crucita indicating the vulnerability of basic services networks, based on the present survey.

Social Vulnerability

Four different questions have been used to encounter social vulnerabilities, as listed in Table 4 using the indicator values in Table 16. Thus, the result has been that the level of vulnerability is mostly average (82.26%), with a quantitative value of 1.20 being near the lower limit of the high level.

High 17,48%	**Medium 82,26%**	**Low 0,26%**

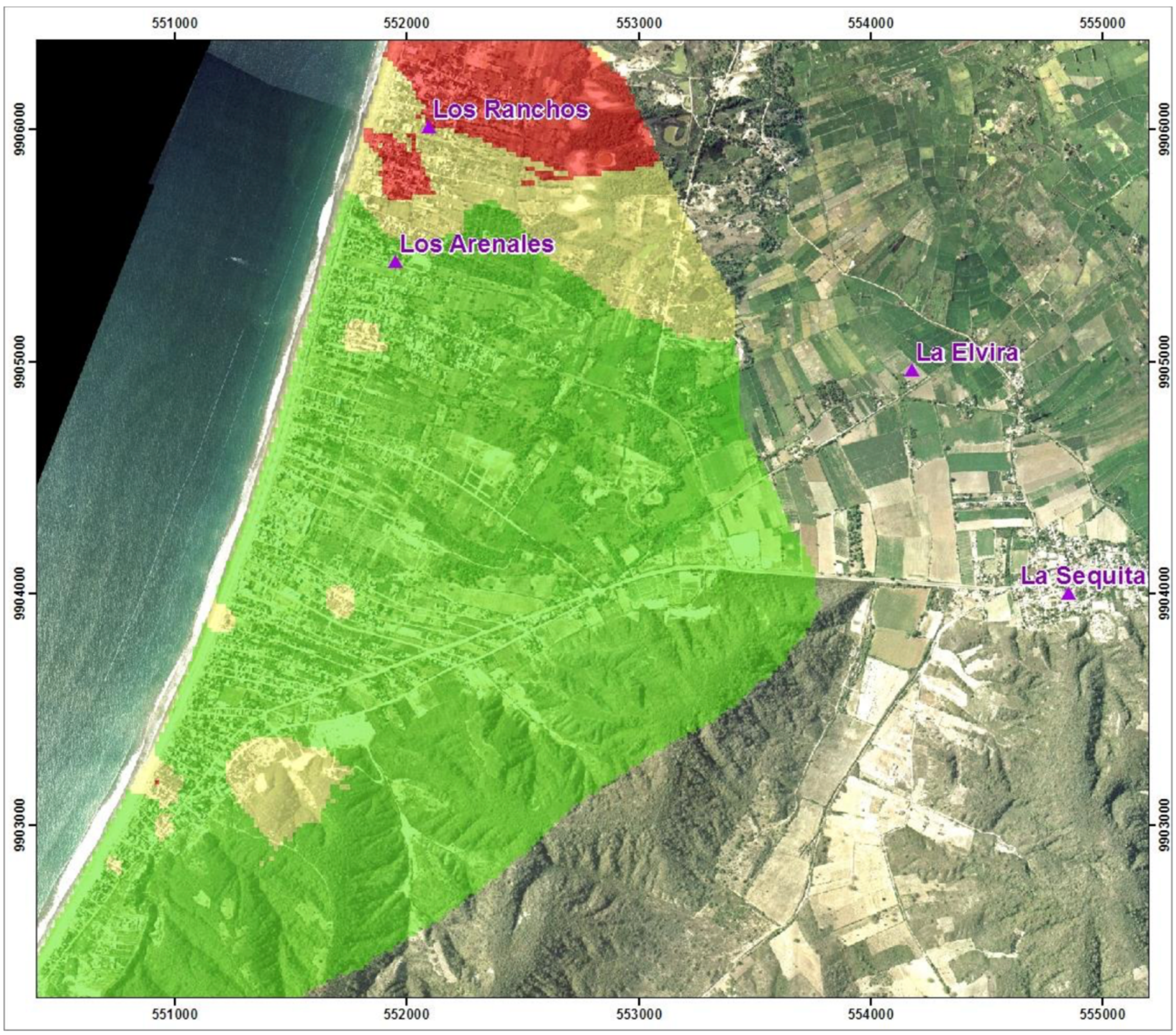


Fig. 9: Map of Crucita indicating the social vulnerability, based on the present survey.

Economic Vulnerability

Three different questions have been used to encounter the economic vulnerabilities, as listed in table 5 using the indicator values in table 17. Thus, the result has been that the level of vulnerability is mainly high (76%), with a quantitative value close to the lower limit of the level high (1.34).

