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EVALUATION OF SEISMIC AND TSUNAMI RESISTANCE OF POTENTIAL SHELTERS FOR VERTICAL EVACUATION IN CASE OF A TSUNAMI IMPACT IN MANTA AND SALINAS, CENTRAL COAST OF ECUADOR

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ABSTRACT

The current study is a pioneer work of an improved technical risk assessment, where alternative solutions are proposed of how lives may be better saved during a potential tsunami impact in the coastal cities of Manta and Salinas in the central coast of Ecuador. As Ecuador has been already the target of several tsunamis during recorded history, further tsunami impacts are rather the rule than the exception. Due to short times between generation and impact of tsunamis and due to long distances to natural elevated safe sites, alternative solutions may be more required such as close-by buildings with certain heights. Those potential shelters as result of vertical evacuation needed to be evaluated for their seismic resistance as well as their resistance towards a tsunami. Both qualifications have been examined by the application of the Modified Italian Methodology in order to calculate the seismic vulnerability index (SVI) and subsequently also in order to determine the tsunami vulnerability index (TVI). In this respect we evaluated 18 buildings of such characteristics in Manta and further 99 in Salinas. Unfortunately, although many buildings stand the applied evaluations, due to the fact that almost all edifices are of private property, both entrance and stairs remain limited for the general public. Therefore, we propose that given regulations need to improve in order to allow the access to the general public during a tsunami emergency within an evacuation plan besides the implementation of an efficient early alert system.

Keywords: *Vertical evacuation, physical structural vulnerability, tsunami resistance, early alert system, Ecuador.*

1. INTRODUCTION

The search of live-saving solutions is the first task of any responsible and efficient risk assessment analysis including all types of natural hazards (Feng & Wang, 2003; Aitsi-Selmi et al., 2015; Kalkman & de Waard, 2017; Solinska-Nowak et al., 2018;). As the impact of tsunamis are mostly time-sensitive, proposals of reduction of loss of lives need to be sometimes creative and certainly on hand if other matters fail such as relocation or missing financial alternatives (Russell, 2005; Olson & Wu 2015; Sellnow & Seeger, 2021). In this respect, when it comes to evacuation routes and safe zones, any meter and or second counts (Gregg et al., 2006; Taubenböck et al., 2009; Wood & Schmidtlein, 2012; 2013). A tsunami is often a destructive and lethal force of nature, especially where human settlements have been constructed in their course of seashore impact (Pararas-Carayannis, 1977; Pararas-Carayannis, 2002; Pararas-Carayannis, 2003; Pararas-Carayannis, 2006; Pheng et al., 2006; Pararas-Carayannis, 2010; Mikami et al., 2012; Rodriguez et al., 2016; Toulkeridis et al., 2017a; Rodriguez et al., 2017; Suárez-Acosta et al., 2021).

Tsunamis occur worldwide, but mostly in the coastal areas of the Pacific Ring of Fire, which includes the coasts of Ecuador in northwestern South America (Pararas-Carayannis, 2012; Chunga and Toulkeridis, 2014; Pararas-Carayannis, 2017; Toulkeridis et al., 2017b). Along an 800 km long coast, the continental part of Ecuador has been impacted by a variety of tsunamis within the recorded history and paleo-tsunami deposits (Chunga and Toulkeridis, 2014; Ioualalen et al., 2014; Chunga et al., 2017; 2018; Toulkeridis et al., 2018; Toulkeridis et al., 2019). There is a high vulnerability of the infrastructure as well as the corresponding settled population, which goes along with a low degree of preparation of both, authorities and the public (Celorio-Saltos et al., 2018; Matheus-Medina et al., 2018; Edler et al., 2020; Martinez and Toulkeridis, 2020).

Inevitably, and due little to no knowledge of previous impacts of tsunamis, the construction along coastal areas prone to tsunamis has let to the establishment of human settlements and associated infrastructure in areas of a high degree of vulnerability towards the impact zones of future tsunamis (Alcántara-Ayala, 2002; Papathoma & Dominey-Howes, 2003; Frankenberg et al., 2013). Massive residences, factories and other industrial or strategic constructions, as well as commercial and touristic activities are among the most inopportune situated places within these zones of high vulnerability in Ecuador and elsewhere (Papathoma et al., 2003; Calgaro & Lloyd, 2008; Calgaro et al., 2014; Barros et al., 2015; Matheus-Medina et al., 2018; Suárez-Acosta et al., 2021).

Additionaly, in many developing countries like in Ecuador, risk assessment and reduction, hazard evaluation, land use, territorial zoning and the need of relocation distant to vulnerable sites is almost never practiced, especially when political and economic crisis are more common than times of prosperity and tranquility. Therefore, living with the natural hazards has been the common policy of Ecuador, when applying risk assessment measures towards recurrent processes of hydro-meteorological or geologic origin, such as floods, droughts, hydric deficit, climate change, mass movements and landslides, volcanic activities, earthquakes and especially tsunamis (Toulkeridis et al., 2007; Padrón et al., 2008; Ridolfi et al., 2008; Padrón et al., 2012; Toulkeridis et al., 2015a; b; Toulkeridis et al. 2016; Vaca et al., 2016; Rodriguez et al., 2017; Toulkeridis and Zach, 2017; Mato and Toulkeridis, 2017; Jaramillo Castelo et al., 2018; Zafrir Vallejo et al., 2018; Aguilera et al., 2018; Palacios Orejuela, and Toulkeridis, 2020; Toulkeridis et al., 2020a; b; Poma et al., 2021). Still, based on recent catastrophic seismic and volcanic events, Ecuador's policy started to develop from a more passive turn towards a more proactive risk assessment, at least from the side of the academy, which proposed a variety of solutions such as improved and more controlled land use management, signage of evacuation routes, drilling of the population and preventive education as well as even mitigation structures where affordable prior potential impacts (Toulkeridis, 2016; Toulkeridis et al., 2020c; Yépez et al., 2020; Herrera-Enríquez et al., 2020).

In case of the coastal part of Ecuador, a high amount of tsunami evacuation signs have been installed, although many more are needed, while several are inadequately placed, indicating a longer than needed path towards safety among other issues (Celorio-Saltos et al., 2018; Matheus-Medina et al., 2018). Hereby, evacuation routes may be often too long in order to arrive safe in case of a short-time warning if any, of a potential tsunami impact (Matheus Medina et al., 2016; Rodriguez et al., 2016; Toulkeridis et al., 2017a). Therefore, as an alternative solution, specific buildings may be used, which should have a sufficient amount of floors for an eventual vertical evacuation within a temporary shelter (Yeh et al., 2005; Park et al., 2012; Matheus Medina et al., 2016; Mostafizi et al., 2019). In order to comply with such requirements, these buildings need to be resistant to strong seismic movements as well as towards the impact of tsunami waves (Lukkunaprasit & Ruangrassamee, 2008; Meyyappan et al., 2013; Navas et al., 2018; Belash & Yakovlev, 2018; Aviles-Campoverde et al., 2021; Del-Pino-de-la-Cruz et al., 2021; Suárez-Acosta et al., 2021).

