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**THE ECONOMIC EVALUATION AND SIGNIFICANCE OF AN EARLY RELOCATION  
VERSUS COMPLETE DESTRUCTION BY A POTENTIAL TSUNAMI OF A COASTAL CITY IN  
ECUADOR**

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**ABSTRACT**

The coastal part of continental Ecuador is highly vulnerable for tsunami hazards as shown in the past two centuries. In order to avoid future devastating destructions in a given part in the coastline, we have estimated the economic effects of a potential future tsunami for one small Pacific town in Ecuador in order to analyze such potential cost of damages and compare it with a proposed resettlement value of the entire town. In past, most of the known resettlement projects have been realized as result of a natural disaster or a planning infrastructure such as hydro-electrical plants. Yet, in this study, we have considered to propose to policy makers and other authorities to take into account that a resettlement plan should be realized prior an impact by one the most deadly natural hazard. The results include four different scenarios of economic losses as a result of a potential tsunami, using human losses as the only variable that vary. Potential economic losses vary from 441 US\$ up to 620 US\$ millions, when compared to a potential resettlement and associated costs based on the four scenarios. The B/C ratio is favorable to town resettlement as Government's preventing policy favoring an intelligent reduction and prevention of vulnerability and loss of human life.

**Key words:** Tsunami, Economic loss, Resettlement, Prevention, Ecuador

## 1. INTRODUCTION

Among earthquakes and floods, tsunamis are one of the most destructive and deadliest natural hazards (Raschky, 2008; Daniell et al., 2010). In recent years many studies have been performed to demonstrate and evaluate the vulnerability of coastal cities, their entire strategic infrastructure and their habitants towards the impact of tsunamis and other associated natural occurring hazards of one or multiple origins (González-Riancho et al., 2015). Four prominent examples of the last dozen of years in Indonesia, Chile and Japan, demonstrate such issue. The 2004 tsunami with a magnitude of 9,3 struck in Indonesia and surrounding countries causing 350,000 deaths and 15 billion US\$ of immediately economic lost (Athukorala and Resosudarmo, 2005; Jayatilleke and Naranpanawa, 2007). The most prominent example may be the case of Japans 9,0 magnitude tsunami of 2011, where besides the 15,853 deaths, 6,023 injured and 3,282 missing people some 300,000 building were destroyed, while 4,000 roads, 78 bridges and 29 railways were severely affected (National Police Agency of Japan, 2015). The economic damage reached approximately 210 billion US\$ of which 66.9 billion were insured lost (Aon Benfield, 2015). Similarly, the 8.8 magnitude tsunami struck in Concepción, Chile in 2010, with a catastrophic effect throughout the country, with some 500 deceased and at least 1,5 million homes damaged of which one third were completely destroyed, leaving an economic loss of approximately 30 billion US\$, of which 8,5 billion insured lost (Barcená et al., 2010). Later in 2015, in the same country another 8,3 magnitude tsunami hit offshore of Coquimbo, with an estimated economic loss between 100 million US\$ up to 1 billion US\$ (USGS, 2015).

Based on the four demonstrated examples it is obvious, that the consequences of any tsunami impact certainly become an economic devastation for any region or city along the coasts worldwide. Therefore, better preventive educational activities and in some cases the construction of mitigation structures supported risk reduction or at least the acceptance of minor remaining risks (González-Riancho et al., 2015). Nonetheless, due to the enormous financial damage a community resettlement should be also considered as part of a plausible mitigation plan. Resettlement requires a careful and detailed planning (English and Brusberg, 2002). A resettlement process implies displacement of human population, where disturbance is calculated as it affects housing, employment, commerce and also ways of living (World Bank, 2004).

However, if damage costs are overwhelming higher than relocation of an entire town, than state or even local governments should consider resettlement as an alternative before certain future disasters take place. The main objective of our study therefore is, to present new data and calculations of how a major strike of a future tsunami may be prevented by a simple relocation of a small city in coastal Ecuador, which may be considered as a pioneer example to be followed.

