ISSN 8755-6839

SCIENCE OF TSUNAMI HAZARDS

Journal of Tsunami Society International

Volume 36 Number 4 2017

ECONOMIC EVALUATION OF RECOVERING NATURAL PROTECTION WITH CONCURRENT RELOCATION OF THE POPULATION THREATENED BY TSUMANI HAZARDS IN CENTRAL COASTAL ECUADOR

Fabián Rodríguez Espinosa[1,2]; Theofilos Toulkeridis[1]*, Rodolfo Salazar Martínez[1,3]; Jessica Cueva Girón[1], Adriana Taipe Quispe[1], Lucía Vernaza Quiñonez[4], Oswaldo Padilla Almeida[1], Fernando Mato[1], Mario Cruz D'Howitt[1], Humberto Parra[1], Washington Sandoval[1] and Willington Rentería[5]

*Corresponding author: ttoulkeridis@espe.edu.ec

[1]Universidad de las Fuerzas Armadas ESPE, Sangolquí, **ECUADOR**.
[2]Facultad de Economía, Pontificia Universidad Católica del Ecuador, Quito, **ECUADOR**.
[3]Laboratorio do Territorio, Universidad de Santiago de Compostela, Lugo, **ESPAÑA**.
[4]Pontificia Universidad Católica del Ecuador Sede Esmeraldas – PUCESE, Esmeraldas, **ECUADOR**.
[5]Instituto Oceanográfico de la Armada INOCAR, Guayaquil, **ECUADOR**.

ABSTRACT

Tsunamis are destructive forces which threaten life, social infrastructure and production, resulting in enormous economic losses. In the last two decades destructive tsunamis as those in Indonesia (2004), Japan (2011) and Chile (2010 and 2015), caused more than 366,353 deaths and economic losses over 355 billions US$. Our present study focuses on a theoretical case of economic and human losses that tsunami impact can have in Muisne, along the central Ecuadorian coast. Using a cost benefit analysis (BCA) framework, we estimate the cost of recovery of a mangrove ecosystem in Muisne, where earthquakes with magnitudes up to 8.8 Mw can generate tsunamis with run-ups up to 43 meters. Economic benefits of environmental goods and services from Muisne mangroves are estimated to reach 16.7 US$ million/year. To maintain local wellbeing and businesses in the region, it is estimated that the mangrove recovery costs may reach up to 7.3 million US$. In terms of preventing loss human loss of life and maintaining human wellbeing, we calculate the value of community relocation to be approximately 93.2 million US$. Therefore, the total economic benefits from a recovering the Muisne ecosystem would be around 109.9 million US$ and the benefit/cost ratio is B⁄C=1.16, meaning that the recovery of the Muisne mangroves has a higher value than resettlement costs, and that makes good public policy sense.

Keywords: *Tsunami strike, Resettlement, Mangrove ecosystem recovery, Benefit / cost ratio, Ecuador*

1. INTRODUCTION

There is a thin line in the evaluation of the economic implications of maintaining or leaving a disaster threatened area, of recovering a naturally protected area and of considering the costs of relocating people in more secure zones, while preserving their jobs, way of life and the needed commerce and business infrastructure. However, destructive tsunamis can cause high economic losses, which can impact enormously the infrastructure of a region and result in high losses of human lives. For example, the 2011 tsunami in Japanw generated from a 9.0 M_w earthquake, caused 15,853 deaths, injured 6,023 and of 3,282 people missing (Chen and Sato, 2013). According to Japan's National Policy Agency 300,000 building were destroyed, as well as 4,000 roads, 78 bridges, and 29 railways were affected. The economic damage reached 210 billion US$, of which some 66.9 billion were insured lost (Aon Benfield, 2015). One year earlier another tsunami from an 8.8 Mw earthquake in Concepcion Chile, resulted in catastrophic damages throughout the country. About 500 people lost their lives, at least 1,5 million homes were damaged, of which one third were completed destroyed. The economic cost of the disaster was estimated at 30 billion US$, with 8.5 insured lost (Barcená *et al*., 2010). A more recent 8.3 Mw tsunamigenic earthquake in 2015 near Coquimbo, Chile, resulted in an estimated loss ranging between 100 million US$ and up to 1 billion US$(CEDIM, 2015; Aránquiz et al., 2016; Ye et al., 2016). On Christmas 2004, a devastating tsunami struck Indonesia and Thailand causing 350,000 deaths and an estimated 15 billion US$ of immediate economic losses (Athukorala & Resosudarmo, 2005; Jayatilleke and Naranpanawa, 2007).

Due to enormous financial damages the recovery of natural defense habitats and community resettlement should be considered as part of any mitigation plan. Resettling the population requires of a very considered, careful and detailed planning, as the International Finance Corporation (IFC) pointed out in their resettlement handbook published in 2002 (English and Brusberg, 2002). A resettlement process implies displacement of human population which may cause disturbance as well, as it affects housing, employment, commerce and often the way of life. However, if the damage costs are overwhelming higher, governments should consider resettlement as an alternative before a disaster strikes.