We have chosen Manta and Salinas, two of the most developed, frequented and touristic coastal cities of Ecuador in order to apply an enhanced risk assessment and management, by evaluating the possibility of using high buildings as potential shelters in case of a tsunami emergency. Such potential may be reached by the determination of the seismic and tsunamic resistance of these edifices when applying the Modified Italian Methodology in order to calculate the seismic vulnerability index (SVI) and subsequently also in order to determine the tsunami vulnerability index (TVI). This pioneering investigation applied on 117 buildings will allow an improved relationship between existing hazard zones and a corresponding land use policy in the coastal area of Ecuador.

2. GEODYNAMIC SETTING AND STUDY AREAS

Ecuador is situated within the interaction of a variety of continental and oceanic tectonic plates, along the Pacific Rim and therefore generated strong seismic activity and subsequently several tsunamis within recorded history (Pararas-Carayannis, 1980; Herd et al., 1981; Kanamori & McNally, 1982; Mendoza & Dewey, 1984; Pararas-Carayannis, 2012; Chunga & Toulkeridis, 2014). Such tsunamis have produced devastating results within coastal areas and its relatively unprepared population as well as their settlements (Gusiakov, 2005; Ioualalen et al., 2011; 2014; Pararas-Carayannis, 2012; Rodriguez et al., 2016; Heidarzadeh et al., 2017). This active continental margin is given due to the geodynamic constellation, which results from the subduction of the oceanic Nazca Plate together with its above-situated Carnegie Ridge below the continental South American and Caribbean Plates, both being separated by the Guayaquil-Caracas Mega Shear (Fig. 1; Kellogg et al., 1995; Gutscher et al., 1999; Egbue and Kellog, 2010).

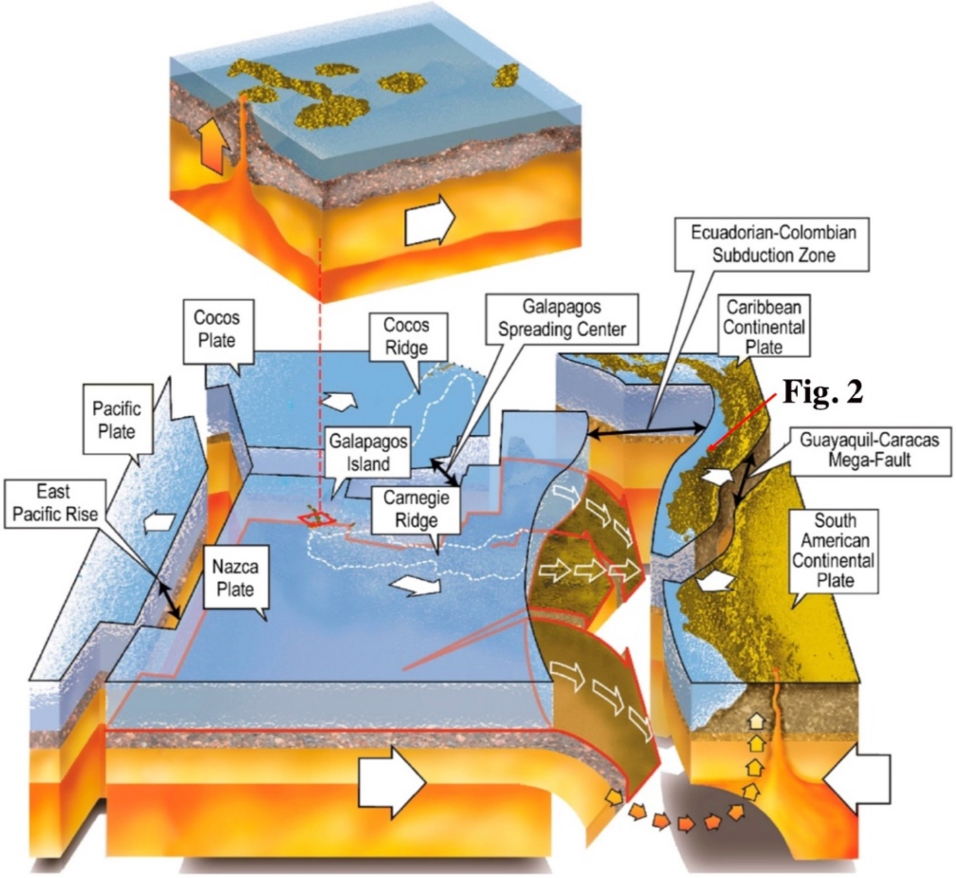

Fig. 1. Geodynamic setting of Ecuador with associated oceanic and continental plates and a variety of plate boundaries, such as the divergent plate boundaries named East Pacific Rise and Galapagos Spreading Center, the convergent plate boundary represented by the Ecuadorian-Colombian Subduction zone,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

This rises to a variety of tsunamis of tectonic as well submarine landslide origin (Moberly et al., 1982; Pontoise and Monfret, 2004; Ratzov et al, 2007; 2010; Ioualalen et al., 2011; Pararas-Carayannis, 2012). Besides the regular tsunamis, also even iminamis may be generated by massive sector collapses of volcanoes in the Galapagos archipelago (Kates, 1976; Cannon, 1994; Keating & McGuire, 2000; Pararas-Carayannis, 2002; Whelan & Kelletat, 2003; McGuire, 2006; Glass et al., 2007; Pinter & Ishman, 2008; Toulkeridis, 2011).

Therefore, Ecuador has been impacted by several seismic and tsunami hazards, based on the occurrence of local earthquakes, such as on January 31, 1906 (8.8 Mw), October 2, 1933 (6.9 Mw), May 14, 1942 (7.8 Mw), December 12, 1953 (7.3 Mw), January 16, 1956

(7.0), January 19, 1958 (7.6 Mw), December 12, 1979 (8.2 Mw), August 4, 1998 (7.2 Mw) and April 16, 2016 (7.8 Mw), besides other less intense occurrences (Berninghausen, 1962; Kanamori and McNally, 1982; Pararas-Carayannis, 2012; Chunga and Toulkeridis, 2014; Toulkeridis et al., 2017a; 2017b; 2018). Furthermore, a variety of distantly-generated tsunamis have impacted Ecuador, such as the tsunami of Japan in March 11, 2011 (8.9 Mw), which resulted to a considerable run-up in the Galápagos islands and the Ecuadorian mainland (Simons et al., 2011; Norio et al., 2011; Rentería et al., 2012; Lynett et al., 2013). A similar event based on a tsunami of Chile in February 27, 2010 (8.8 Mw) had only minor effects in the Galapagos Islands, as the main waves impacted during times of low tide (Rentería et al., 2012; Lynett et al., 2013)

The study area comprises the cities of Manta and Salinas, which are situated on the central coastal area of the Province of Manabí and Santa Elena respectively. Both are considered to hold the touristically most active and frequented beaches of the entire country. The economic development of both cities due to the fishing industry, import and export activities and strong tourism, has led to a considerable prosperity and hereby a dense human settlement along the oceanic shore close to the nice beaches (Fig. 2 and 3).

The peninsula of Salinas in the province of Santa Elena in western Ecuador, is without doubt the most touristic developed city of the entire country, receiving annually hundreds of thousands of visitors, making it to a perfect target within an upcoming tsunami, as most of the tourists are unaware of such hazards (Matheus-Medina et al., 2018; San Martin et al., 2018). The mostly flat areas of Salinas are made of Quaternary deposits of sandstones, conglomerates and calcareous banks of the Tablazo formation (Bosworth, 1922; Sheppard, 1930; Marchant, 1961; DeVries, 1988). Between this formation and specially in the western side of Salinas, appear several Cretaceous outcrops with more resistant rocks of mostly volcano-clastic origin mixed with some intercalated lavas and sedimentary rocks belonging to the Cayo Formation (Bristow, 1976; Wallrabe-Adams, 1990). To the eastern side of Salinas towards higher morphological elevations appear Eocene clastic sedimentary rocks of the Ancón Group (Stainforth, R. M. (1948; Jaillard et al., 1995).