## 2. GEODYNAMIC SETTING AND PROBABILITY OF TSUNAMIS

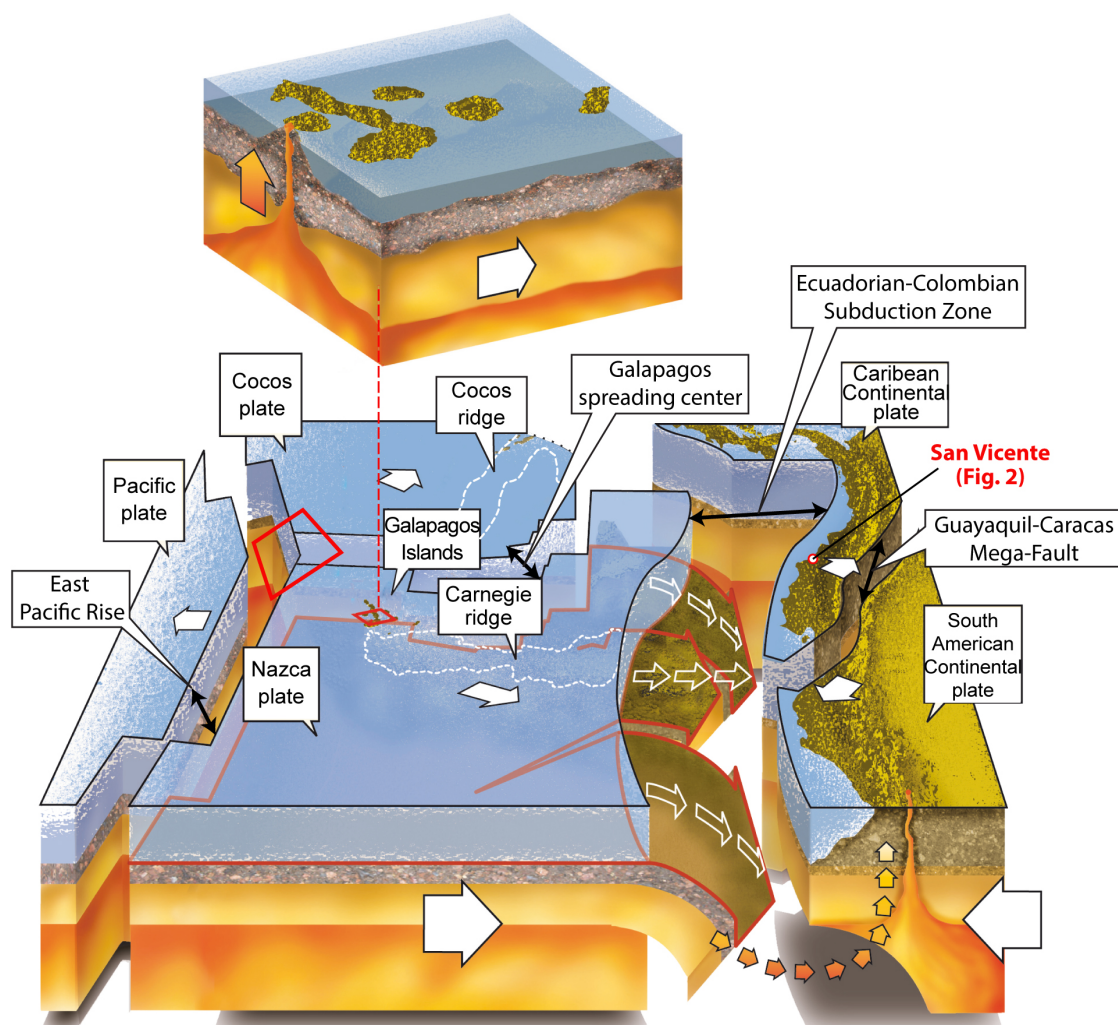
Due to its active geodynamics the Ecuadorian continental platform similar to almost all other countries along the Pacific Rim is a frequent target of tsunami impacts (Gusiakov, 2005; Pararas-Carayannis, 2012). The active continental margin and associated subduction zone between the oceanic Nazca Plate with the continental South American and Caribbean Plates, both separated by the Guayaquil-Caracas Mega Shear (Kellogg and Vega, 1995; Gutscher et al., 1999; Egbue and Kellogg, 2010) give rise to tsunamis of tectonic as well submarine landslide origin (Shepperd and

Moberly, 1981; Pontoise and Monfret, 2004; Ratzov et al, 2007; 2010; Ioualalen et al., 2011; Pararas-Carayannis, 2012). A further origin if tsunamis have been credited to the Galápagos volcanism (Toulkeridis, 2011). The active Galápagos hotspot has produced several voluminous shield-volcanoes, most of which are inactive due to the ESE-movement of the overlying Nazca oceanic plate (Holden and Dietz 1972; Toulkeridis, 2011). The main Galápagos Islands are located south of the E-W-trending Galápagos Spreading Center, east of the N-S-trending East Pacific Rise and some 1000 km west of the Ecuadorian mainland. Due to the volcanic activity and the subsequent plate drifting, two aseismic volcanic ridges were created. The first being the Cocos Ridge is moving to the NE while the second, being the Carnegie Ridge is moving to the East above the Cocos and Nazca Plates, respectively (Harpp et al., 2003). These submarine extinct volcanic ridges are the result of cooling/contraction reactions of magma, as they slowly sunk below the sea surface due to the lack of magma supply, lithospheric movement and strong erosional processes. With time, these submarine volcanic ridges as well as various microplates, have accreted on the South American continent (Reynaud et al., 1999; Harpp and White, 2001). Nonetheless, such aseismic ridges like the Carnegie Ridge become an obstacle in the oblique subduction process and may generate within the subduction zone a potential valve of tsunamis along the Ecuadorian coast (Pararas-Carayannis, 2012). The Carnegie Ridge collides towards the Ecuadorian continental margin with a velocity of as low as 5 cm per year at a latitude between 1°N and 2°S (Pilger, 1983). Further local tsunamis may be generated by seismotectonic extensional processes in some areas along the Ecuadorian coast like in the Gulf of Guayaquil besides other zones (Pararas-Carayannis, 2012).

