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Assessment of Relative Vulnerability Index of Buildings to Coastal Hazards along the East Coast of Cuddalore, Tamil Nadu Using GIS Application, A Case Study

[1]K. Ayyappan, [1]K.Thiruvenkatasamy and [2]T. Arumugam
[1]Harbour and Ocean Engineering, AMET University, 603112 Chennai, India
[2]Anna Institute of Management, 600028 Chennai, India

Abstract: The 26th December 2004 Tsunami that wreaked destruction in the East coast of Tamil Nadu, India, immediate recovery of coastal society and infrastructure is needed to restore the livelihood of local peoples. The factors leading to higher exposure to the Tsunami is essential for improving coastal management should be thoroughly understood in order to rebuild infrastructure which are near shore in a safer way. Important factor for an effective warning system are coastal vulnerability assessment and risk modeling and they contribute significantly in the reduction of risk. A successful hazard mitigation planning operation depends upon the sufficient scientific knowledge on the relative vulnerability of the houses in a hazard prone area. Using an enhanced version of Papathoma Tsunami Vulnerability Assessment Model, a relative vulnerability index of buildings in the coastal area that are prone to coastal hazards such as the Tsunami and storm surges were calculated. A combination of structural vulnerability of buildings and the water level during the hazard and using Analytic Hierarchy Process (AHP) for weighting the various impact elements in order to limit concerns about subjective ranking of elements in the original model are used in the calculation of relative vulnerability index. The model was tested using the data collected from coast of Cuddalore. In order to take a vulnerability assessment it is vital to list out all vulnerable parameters in the study area pertaining to its population, socio-economic aspects and built environment. A list of impact elements for each of these parameters were identified. Widespread field survey was carried out and data on the impact element were collected from the local people. The locations of every household was mapped using an Arc PAD and questionnaire was used to collect data on the impact elements identified for calculating the relative vulnerability index of buildings in villages. Using the Papathoma Tsunami vulnerability assessment model the relative vulnerability index of individual buildings in coastal areas of Cuddalore was calculated which takes into account the indices on exposure vulnerability, structural vulnerability and protection. Large scale maps showing the relative vulnerability indices of buildings in the hazard prone areas would be of immense use in relief and mitigation operations.

Key words: Building vulnerability, remote sensing, Tsunami hazards, GIS, Papathoma, vulnerability

INTRODUCTION

Vulnerability assessment models are used to calculate relative vulnerability index of buildings in the coastal area that are prone to coastal hazards such as the Tsunami and storm surges with which a database is built. In order to, carry out a vulnerability assessment it is vital to list all vulnerable parameters in the study area with respect to its socio-economics, population, ecosystems and built environment. A list of Impact elements for each of these parameters were identified. Widespread field survey is required to collect data on the impact element from the local people. For every household, data is collected on their location using GPS, building material, house type along with the appropriate social economic data. a combination of structural vulnerability of buildings and the water level during the hazard, socio and economic attributes of each of the houses are used to calculate the relative vulnerability index for every house.

Vulnerability to environmental hazards means the prospective for loss. Vulnerability varies over time and space, since, losses vary geographically, over time and among different social groups. Within the hazard literature, vulnerability has various connotations, based on the research orientation and perception (Dow, 1992; Cutter, 1996, 2001). The important factor for an effective warning system are coastal vulnerability assessment and risk modelling and they contribute considerably to reduce the disaster risk. The knowledge about component at risk, their vulnerability, coping and adjustment mechanisms are

Corresponding Author: K. Ayyappan, Harbour and Ocean Engineering, AMET University, 603 112 Chennai, India

a prerequisite for the setup of people centered warning system, recovery policy planning and local specific evacuation planning. Earlier the quantification of vulnerability mainly depending on economic damage assessment. Later and according to the three pillars of sustainable development indicators for the physical dimension of vulnerability and socio-economic were taken for calculation.

The 2004 Sumatra Tsunami left a deep and dark footprint on East Coast of Cuddalore Tamil Nadu, India which was one of the badly affected areas in the mainland. Cuddalore, the largest fishing and harbor area of which 600 people lost their lives and plenty of property and assets were destroyed when the Tsunami waves hits Cuddalore coast in December 2004. However, the fishing villages were rebuilt and over 351 Tsunami rehabilitation houses were made by the efforts of the government and non-governmental organizations.