High 76%	**Medium 24%**	**Low 0%**

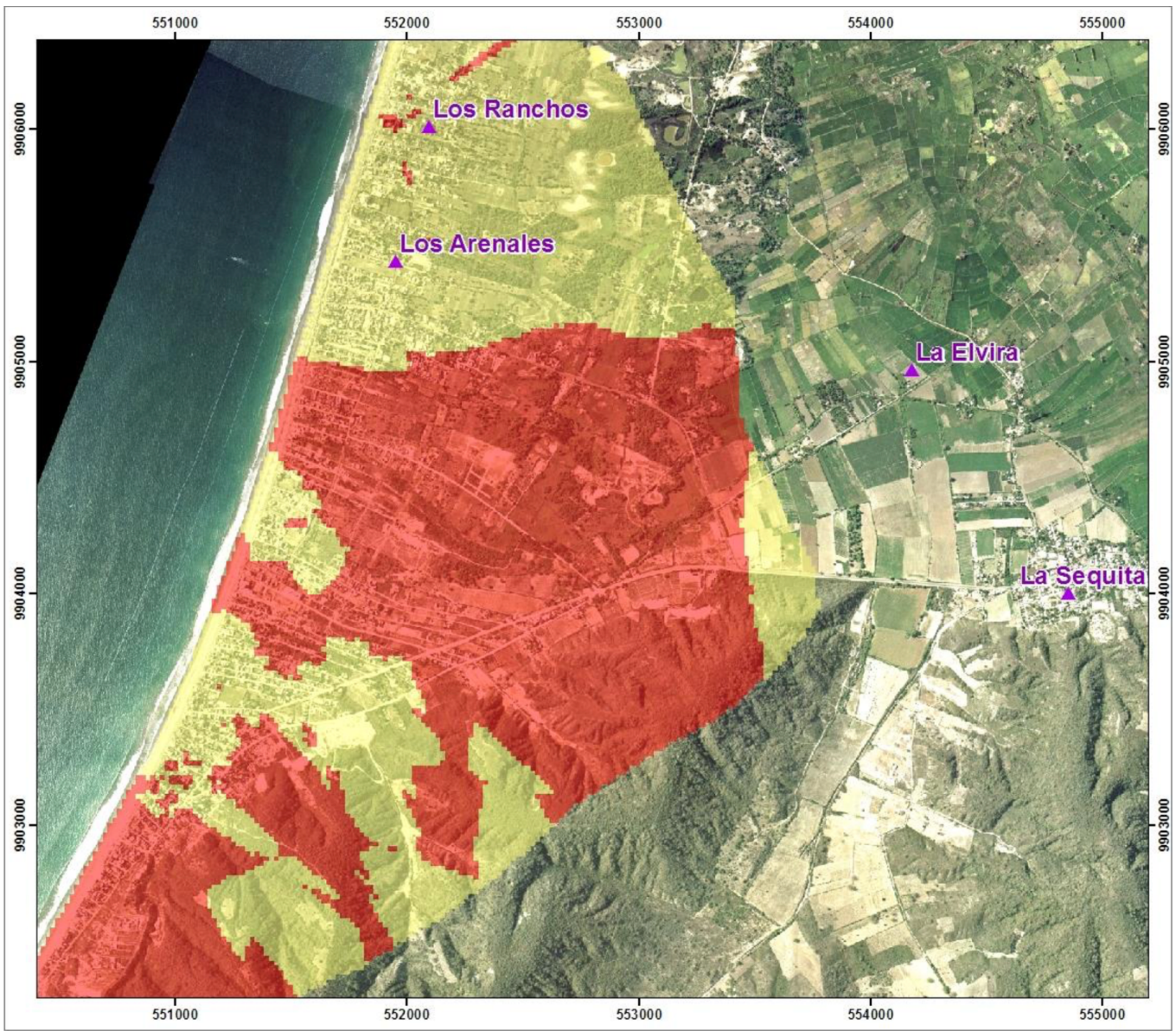


Fig. 10: Map of Crucita indicating the economic vulnerability, based on the present survey.

Vulnerability in Education

Two different questions have been used to find social vulnerabilities, as listed in table 6 using the indicator values in table 18. Thus, the result has been that the vulnerability level is mostly high (85%), with a near quantitative value at the lower limit of the high level (1.41).