Manta, which is the most important oceanic port of Ecuador (Carvache-Franco et al., 2018; González Santa Cruz et al., 2019; Carvache-Franco et al., 2020). It is mostly upon sediments of the Tablazo formation with some minor parts of sediments of the early middle Miocene Tosagua Formation within the western side of the city (Stainforth, 1948; Whittaker, 1988). The Manta peninsula and therefore most of the city is elevated right next to the beaches during a recent Plio-Queternary uplift based mainly on the subducted Carnegie Ridge (Pedoja et al., 2006; Freisleben et al., 2021).

Fig. 2. Geographic setting of the study areas with the cities of Manta and Salinas. Width of image is of about 17 km. Both images were taken from Google Earth in 2021.

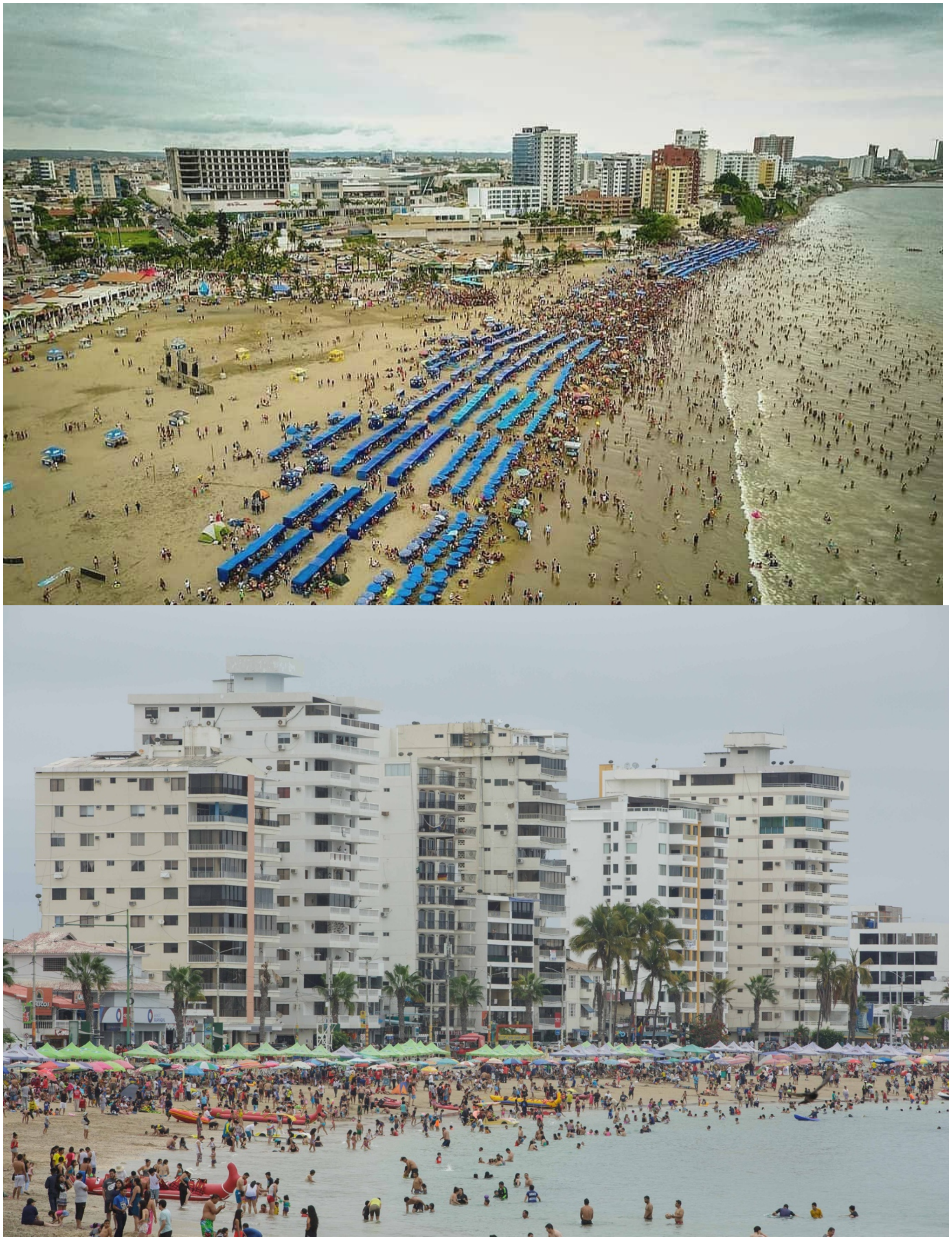

Fig. 3. Typical tourist activity on the beaches of Manta (upper image) and Salinas (lower image). Credit: GAD de Manta and Alexander Moya.

The problems and inadequate signage of tsunami warnings and indication of safe areas are omnipresent. One example may serve o explain such issue. In figure 4, we may demonstrate a case where in the northern side of the Salinas peninsula (Fig. 4a), just 260 meters of the beach (Fig. 4b), there is a correct signage of the safe areas with contradictory indication of the safest spot. Those citizens or tourists who would look to the signage towards east and may direct themselves towards this direction would have to evacuate for a distance of 1930 meters, while standing on the same spot, but watching the signage towards west, people would have to cross some 4700 meters to reach a safe, elevated site (Figure 4c).