From the known record, the Ecuadorian shoreline has witnessed a dozen times impacts of tsunamis by mainly local origins in the last two centuries with various intensities one being of up to 8.8 Mw in 1906 (Rudolph and Szirtes, 1911; Kelleher, 1972; Beck and Ruff, 1984; Kanamori and McNally, 1982; Swenson and Beck, 1996; Pararas-Carayannis, 2012), while evidences of paleo-tsunami deposits are scarce (Chunga and Toulkeridis, 2014). Other prominent examples of tsunamis along the Ecuador–Colombia subduction zone include tsunamis in 1942 (Mw=7.8), 1958 (Mw=7.7) and 1979 (Mw=8.2) within the 600-km long rupture area of the great 1906 event (Collot et al., 2004). While the 1906 event caused the death of up to 1500 persons in Ecuador and Colombia with an unknown financial damage to the existing infrastructure, the 1979 tsunami killed in Colombia at least 807 persons and destroyed approximately 10,000 homes, knocking out electric power and telephone lines (Pararas-Carayannis, 1980).

The evaluation of the last marine quakes, which generated tsunamis, suggests that the probability of a major or great earthquake in this margin region is enormous, especially as there must be substantial strain accumulation in this region (Pararas-Carayannis, 2012). Additionally, given into consideration that the last earthquake in 1979 did not release the amount of energy as the 1906 event, there is a high probability in the near future, that an earthquake within the Ecuadorian-Colombian trench may generate a tsunami of similar magnitude to that of 1906, which might be even more destructive than the one in the past if it occurs near high tide (Pararas-Carayannis, 2012). The potential of high losses and damage is given by the fact that the infrastructure of the fishing, tourism and other industries and the movement to live along the beaches, have been highly developed within the last decades along the Ecuadorian coasts. Based on historic know tsunamis in Ecuador of the last two centuries, the probability of a strike in 2015 is of about 87%.

The village of San Vicente in central Manabí Province is exclusively composed by quaternary sediments of the so-called Canoa formation (Bianucci et al., 1997) and is situated along the Ecuador–Colombia subduction zone, exactly east of the W-E striking Carnegie Ridge at a latitude of 0.35°S (Fig. 1). This region is being highly vulnerable to tsunamis, flooding, landslides and mud flows (Cruz D' Howitt et al., 2010).



**Figure 1:** Geodynamic setting of Ecuador, the Galapagos Islands and the Carnegie Ridge. Adapted from Toulkeridis, 2013