High 85%	Medium 15%	Low 0%

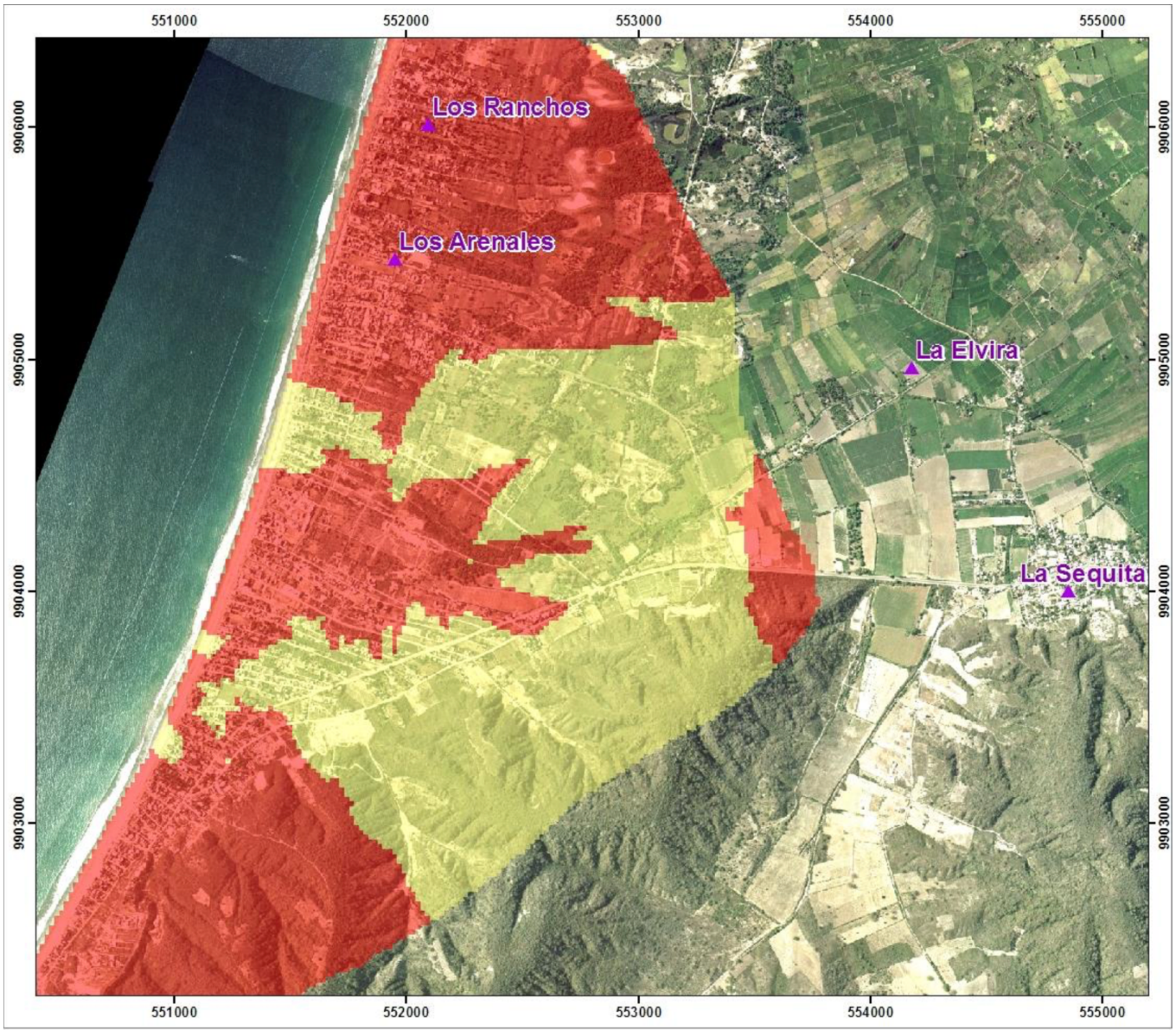


Fig. 11: Map of Crucita indicating the educational vulnerability, based on the present survey.

Cultural Vulnerability

Two different questions have been used to encounter cultural vulnerabilities, as listed in Table 7 using the indicator values of Table 19. Thus, the result has been that the level of vulnerability is high (99%), with a quantitative value close to lower limit of the high level (1.47).

