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EVALUATION OF THE PHYSICAL VULNERABILITY TO EARTHQUAKES AND THEIR ASSOCIATED PHENOMENA, NARIÑO COAST (COLOMBIA).

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Universidad del Valle OSSO

Observatorio Sismológico
del Suroccidente - OSSO
Universidad del Valle.

CON EL APOYO DE:

Corporación OSSO

Peralta, H. [1]; Arellano, J. [2]; Leusson, A. [2]; Quiñones, J. [2]; Camacho, R. [2]; Llanos, L. [1]; Mendoza, J. [1].

Supervision: Meyer, Hj. [1] ; Velásquez, A. [1].

INTRODUCTION.

The Pacific Coast between Ecuador and Colombia (-1 to +4 degrees in Latitude), has been the scenario of diverse disasters caused by earthquakes; best documented are those of January 31, 1906 and December 12, 1979, having magnitudes of Mm 8,4 and 8,1 (Okal, 1992). On both occasions, strong and lasting vibrations (more than 4 minutes in 1906), soil liquefaction and tsunami destroyed the settlements located on lower lands of floodable forests, of marine and alluvial origin, in the deltas of the Mira and Patía rivers. The 1979 earthquake produced regional earth subsidence along 275 km of the deltas, with amounts up to 1,6 m (Herd, et al, 1981). Three other earthquakes of smaller magnitudes, but stronger than M = 7,5, occurred in 1925, 1942 and 1958.

The evaluation was carried out as part of the Program for Prevention Strengthening and Earthquake Risk Mitigation in Tumaco and in Coastal Municipalities of the Nariño department. This program is lead and financed by the Colombian government through the Directorate General for the Disaster Management and Prevention, with financial support of the National Calamity Fund.

The phenomena considered are vibrations, soil liquefaction and the impact and flooding caused by tsunami waves.

The study aimed at identifying the vulnerability related to the most probable and severe phenomenon that can affect to the exposed elements: housing and urban systems (lifelines and essential buildings). The purpose is to strengthen mitigation plans and actions in the short, medium and long term, to serve as input for Contingency Plans, and to contribute to the adjustment of territorial and landuse planning.

1. STUDY AREA

Located in the NW of South America, in the SW corner of Colombia (Figure.1), the study area is civered with young soils, among which there is an exposed fringe of Tertiary rocks. Settlements are located on lower lands, sandbars of marine origin, tidal deposits (from normal tides of 3,5 m), mangrove swamp areas and alluvial deposits. The height over the sea level doesn't exceed 5 m and the annual rain exceeds 2800 mm on average.