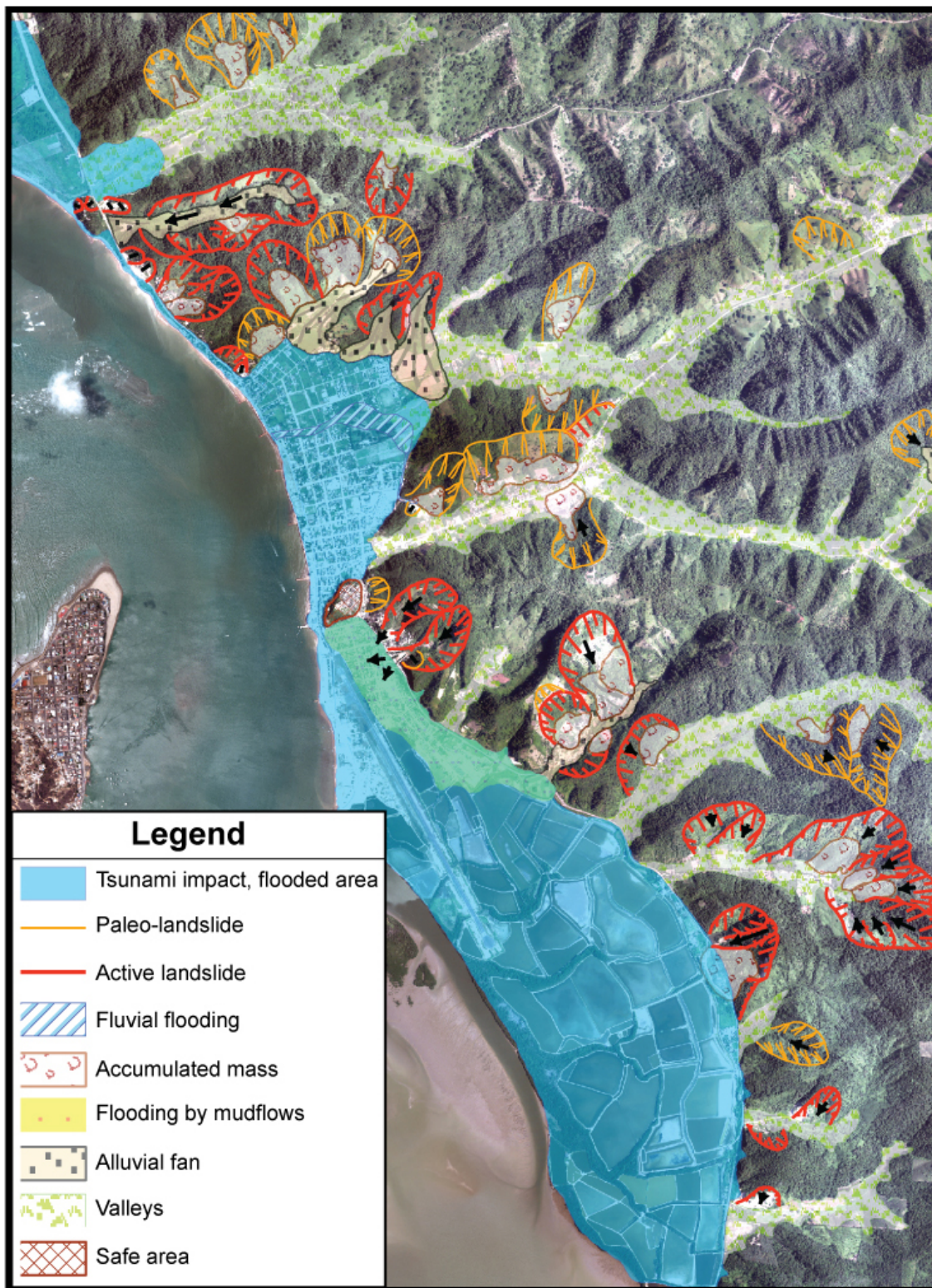
### 3. METHODOLOGY

#### 3.1 Mapping

The region around San Vicente, an area of approximate 33 km<sup>2</sup> (urban area), has been classically field-mapped and additionally interpreted by air photography evaluation. The resulting hazard maps are focused on tsunamis, landslides and mudflows as well as flooding by overflow of



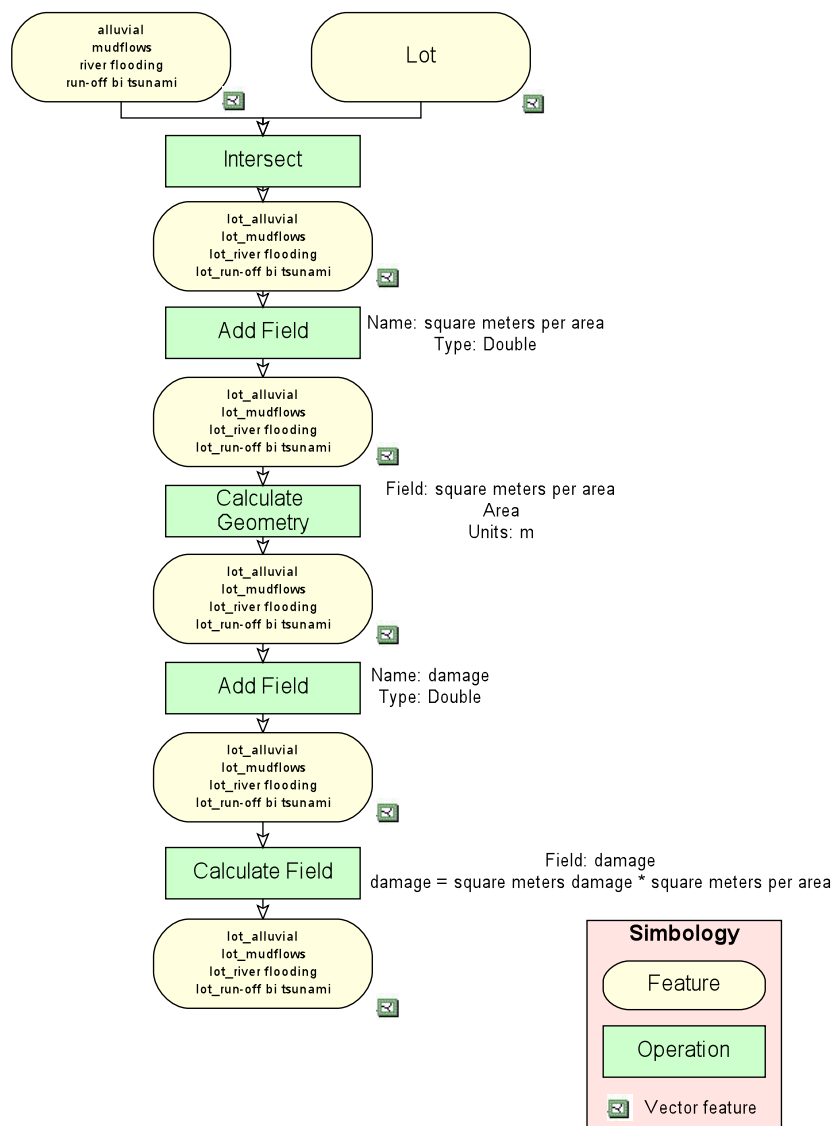
rivers and eventual high precipitation rates. All potential hazards besides the tsunami impact have been overlapped in a multi-hazard map (Fig. 2).



**Figure 2:** Multi-hazard map of San Vicente area

### 3.2 Calculating the cost of involvement for each hazard type

In order to know the specific value of each lot, the value has been calculated per square meter of each lot in accordance with its corresponding zoning. The value per square meter of each lot has been calculated pending and according to the area where it has been located. This value has been stored it in the field “damage\_square meter”. With this coverage and by using ArcGIS Spatial Analyst the Intersect operation was performed with the areas (shapes) of alluvial fans, mudflows, and river flooding and flooding by tsunamis. This allowed identifying the lots affected by each mentioned hazard. With each calculated cover, two additional fields were generated. First is the area (area\_square meter) and second is the damage (damage\_square meters per area). Damage was calculated by the cost of the damage multiplied with area involved or affected. This resulted to an addition of all values leading to the final sum of economic damage by all hazards. All steps are illustrated in Fig. 3.