High 99%	Medium 1%	Low 0%

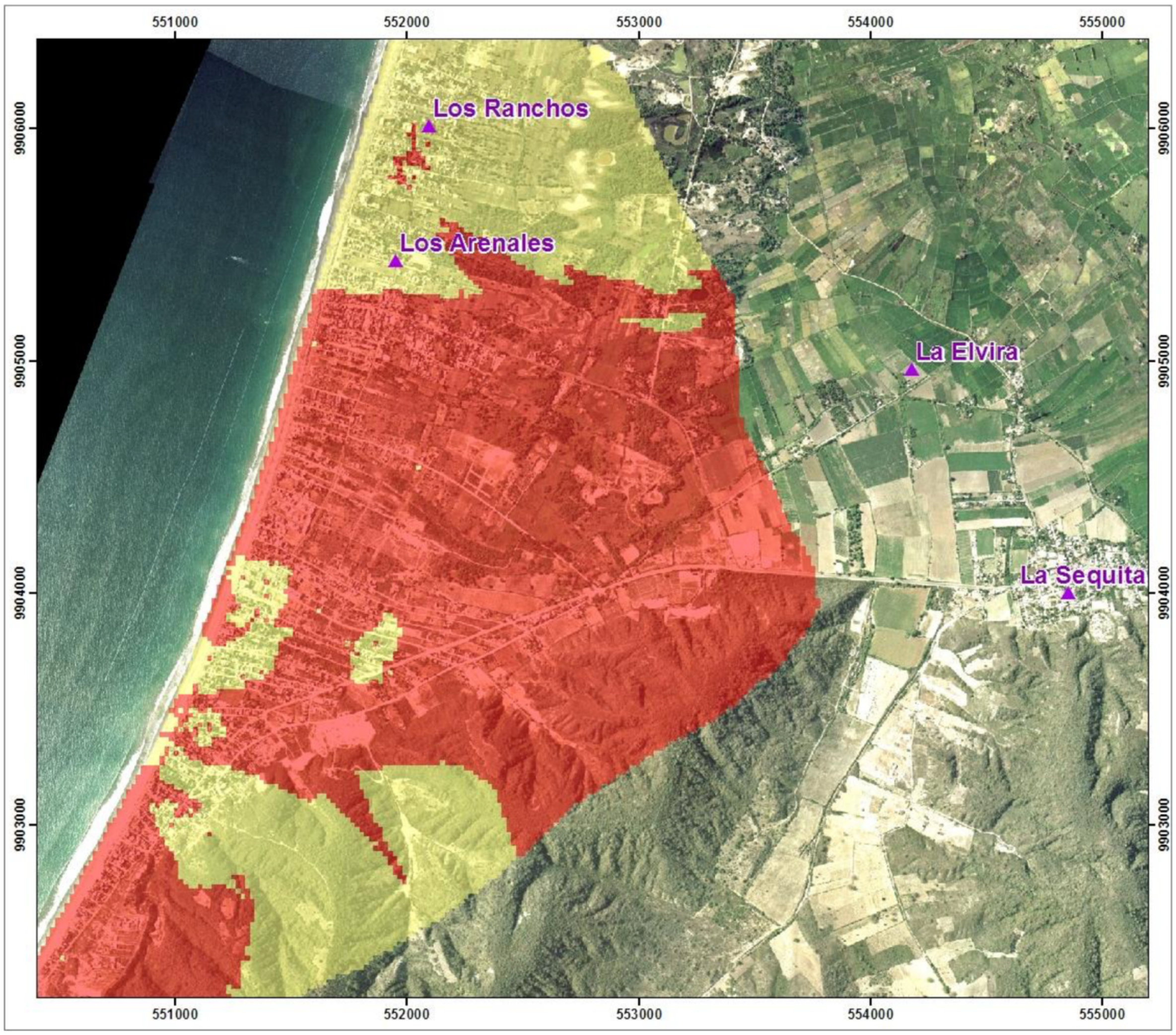


Fig. 12: Map of Crucita indicating the cultural vulnerability, based on the present survey.

Community capacity

Three different questions have been used to encounter cultural vulnerabilities, as listed in table 8 using the indicator values in table 20. Thus, the result has been that the capacity level is low (100%), with a quantitative value close to upper limit of the high level (1.94).

Low 100%	**Medium 0%**	**High 0%**

Fig. 14: Map of Crucita indicating the vulnerability of the community capacity, based on the present survey.

For the development of the present analysis on the results of the institutional level, a sample of ten institutions have been selected. For the purposes of interviews and surveys, it corresponded to the level of institutional policy vulnerability, vulnerability of essential elements and institutional capacity. The identified institutions are: Crucita Parish Council, Political Tenure, Crucita Fire Department, 25 de Mayo School, Juan Benigno Vela School, Ecuador Navy-Harbor Captaincy, National Police, National Telecommunications Corporation, Crucita Health Center, Municipal Tourism Company.

Institutional Policy Vulnerability

Below are the results obtained for each type of vulnerability (institutional policy and essential elements) and institutional capacity through the introduction of the following five queries, as listed in table 9 using the indicator values in table 21. Thus, it has been obtained as a result that the level of vulnerability is mostly high (80%), with a quantitative value close to the upper limit of the high level (1.70).

High 80%	**Medium 20%**	**Low 0%**

Vulnerability of Essential Elements

Five different questions have been used to encounter the vulnerabilities of the essential elements, as listed in table 10 using the indicator values in table 22. Thus, the result has been that the vulnerability level is high (96%), with a value quantitative close to the upper limit of the high level (1.52).

High 96%	**Medium 4%**	**Low 0%**

Institutional capacity

Three different questions have been used to find out the level of institutional capacity, as listed in table 11 using the indicator values in Table 23. In terms of institutional capacity, the result has been that the capacity level is low, with a value quantitative close to the upper limit of the high level (1.50).

Low 100%	**Medium 0%**	**High 0%**

After having performed the individual estimation of each type of vulnerability (physical, services, social, economic, educational, cultural, institutional and essential elements) and capacity (community and institutional), it has been determined that a level of a general vulnerability, which for effect of the present study has been called "total or population vulnerability". Such vulnerability defines in general terms the condition of the vulnerability of the population in relation to tsunami hazards, where there are factors that influence the rest, which allows us to establish a road map for reducing vulnerability. Based on the above, it has been possible to identify that the types of vulnerability that influence the increase in vulnerability are those related to the knowledge and culture of the population, because there are physical conditions determined by elements that are difficult to modify territorially, like the location of homes, institutions and essential elements in the studied territory.