Study area: Cuddalore District is located about 160 kmsec South of Chennai, the state capital. The area of the district is 3706 km^2. Cuddalore (110 44'45" N and 790 45'56" E), a large industrial town which has experienced coastal development at a quick rate and largest fishing area. Cuddalore District is surrounded on the North by the Villupuram District and the Union territory of Puducherry, on the East by the Bay of Bengal. The coastal stretch of Cuddalore extends from Gadilam Estuary in the North to Pichavaram mangroves in the South, a total length of 42 km along the Bay of Bengal.

MATERIALS AND METHODS

Papathoma Tsunami Vulnerability Assessment (PTVA-3) Model: The Papathoma Tsunami Vulnerability Assessment (PTVA) Model was built to provide first order assessments of building vulnerability to Tsunami and the output of the model assessment is a "Relative Vulnerability Index" (RVI) score for every building (Papathoma, 2003; Papathoma and Dominey-Howes, 2003; Papathoma *et al*., 2003). It was revised later to take recently published data about attributes that affect building vulnerability (not obtainable when the original model was built by Papathoma) to Tsunami into account and to initiate a mathematical mechanism (an Analytic Hierarchy Process or AHP) for weighting the different attributes in order to limit concerns about individual ranking of attributes in the original model. The model has newly been applied and tested in the United States (Dominey-Howes, 2007; Dall'Osso *et al*., 2009).

Structure of the revised model and its attributes: The RVI of the buildings was made depending on the guidelines adopted in the Coastal Risk Analysis of Tsunamis and Environmental Remediation project (CRATER) wherein the revised the Papathoma Tsunami Vulnerability Assessment (PTVA) Model was used. The RVI score of building is calculated as a weighted sum of two separate elements namely the vulnerability of building due to its contact with water (WV) and the Structural Vulnerability (SV):

$$RVI = 2/3*(SV)+1/3(WV)$$

Where:

WV = The standardized score for the Vulnerability of Water intrusion and
SV = The standardized score for the Structural Vulnerability

The Structural Vulnerability "SV" of a building was determined by the attributes of the building structure (Bv), depth of flood water (Ex) at the point where building is located and the degree of Protection (Prot) that is provided to that building by any natural or artificial barriers:

$$\text{Strutural vulnerability} = (Bv)\cdot(Ex)\cdot(Prot)$$

Where:

Bv = The standardized score of building vulnerability ranging from 1 (minimum vulnerability) to 5 (maximum vulnerability)
Prot = The standardized score of protection that is provided to the building by any barriers which ranges between 5 (no protection) and 1(maximum protection)
Ex = The standardized score for exposure which is given by the depth of water expected at the building location

"Ex" ranges between 1 and 5 (1 = minimum water depth, 5 = maximum water depth).

Spatial data collected collection using ArcPAD GPS in Cuddalore: In order to, carry out a vulnerability assessment it is vital to list all vulnerable parameters in the study area with respect to its socio-economics, population, ecosystems and built environment. A list of impact elements for each of these parameters were identified. Impact elements are those characteristics of the parameter measured that could be generally affected by the Tsunami waves. Widespread field survey were carried out and data on the impact element were collected from