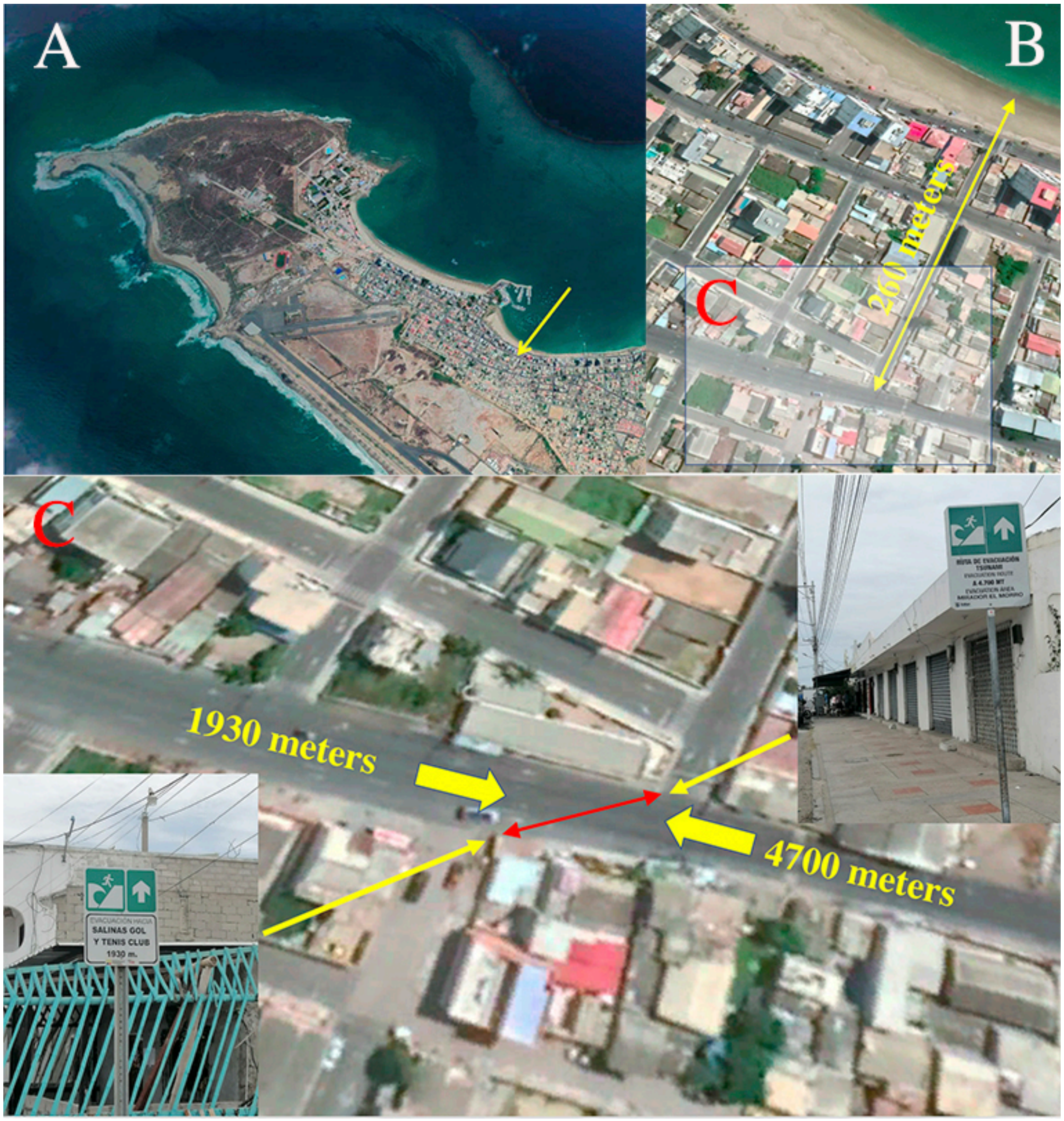

Fig. 4. Inadequate signage of tsunami warnings and safe areas in Salinas. Explained in the text.

3. METHODOLOGY

A total of 117 buildings have been encountered along the coastline of Manta (18) and Salinas (99), which were subsequently evaluated for their seismic as well as tsunami resistance (Fig. 3) in order to assess their feasibility as provisional shelters for vertical evacuation in case of an impact by a tsunami. The elevation of the tsunami impact has been considered to be of 24 meters based on a given picked simulation as chosen from many. The pre-selection of buildings was performed according to their height, considering those with more than four floors. The evaluation of each building was performed by couples of trained personnel with civil engineering expertise in order to minimize any subjectivity.

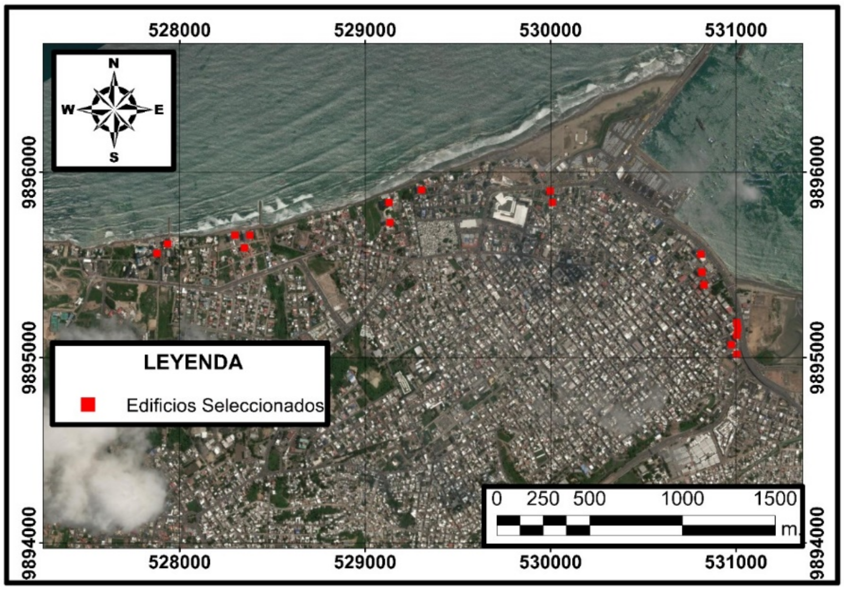

Fig 5. Map with the location of the 18 evaluated buildings in the city of Manta.

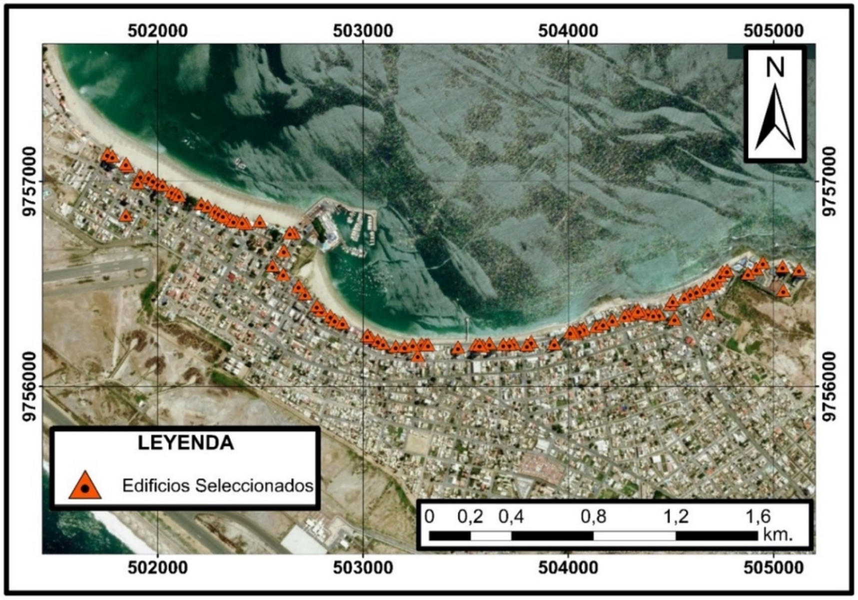

Fig 6. Map with the location of the 99 evaluated buildings in the city of Salinas.

Within this field approach, basic data were collected such as name of the building, geographical location, address, total number of floors, number of floors below and above surface, average altitude of each floor, area and year of construction, current use as well as capacity. After this initial data collection, an evaluation was conducted in order to reveal the seismic resistance of each building, by using a dozen of criteria based on the Modified Italian Methodology. This has served in order to calculate the seismic vulnerability index (SVI) prior to the tsunami impact evaluation (Table 1; Calvi et al., 2006; Amellal et al., 2012; Kassem et al., 2019). Furthermore, we added an additional evaluation, for the corresponding tsunami resistance of each building (Table 2). Hereby, the tsunami evaluation contained ten criteria which were defined by following the Guidelines for Design of Structures for Vertical Evacuation from Tsunamis of the Federal Emergency Management Agency of the United States of America (FEMA, 2019).