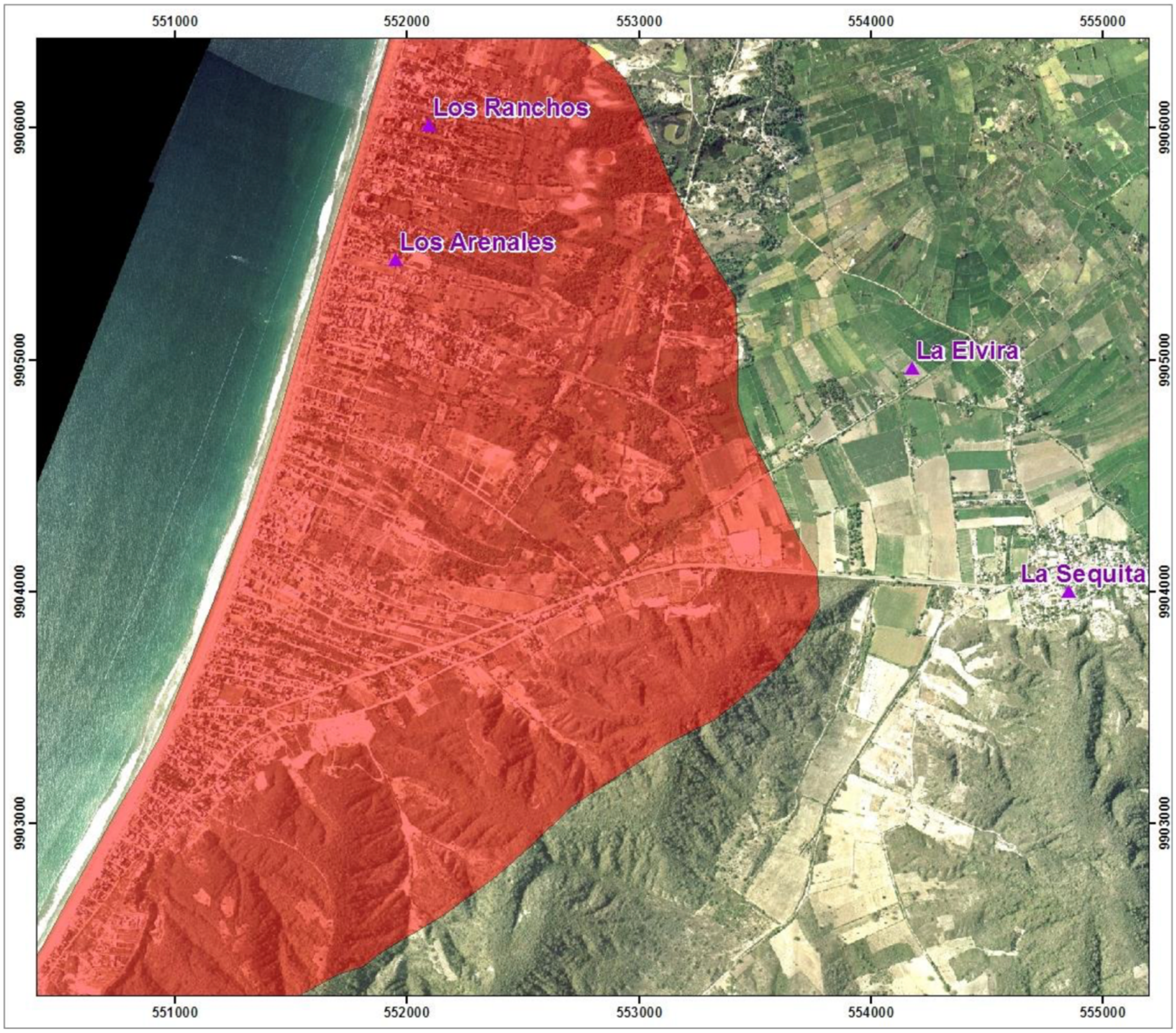


Fig. 15: Map of Crucita indicating the overall vulnerability, based on the present survey.

Public Vulnerability

When performing comparative exercises with real cases and cases where the existing conditions are modified after a vulnerability reduction process, an average reduction of vulnerability of up to 52% has been obtained. Therefore, the factors that influence the increase in vulnerability are social, educational, cultural, institutional and community and institutional capacities. Being these, factors that have been subject to the organization and participation of community and institutional performer. In conclusion after having realized the analysis of each of the types of vulnerability and crossing with the results of institutional and community capacity, the result has been that the level of population vulnerability has been high (93%, 1.63).

Low 92,5%	**Medium 7,5%**	**High 0%**

5. SUMMARY AND CONCLUSIONS

The conclusions have been defined based on eight axes of interest, prioritized from the obtained results, from which the following points may be deduced:

1. *The location of Crucita in relation to the subduction zone determines the level of exposure of the Parish towards tsunami hazards.*

Crucita is located approximately 75 km east from the edge of the subduction zone, within the cenral area of the Manabi province, where historically the highest number of seismic events have been concentrated, respectively. This places Crucita in a condition of high exposure for the population, their homes, buildings, livelihoods and basic services. In the same way, the location of buildings and houses in relation to the edge of the high tide, determine that the population's exposure to the tsunami hazards is high, as a consequence that approximately 97% of buildings and homes are less 1000 m from the edge of the high tide.

2. *The variation of people according to the time of year and day of the week increases the number of inhabitants susceptible to be affected by the tsunami occurrence.*

Until 2001, Crucita have had a total population of 11,068 inhabitants, while in 2010 it increased to 14,050 inhabitants with an annual growth rate of 2.65%, indicating that the Parish has a tendency of population growth. On the other hand, being a local, national and international tourist destination, the population increases between 20 and 80%, according to the time of year and day of the week, and therefore the number of people susceptible to be affected by the occurrence of tsunamis.

3. *The inadequate land use and occupation increases the level of Parochial vulnerability towards tsunami hazards.*

The commercial, tourist and residential growth of Crucita has been developed along 13 km of beach area, in two consolidated areas being less than 1 km from the edge of the high tide, such as Parrish Cabecera and the north central sector of the main Parrish. Areas where narrow roads without a direct connection to a safe meeting point, as well as the construction of condominiums at the height of high traffic roads, do not allow a fast evacuation in the event of a tsunami warning or the occurrence of it. On the other hand, there are extensive areas that are not well established and have as their current land use, urbanization and development of tourism activities, which, in the absence of adequate urban and road planning, contributes to the increase of Parochial vulnerability in relation to road variables, infrastructure and evacuation routes.

4. *The high recurrence of tsunamis determines that the Parish could be affected by the occurrence of tsunamis.*

In the period between the years 1800 and 2017, there has been one tsunami of tectonic origin in the coasts of Manabi and six that affected the Ecuadorian coast. This indicates that the recurrence of local tsunamis is medium high, while the recurrence of distant tsunamis is very high, despite the fact that their wave propagation through the Pacific Ocean did not reach Ecuadorian coasts, with the exception of the tsunami generated by the Japanese earthquake in 2011.

5. *Tsunami hazards in relation to the probability of flooding due to the displacement of salt water to the coast, is high for the population being located less than 1000 m from the edge of the high tide*

6.