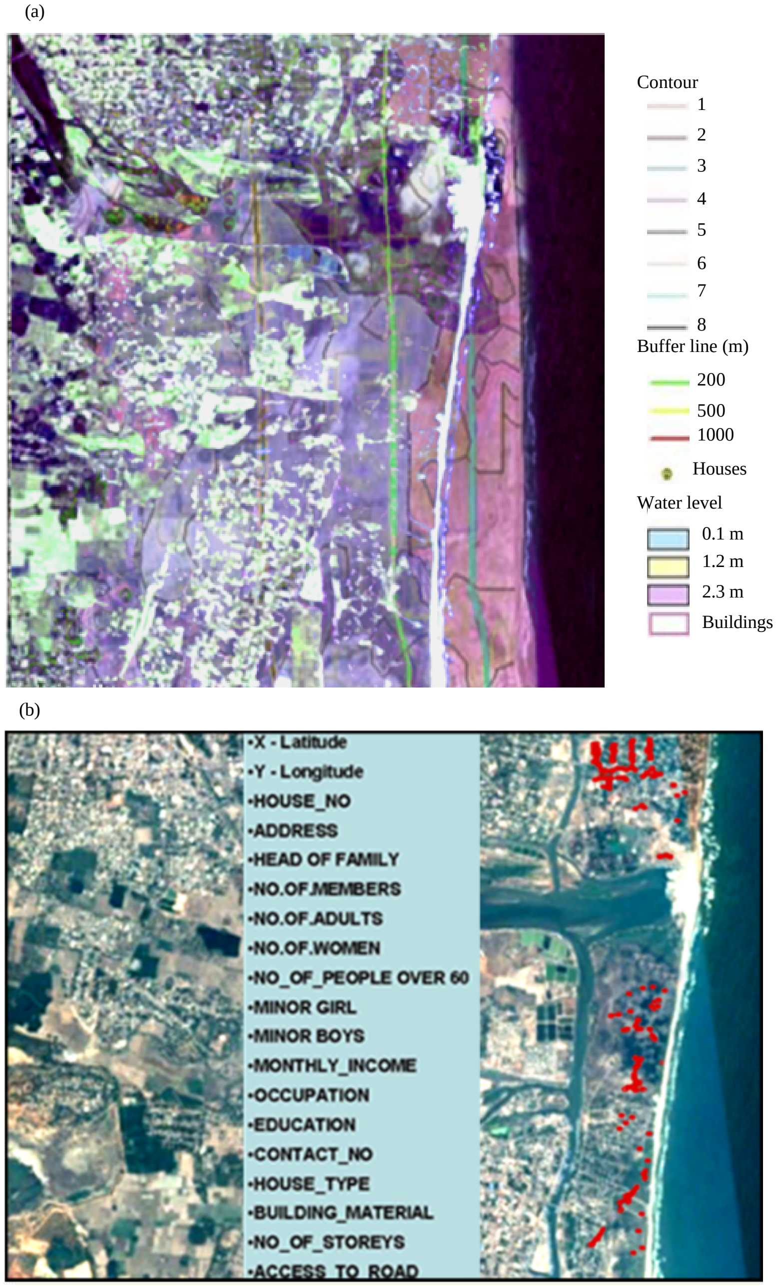

Fig. 1: a, b) Field data collected in Cuddalore

the local people. The location of major infrastructures, road networks etc. were collected using ArcPAD GPS. The location of every household was mapped using an ArcPAD and questionnaire was used to collect data on the social economic of every house hold (Fig. 1a, b). The data collected include, X, Y-coordinate, house no, address, name of the family head, No. of members No. of adult males, No. of women, No. of people over 60/invalids, minor children girl monthly income, occupation (boat/land, etc.), education level, contact No. House type, building material, No. of storey's, access to roof, distance from shore water level at the time of inundation.

Calculation of relative vulnerability indices for buildings at cuddalore: This research was undertaken to assess the vulnerability of existing buildings at Cuddalore to future Tsunami. The PTVA-3 Model calculates a Relative

Fig. 2: Different types of houses in Cuddalore field photographs

Fig. 3: Different building types of houses in cuddalore

Vulnerability Index (RVI) for every inundated structure in Cuddalore by taking into consideration the exposure vulnerability, the structural vulnerability and the protection offered to the building both in terms of natural and man-made structures.

Structural vulnerability of buildings at Cuddalore: The coastal houses in Cuddalore ranges from huts with thatched roofs to well built concrete houses. Since, the type of houses and the building material were the most important factors deciding the structural vulnerability of the building. Data was collected on the foundation type, type of houses, material used and roof details. The vulnerability for every building was calculated by considering the contributions made by the following attributes (Fig. 2 and 3).

Type of house: The houses were categorized as huts or tiled or thatched houses, concrete houses and weightages were calculated based on the vulnerability of every house type. Apparently, concrete houses were more resistant and therefore, less vulnerable when compared to the huts or tiled houses.

Foundation: The houses either had simple mud foundation or concrete foundation in this area. More resistance to scouring effect of water flow was offered by deep foundation and can counter the impact of a wave on the walls of the building. Buildings with shallow or surface spread foundations suffered the heaviest levels of damage (Darlymple and Kriebel, 2005; Reese *et al*., 2007) during 2004 Tsunami.

$$Bv = w1(T)+w2(F)+w3(M)+w4(S)$$

Where:

T = The Type of house
F = The Foundation
M = The Material used
S = The number of story's in the building.
wI = The weighting coefficient of each attribute

It is apparent that all attributes cannot have equal weightages since they definitely not have equal effect on the vulnerability of the building. Hence, comparisons between attributes were carried out using an evaluation matrix by means of MACBETH Software, a particularly designed platform for multi criteria analysis and decision making (Costa *et al*., 2004; Costa and Chagas, 2004).