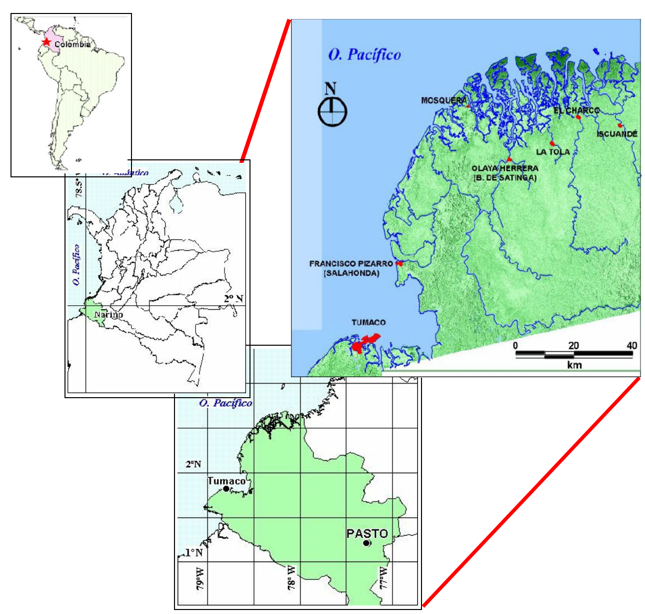


Figure 1. *General location.*

The project includes the urban area of Tumaco (Tumaco and El Morro islands and a continental portion), Salahonda, Mosquera, Bocas de Satinga, El Charco and 29 smaller towns, extending over about 210 lineal km on the coastline and lower islands of floodable forests. Because of a lack of cartography for the region under study, Intera radar (1992) and RadarSat (1997) images were used to produce the radar-map in Figure 2. This region is a fifth part of the Pacific Coast in Colombia. The population involved is a quarter of a million, of which about 160 000 live in Tumaco. Itumaco's population has more than doubled since the last earthquake and tsunami, in 1979 (DANE, 2003).

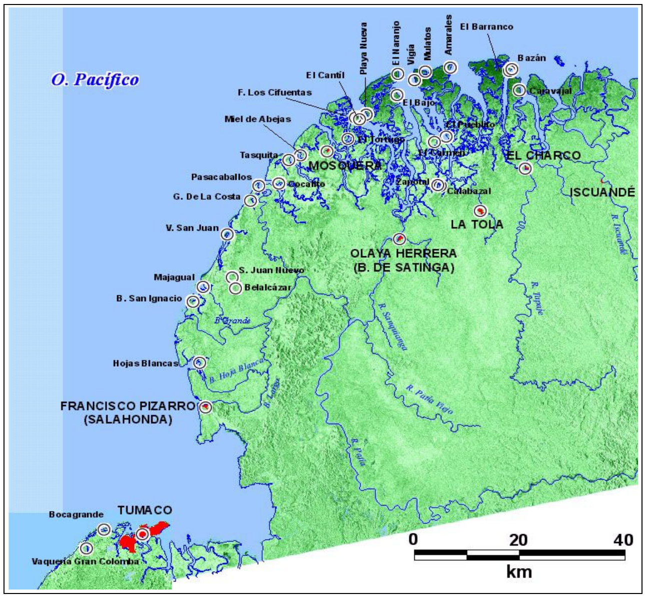


Figure 2. *Area under study.*

2. METHODOLOGY.

We worked with two approaches to evaluate the physical vulnerability in a qualitative way, with an intermediate level, that is to say, without evaluation of individual structures. The first one, a definition of exposure scenarios based on thematic cartography: maps of liquefaction potential (Infgeominas, DIMAR, OSSO, 2002) and floodability (DIMAR - CCCP, 2002), historical information (oral tradition, previous documents) and field observations. The second one was an evaluation of the resistance of the exposed elements to the threats of the considered phenomena, based on constructive and structural characteristics, age, conservation conditions, materials and their arrangement on the land.

Picture 1. *Aspects of exposure and resistance.*

Because of its quick and simple character, the methodology allows to identify the most vulnerable environments and components and to prioritize individual, collective, and institutional mitigation actions as well as official policies.

Tumaco was sectorized based on physical-natural and constructive traits (position with regard to the sea, floodability, land type, urban typologies and materials, height and foundation of housings). 34 sectors were identified: 17 on Tumaco island, eleven on El Morro island, and six on the mainland (Figure 3).

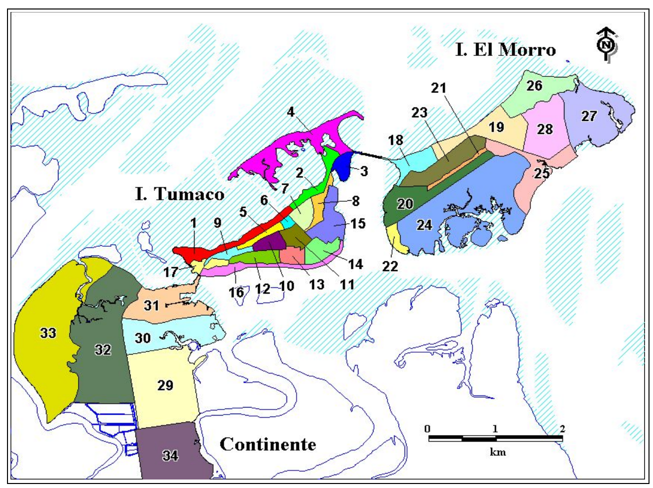


Figure 3. *Tumaco sectorization.*

The other populations were zoned based on physical - environmental and constructive typologies criteria, with field work and aerial inspections. Picture 2 illustrates the case of Mosquera.