On the other hand, natural habitats such as mangroves play an important role of reducing the impact of a tsunami (Mazda et al., 2006; Tanaka et al., 2007; Chatenoux and Peduzzi, 2007; Tanaka, 2009; Osti et al., 2009). A report from the Environmental Justice Foundation points out the overall importance of mangroves as natural barriers against typhoons, cyclones, hurricanes, and tsunamis (EJF, 2006). Mangroves help minimize the loss of human life and damage to property by reducing the heights and speed of tsunami waves, as well as redistributing the incoming water flow throughout channels and creeks (EJF, 2006). Therefore, governments as well as regional or even local authorities should consider mangroves in recovering or reforestation costs as part of a useful disaster mitigation investment.

Ecuador has been in past particularly vulnerable to a variety of natural hazards (Charvériat, 2000; Guha-Sapir et al., 2004; Cavallo and Noy, 2009; Toulkeridis, 2011; 2013; Toulkeridis and Zach, 2016; Mato and Toulkeridis, 2017). Ecuador´s extensive coastlines are vulnerable to tsunamis and earthquakes because of the region's geodynamic location on the continental shelf and the proximity to the Ecuadorian trench, where the Nazca oceanic plate subducts below the Caribbean and South American continental plates (Kellogg and Vega, 1995; Gutscher et al., 1999; Gusiakov, 2005; Egbue and Kellog, 2010; Pararas-Carayannis, 2012). At least six notable tsunamis occurred in the Ecuadorian coasts. A magnitude 8.8 M_w earthquake and destructive tsunami in 1906 struck the Esmeraldas Province, causing up to 1,500 deaths and the destruction of 450 houses (Kanamori and McNally, 1982; USGS, 2016; Chunga et al., 2017). In this context, a recent study demonstrated a small coastal village named San Vicente to be highly vulnerable to tsunamis, flooding, landslides and mud flows. Due to the village's vulnerability, it was documented that recovery of the habitat with mangroves and resettlement may be relatively cheap and efficient mitigation investment to draw up for public policy attention (Cruz D' Howitt et al., 2010; Rodriguez et al., 2016).

2. TSUNAMI HAZARDS IN THE AREA OF MUISNE AND SURROUNDING

Tsunamis can an enormous impact on coastal areas. Abe et al. (2012) determined that Japan's 2011 tsunami inundation reached a maximum of 4 km inland, but based on measurements of debris deposits it was determined that 90 percent of the inland inundations reached less than 2.5 km. Once the transects for the determination of inundation were settled, they added the topography (elevation) features using RTK GPS instruments. This allowed for a more accurated determination of the extent of tsunami deposits and inundation distance in the field (Abe et al., 2012).

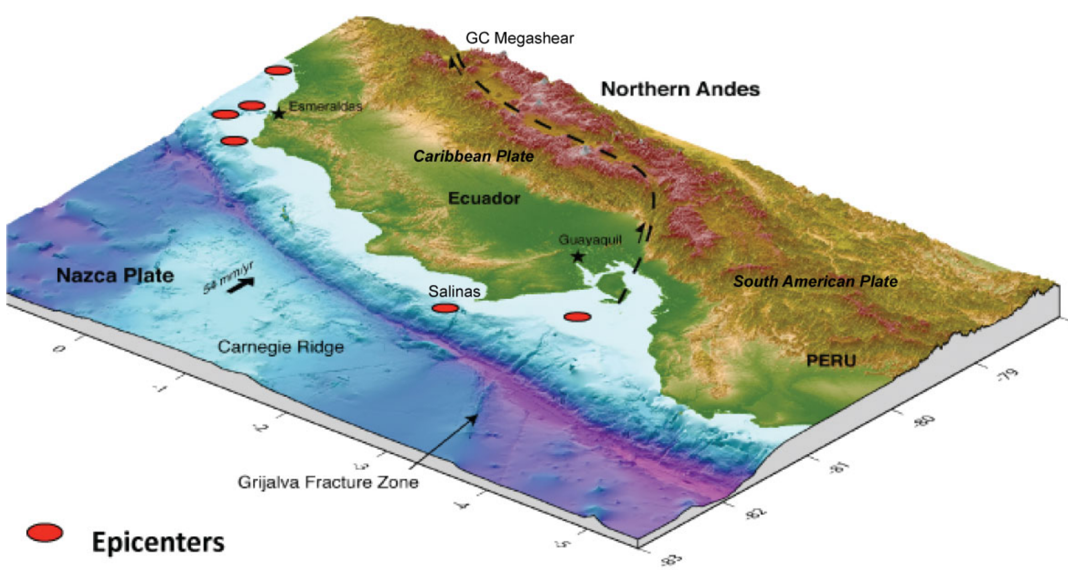

Fig. 1: Panoramic view of the morphology of western Ecuador and location of seismic epicenters, which generated tsunamis in the last 110 years. (Adapted and modified from Collot et al., 2004).