Table 1: Modified Italian Methodology to calculate the SVI (Aguiar&Rivas, 2018)

Criteria	**Classes / Ki**			Weighting **Wi**
	A	**B**	**C**	
1. Organization of the resistant system	0	6	12	1,00
2. Quality of the resistant system	0	6	12	0,50
3. Conventional Resistance	0	11	22	1,00
4. Position of the building and foundations	0	2	4	0,50
5. (Floor)Slab	0	3	6	1,00
6. Floor configuration	0	6	12	1,00
7. Configuration in Elevation	0	11	22	1,00
8. Connection in critical elements	0	3	6	0,75
9. Low ductility elements	0	6	12	1,00
10. Non-structural elements	0	4	10	0,25
11. State of Conservation	0	10	20	1,00
12. Structure reinforced after earthquake	0	11	22	1,00

Table 2. Methodology to calculate the tsunami vulnerability index

Criteria	**Classes / Ki**			Weighting **Wi**
	A	**B**	**C**	
1. Building orientation	0	6	12	1,2
2. Access. Entrance	0	6	12	1,2
3. Access. Stairs	0	6	12	1,2
4. Building location. Potential hazards	0	6	12	0,5
5. Building location. Parking, traffic, streets	0	6	12	0,5
6. Structural system	0	6	12	1,0
7. Foundation system	0	6	12	0,5
8. Year of construction	0	6	12	1,0
9. Building Height	0	11	22	1,5
10. Floor system	0	6	12	1,0

In both the seismic and the tsunami evaluation of vulnerability, each criterion was classified in three vulnerability classes, being "A", "B" and "C". In this case "A" shall represent the most resistant building, while "C" shall reflect the most vulnerable structure, where each class corresponds to a value (Ki). Furthermore, each criterion was assigned to a fixed weighting coefficient (Wi) according to the importance of the criteria. The total seismic and tsunami vulnerability index for each building was calculated according to the equation:

$$IV=i=112\ Sor\ 10(T)\quad Ki\, Wi$$

According to table 1, the maximum value for the seismic vulnerability index is 143 while the maximum value for the tsunami vulnerability index is 130.2 (Table 2). Considering the aforementioned, the following general categorization for vulnerability is proposed:

Resistant structure
if $Iv \leq 30$
Highly vulnerable structure
If $Iv \geq 80$
Further evaluation is needed:
If $30 < Iv < 80$

This occurs especially with the calculation of the ratio between the building height and the vibration period of the structure (Duque Eslava et al., 2017; Aguiar and Zambrano 2018; Rodriguez, 2019).

4. RESULTS AND DISCUSSION

In order to evaluate the seismic vulnerability of the structures located in Salinas and Manta, the modified Italian methodology was used; in addition, to evaluate the resistance to tsunamis, parameters extracted from the FEMA were used. Through the results obtained, it was possible to categorize each of the buildings and identify those that can be considered as safe shelters in the event of a needed vertical emergency evacuation. These evaluation methods are fast, so it is advisable to accompany them with other analyzes or studies that allow to complement them and, in this way, obtain more effective results.

4.1 Salinas

A high rate of seismic activity brings with it great possibilities that after the occurrence of any of them, a tsunami may occur that impacts the buildings located a few meters from the coastline of the city of Salinas, which is why the city needs to have available relevant evacuation plans for the population in order to safeguard as many lives as possible. From the tip of San Lorenzo to the La Ensenada sector along a coastline of approximately 4.00 km, 99 buildings were identified subject to evaluation. Of these 90 were evaluated thanks to the collection of data in the field and making use of other additional information means, which represents 91% of the evaluated structures. The remaining 9% represents a total of nine structures that were not possible to be analyzed mainly due to the lack of information and collaboration on the part of the managers of the respective residences (Table 3; Fig. 7 and 8).

Table 3: Summary of seismic and tsunami vulnerability index (SVI & TVI) of ninety buildings in Salinas, while on nine additional recognized buildings we were denied access (see text).

N°	Building	SVI	TVI	N°	Building	SVI	TVI
1	VISTAMAR	24,50	29,4	46	EL DORAL	38,50	50,4
2	ALDILÁ	55,50	60,2	47	COSTA AZUL	54,75	36,6
3	VIRREINA DEL MAR	58,75	48,2	48	BAHÍA CHIPIPE	40,00	34,8
4	PRINCESA DEL MAR	60,25	40,4	49	EL NAVEGANTE	32,50	53,4
5	REY DEL MAR	68,25	46,7	50	AQUARIUM	29,50	43,2
6	CASAMAGNA	26,25	30,9	51	CALIPSO	64,25	31,8
7	EL EXCLUSIVO	43,00	49,2	52	RIVIERA DEL MAR	35,00	40,8
8	SOLARIS	51,25	48,4	53	ATLANTIC	61,50	34,8
9	GALAXIE	47,50	52,8	54	LA PLAYA	85,75	40,8
10	SORRENTO	59,50	42,0	55	LA ENSENADA	31,00	48,0
11	ANCONA	31,75	46,2	56	EL VELERO AZUL	29,00	42,0
12	CASTELLAMARE	26,00	35,0	57	NEPTUNO	39,50	43,2
13	MANSIÓN DEL MAR	44,75	40,8	58	EL TIBURÓN	60,00	39,0
14	SAINT TROPEZ	49,75	40,4	59	CASA BLANCA	41,50	50,4
15	EL CAPITÁN	67,25	53,4	60	EL PLAZA	50,50	55,2
16	MEDITERRANE	43,50	36,0	61	PLAYASOL	29,50	48,0
17	CASTENUOVO	70,25	34,2	62	GIRALDA	46,50	43,2
18	TESORO DEL MAR	34,50	39,6	63	PLAYAMAR	64,50	47,4
19	REMOLINO	46,75	41,0	64	SOLANA	73,00	50,4
20	VISTA MARINA	70,50	36,8	65	COSTA BRAVA	59,50	45,0
21	AQUA SOL	26,50	34,8	66	CABO AZUL	29,50	45,0
22	EL PICUDO	62,50	49,2	67	CORAL DE CHIPIPE	40,50	40,2
23	ANACAPRI TORRE A	26,25	39,8	68	MARENOSTRUM	25,00	34,2
24	HOTEL COLÓN SALINAS	49,25	30,2	69	HOTEL SUITES SALINA	40,00	37,8
25	EL EMPERADOR	42,50	42,0	70	DUQUESA DEL MAR	27,00	42,6
26	MONTECARLO	29,50	40,8	71	ALBACORA	76,50	49,2
27	REMANSO	31,25	39,0	72	HOTEL BLUE BAY	39,00	44,9
28	CONDESA DEL MAR	71,50	47,4	73	ALAMAR	26,50	35,4
29	EL REFUGIO	36,50	48,6	74	GIRASOL	48,00	53,6
30	ACROPOLIS	36,50	40,2	75	HOTEL MALECÓN	33,50	41,8
31	SANTORINI	65,50	35,4	76	CORBETA	71,50	43,2
32	CORINTO	28,00	47,4	77	LAS PALMERAS	56,50	50,8
33	BAY POINT	22,75	32,4	78	LA GOLETA	69,50	46,2
34	PETROPOLIS	34,50	49,2	79	LAS CANARIAS	56,50	45,6
35	TERRAMAR	87,25	31,8	80	EL CONQUISTADOR	41,50	40,8
36	TORREMAR	56,50	49,2	81	BALBOA	67,00	43,2
37	PERLA DE MAR	57,00	50,4	82	MAR DE PLATA	86,50	43,2
38	PORTOFINO	27,75	40,8	83	KONA BAY	29,50	24,2
39	PERLAZUL	22,75	27,0	84	VENTURA	29,00	47,4
40	AQUAMIRA	29,50	36,6	85	PUNTA DE PACÍFICO	27,00	29,4
41	MÁLAGA	21,00	19,8	86	EL MIRADOR	70,50	43,2
42	IBIZA	27,00	38,4	87	EL ALMIRANTE	49,00	40,4
43	LA SIESTA	74,50	36,0	88	BARLOVENTO	80,25	48,6
44	TORRE BLANCA	43,50	43,2	89	COSTA BELLA	74,25	48,6
45	TORREMOLINOS	42,50	50,4	90	COMODORO	47,00	43,2

Some 64% and 85% of structures have a seismic and tsunami vulnerability index between 30 and 80 respectively. For this reason, these intermediate values do not allow the structures to be categorized as safe or vulnerable. Therefore, additional studies should be considered to help improve their classification and define their vulnerability range.