The topographic and bathymetric characteristics of Crucita and its beaches are favorable for flooding due to tsunami, since there is an average slope of 2% in the case of the bathymetry and average levels of 12 m above sea level in the case of the flat surface of the parish. Considering also that the northern limit of the Parish is delimited by the basin of the river Portoviejo, where communities settled in the vicinity of the banks of the existing river. The tsunami hazard map indicates that there is a high probability of flooding by tsunami with up to the maximum height of 12 masl, affecting by direct impact more than 95% of the flat surface of the parish

7. *The Parochial vulnerability level, resulted to be of a high vulnerability with 100% of the cases, being defined from the analysis of the physical variables of housing and service, social, educational, economic, cultural and institutional policies*

The current analysis yielded several results, such as that 91% of the homes have a high level of vulnerability in physical structure, due to the fact that most of the structural condition of the houses have been constructed of wood and concrete, with roofs is made of wood and zinc beams, havin in average one floor, being constructed between 1980 and 2000 and being located at a distance of less than 500 m from the edge of the high tide on a flat surface.

100% of service networks have a high level of vulnerability, because basic services do not have any redundancy and are dependent on the cantonal level for their functionality, despite the fact that service coverage is greater than 70%, with the exception of the sewer that does not exist. Some 82.26% of the inquired families have a medium level of social vulnerability, although in most cases the participation level has been infrequent. Additionally, the members of the family are in an age of dependency.

Some 76% of the families have a high level of economic vulnerability with a tendency to average, because most of the average family income is less than a minimum wage. The type of housing is light house or villa, but the level of overcrowding is in the usual range of average people per family.

Approximately 85% of families have a high level of educational vulnerability, because there are no educational and training programs aimed to prepare the population to act and reduce their vulnerability to tsunami hazards, as well as awareness campaigns, although the population in its majority has access to education.

Almost all (99%) of the families have a high level of cultural vulnerability, due to the fact that the majority of the population does not have the experience of having experienced a tsunami impact, which has been evidenced by the tsunami warning due to the 8.9

earthquake that occurred in Japan in 2011. A large number of families have a skeptical of the tsunamis and the signals prior to their occurrence.aptitude about the occurrence of tsunamis in Ecuadorian coasts. However, they have knowledge about the origin. Eight out of ten institutions in the Parish, have a high level of vulnerability, as there is no complete compliance with national and local policies for risk management. These institutions do not count with a budget for the development of DRR actions, management institutions plans of risks and training for staff on the subject of risk management. Some 96% of the essential elements have a high level of vulnerability, despite having a high level of importance for citizens in normal situations and with greater emphasis on emergency situations to ensure the continuity of humanitarian rights such as access to education and health in emergency situations.

7. *The level of Parochial capacity, defined from the analysis of institutional and community capacity variables, yielded as a result that vulnerability for 100% of cases is high*

All of the institutions (100%) have a low capacity to respond to a tsunamigenic event, because there is no Parochial CEO or it does not work, as well as an alarm system for tsunamis, emergency or contingency plans and risk maps. Evacuation routes and meeting points are not marked, although there are response organizations in the parish, temporary shelters and participation of once every year in simulation exercises with educational establishments. 100% of the families have a low capacity for risk reduction and response, due to the fact that there are no Risk Management Committees, Community Emergency Brigades and Parochial Contingency Plans. There is a lack of knowledge of meeting points, evacuation routes and temporary shelters. The participation in simulation exercises or drills is low and there is a lack of emergency family plans.

8. *The total vulnerability of the Parish in relation to the types of vulnerability analyzed in this study, as well as the capacities identified, determined that the level of the Parochial vulnerability is high.*

This is due to the fact that the study elements with the highest incidence for the determination of final results are institutional and community capacity, followed by physical structure vulnerability and service networks, institutional, cultural and educational policy. Therefore, vulnerability reduction actions should be aimed at improving institutional and community capacities, which in terms of incidence are 48% important. Also, reducing to the minimum the institutional, cultural and educational political vulnerability, which in incidence methods have a 16% importance.

With respect to physical structure vulnerabilities, service networks and essential elements, prospective actions should be taken to avoid the increase of vulnerability linked to development. In the same way, the reduction of social and economic vulnerability will depend on the application of policies that resolve unsatisfied basic needs. By modifying the indicated values of vulnerability and capacity, the result is the reduction of the Parochial vulnerability by 46%. Varying from 1.65 points typified as high, to 0.89 points typified as average.

6. REFERENCES

Beck, S. L., & Ruff, L. J. (1984). The rupture process of the great 1979 Colombia earthquake: Evidence for the asperity model. Journal of Geophysical Research: Solid Earth, 89(B11), 9281-9291.

Berninghausen, W.H., 1962. Tsunamis reported from the west coast of South America 1562-1960. Bull. of the Seismological Soc. of America, 52 (4): 915-921.

Cruz D´Howitt, M. and Vásquez, N., 2010: Elaboración de 33 cartas - croquis de amenazas por tsunami y análisis de riesgos en la costa ecuatoriana utilizando indicadores geomorfológicos y socio-ambientales. Revista Geoespacial, 7: 1-20

Chunga, K., & Toulkeridis, T. (2014). First evidence of paleo-tsunami deposits of a major historic event in Ecuador. Science of Tsunami Hazards, 33(1): 55-69.

Delouis, B., Nocquet, J. M., & Vallée, M. (2010). Slip distribution of the February 27, 2010 Mw= 8.8 Maule earthquake, central Chile, from static and high-rate GPS, InSAR, and broadband teleseismic data. Geophysical Research Letters, 37(17).

Dumont, J. F., Santana, E., & Vilema, W. (2005). Morphologic evidence of active motion of the Zambapala Fault, Gulf of Guayaquil (Ecuador). Geomorphology, 65(3), 223-239.