The specific geodynamics and the geological setting of Muisne and its surrounding have been analyzed and presented in Toulkeridis et al. (2017a; Fig. 1). The area of Muisne is threatened by a variety of tsunami scenarios (Fig. 1, 2, 3), all of which would affect severely this part of the Ecuadorian coastline. Extremely destructive tsunamis may be generated by earthquakes with magnitudes of up to 8.8 M_w and wave run-ups may have runups of up to 43 meters (Toulkeridis et al., 2017a). These parameters have been based on the modeling of tsunamis along the coast taking into consideration past tsunamis of local origins during the last two centuries (Rudolph and Szirtes, 1911; Kelleher, 1972; Beck and Ruff, 1984; Kanamori and McNally, 1982; Swenson and Beck, 1996; Pararas-Carayannis, 2012; Toulkeridis et al., 2017b; 2017c; Rodriguez et al., 2016), while evidences of paleo-tsunami deposits are scarce (Chunga and Toulkeridis, 2014; Chunga et al., 2017).

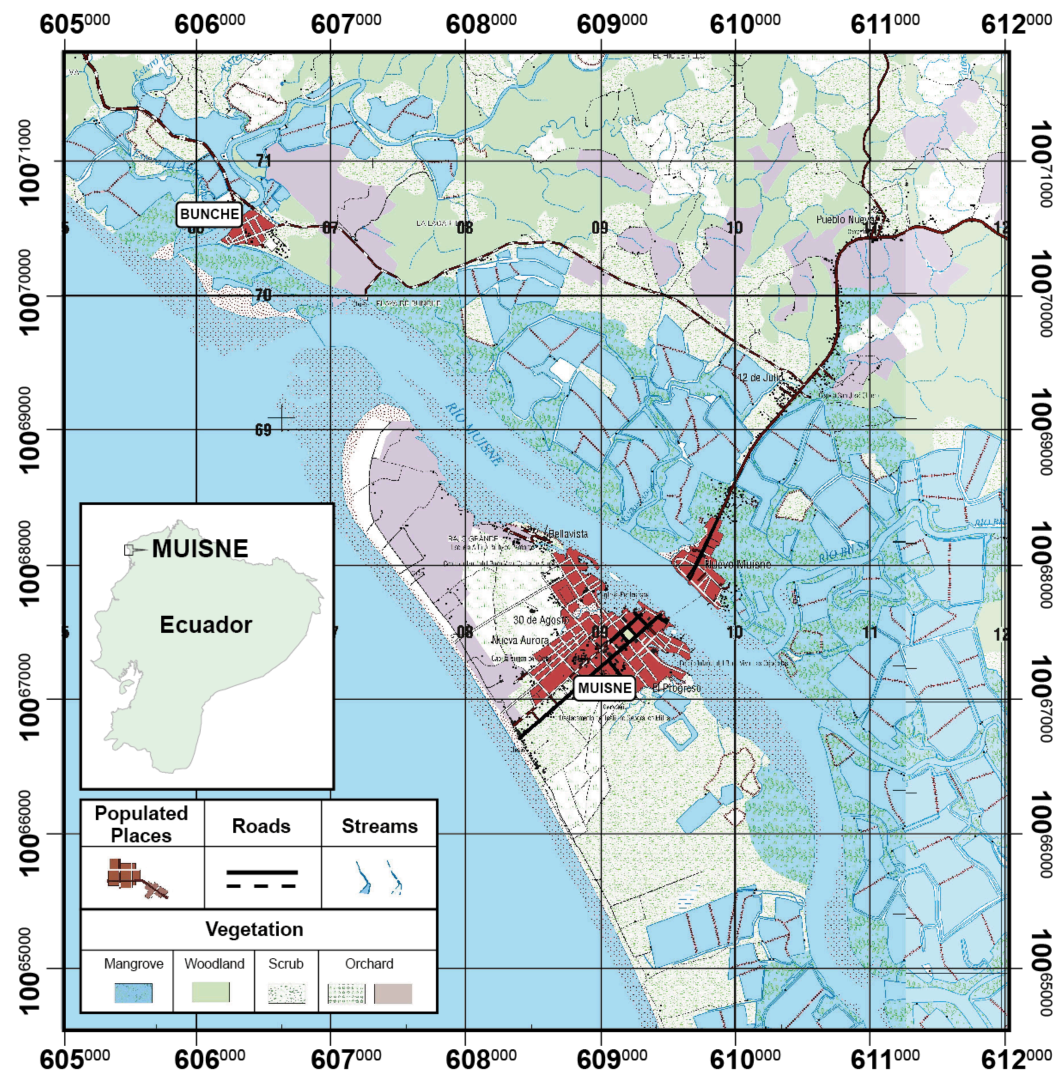

Fig. 2: Location of Muisne and Bunche within Ecuador and topographic area of the mentioned sites

The most prominent examples of tsunamis along the Ecuador–Colombia subduction zone include those generated from earthquakes in 1906 (M_w=8.8), in 1942 (M_w=7.8), in 1958 (M_w=7.7), in 1979 (M_w=8.2) and in 2016 (M_w=7.8) within the 600-km long rupture area of the great 1906 event (Collot et al., 2004; Toulkeridis et al., 2017b; 2017c). While the 1906 event caused the death of up to 1500 persons in Ecuador and Colombia, the 1979 tsunami killed in Colombia at least 807 persons (Pararas-Carayannis, 1980).