Of the 90 buildings evaluated, only 23 of them obtained a seismic vulnerability index of less than 30, which categorizes them as seismically resistant and safe structures. However, only 5 of the 23 have a vulnerability index to tsunami less than 30 (Vistamar, Perlazul, Málaga, Kona Bay and Punta Pacífico), which represents 5% of structures that can be considered as safe in the event of the two natural events and that can be used as temporary shelters for emergent vertical evacuation. Those buildings whose seismic vulnerability index is less than 30 but their vulnerability index against tsunami is higher, it was mainly due to the limitations found in the accesses and internal stairways that did not have an adequate capacity of users in case of vertical evacuations that require access to high places at optimal times.

In order to improve the category of those buildings whose vulnerability index to tsunami exceeded 30 points and after analyzing different alternatives with which, through its adaptation, a building improves its vertical evacuation capacity in the event of a tsunami, it must be defined that the most efficient proposal is the implementation of external emergency stairs. For this, an exterior staircase model needs to be designed for a nine-story building (Marenostrum). This proposal, being calculated, would result to a referential budget of some 27,884.33 USD, not including VAT. This budget is not fixed because, depending on the number of floors and dimensions calculated according to the building where it is going to be built, the costs will vary. Considering the relative magnitude of structural costs versus total construction costs in the design of buildings suitable for vertical evacuation in the event of tsunamis, a structure resistant to tsunamis, earthquakes and progressive collapse is expected to experience an increase in the order of 10% to 20% in total construction costs over those required for traditional buildings.

It is fundamental that the structures defined as safe places for vertical emergency evacuation are far from potential dangerous or hazardous places (gas tanks, gas stations, ports, among others) in order to avoid possible additional accidents that put the population at risk. In addition, structures suitable for vertical evacuation need to consider, for a reaction time of 30 minutes, to be located a maximum of 1.60 km from any given starting point, or 3.21 km between structures, so that an average healthy person traveling 1.8 m / s can arrive and be safe.

When designing and building a structure, both seismic and tsunami resistance parameters should be considered in order to serve as safe shelters for vertical evacuation in the future. Mainly improving the accesses and internal stairs by making them wider, thus avoiding crowds, accidents and optimizing the time and fluidity of movement of the personnel. It is recommended to use the buildings categorized as earthquake resistant tsunami for vertical evacuations because in Salinas there is little presence of high points to perform appropriate horizontal evacuations in case the arrival time of the tsunami does not allow the population to reach a safe site. In addition, it is recommended to accompany other studies, both the modified Italian methodology and the FEMA to complement them, such as an equivalent system of one degree of freedom as proposed national regulations in order to obtain more efficient categorizations. Since 96% of the buildings in Salinas are residential, whose entry is strictly allowed only for apartment owners, it is necessary to make agreements between the municipality and the building owners in order to allow the use of

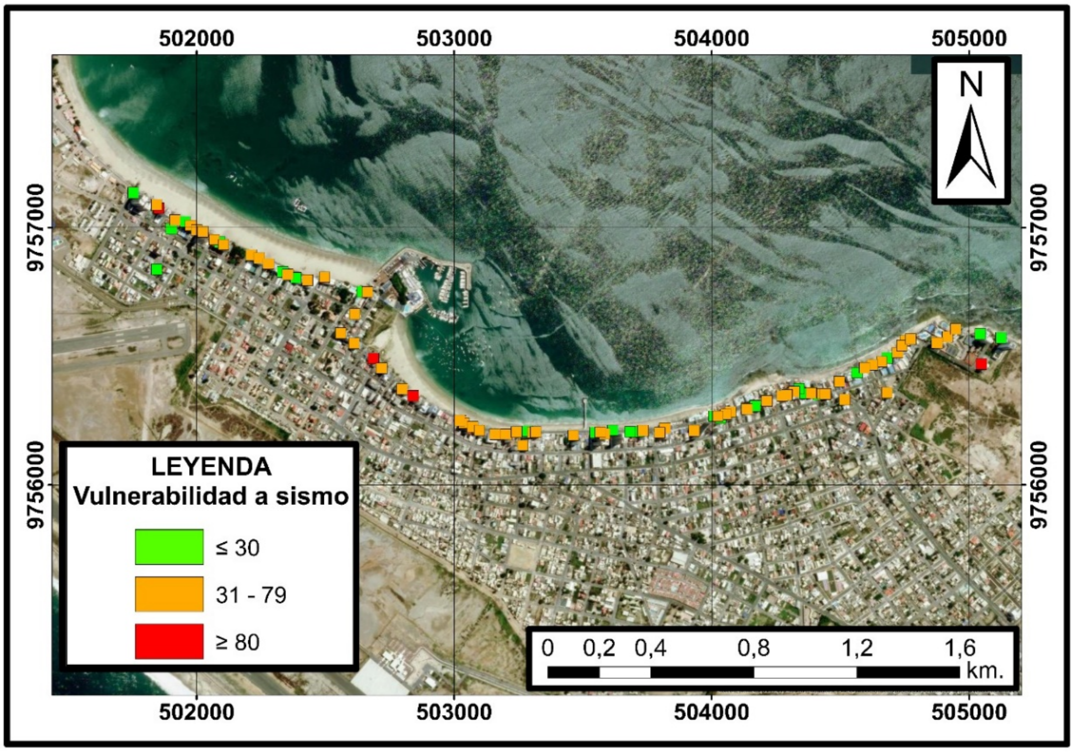

Fig 7. Map of the three categories assigned to seismic vulnerability of the 99 (90) evaluated buildings in the city of Salinas.