Dumont, J. F., Santana, E., Bonnardot, M. A., Pazmiño, N., Pedoja, K., & Scalabrino, B. (2014). Geometry of the coastline and morphology of the convergent continental margin of Ecuador. Geological Society, London, Memoirs, 41(1), 327-338.

Gutscher, M.A., Malavieille, J.S.L., Collot, J.-Y., 1999. Tectonic segmentation of the North Andean margin: impact of the Carnegie Ridge collision. Earth and Planetary Science Letters 168, 255–270. Gutscher, M.-A., Spakman, W., Bijward, H., Engdahl, E.R., 2000. Geodynamics of flat subduction: Seismicity and tomographic constraints from the Andean margin. Tectonics 19 (5), 814–833.

Harden, C. (2001). Sediment movement and catastrophic events: The 1993 rockslide at La Josefina, Ecuador. Physical Geography, 22(4), 305-320.

Herd, D. G., Youd, T. L., Meyer, H., Arango, J. L., Person, W. J., & Mendoza, C. (1981). The great tumaco, colombia earthquake of 12 december 1979. Science, 211(4481), 441-445.

INDECI- DINAPRE- UEER (Instituto Nacional de Defensa Civil - Dirección Nacional de Prevención - Unidad de Estudios y Evaluación de Riesgos), 2006: Manual Básico para la Estimación del Riesgo. Lima, Perú: 73pp

Jaramillo Castelo, C.A., Padilla Almeida, O., Cruz D´Howitt, M. and Toulkeridis, T. (2018). Comparative determination of the probability of landslide occurrences and susceptibility in central Quito, Ecuador". 5th International Conference on eDemocracy and eGovernment, ICEDEG 2018, 136-143.

Kanamori, H. and McNally, K.C., 1982. Variable rupture mode of the subduction zone along the Ecuador-Colombia coast. Bulletin of the Seismological Society of America, 72(4): 1241-1253.

López, M. C. (2013). Cronología de tsunamis en ecuador desde 1586 a 2012. La Técnica, (11): 50-59.

Lynett, P., Weiss, R., Renteria, W., Morales, G. D. L. T., Son, S., Arcos, M. E. M., & MacInnes, B. T. (2013). Coastal impacts of the March 11th Tohoku, Japan tsunami in the Galapagos Islands. Pure and Applied Geophysics, 170(6-8), 1189-1206.

Massonne, H. J., & Toulkeridis, T. (2012). Widespread relics of high-pressure metamorphism confirm major terrane accretion in Ecuador: a new example from the Northern Andes. International Geology Review, 54(1), 67-80.

Mato, F., & Toulkeridis, T. (2017). The missing Link in El Niño's phenomenon generation. Science of Tsunami Hazards, 36(3), 128-144.

Mendoza, C., & Dewey, J. W. (1984). Seismicity associated with the great Colombia-Ecuador earthquakes of 1942, 1958, and 1979: Implications for barrier models of earthquake rupture. Bulletin of the seismological society of America, 74(2), 577-593.

Navas, L., Caiza, P. and Toulkeridis. T., 2018: An evaluated comparison between the molecule and steel framing construction systems – implications for the seismic vulnerable Ecuador. Malaysian Construction Research Journal, 23: in press

NEC (Norma Ecuatoriana de la Construcción), 2014: Geotecnia y diseño de cimentaciones en el Ecuador, Acuerdo ministerial 0028. 19 de agosto de 2014:18-19.

Norio, O., Ye, T., Kajitani, Y., Shi, P., & Tatano, H. (2011). The 2011 eastern Japan great earthquake disaster: Overview and comments. International Journal of Disaster Risk Science, 2(1), 34-42.

Okuwaki, R., & Yagi, Y. (2017). Rupture Process During the Mw 8.1 2017 Chiapas Mexico Earthquake: Shallow Intraplate Normal Faulting by Slab Bending. Geophysical Research Letters, 44(23).

Pararas-Carayannis, G. (1980). Earthquake and tsunami of 12 December 1979 in Colombia. Tsunami Newsletter, 13(1), 1-9.

Pararas-Carayannis, G. 1980: The Earthquake and Tsunami of December 12, 1979, in Colombia. Intern. Tsunami Information Center Report, Abstracted article in Tsunami Newsletter, Vol. XIII, No. 1.

Pararas-Carayannis G., 1983. The Tsunami Impact on Society. Tsunamis - Their Science and Engineering.: Terra Scientific Publishing Company, Tokyo, pp. 3-8 ,1983.

Pararas-Carayannis, G. 1988. Risk Assessment of the Tsunami Hazard in Natural and Man-Made Hazards, In Natural and Man-Made Hazards, D. Reidal, Netherlands, pp.171-181, 1988 (LL).

Pararas-Carayannis, G., 2010: The earthquake and tsunami of 27 February 2010 in Chile– Evaluation of source mechanism and of near and far-field tsunami effects. Science of Tsunami Hazards, 29, 2: 96-126.

Pararas-Carayannis, G., 2012: Potential of tsunami generation along the Colombia/Ecuador subduction margin and the Dolores-Guayaquil Mega-Thrust. Science of Tsunami Hazards, 31, 3: 209-230.

Pararas-Carayannis, G., 2014. The Great Tohoku-Oki earthquake and tsunami of March 11, 2011 in Japan: A critical review and evaluation of the tsunami source mechanism. Pure and applied geophysics, 171(12): 3257-3278.