**Figure 3:** Sketch of all operations leading to the calculation of the costs produced by the damage of a variety of hazards in the San Vicente area.

On the other hand, the theoretical framework that encompasses economic analysis of a potential tsunami in San Vicente is the cost benefit analysis (BCA) which is used to evaluate financial consequences of decision making and its main objective is to increase public welfare (Zerbe et al., 2010). Benefit-cost analysis has been used by the US Army Corps of Engineers early in the twentieth century to evaluate dam and canals projects (Zerbe et al., 2010). This infrastructure has been of fundamental importance because it requires significant allocations of Government's budget (Zerbe et al., 2010). Prior to the US Army Corps, the French Government developed this tool to analyze public investments (Hanly and Spash, 1993). Later, it was an economist named Vilfredo Pareto in 1930, who settled the standards for BCA in the economic field through his work on income distribution and economic efficiency published much earlier in 1896. Then, in 1939 Nicholas Kaldor revised the concept of efficiency to a broader approach so that the Pareto criterion could be satisfied (Kaldor, 1939). This newly approach allowed projects were economic gains exceed economic losses fits the Pareto criterion (Zerbe et al, 2010).

In this study, we used a benefit cost ratio to set a comparison between potential tsunami losses and San Vicente resettlement costs. According to Randall (1987), any project which a ratio  $B/C \geq 1.0$  is considered acceptable. The benefit cost ratio is expressed as follows:

$$\frac{B}{C} = \frac{\sum_{t=0}^T \frac{b_t}{(1+r)^t}}{\sum_{t=0}^T \frac{c_t}{(1+r)^t}} \quad (1)$$

where,  $b_t$  are benefits of the project over time,  $c_t$  are the cost over time,  $r$  is the discount rate, and  $t$  is the time period. In this study, benefits are denoted by bypassed cost of potential tsunami effects on San Vicente infrastructure, commerce, and human life through potential householders' income loss. Costs measure the resettlement cost of the entire community of San Vicente, which includes land acquisition costs.

We estimated benefits or avoided costs from the potential losses in land production which includes agricultural, livestock, fishing and aquaculture profit losses if a tsunami takes place, and it would take three years to have a full recovery from devastation, three years seems reasonable because recovering from tsunami effects it would require recuperate soil, acquiring new seeds and/or animals, planting, thinning and pruning, feeding animals, and wait to harvesting time. Additionally, fishing equipment such as boats, canoes and bongos potential losses were included and we counted as capital losses.

Tourism sector was also included in potential loses, ant it was estimated from annual profits from several tourism activities in the area such as traditional sea food sales, hotel reservations, handcrafts sales, and so on. This information was recovered from the Territorial Development Strategic Plan of San Vicente parish (GAD San Vicente, 2011; GAD Canoa, 2011). Infrastructure potential losses were measured from local and national investment on infrastructure such as a highway passing by San Vicente, San Vicente's jetty, and a recreational park (MTOP, 2012).

Housing and property losses were estimated by means of two practical approaches due to the lack of real cadastral information in the municipality of San Vicente. One approach was estimated through the established percentages contained in the urbanism code of Galicia, Spain (Código de Urbanismo de Galicia, 2015) that explains the proportional relation of land use areas and the minimum spaces considered for constructions in a sustainable space when organizing the land of a community. These spaces on and under the land surface are associated to residential, industrial, commercial, hotel, green and community areas, as well as basic public services and communications. The construction costs for urbanization in Granada, Spain (Colegio Oficial de Arquitectos de Granada, 2012) were considered to estimate the losses in US dollars. This first approach makes use of the measured areas calculated in the San Vicente's cartography, the estimation of constructed and non-constructed areas using visual analysis on orthophotos, the cost of the square meter of construction provided by a five type classification (Dávila, 2015) corrected using interpolated values from the analysis and evolution of the main components costs of construction (Alemán et al., 2012) prepared by the Escuela Superior Politécnica del Litoral (ESPOL) Ecuador using the formula:

$$Cf = 1/n \cdot cctn \cdot cce \quad (2)$$

where Cf is the correction factor for cost of construction (m<sup>2</sup>), cct is the cost of construction (m<sup>2</sup>) by type of construction, cce is the cost of construction (m<sup>2</sup>) provided by the ESPOL study and n is the number of lots. Finally, the cost of loss per lot was calculated by the following expression:

$$Ctl = cct \cdot a \cdot (pcl + ptl) \cdot Cf \quad (3)$$

where Ctl is the total cost of a lot, cct is the cost of construction (m<sup>2</sup>) by type of construction, a is the area of the lot, plc is the percentage of area constructed in a lot, ptl is the percentage of land area in a lot and Cf is the correction factor.