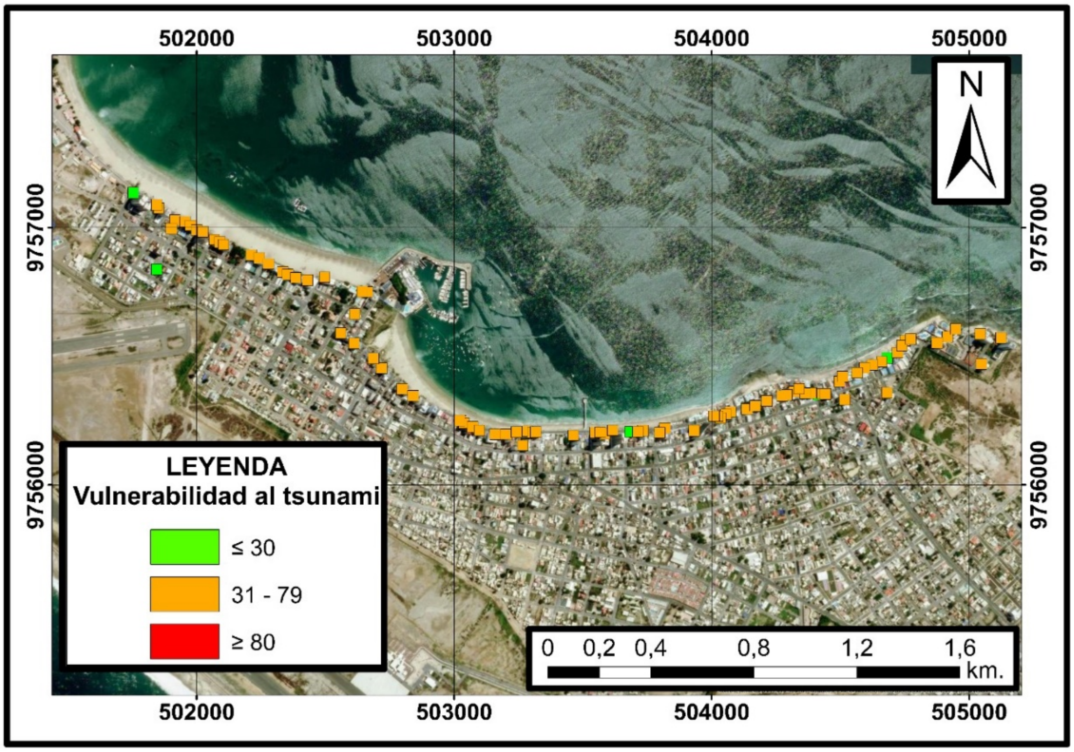

Fig 8. Map of the three categories assigned to tsunami vulnerability of the 99 (90) evaluated buildings in the city of Salinas.

promoting the sense of collaboration and empathy between human beings. For buildings that are already built and do not have these attributes, it is recommended to expand the entrances to the building and also the vertical circulation by adapting external stairs, as suggested before. In addition to the implementation of external emergency staircases, the possibility of defining a strategic space in the city to implement ad-hoc buildings, as has already been done in other countries, can be considered as a vertical evacuation alternative that, in addition to providing room for more people to protect themselves, they can provide other uses during non-emergency times such as, for example religious, sports, community, among others and thus, take full advantage of the benefits that this type of construction has. The design of emergency stairs for vertical evacuation is advisable to carry out with X-shaped diagonals on each floor, which with this implementation will help the structure to be more solid throughout its height and the displacement in the head of the same will not be so considerable.

4.2 Manta

In order to realize the current evaluation in Manta, 18 buildings were pre-selected, among which there are three that are for public use, three banks, four hotels, seven for residential use and one whose construction is suspended (Table 4). It is worth mentioning that one building was not worked on because there was not enough information for its evaluation. Before the 1998 earthquake whose epicenter was in the city of Bahia and which slightly affected some cities of Manabí, eight (44.44%) buildings were built. Another eight (44.44%) were built after this event and after the earthquake of April 16, 2016 (Mw 7.8) two buildings were built, which means that they are less than five years old. The total construction area of the 18 pre-selected buildings gives a total of 18757.18 m^2, and an average area of 1042.07 m^2. The El Dorado II building is the one with the largest construction area (3150 m^2), followed by the Poseidón Hotel (2252 m^2) and the Vigía (1800 m^2). It should be noted that a larger construction area presents a greater capacity in case of an evacuation (Fig. 9 and 10).

Table 4: Summary of seismic and tsunami vulnerability index (SVI & TVI) of 18 buildings in Salinas, while one additional recognized building was denied access (see text).

N°	Building	SVI	TVI	N°	Building	SVI	TVI
1	Corporación Nac, Electr.	28,00	35,0	**10**	Hotel el Navegante	56,25	38,4
2	Empresa Públ. Aguas Manta	84,25	88,5	**11**	Edif. el Dorado II	45,50	64,8
3	Edif. Sin Nombre 1	117,75	85,8	**12**	Edif. Ibiza	24,00	27,4
4	Edif. Sin Nombre 2	117,75	81,3	**13**	Edif. las Olas	36,25	52,5
5	Edif. Banco Pichincha	47,25	66,0	**14**	Edif. Oasis Marino (Abandon.)	113,00	66,0
6	Banco de Bank	29,00	29,8	**15**	Edif. Buzios	26,75	31,4
7	Edif. el Vigía	110,25	80,2	**16**	Edif. Manta Host	29,75	35,2
8	Museo Centro Cult. Manta	46,00	40,8	**17**	Hotel Poseidón	51,00	35,4
9	Balandra Hotel	41,25	43,6	**18**	N.D.		

Most of the buildings, a total of ten, have more than ten floors. While six have less than ten floors and only two have more than twenty floors. Six of the eighteen buildings do not have floors below the surface, the rest have a maximum value of seven basements, this being the case of the Hotel Manta Host. The maximum floor height is 4 m and the minimum 2.5 m, of the total of buildings only six have a floor height greater than or equal

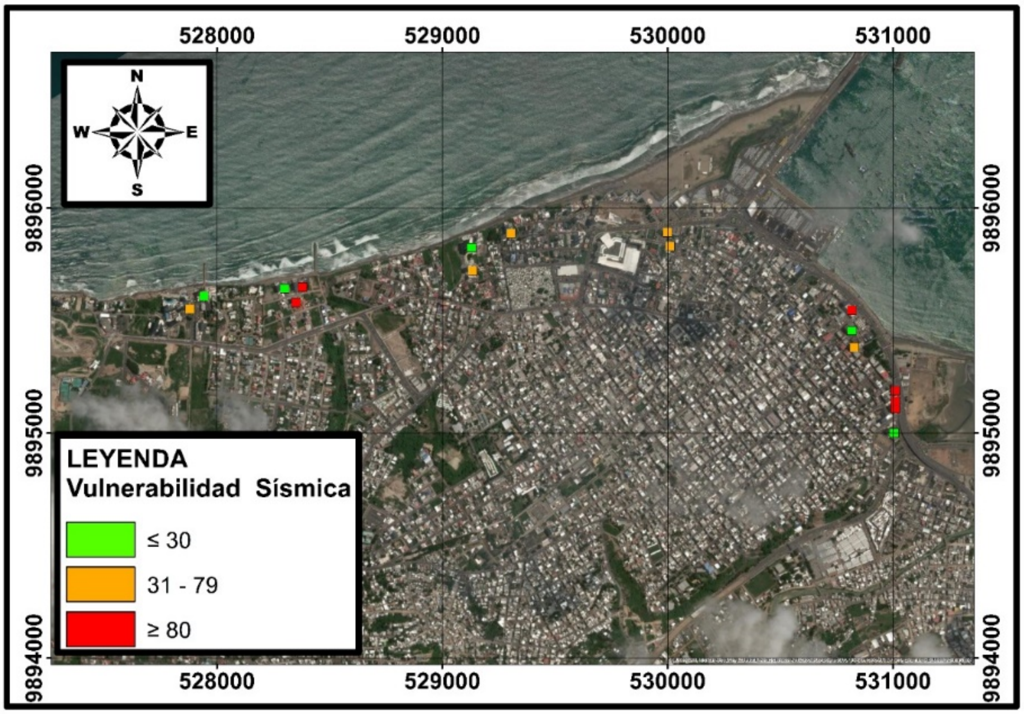

Fig 9. Map of the three categories assigned to seismic vulnerability of the 18 (17) evaluated buildings in the city of Manta.