Pararas-Carayannis, G. and Zoll, P., 2017: Incipient evaluation of temporal el nino and other climatic anomalies in triggering earthquakes and tsunamis – case study: The earthquake and tsunami of 16thapril 2016 in Ecuador. Science of Tsunami Hazards, 36(4), 262-291.

Pararas-Carayannis, G., 2018: Brief history of early pioneering tsunami research – Part A. Science of Tsunami Hazards, 37(1), 49-129.
PNUD-SNGR (Programa de Naciones Unidas para el Desarrollo - Secretaría Nacional de Gestión de Riesgos) de Ecuador, 2011: Sistematización de la Metodología de Análisis de Vulnerabilidades a nivel Municipal. Quito, Ecuador: 15pp
PREDECAN (Prevención de Desastres en la Comunidad Andina), 2009: Serie: Experiencias significativas de desarrollo local frente a los riesgos de desastres: Proyecto piloto participativo en gestión local del riesgo de desastres en el cantón Portoviejo. Lima, Peru: 40pp
Rentería, W., Lynett, P., Weiss, R. & De La Torre, G. (2012). Informe de la investigación de campo de los efectos del tsunami de Japón Marzo 2011, en las islas Galápagos. Acta Oceanográ ca del Pací co. Vol. 17(1): 177 - 203.
Rodriguez, F., Toulkeridis, T., Sandoval, W., Padilla, O., & Mato, F. (2017). Economic risk assessment of Cotopaxi volcano, Ecuador, in case of a future lahar emplacement. Natural Hazards, 85(1), 605-618.
Schuster, R. L., NietoThomas, A. S., O'Rourke, T. D., Crespo, E., & Plaza-Nieto, G. (1996). Mass wasting triggered by the 5 March 1987 Ecuador earthquakes. Engineering geology, 42(1), 1-23.
Simons, M., Minson, S.E., Sladen, A., Ortega, F., Jiang, J., Owen, S.E., Meng, L., Ampuero, J.P., Wei, S., Chu, R. and Helmberger, D.V., 2011. The 2011 magnitude 9.0 Tohoku-Oki earthquake: Mosaicking the megathrust from seconds to centuries. science, 332(6036), pp.1421-1425.
Toulkeridis, T., 2011: Volcanic Galápagos Volcánico. Ediecuatorial, Quito, Ecuador: 364 pp
Toulkeridis, T., 2013: Volcanes activos Ecuador. Santa Rita, Quito, Ecuador: 152pp
Toulkeridis, T., & Zach, I. (2017). Wind directions of volcanic ash-charged clouds in Ecuador–implications for the public and flight safety. Geomatics, Natural Hazards and Risk, 8(2), 242-256.
Toulkeridis, T., 2016: The Evaluation of unexpected results of a seismic hazard applied to a modern Hydroelectric center in central Ecuador. Journal of Structural Engineering (India), 43, 4: 373-380.
Toulkeridis, T., Arroyo, C.R., Cruz D'Howitt, M., Debut, A., Vaca, A.V., Cumbal, L., Mato, F. and Aguilera, E., 2015. Evaluation of the initial stage of the reactivated Cotopaxi volcano-analysis of the first ejected fine-grained material. Natural Hazards and Earth System Sciences Discussions, 3: 6947-6976.
Toulkeridis, T., Chunga, K., Rentería, W., Rodriguez, F., Mato, F., Nikolaou, S., D'Howitt, M.C., Besenzon, D., Ruiz, H., Parra, H. and Vera-Grunauer, X., 2017b. The 7.8 M w Earthquake and tsunami of 16th April 2016 in Ecuador: Seismic Evaluation, Geological Field Survey and Economic Implications. Science of Tsunami Hazards, 36(4): 197-242.
Toulkeridis, T., Parra, H., Mato, F., Cruz D´Howitt, M., Sandoval, W., Padilla Almeida, O., Rentería, W., Rodríguez Espinosa, F., Salazar Martinez, R., Cueva Girón, J., Taipe Quispe, A. and Bernaza Quiñonez, L., 2017a: Contrasting results of potential tsunami hazards in Muisne, central coast of Ecuador. Science of Tsunami Hazards, 36: 13-40.

Toulkeridis, T., Mato, F., Toulkeridis-Estrella, K., Perez Salinas, J.C., Tapia, S. and Fuertes, W., 2018: Real-Time Radioactive Precursor of the April 16, 2016 Mw 7.8 Earthquake and Tsunami in Ecuador. Science of Tsunami Hazards, 37: 34-48

USGS (United States Geological Service), 2016: M7.8 - 29km SSE of Muisne, Ecuador.http://earthquake.usgs.gov/earthquakes/eventpage/us20005j32#general

Ye, L., Kanamori, H., Avouac, J. P., Li, L., Cheung, K. F., & Lay, T. (2016). The 16 April 2016, M W 7.8 (M S 7.5) Ecuador earthquake: A quasi-repeat of the 1942 M S 7.5 earthquake and partial re-rupture of the 1906 M S 8.6 Colombia–Ecuador earthquake. Earth and Planetary Science Letters, 454, 248-258.

Zafrir Vallejo, R., Padilla Almeida, O., Cruz D´Howitt, M., Toulkeridis, T., Rodriguez Espinosa, F., Mato, F. and Morales Muñoz, B. (2018). Numerical probability modeling of past, present and future landslide occurrences in nothern Quito, Ecuador – Economic implications and risk assessment”. 5th International Conference on eDemocracy and eGovernment, ICEDEG 2018, 117-125.