The Exposure ("Ex"): The exposure component relates to the depth of water level at the point where the building is located. The level of structural damage is expected to increase with water depth because the pressure applied to the building and the flow velocity is direct functions of flow depth (Fritz *et al*., 2006). The elevation of the house from the mean sea level and the distance of the houses from the shore are the two factors which are considered in order to calculate the exposure vulnerability of the buildings. House at higher elevation and further away from the shore were deemed to be less vulnerable than the houses at the lower elevation and closer to the shore. Elevation contours were made using high resolution

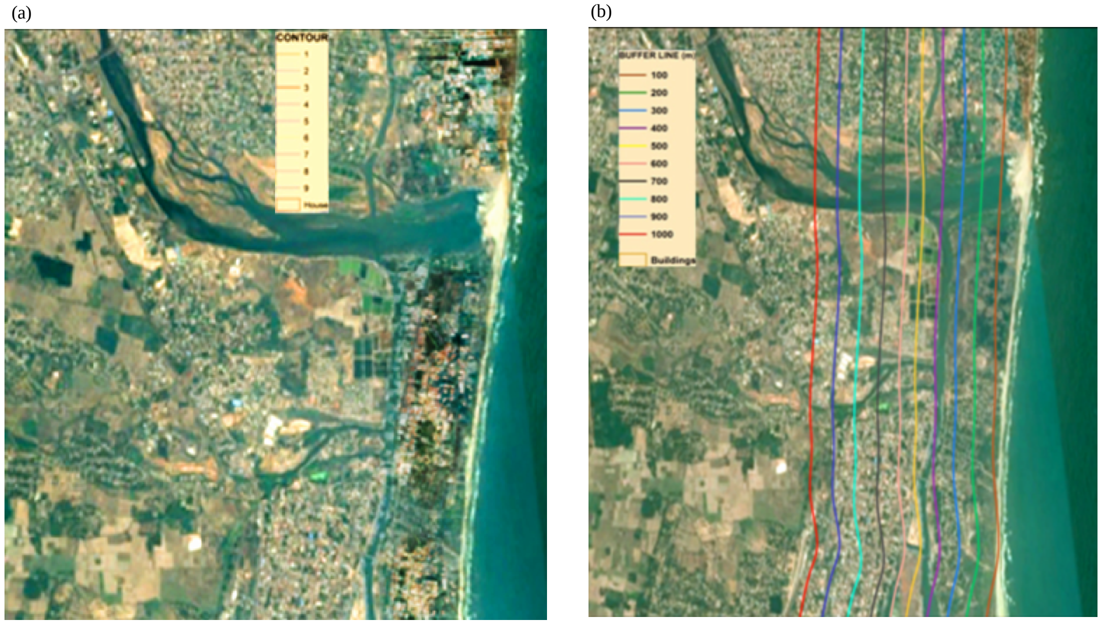

Fig. 4: a, b) Distance between the elevation contour and buffer line from the shoreline

SRTM were used for the study area. The distance of the house from the shoreline was calculated for generating buffers at different intervals from the shoreline. Figure 4 shows the exposure vulnerability of the buildings in Cuddalore.

Calculation of vulnerability to water intrusion: Using the numerical models, the water level at Cuddalore due to the 2004 Sumatra Tsunami was calculated. These models were built to forecast the extent of inundation and run-up using a finite difference code Tunami N2 on nested grids resulting from high resolution elevation and bathymetry datasets. To replicate the correct wave dynamics during inundation, exact and high resolution topographic and bathymetry datasets obtained from Indian remote sensing satellite Cartosat and C-Map and NHO data charts for near-shore areas. The General Bathymetry Chart of Oceans (GEBCO) digital atlas was used to populate the deep sea regions. Tools were developed to combine the datasets obtained from different sources and computational grids were made to form a seamless data for numerical model. A water level map was made by overlying the numerical model outputs on Cuddalore base map. This was then used to calculate the water level at each individual house in the study area (Fig. 5).

Fig. 5: Exposure vulnerability of the houses in Cuddalore

Exposure vulnerability of the houses in Cuddalore

The protection factor ("Prot"): Natural defenses such as mangroves, coconut plantation and casuarinas, sand dunes and man-made structures like sea walls, dykes offers resistance to the advancement of the Tsunami wave thereby offering protection to the adjacent coastal areas. During the Indian Ocean Tsunami mangroves, coconut plantation and casuarinas withstood the Tsunami waves as natural barriers and saved many lives and property in Tamil Nadu coast. However, no such coastal protection was found along East Coast of Cuddalore.