The second approach considers the variable population (INEC, 2010) of San Vicente due to the urbanism code of Galicia uses the number of residential buildings and population distribution to calculate the different percentages of the different land use areas as well as utilities, services and common places for a new urbanization. The number of housing units needed was calculated as a ratio of 4 people per family, each family with a department of 70 m<sup>2</sup> and two departments per building (residential area). The population is 31.904 inhabitants and the residential area 279.160 m<sup>2</sup>. Potential lost earnings as a result of a tsunami was measured based on the human capital approach to measure loss used in the United States instead of the willing to pay approach because we did not measure the value of life, which the latest approach is more appropriate (King and Smith, 1988). There are several conceptual models to estimate earning losses, but the human capital approach is the most widely used. In addition, we modified the model because we did not have the age when death occurred; neither had we differentiated between genders. We also did not consider not market losses, personal consumption offset, taxes (Government losses) and work life discounts. We simply took in account life expectancy (*E*), annual income (Income per capita for Ecuador (*Ii*), and the number of householder's death (*di*). Based on these information constraints, an equation to measure Potential Income lost (*Rp*) can be defined as follows:

$$Rp = i = 1/n \cdot E \cdot di \quad (4)$$



Annual income earnings  $I_i$  were discounted using the Banco Central of Ecuador borrowing rate, which is 0,0498, in addition we adjusted  $I_i$  to Ecuadorian inflation rate of 0,0353.

Resettlement cost included ( $RC$ ) two major components, land acquisition ( $L$ ) and housing, public services and infrastructure cost for a new community ( $C_n$ ). Land acquisition was very straightforward estimation, price of land at the area (average price paid in historical land transactions in the area) and land's area, which was estimated using SIG tools ( $L = p \times Q$ ). Resettlement cost of the new community ( $C_n$ ) was more difficult since we had to include values for each public services, housing for householder, public buildings, open spaces, schools, hospitals, communication networks, commercial buildings and, so on. There are no known information regarding towns' planning and development from Ecuador, therefore we used instead guidelines and regulations from Communities of Granada and Galicia (Spain) for urban land and use planning. This happened because these communities share similar vision of how to display the man-land relationship with towns in Ecuador. These guidelines and regulations relate people with building area and these with minimum required space that it should take in account to build a sustainable space. Resettlement cost can be defined as:

$$RC = i = 1nL, C_n \quad (5)$$

#### 4. RESULTS AND DISCUSSION

This study assumes that a tsunami would affect San Vicente town, having a probability of occurrence of 87 % being relatively high. Yet, if this natural hazard occurs it would have enormous effect not only in San Vicente, but in the country as well. We calculated and evaluated four different scenarios to estimate economic losses based on probable householders' death toll. In every scenario losses are significant as Table 1 indicates, the first scenario reaches almost 621 million US\$ and goes down to 441 million US\$ in the fourth scenario. Each scenario represents the avoided economic cost when compares to the resettlement cost. The analysis did not take in account several cost such as market losses, commerce, personal consumption offset, local such as property taxes and government taxes such as income, value-added tax, neither income increases throughout time, and work life discounts. Thus, these estimates could be much higher.

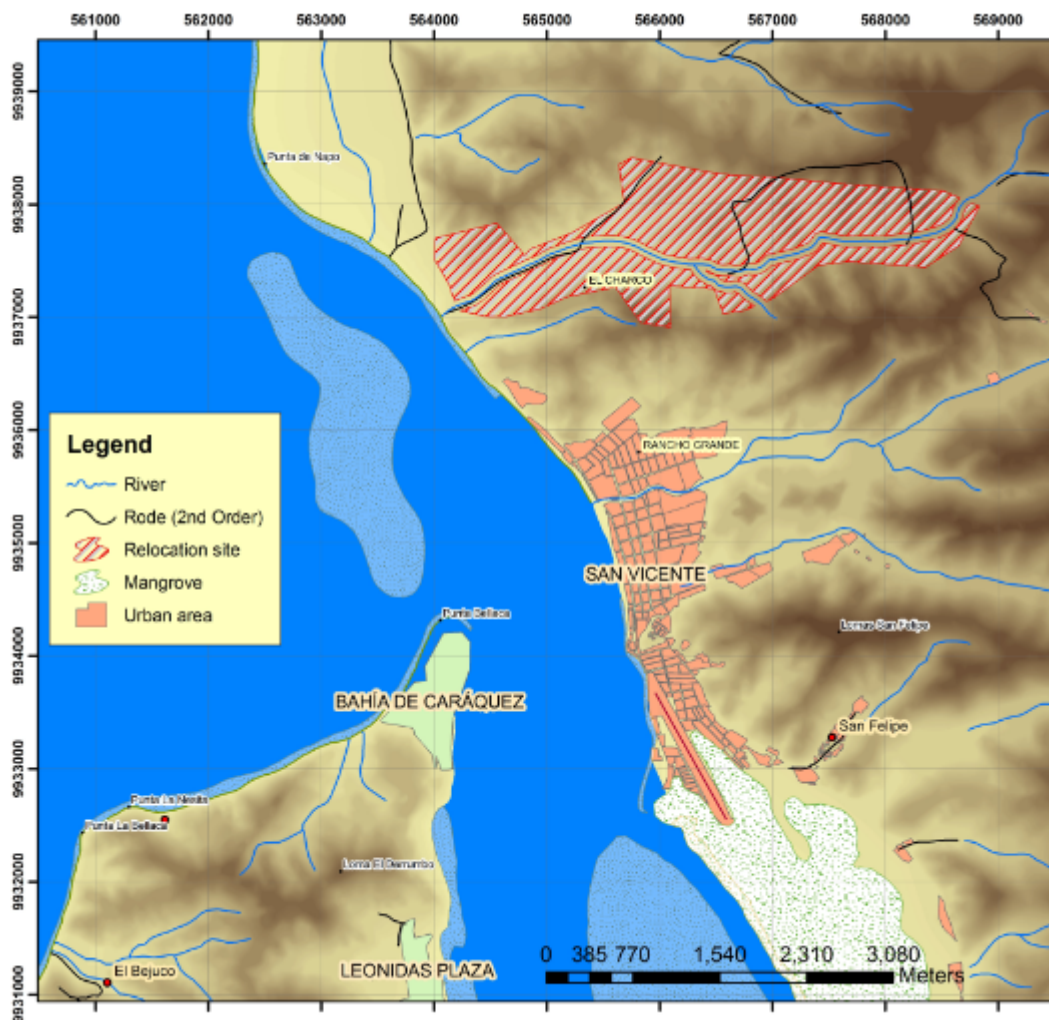
**Table 1:** Estimated economic losses if a tsunami hits the city of San Vicente, assuming 90% (Scenario 1), 80% (Scenario 2), 70% (scenario 3) and 50% (scenario 4) of death toll of San Vicente householders.