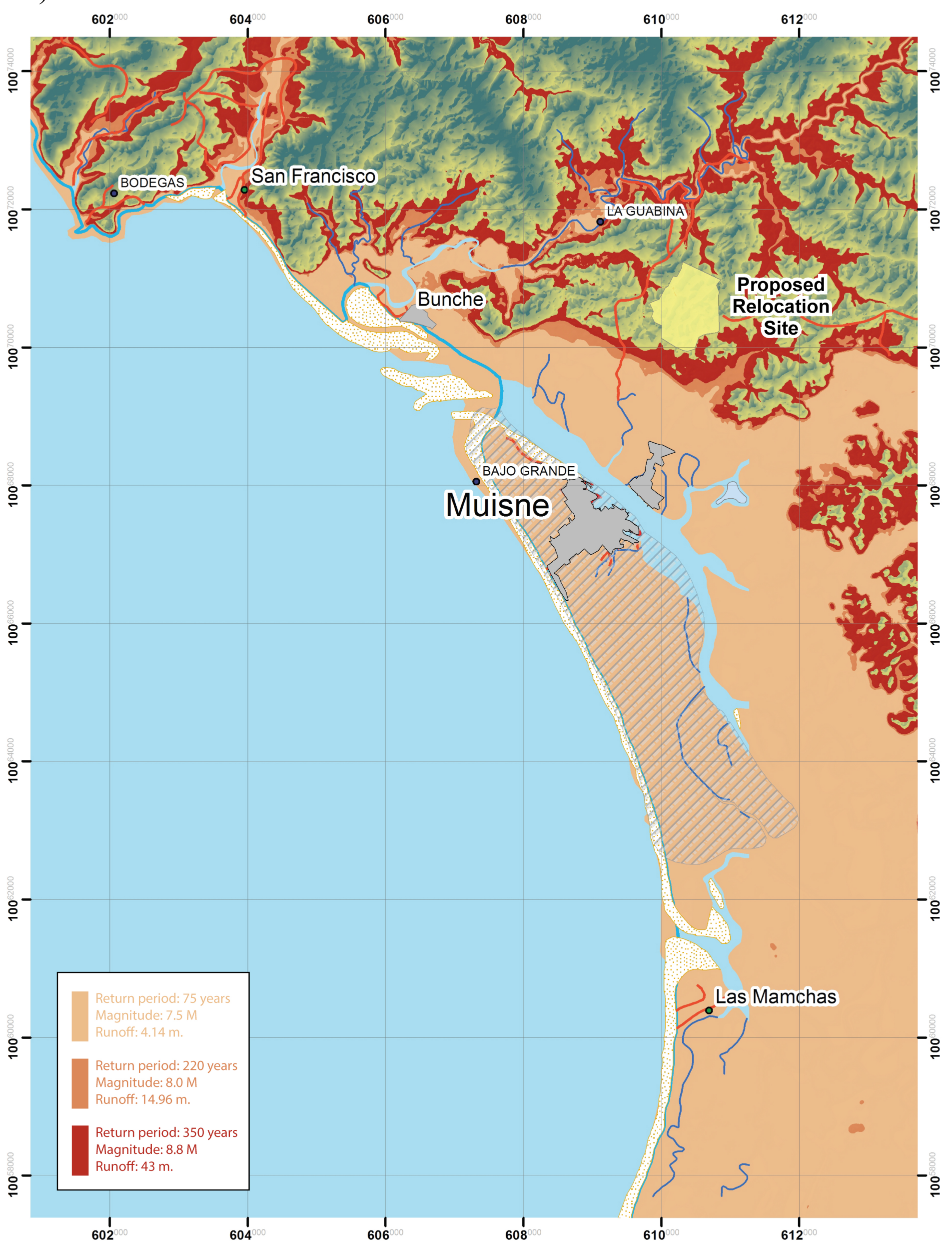

Fig. 3: Tsunami hazard modeling of three different scenarios, based on Toulkeridis et al. (2017). Location of Muisne, Bunche and proposed relocation site (in yellow).

3. COSTS OF HABITAT RECOVERY AND COMMUNITY RELOCATION

The economic analyses for mangroves habitat recovering and community resettlement has been based on a cost benefit analysis (BCA) framework. BCA framework is perfectly suited to analyze public investment, which is the essential in our analysis (Zerbe et al., 2010; Hanly and Spash, 1993). We have used a benefit cost ratio to set up a comparison between potential economic damages due to the impact of a tsunami, habitat recovering and community resettlement costs in Muisne. The benefit cost ratio has been expressed as follows:

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

Where, bt are benefits of the project over time, ct are the costs 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 economic damages on the infrastructure of Muisne only. We did not take into account other potential economic damages on commerce, fisheries, agriculture, livestock production as well as human life through potential householders' income loss as Rodriguez *et. al* (2016) pointed out in their study on potential effects of a tsunami in another coastal town in Ecuador. The resettlement costs of the entire community of Muisne, includes land acquisition cost.