Picture 2. *Sectorization of the Mosquera municipality.*

A regional zonification (preliminary) was made pondering the exposure to impact and the floods caused by tsunami, with cartography obtained from radar images, historical testimonies and physiographical and geomorphological criteria (Figure. 4).

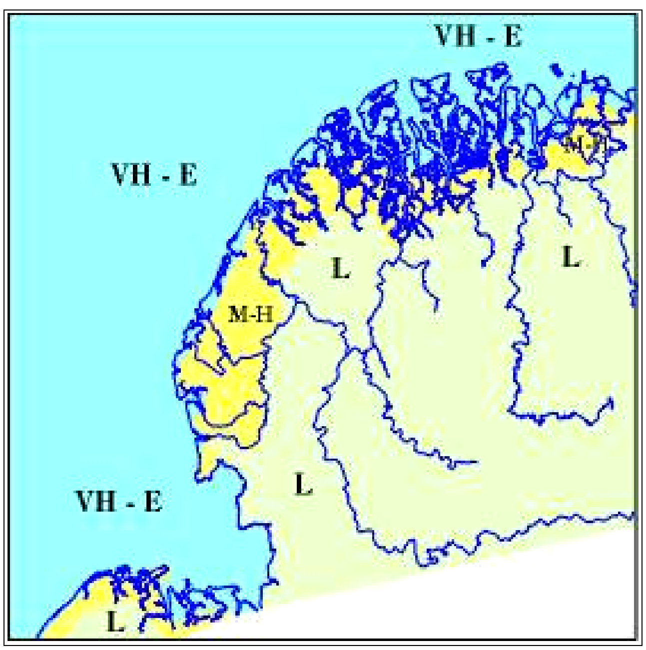


Figure 4. *Regional zonification for the exposure to impact and flooding caused by tsunami.*

The first area, Very High to Extreme exposure (VH-E), includes lands and seetlements located in front of the sea or in mouths of rivers with a kilometer or more in width, having (or not) natural protection barriers, in floodable forests fully influenced by tides.

The second area, Medium to High (M-H), includes lands that face the sea in less proportion, protected by islands and by the shape of estuaries and rivers, but still in areas of floodable forests.

The third area, Low exposure (L), includes coastal areas of estuaries and riversides of narrow rivers, placed over alluvial sediments with a heights of 4 m ASL. The tide still influences the shores.

3. RESULTS.

The regional value of effective peak ground acceleration on rock is 0,40 g, for an earthquake return period of 450 years (AIS, 1997). This value could be incremented in settlements located on geologically young lands.

Picture 3. *House of damaged wood.*

80% of the populations have a high to extreme degree of exposure to tsunami impact, because they are in front of the sea, without the protection of low seas lands (lower) or wave-obstructing forest, with no high places or any areas appropriate for evacuation. The remaining 20% has minor exposure, since these are far from the coast. However, their degree of exposure to seiches can be high.

Picture 4. *Direct exposure to the tsunami impact, in sector 1 of the Tumaco Island.*

Picture 5. *Direct exposure to tsunami impact, in the municipality of Tumaco, Villa San Juan.*

The hygienization and basic services systems (water, sewer system, waste, electricity and telecommunications) are already a "true disaster" in the mayority of the populations. This is because many of these never were in operation, or do not operate at the present; if in partial operation, they are very vulnerable physically and functionally.