	SCENARIO 1 <sup>1</sup>	SCENARIO 2 <sup>2</sup>	SCENARIO 3 <sup>3</sup>	SCENARIO 4 <sup>4</sup>
EARNINGS LOSSES	275,988,937.54	245,323,500.03	214,658,062.53	96,117,845.44
LAND LOSSES	22,549,178.49	22,549,178.49	22,549,178.49	22,549,178.49
PROPERTY LOSSES	303,928,877.94	303,928,877.94	303,928,877.94	303,928,877.94
INFRASTRUCTURE	11,508,905.74	11,508,905.74	11,508,905.74	11,508,905.74
CAPITAL/EQUIPMENT	358,353.83	358,353.83	358,353.83	358,353.83
TOURISM LOSSES	6,631,176.42	6,631,176.42	6,631,176.42	6,631,176.42
<b>TOTAL 90%</b>	<b>620,965,429.96</b>	<b>590,299,992.46</b>	<b>559,634,554.95</b>	<b>441,094,337.87</b>

The analysis shows that earnings and property losses are the most important values for each scenario. Potential earnings and property losses combined reach an average of 512 million US\$ of all scenarios, which is 92% of the total cost. As it was expected, earning losses would reduce in each scenario and its participation in total lost declines due to it is the only variable which really changes. Earning losses in scenario 1 is 44% of total economic losses and it is only 22% in scenario 4.

Current analysis did not consider recovery and reconstruction cost. In this kind of natural disaster, experiences from other cities around the world can show that it would take several weeks to fill basic needs such as food and water up to several years such us infrastructure and business. Then, in a different phase of this study, these costs should be evaluated as well.

Regarding the resettlement cost, land acquisition reached 1,8 million US\$, this value is based on land extension area of 357,61 ha including 26,25 linear park which runs along zone riverside (Fig. 4) multiply by 5.170,17 US\$/ha which is the average price in local land transactions.



**Figure 4:** Relocation site to be built for “new” San Vicente

The resettlement cost for a new city (*C<sub>n</sub>*) reached 374,4 million US\$. This value includes residential cost, open and public spaces, recreational parks, school buildings, communication network, commercial buildings, social gears, hotel areas, industrial area, churches, hospitals, other social and public services, and open community spaces. The summary of the resettlement costs detailed in Table 2 and provide a total cost for reconstruction being approximately \$ 374'433,189.46 US\$.