Resettlement costs (RC) have two major components, land acquisition (L) and housing, public services and infrastructure costs for a new community (Cn). Land acquisition has been a relatively straightforward estimation, price of land at the area (average price paid in historical land transactions in the area) and land's area, which has been estimated using SIG tools ($L=p\times Q$). Resettlement costs of a new community (Cn) has been 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 among others. There has been a lack of information regarding towns' planning and development from Ecuador; instead we have used guidelines and regulations from Communities of Granada and Galicia (Spain) for urban land and use planning. We have used such information as these communities share a similar vision of how to display the man-land relationship with towns in Ecuador. These guidelines and regulations relate people with building areas and these with the minimum required space that it should take into account to build a sustainable space. Resettlement costs have been defined as:

$$Rs=i=1nL,Cn \qquad (2)$$

In addition, we included as part of the total costs, all recovering costs needed to a mangrove habitat functioning. Recovering costs included mangle tree planting, recovering natural hydrological function. Furthermore, recovering costs included soil recuperation costs that included recovering soil natural functioning from abandoned shrimp's farms, as well as recovering of soil functioning from areas where the city of Muisne is currently located and soil contamination related to the city (Table 1). The values of these different costs were estimated from different mangle recuperating studies

(Bayraktarov et al., 2016; GreenFlash Technologies, 2015; Shinde and Donde, 2015; Qadir et al., 2014; Dominati and Mackay, 2013; Marchand, 2008; Goldstein and Ritterling, 2001; Lewis, 2001).

Table 1: Estimates of costs implied in the recovery of the mangrove ecosystem of Muisne

MANGROVE RECOVERING COSTS	AREA (ha)	COSTS/UNIT (US$/ha)	TOTAL COSTS (US$)
PLANTING MANGLE TREES	591,3	8961	5.298.639,30
RECOVERING TIDAL FLOW	591,3	700	413.910,00
RECOVERING SALT-SOIL	290,8	1191	346.342,80
RECOVERING COMPACTED-SOIL	68,9	300	20.670,00
RECOVERING SOIL CONTAMINATION	300,5	4200	1.262.100,00
TOTAL	1842,8	15352	7.341.662,10

The total costs now may be defined as:

$$TC=Rs,Rc \tag{3}$$

where,

$Rs=Resettlement\ cost\ in\ US\$$

$Rc=Mangrove\ recovering\ cost\ \ in\ US\$$

The total costs of the city of Muisne resettlement reached a value of about 93.15 million US$, being approximately 5 million US$ more than the Ecuadorean´s governmental estimation of its resettlement program of Muisne in Bunche.

Furthermore, the Muisne mangrove ecosystem benefits have been defined as the sum of all benefits from a healthy and well-functioning ecosystem and the avoided costs of housing and infrastructure. Therefore, the total benefits of Muisne' mangrove ecosystem may be defined as:

$$TB=i,jnBi,ACj \tag{4}$$

where
$Bi=$ *Economic benefits from ecosystem goods and services in US$*
$ACj=$ *Avoided cost of Muisne housing and infrastructure in US$*

Economic values of total benefits have been estimated from studies regarding environmental services in mangrove forests and potential earnings and/or ecosystem services monetary value assessment (Malik et al., 2015; UNEP, 2011; UNEP, 2014; Giri et al., 2008; Corbishley and Pearce, 2007; Shuichi, 2004; Rivera, 2001; Sathirathai, 2000; Cabrera et al., 1998; Gammage, 1997; Barbier et al., 1997; Padilla and Janssen, 1996; Pearce, 1993; Ruitenbeek, 1992). Based on these studies, we have estimated the value of Muisne's mangrove ecosystem and its services. The highest value has been calculated from fisheries (Table 2) and it is estimated from all efforts to capture fish species that use mangrove forest as a nursery area, being some 93,149,958.06 million US$.

Table 2: Economic benefits estimation of Muisne's mangrove good and services

MANGROVE SERVICES	US$/ha/yr	Total Benefits
FLOOD MITIGATION	911,00	1.678.790,80
FILTERING NUTRIENTS AND CONTAMINANTS	1.800,00	3.317.040,00
DECOMPOSITION OF WASTE	127,00	234.035,60
SOIL CARBON STORAGE (937 Tc-ha-1)	327,95	604.346,26
MANGROVE CARBON STORAGE (2,42 Tc/ha)	0,93	1.709,20
FISHERIES	5.500,00	10.135.400,00
COASTLINE PROTECTION	238,93	440.305,36
RESEARCH VALUE	184,40	339.812,32
TOTAL	9090,21	16.751.439,54

Flood mitigation, which is the environmental service provided by a mangrove forest in case of an impact by a tsunami, is also important in economic terms with an estimated 1.7 million US$. Even though table 2 lists just a few of goods and services that a mangrove may provide, the total amount of 16.7 million US$ per year is a significant economic benefit.

Furthermore, potential losses of housing and infrastructure in the Island of Muisne and of "Nuevo Muisne", an illegitimate settlement the continent just in front of the main city of Muisne, has been estimated to strike some 93,149,958.06 million US$. The analysis did not take into account several costs such as market losses, commerce, potential earnings losses and personal consumption offsets. We did not consider both local and government taxes such as property taxes and income tax, value-added tax, neither income increases throughout time, and worklife discounts. Thus, these estimates certainly will be much higher.