The density of housings on the Tumaco island has increased significantly; in some sectors the number of housings made of rigid materials have been multiplied 6,6 times with regard to data of the year 1984 and the density of inhabitants went from less than 200 to near 400 per hectar. The destruction of housings in 1979 (aprox. 1080), was concentrated on sectors 1, 2, 9, 10, 11 and 16. This study estimates that similar vibrations today would destroy 4000 housings in the same sectors.

Among the essential buildings, the Fire Dept., the Hospital and the public schools stand out for their physical vulnerability .

The institutions and the community have poor levels of preparation for disasters, this is because they ignore the threats and vulnerabilities, they lack of appropriate planning and because the endowment are insufficient.

4. SOCIALIZATION.

The socialization of this project was carried out with public and private institutions, aid organizations, municipal authorities and communities. It included radio and local TV programs and workshops about the threats, land typologies, and mitigation considerations for the phenomena under study. Scaled models of typical housings on shake-tables were used for illustration, with and without reinforcement, mounted on glass boxes that were artificially induced to liquefaction with a wooden board on wheels.

Picture 6. *Didactic models with the purpose of showing the vibration of the ground (seismical table), liquefaction (sand boxes) and the housings turn over (miniature model).*

The results of this evaluation were synthesized on educational posters, being this channel the most recommended one by the communication specialists who study the cultural conditions of the region (oral tradition, low literacy levels).

5. VULNERABILITY SCENARIOS.

The earthquake of December 12 of 1979, though of smaller duration than the one of 1906, caused very strong vibrations, such that nobody could remain standing. For many coastal settlements, there is only very limited information on the seismic vibration effects, because the subsequent tsunami contributed to the overall losses to

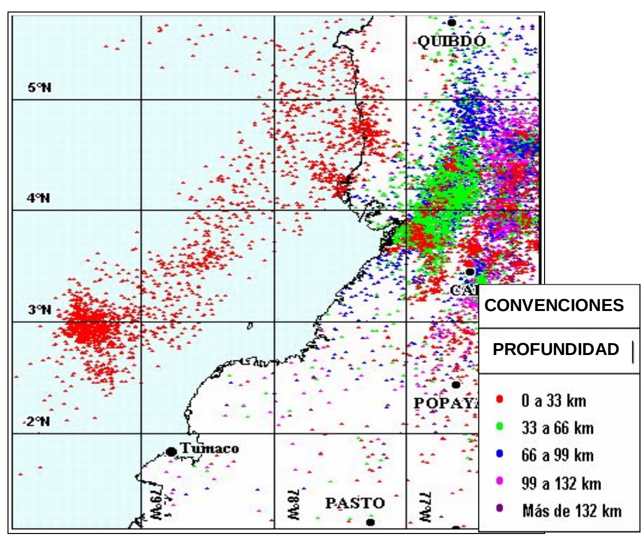


Figure 5. *Earthquake epicenters (OSSO, 2003).*

Picture 7. *Destruction of pile-supported housings, Tumaco 1979.*

The impact of the tsunami of 1906 led to the relocation of towns near the sea to an inland location, in estuaries protected by forest barriers or mangrove swamp; this in turn led to changes in the economic activity from "sea-based" to agricultural ones (Mosquera et al., 1999). These authors point out that "... those earlier settlers of the new establishments arisen during the XX century, seem to have forgotten and to reject the risks that forced their grandparents to abandon the beaches."

Picture 8. *San Juan de la Costa, swept away in 1906 and 1979 (1988).*

Based on the magnitude of historical earthquakes and tsunami (1906, 1979), three types of scenarios can represent the occurrences, depending on tide levels (low, middle or high).

The most pessimistic scenario is an extreme earthquake, such as that of 1906, but during high tide. The seismic shaking alone would cause enormous damage in the present built environment; these include damage to wooden structures due to unappropriate tying of the beams; liquefaction would affect extended low areas, beaches, barriers and urbanized landfills; tsunami waves would devastate most of the settlements, including Tumaco, even with their natural barriers (areas of low seas or " lower"). The seiches could strongly affect the inland riverside dwellings. Even though the return period of an earthquake of this size in the region is unknown (it could be several centuries), this scenario would be very difficult, almost impossible to manage.