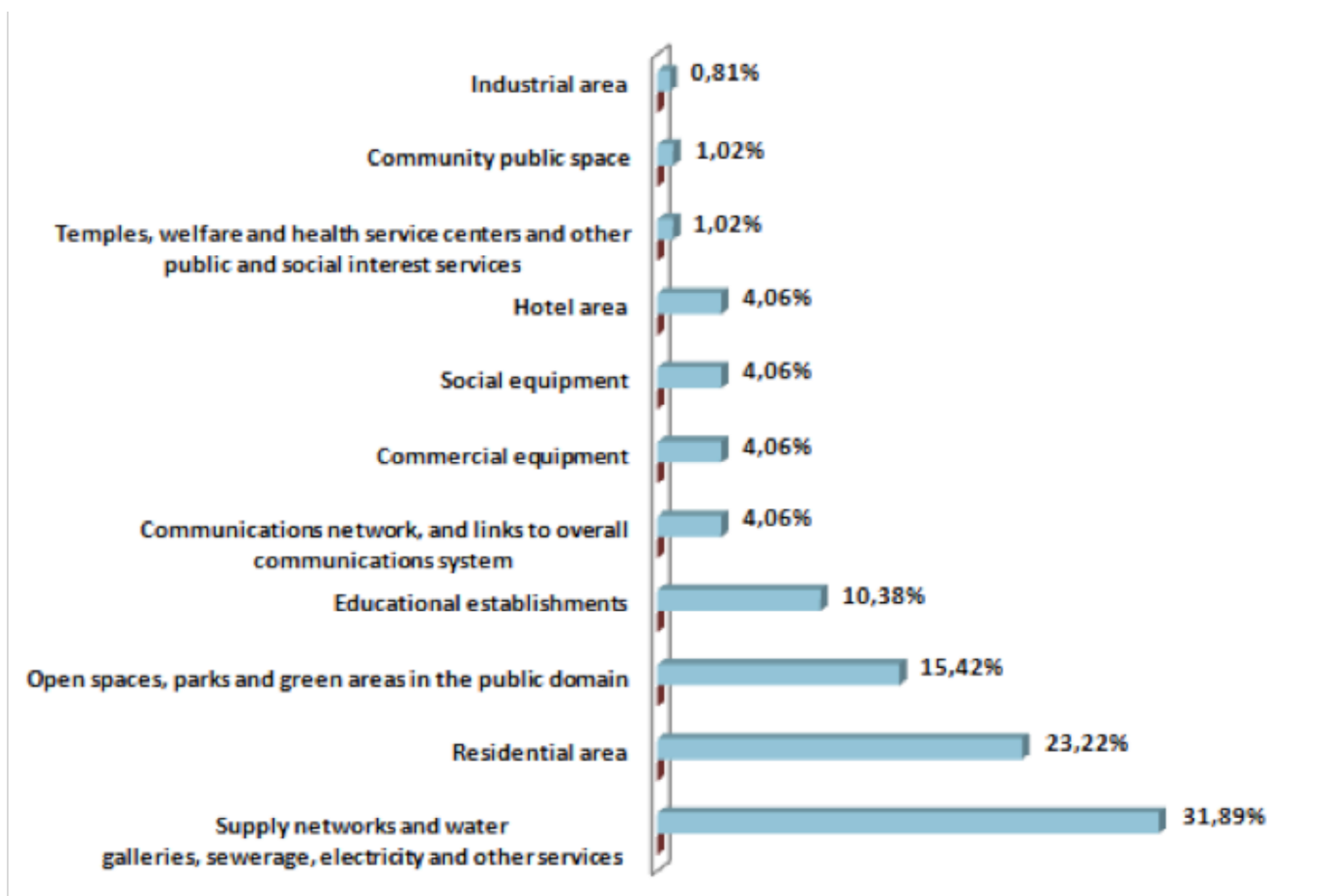
**Table 2:** Construction costs

Concept	Costs based on estimated areas
1 SUPPLY NETWORK AND BASIC SERVICES	119.417.676,79
2 RESIDENTIAL AREA	86.928.245,16
3 OPEN SPACES OF PARKS AND GREEN AREAS	57.723.614,60
4 EDUCATIONAL INFRASTRUCTURE	38.865.171,25
5 COMMUNICATIONS NETWORK	15.212.442,90
6 COMMERCIAL EQUIPMENT	15.212.442,90
7 SOCIAL EQUIPMENT	15.212.442,90
8 HOTEL AREA	15.212.442,90
9 INDUSTRIAL AREA	3.042.488,58
10 PUBLIC AND SOCIAL INTEREST SERVICES	3.803.110,73
11 COMMUNITY PUBLIC SPACE	3.803.110,73
Total cost of reconstruction	374.433.189,46

We selected this first approach to evaluate if e resettlement is feasible because it provides more detail in different costs involved town reconstruction. Yet, with the second approach, we had an increase of 5% in resettlement value.

The special distribution of new buildings and other areas as a percentage of the total area is presented in figure 5. Complete resettlement cost reaches 376.28 million US\$. Yet, as in the case of the avoided cost, resettlement is a process that takes several months, even years. We limited our analysis to building a new town with all facilities, however resettlement means not only constructing a new town, it also means contacting beneficiaries, discussing alternatives, socializing towards get consensus in the population. All these transaction cost should be considered and would rise the resettlement cost.

The estimate resettlement cost is compared to previously establish avoided cost in order to establish the avoided cost-resettlement cost ratio. The ratio indicates that if a project such as what we are proposing here is valuable in the economic sense. Therefore, the ratio implies that each scenario has a higher value than any resettlement cost (Table 3), meaning that in terms of human life, housing, and infrastructure and business relocation of San Vicente should be considered by authorities and policy makers.



**Figure 5:** Percentage and relation of areas to be built for a “new” San Vicente

**Table 3:** Avoided/Resettlement Cost Ratio

	AVOIDED COSTS, DIFFERENT SCENARIOS				RESETTLEMENT COSTS
	1	2	3	4	
ECONOMIC COSTS	620.965.430	590.299.992	559.634.555	441.094.338	376.282.083
RATIO B/C	1,65	1,57	1,49	1,17	1,00

## 5. CONCLUSION

Resettlement usually occurs after a disaster strikes, but in terms of human life, this should not be the case for the regular public policy. That results, that in this study for the town of San Vicente in western Manabi Province, we were able to present how using well-known evaluation tools such as BCA, SIG and other analysis tools can help policy makers to prevent future disastrous results by all means in order to accomplish an intelligent prevention and reduction of vulnerabilities and losses of life.

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