The total economic benefits from recovering the ecosystem of Muisne would be some 109.9 million US$. Additionally, we calculated the benefit/cost ratio to observe if this resettlement proposal makes an economic sense, resulting to a $BC=1.16$, which indicates an economic benefit. Therefore, the ratio allows us to conclude that in terms of human life, housing, and infrastructure and business relocation of Muisne should be severely considered by the state, regional and local authorities as well as policy makers.

4. CONCLUSIONS

We estimated the value of a mangrove ecosystem recovery to influence policy decision making, as such reforestation helps to protect or mitigate susceptible areas of tsunamis in Muisne, along the central coast of Ecuador. The estimated mangrove recovery raised to some 109.9 million US$, which is significant, and hereby higher than the resettlement costs of the actual site of Musine Recovering Muisne mangrove will provide an estimate of 16 US$ million annually and secure ways of living of approximately 60% of the actual population. The B/C ratio of 1.16 demonstrates that such a project as proposed is of high efficiency. This calculated ratio also allows to conclude, that recovering of the Muisne mangrove at any scenario has a higher value than the potential resettlement costs. Therefore, the mangrove recovering means in terms of ways of living, housing, infrastructure and business relocation of Muisne needs to be considered by the policy makers. As resettlement usually occurs after a disaster stroke, our study suggests a preventing public policy, by using well-known evaluation tools such as BCA, SIG and other analysis tools.

ACKNOWLEDGMENTS

We thank the Universidad de las Fuerzas Armadas ESPE for logistic and financial support. Fernando Mato acknowledges support from the Prometeo Project of the National Secretariat of Higher Education, Science, Technology and Innovation (SENESCYT), Ecuador.

REFERENCES

Abe, T., Goto, K. and Sugawara, D. 2012: Relationship between the maximum extent of tsunami sand and the inundation limit of the 2011 Tohoku-oki tsunami on the Sendai Plain, Japan. Sedimentary Geology 282: 142-150.

Aon Benfield, 2015. 2014 Annual Global Climate and Catastrophe Report, Impact Forecasting. Aon Benfield Risk, Reinsurance and Human Resources. Aon plc.: 68pp

Aránguiz, R., González, G., González, J., Catalán, P.A., Cienfuegos, R., Yagi, Y., Okuwaki, R., Urra, L., Contreras, K., Del Rio, I. and Rojas, C., 2016. The 16 September 2015 Chile tsunami from the post-tsunami survey and numerical modeling perspectives. Pure and Applied Geophysics, 173(2), pp.333-348.

Athukorala, P.C. and Resosudarmo, B.P., 2005. The Indian Ocean tsunami: Economic impact, disaster management, and lessons. Asian Economic Papers, 4(1): 1-39.

Barbier, E.B., Acreman, M. and Knowler, D., 1997: Economic valuation of wetlands: A guide for policymakers and planners, the Ramsar Convention Bureau, Gland, Switzerland: 116-149.

Barcená, A., Prado, A., López, L. and Samaniego, J.L., 2010. The Chilean earthquake of 27 of February 2010: an overview. Disaster Assessment Unit of ECLAC, United Nations Publications, Santiago, Chile: 32pp.

Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., PossIngham, H.P., MumBy, P.J. and Lovelock, C.E., 2016. The cost and feasibility of marine coastal restoration. Ecological Applications, 26(4): 1055–1074.

Beck, S.L. and Ruff, L.J., 1984: The rupture process of the great 1979 Colombia earthquake: evidence for the asperity model. J.Geophys. Res.89: 9281–9291

Cabrera, M.A. Seijo, J.C., Euan, J. and Pérez, E., 1998: Economic Values of Ecological Services from a Mangrove Ecosystem. Intercoast Network, International Newsletter of Coastal Management # 32. Focus on: Coastal Economics. Narragansett, Rhode Island: 1-2.

Cavallo, E.A. and Noy, I., 2009: The economics of natural disasters: a survey. IDB WORKING PAPER SERIES No. IDB-WP-124: 49pp

CEDIM, 2015: Massive deadly earthquake near Illapel (Coquimbo coast), Chile - at least 16 people killed - Pacific Ocean tsunami. At http://earthquake-report.com/2015/09/16/massive-earthquake-near-coast-of-central-chile-on-september-16-2015/

Charvériat, C., 2000: Natural disasters in Latin America and the Caribbean: An overview of risk. Research Department Working papers series, 434: 104pp

Chatenoux, B. and Peduzzi, P., 2007. Impacts from the 2004 Indian Ocean Tsunami: analysing the potential protecting role of environmental features. Natural Hazards, 40(2): 289-304.

Chen, S.W. and Sato, M., 2013. Tsunami damage investigation of built-up areas using multitemporal spaceborne full polarimetric SAR images. IEEE Transactions on Geoscience and Remote Sensing, 51(4), pp.1985-1997.

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

Chunga, K., Toulkeridis, T., Vera-Grunauer, X., Gutierrez, M., Cahuana, N. And Alvarez, A., 2017: A review of earthquakes and tsunami records and characterization of capable faults on the northwestern coast of Ecuador. Science of Tsunami Hazards, 36: 100-127.