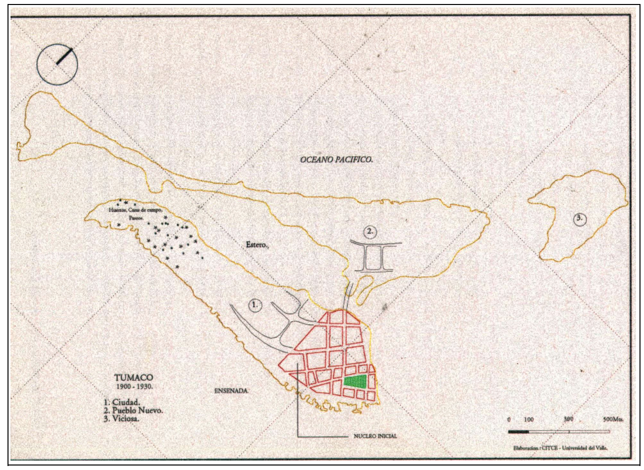


Figure 6. *Tumaco 1906-1930.*

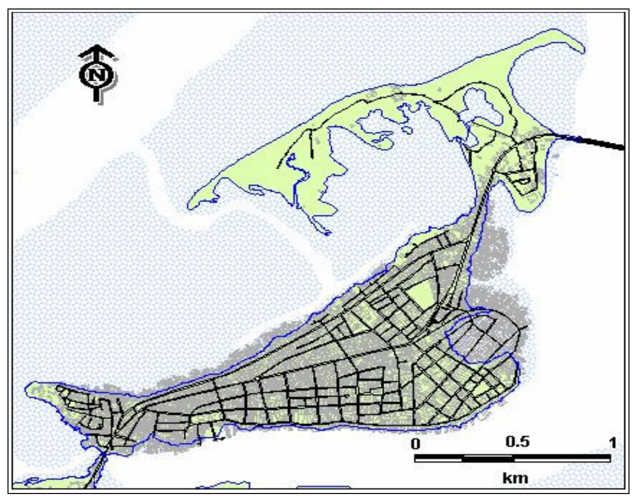


Figure 7. *Tumaco, 2002 (Source: CCCP, 2002).*

The most optimistic scenario is based on an earthquake of a smaller magnitude, around 7,5. It would cause damage in the present built environment with effects concentrated on landfill areas (most of which were built in Tumaco after 1958). This scenario includes liquefaction in tidal lands, beaches and river banks.

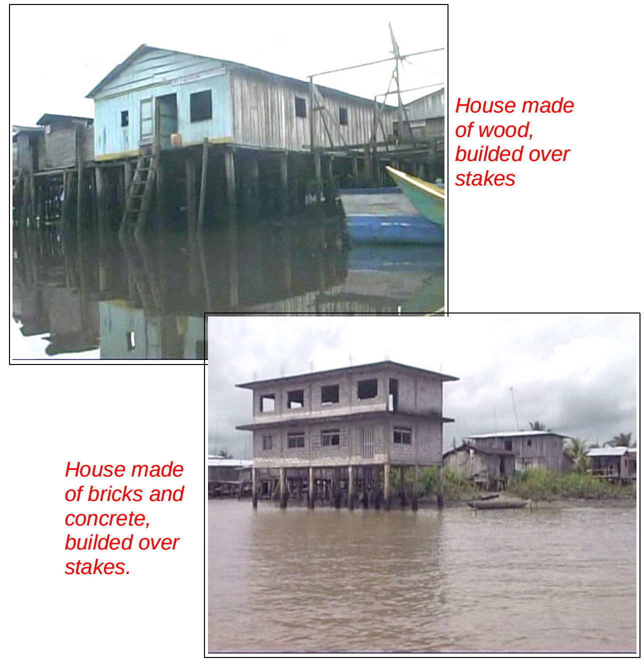
Picture 9. *Streets covered with garbage, in sectors of urban expansion in the mainland zone, 2003.*

Leading the recommendations of the National Program for Tsunami Prevention in the Pacific Coast, an intermediate scenario has been selected. It is induced by an earthquake such as that of 1979 during mid- tide conditions.