Calculating the weightages for attributes: In calculation of a building vulnerability or exposure all the attributes cannot have equal weightages. For example, the type of houses and building foundations were more significant than the number of storey's in terms of vulnerability calculation. To address concerns of individual weighting of the attributes, however, weights have been recalculated here via pair-wise matches between each of the attributes (Dallo'Osso and Dominey-Howes, 2009). Comparisons between attributes were carried out using an elevation matrix by means of the M-MACBETH Software, a particularly designed platform for multi criteria analysis and decision making (Costa *et al.*, 2004; Costa and Chagas, 2004). MACBETH is the acronym of "Measuring Attractiveness through a Category Based Evaluation Technique" which is the aim of Analytic hierarchy process. All attributes implicated in the calculation of particular vulnerability components were compared and the software calculated the relative weight of every attribute. The same processes were repeated for the safety factors. Using this approach, weights for various attributes have been calculated and the inevitable individual component of the decision making process have been reduced to minimum (Dallo'Osso and Dominey-Howes, 2009).

RESULTS AND DISCUSSION

The relative vulnerability index of the buildings were calculated depending on the structural vulnerability, exposure and the protection parameters after assigning weightages to every attributes selected for calculating the subjective vulnerabilities (Fig. 6 and 7).

$$SV = (Bv)\cdot(Ex)\cdot(Prot)$$

After the Tsunami, the affected the coastal region of cuddalore region people in the area were shifted to Tsunami resettlement houses specially designed and constructed to withstand coastal hazards. However, the study clearly shows that the houses in a part of the resettlement area have relatively moderate to high vulnerability even though these buildings are special type of hazard resistant buildings which may be due to the land elevation and nearness to the shoreline.

Elevation and distance from the shore plays a vital in deciding whether the house will be inundated or not. However, results clearly shows that building have high vulnerability even though they might be away from the shoreline are more vulnerable than the building with low vulnerability and located close to the shore. The result clearly indicates that vulnerability of building to coastal hazards is therefore not dependent upon a single factor but a combination of attributes contributing towards the exposure vulnerability, building vulnerability and protection factors offered to the building. This scientific investigation would be of enormous use to the government departments who can plan their disaster mitigation plans by first relocating the people in the building that have the highest RVI score.

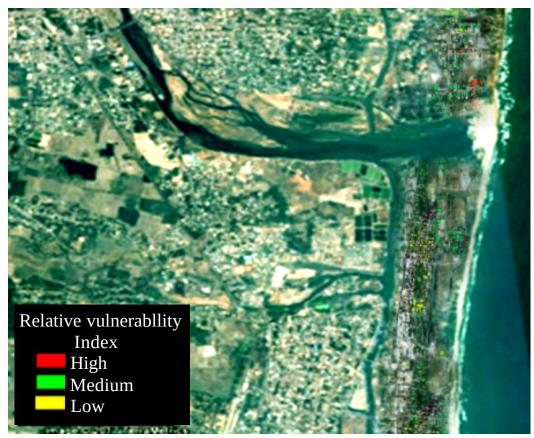

Fig. 6: Relative vulnerability index for buildings at Cuddalore calculated using PTVA Model

Fig. 7: Tsunami resettlement houses in Cuddalore

CONCLUSION

The original PTVA Model is a useful application for providing primary assessments of the vulnerability of buildings. The PTVA Model is improved in two methods. First method, it was introduced an entirely new set of attributes that are now known to affect the vulnerability of buildings to damage in Tsunami those related to water intrusion. Second method, it was introduced a multi-criteria approach to the assessment of building vulnerability. This approach based on pair wise comparison between attributes is a method normally used in multi-criteria analysis and analytic hierarchy process. Thanks to this technique, the contribution made by separate attributes to the overall structural vulnerability of a building can be compared via. a thorough mathematical approach. This avoids biases and reduces to a minimum the unavoidable individual component of every decision-making process and a concern associated with the original PTVA Model. It was tested the revised method (PTVA-3) at Cuddalore, Tamil Nadu and it has provided a clear approach for assessing the vulnerability of buildings to Tsunami in the absence of fully validated vulnerability models. Outputs of the PTVA-3 include thematic vulnerability maps displaying the relative vulnerability index of each building. Vulnerability maps may be used by Government authorities for future urban planning, to develop disaster management plans and decide whether further prevention measures should be considered. The PTVA-3 Model is depends on the use of GIS. GIS is a very common and easy-to-use approach to the management of spatial datasets. Once data about building attributes and the RVI of buildings are entered into a GIS, they can be retrieved, modified and kept up to date very easily.

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