Collot, J.Y., Marcaillou, B., Sage, F., Michaud, F., Agudelo, W., Charvis, P., Graindorge, D., Gutscher, M.A. and Spence, G., 2004. Are rupture zone limits of great subduction earthquakes controlled by upper plate structures? Evidence from multichannel seismic reflection data acquired across the northern Ecuador–southwest Colombia margin. Journal of Geophysical Research: Solid Earth, 109(B11).

Corbishley, J. and Pearce, D., 2007: Growing trees on salt-affected land, ACIAR Impact Assessment Series Report No. 51: 46 pp.

Cruz D'Howitt, M., M.C, Acosta, and N.E. Vásquez. 2010. Riesgo por Tsunami en la Costa Ecuatoriana. Instituto Panamericano de Geografía e Historia, Sección Nacional del Ecuador , Organización de los Estados Americanos – OEA. Publicaciones.15pp.

Dominati, E. and Mackay, A., 2013: An Ecosystem Services Approach to the Cost of Soil Erosion and Value of Soil Conservation, Report prepared for: Hawke's Bay Regional Council, Land and Environment, AgResearch Limited-Grasslands Research Centre, Palmerston North, New Zealand: 50 pp.

Egbue, O. and Kellogg, J., 2010: Pleistocene to Present North Andean "escape". Tectonophysics 489: 248-257.

EJF, 2006: Mangroves: Nature's defence against Tsunamis—A report on the impact of mangrove loss and shrimp farmdevelopment on coastal defences. Environmental Justice Foundation, London, UK. 33 pp.

English, R., and Brusberg, F.E., 2002. Handbook for Preparing a Resettlement Action Plan. International Finance Corporation, Environmental and Social Development Department. Washington DC. 93 pp.

Gammage, S., 1997: Estimating the Returns to Mangrove Conversion: Sustainable Management or Short Term Gain?, Environmental Economics Programme Discussion Paper DP 97-02, International Institute for Environment and Development IIED, London UK: 56 pp.

Giri, C., Zhu, Z., Tieszen, L.L., Singh, A., Gillette, S. and Kelmelis, J.A., 2008: Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia, Journal of Biogeography 35: 519–528.

Goldstein, M. and Ritterling, J., 2001: A Practical Guide to Estimating Cleanup Costs, U.S. Environmental Protection Agency Papers. Paper 30: 103-121

GreenFlash Technologies LLC, 2015: Saline-Sodic Soils Remediation, GreenFlash Technologies LLC-Solutions Driven by Nature, Costa Mesa CA: 7 pp.

Guha-Sapir, D., Hargitt, D. and Hoyois, P., 2004. Thirty years of natural disasters 1974-2003: The numbers. Presses univ. de Louvain, Belgium: 190pp

Gusiakov, V.K., 2005: Tsunami generation potential of different tsunamigenic regions in the Pacific. Marine Geology, 215, 1-2: 3-9.

Gutscher, M.A., Malavieille, J.S.L. and Collot, J.-Y., 1999: Tectonic segmentation of the North Andean margin: impact of the Carnegie ridge collision. Earth Planet. Sci. Lett. 168: 255–270.

Hanley, N. and Spash. C.L., 1993: Cost-benefit Analysis and the Environment.Aldershot, Hants, England: E. Elgar: 288pp

Jayatilleke, B. and Naranpanawa, A., 2007. The economic effects of the Asian tsunami on the tear drop in the Indian Ocean: a general equilibrium analysis. South Asia Economic Journal, 8(1): 65-85.

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), pp.1241-1253.

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), pp.1241-1253.

Kelleher, J.A., 1972: Ruptures zones of large South American earthquakes and some predictions. Journal of Geophysical Research, 77, 11: 2087-2103.

Kellogg, J.N. and Vega, V., 1995: Tectonic development of Panama, Costa Rica and the Colombian Andes: Constraints from Global Positioning System geodetic studies and gravity. Geol. Soc. Am. Special Paper 295, 75–90.

Lewis III, R.R., 2001: Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration, In: Proceedings of the Mangrove Valuation Workshop, Universiti Sains Malaysia, Penang, 4-8 April, 2001. Beijer International Institute of Ecological Economics, Stockholm, Sweden: 18 pp.

Malik, A., Fensholt, R., and Mertz, O., 2015: Economic Valuation of Mangroves for Comparison with Commercial Aquaculture in South Sulawesi, Indonesia, Forests, 6: 3028-3044.

Marchand, M. 2008: Mangrove restoration in Vietnam: Key considerations and a practical guide. Report prepared for WRU / TUD, T2666. Deltares: 42 pp.

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

Mazda, Y., Magi, M., Ikeda, Y., Kurokawa, T. and Asano, T., 2006. Wave reduction in a mangrove forest dominated by Sonneratia sp. Wetlands Ecology and Management, 14(4): 365-378.

Osti, R., Tanaka, S. and Tokioka, T., 2009. The importance of mangrove forest in tsunami disaster mitigation. Disasters, 33(2): 203-213.

Padilla, J.E. and Janssen, R., 1996: Extended benefit-cost analysis of management alternatives: Pagbilao mangrove forest, Journal of Philippine Development, 42, XXII No. 2: 339-363.