Picture 10. *Overpopulation of the Tumaco Island, 2003.*

This scenario can be synthesized in the following aspects:

Strong vibrations along the whole of Nariño prevent the inhabitants from staying on foot and reacting properly; the partial or total collapse of most of the housings made of brick and concrete; crackings in several of the essential buildings and the collapse of some of them, also for liquefaction; fall of powerline towers and poles, short-circuits, blackouts and fires; severe damage in the water supply system, many ruptures in the main water pipe and in the water intake. About 15 minutes later a tsunami wave appears in the north part of the Nariño coast battering on the beaches, islands and near populations, destroying many housings with its impact; half an hour after the earthquake, the waves arrive to Tumaco and in spite of loosing force and height colliding against barriers and protective lowlands, they cause damage and additional victims. The tsunami spreads through estuaries and rivers that inundate a great part of El Charco and the other populations.



Picture 11. *Change of flexible materials for rigid ones.*

This study leads to a conclusion that justifies great part of its focus and purpose: the causes of physical vulnerability are frequently so elementary (González,1991), that many times their mitigation is feasible without exorbitant resources and state intervention.

6. TOWARD FUTURE SCENARIOS WITH MITIGATION AND PREVENTION.

This project recommends the formulation of a program for risk mitigation on the Nariño Coast with the following strategies:

1. An educational strategy, informing the people of the natural threatening phenomena and the practical ways to handle the risks. Design and application of academic contents about the environment of the region and the management of risks.

2. Urban planning and land uses. Adjustments to plans of territorial planning, based on the risks, threats and vulnerabilities identified in the regíon.

3. The relocation of populations most exposed to tsunami. Identification of safer areas inside the region. Recovery of natural barriers, to soften the tsunami impact.

4. The reinforcement of housings. By providing incentives for the reinforcement of housings that are not exposed to tsunami. By upgrading and training the builders of the region.

5. The reinforcement of vital transportation routes. It has the purpose to reduce the structural and functional vulnerability of the higienization systems and basic services, road infrastructure and transportation., by means of programs for structural reinforcement, operation and maintenance.

6. The reinforcement of essential facilities. Structural and not structural intervention of constructions and structures indispensable for the community attention and of special occupation in the whole region.

7. Scientific and technical. Continuity and improvement of the tsunami inundationsmodel; Studies on the evaluation of multitemporal coast changes ; seismicity-tectonic model, stratigraphy (paleo-tsunami, paleo-seismicity), geodetic observations - interferometry for the regional level changes, evaluations of lands (to improve the zonifications carried out in the municipalities), among others.

The activities derived from this program are expected to dynamize the regional economy.

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Autors:

Peralta, H.[1]; Arellano, J.[2]; Leusson, A. [2]; Quiñones, J. [2] ;Camacho, R. [2]; Llanos, L [1]; Mendoza, J[1].

Supervision: Meyer, Hj. [1] ; Velásquez, A. [1]**.**

1. Universidad del Valle. Observatorio sismológico del Suroccidente - OSSO. A. Aéreo 25360; Tel. (92) 339 7222, 330 1661; Fax (92) 3313418, Cali-Colombia.

E-mail:
heperalt@osso.univalle.edu.co;
lfllanos@osso.univalle.edu.co;
jomendoz@osso.univalle.edu.co;
ave@osso.univalle.edu.co;
hjm@osso.univalle.edu.co

2. Grupo de apoyo técnico local, Tumaco. Centro comercial Miramar local 103.
E-mail: jorarellanog@hotmail.com;
johanamq@hotmail.com;
roccaic@hotmail.com.