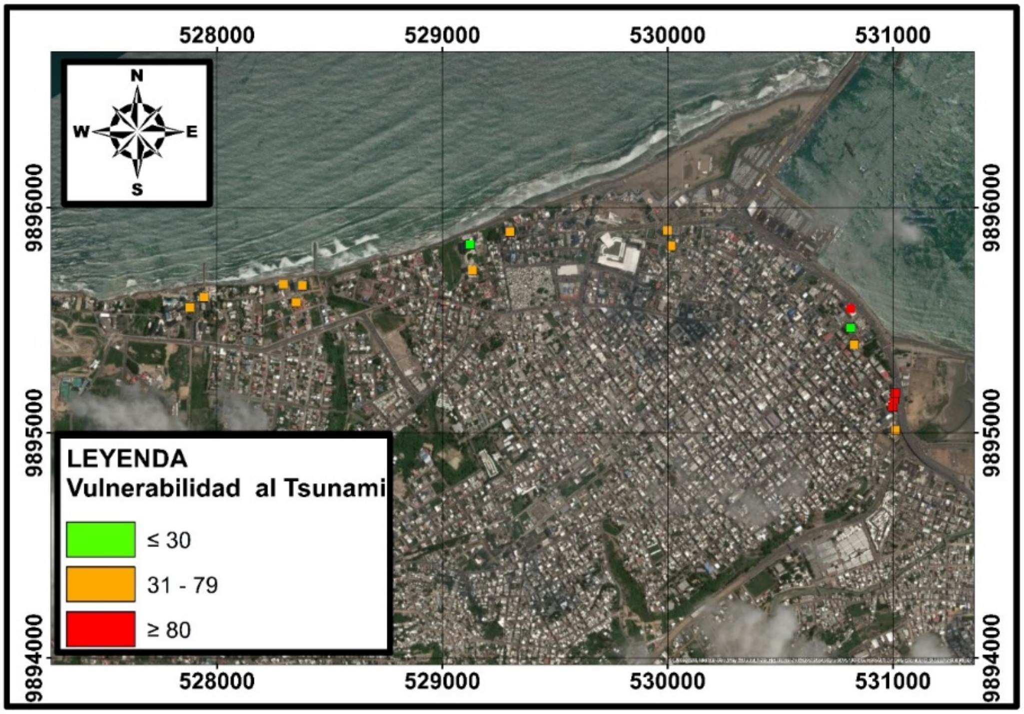

Fig 10. Map of the three categories assigned to tsunami vulnerability of the 18 (17) evaluated buildings in the city of Manta.

to 3 m, while the most frequent floor heights found during the inspection was 2.8 m. Seven of the eighteen buildings are on the beachfront, of the 17 buildings evaluated, one only is uninhabited and abandoned, one is in the process of being reinforced and two show obvious damage. Among the buildings analyzed, it was obtained as a result that five structures, which represent approximately 27.78%, have a seismic vulnerability index ≤30. While buildings with a vulnerability index ≥ 80 add five of them (27.78%), which means that they are highly vulnerable. In the same way, those structures that exhibit a seismic vulnerability index between 30 and 80 are a total of seven (38.88%), for this reason they may require an additional evaluation. The remaining 5.55% or one of eighteen buildings, corresponds to that building in which the required information was not obtained, either due to the lack of collaboration of the administrators or for their safety.

The minimum value of the seismic vulnerability index is 24 belonging to the Ibiza building. The highest values of the vulnerability index are obtained, as expected, by the two buildings that presented obvious damage due to the damage suffered previously and the abandoned building, as can be seen listed in Table 4. Due to the danger that these represent in future seismic events, both for adjacent buildings and for the population, a controlled demolition should be taken considered. Of the buildings evaluated, five (11.11%) have a vulnerability index lower than 30, six (61.11%) yield a vulnerability index to tsunamis between 30 and 80, therefore, they require additional studies in order to know what category could be assigned to them. Four (22.22%) have an index higher than eighty, which means that they are very vulnerable to a tsunami and there are three (5.56%), which did not access the necessary information for their respective evaluation.

Therefore, once the evaluation of the 18 pre-selected buildings is completed, only two (11.11%) buildings are classified as resistant to both hazards (earthquake and tsunami). The aforementioned buildings are Banco del Bank and Edificio Ibiza, among the attributes that helped these structures present a vulnerability index lower than 30, the following may be mentioned, they are rigid structures, they have a good state of conservation, they were repaired at the masonry or structural level and are taller than the maximum height the wave would reach. Of the safe buildings, its orientation is parallel to the most potential direction of the incoming tsunami wave from the Pacific coast, which makes it experience smaller hydrodynamic forces. One of these buildings is located on the first line of the beach; it is in a critical zone of the tsunami and has entrances wide enough to allow the access of several persons and thanks to the breadth of their construction area and number of floors they allow to shelter a large number of people.

On the other hand, there are three buildings that were categorized as earthquake resistant but have a tsunami vulnerability index between 30 and 36, this value was obtained mainly because there is an important limitation for vertical evacuation with regard to access to stairs and due to because it is located in front of a very busy road. An alternative to improve this problem is the implementation of improvements in the accesses of the stairs, in this way the vulnerability index to tsunamis would be reduced, turning it into a potential refuge for efficient vertical evacuation, considering the evolution of capacities and smart building technologies. It is vital to unequivocally define the responsibility for opening the vertical shelter and assign additional emergency support personnel (FEMA, 2019).

Physical adaptations are proposed to improve vertical circulation at the adequate shelter level of the structure, such as the installation of supplementary entrances, ramps or stairs, which should preferably be exterior, since they are easy to build and do not present obstructions that affect its visibility (FEMA, 2019). As an additional option, the municipality of the city of Manta should consider the design and construction of a public and accessible multipurpose tsunami-resistant building that is located in a central part of the critical zone and that is not located near the buildings that are considered safe, so that in this way people who cannot reach these buildings evacuate to this building. All proposed activities in the event of a potential incoming tsunami disaster are pending the implementation of an early warning system as proposed in a variety of studies (Toulkeridis et al., 2017; 2018; 2019).

5. CONCLUSIONS

Populations and the corresponding tourists of the cities of Manta and Salinas have only a limited time to reach an elevated, safe area in case of an impact of an incoming tsunami and those distances are too long or too far for the available. Therefore, for both sites we evaluated the possibility of vertical evacuations within existing buildings of more than four floors close to the shoreline

Based on the vulnerability evaluation of seismic and tsunami resistance of the 117 pre-selected buildings along the Pacific Ocean in Manta and Salinas, we may ascertain that several of the buildings could withstand a seismic event and most potentially an impact by a tsunami.

Most of the evaluated buildings have a limited if any capacity of receiving the escaping public in case of an incoming tsunami, as being almost all in private property, lack to allow other than residents to enter the buildings and perform a vertical evacuation. Many buildings could improve their tsunami performance if access is improved, ideally through external adaptations.

It is necessary to implement an early alert system for tsunamis and have an agreement between municipality and owners of the buildings, which will allow the escaping public and tourists to enter the buildings and stay safe in elevated floors during a tsunami crisis.

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