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., 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.

Pearce, D.W., 1993: Economic Values and the Natural World, The MIT Press. Cambridge, Massachusetts: 143pp

Qadir, M., Quillerou, E., Nangia, V., Murtaza, G., Singh, M., Thomas, R. J., Drechsel, P. and Noble, A.D., 2014: Economics of salt-induced land degradation and restoration. Natural Resources Forum, 38: 282-295. doi: http://dx.doi.org/10.1111/1477-8947.12054

Rivera, E.S., 2001: Valoración Económica de Servicios Ambientales Prestados por Ecosistemas: Humedales en México, Estudios PEA-RI-2001-001 Instituto Nacional de Ecología, Dirección General de Investigación en Política y Economía Ambiental, Secretaría de Medio Ambiente y Recursos Naturales SEMARNAT, México DF: 45 pp.

Rodriguez, F., D'Howitt, M.C., Toulkeridis, T., Salazar, R., Romero, G.R., Moya, V.R. and Padilla, O., 2016: Economic evaluation and significance of early relocation vs. complete destruction by a potential tsunami of a coastal city in Ecuador, Science of Tsunami Hazards., 35 (1): 18-33.

Rudolph E. and Szirtes S., 1911: Das kolumbianische Erdbeben am 31 Januar 1906, Gerlands Beitr. z. Geophysik, 2: 132- 275.

Ruitenbeek, H.J., 1992: Mangrove Management: An Economic Analysis of Management Options with a Focus on Bintuni Bay, Irian Jaya, EMDI Environmental Reports 8, Dalhousie University, Halifax, Nova Scotia: 53 pp.

Sathirathai, S., 2000: Economic Valuation of Mangroves and the Roles of Local Communities in the Conservation of Natural Resources: Case Study of Surat Thani, South of Thailand, Research Reports-International Development Research Centre, Ottawa, Canada: 38 pp.

Shinde, P. S. and Donde, S.S., 2015: Impact of mangrove pollution and devastation: a study for sustainable measures, International Research Journal of Natural and Applied Sciences, 2, (6): 178-185.

Shuichi, I., Kiyoshi, F., Motohiro, K., Ryo, W., and Shinji, T., 2004: Relationship between mangrove vegetation and micro-topography, and carbon storage of Kandelia candel (L.) Druce forests in Amami-ohshima Island, southwestern Japan, Japanese Journal of Forest Environment, 46:1 9-19.

Tanaka, N., 2009. Vegetation bioshields for tsunami mitigation: review of effectiveness, limitations, construction, and sustainable management. Landscape and Ecological Engineering, 5(1): 71-79.

Tanaka, N., Sasaki, Y., Mowjood, M.I.M., Jinadasa, K.B.S.N. and Homchuen, S., 2007. Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami. Landscape and Ecological Engineering, 3(1): 33-45.

Toulkeridis, T., 2011: Volcanic Galápagos Volcánico. Ediecuatorial, Quito, Ecuador: 364 pp

Toulkeridis, T., 2013: Volcanes Activos Ecuador. Santa Rita, Quito, Ecuador: 156pp

Toulkeridis, T. and Zach, I., 2016: Wind directions of volcanic ash-charged clouds in Ecuador – Implications for the public and flight safety. Geomatics, Natural Hazards and Risks, DOI:10.1080/19475705.2016.1199445

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., 2017b: Real-Time Radioactive Precursor of the April 16, 2016 Mw 7.8 Earthquake in Ecuador. Lecture Notes in Computer Science, Proceedings ITISE 2017, Granada, Spain: 207-219.

Toulkeridis, T., Chunga, K., Rentería, W., Rodriguez, F., Mato, F., Nikolaou, S., Cruz D´Howitt, M., Besenzon, D., Ruiz, H., Parra, H. and Vera-Grunauer, X., 2017c: The 7.8 M_w Earthquake and Tsunami of the 16th April 2016 in Ecuador - Seismic evaluation, geological field survey and economic implications. Science of Tsuanami Hazards, in press

UNEP (United Nations Environment Programme), 2011: Economic Analysis of Mangrove Forests: A case study in Gazi Bay, Kenya, UNEP, iii+: 42 pp.

UNEP (United Nations Environment Programme), 2014: The Importance of Mangroves to People: A Call to Action. van Bochove, J., Sullivan, E., Nakamura, T. (Eds). United Nations Environment Programme World Conservation Monitoring Centre, Cambridge: 128 pp.

USGS (United States Geological Survey), 2016: Earthquake Hazards Program. http://http://web.archive.org/web/20130502223428/http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/usc0001xgp.php

Ye, L., Lay, T., Kanamori, H. and Koper, K.D., 2016. Rapidly estimated seismic source parameters for the 16 September 2015 Illapel, Chile M w 8.3 earthquake. Pure and Applied Geophysics, 173(2), pp.321-332.

Zerbe, R.O Jr, T.B. Davis, N. Garland, and T. Scott. 2010. Toward Principles and Standards in the Use of Benefit-Cost Analysis. Benefit Cost Analysis Center, University of Washington. Seattle WA: 115 pp.