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GIS based methodology to assess the relative vulnerability index of buildings to coastal hazards - Coastal Karaikal - A case study

T Arumugam[1], M.Suresh Gandhi[1], T Mageswaran[1] , Tune Usha[2] & Suresh N[1]

1. Department of Geology, University of Madras, Chennai- 600 025, India
2.Integrated Coastal and Marine Area Management, (ICMAM), Pallikaranai, Chennai-600 100, India

[E.Mail: msureshgandhi@gmail.com]

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Relative vulnerability index of individual buildings in coastal areas of Karaikal was calculated using the Papathoma Tsunami Vulnerability Assessment Model which takes into account the indices on structural vulnerability, protection and exposure vulnerability. The locations of each 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. 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.]

Introduction

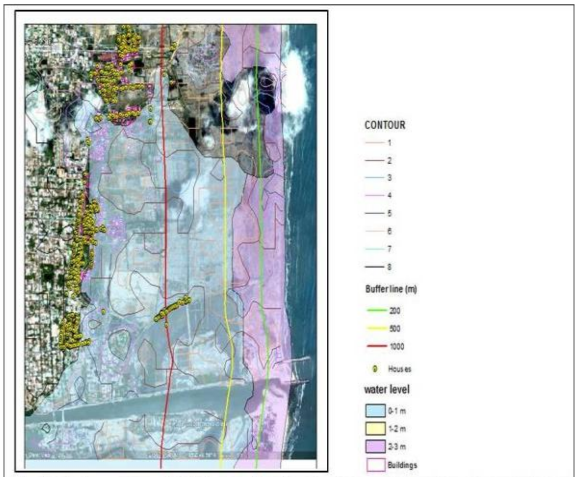
Coastal systems are characterized by important ecological and natural values; their high habitat and biological diversity is fundamental to sustain coastal processes and provide ecosystem services which are essential also for human well-being[1]. In order to carry out a Vulnerability assessment it is imperative to list all vulnerable parameters in the study area with respect to its population, built environment, socio-economics, ecosystems and environment. Relative vulnerability index is calculated for each house using a combination of structural vulnerability of buildings, and the water level during the hazard, socio and economic attributes of each of the houses.

The 2004 Sumatra tsunami left a deep and dark footprint on coastal Karaikal in South East India, which was one of the worst affected areas in the mainland. Karaikal, the largest fishing and harbor town of which 105 people lost their lives and lots of property and assets were destroyed when the tsunami waves hits Karaikal coast in December 2004. However, the fishing villages were rebuilt and over 500 tsunami rehabilitation houses were made by the efforts of the government and non- governmental organizations. Coastal vulnerability assessment and risk modelling is an important component for on effective warning system and contributes significantly to disaster risk reduction. The knowledge about element at risk, their susceptibility, coping and adaption mechanisms are a precondition for the setup of people centered warning structures, local specific evacuation planning and recovery policy planning.

Materials and Methods

The study area Karaikal (Latitude 10^{o} 55’ N; Longitude 79^{o} 52 E) is a major port city of East Coast of India and a municipality in Karaikal district in the Union Territory of Puducherry, India. Geologically the area is covered completely by a thick mantle of alluvium of variable thickness, the lie of the region is flat having a gentle slope towards the Bay of Bengal in the east.

The Papathoma Tsunami Vulnerability Assessment (PTVA) Model was developed 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 each building[2-4.] This model has recently been applied and tested in the United States[5,6] .



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79.84167	10.93265	18	Ganesh Nagar 1st Cross Street	-	5	<Nul	Ramachandran	4	1	2	-	1	2000	Car Driver	B.Com
79.84169	10.93225	19	Ganesh Nagar 1st Cross Street	1	6	15	Pichairaj	7	2	3	1	-	2000	Iddly Shop	10th
79.84169	10.93228	19	Ganesh Nagar 1st Cross Street	1	7	<Nul	Gurumoorthy S	9	6	4	-	2	6000	Govt Retired	MBA
79.84169	10.93222	21	Ganesh Nagar 1st Cross Street	-	8	22	Ezhil Arasu	3	1	1	-	1	30000	Cooperative Bank Manager	MBA
79.84166	10.93221	22	Ganesh Nagar 1st Cross Street	1	9	<Nul	Lakshmanan	4	1	1	-	1	5000	Private	Graduate

Figure. 1a. Field data collected in Karaikal

The RVI of the buildings was generated based 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. RVI score of building is calculated as a weighted sum of two separate elements namely the structural vulnerability (SV) and the vulnerability of building due to its contact with water (WV)

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

Where "SV" is the standardized score for the structural Vulnerability and "WV" is the standardized score for the vulnerability of water intrusion. 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.

Structural Vulnerability = (Bv). (Ex). (Prot)

Where "Bv" is the standardized score of building vulnerability ranging from 1 (minimum vulnerability) to 5 (maximum vulnerability). "Prot" is 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" is 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).

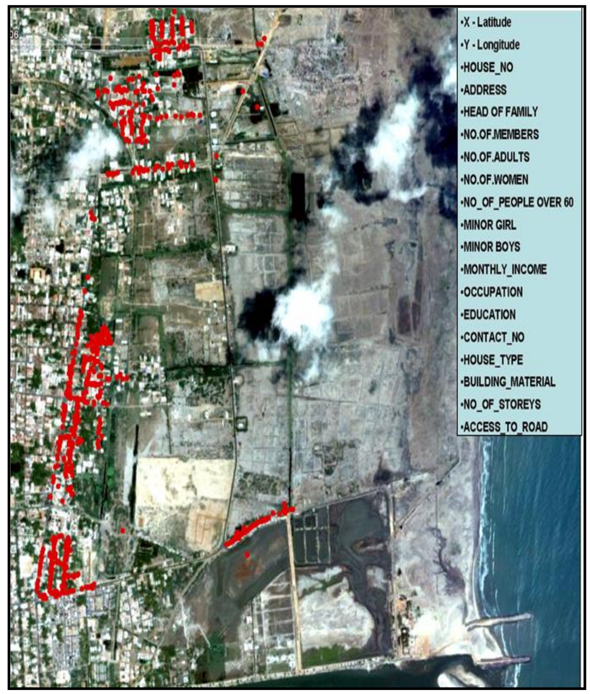

Figure. 1b. Field data collected in Karaikal

Results

In order to carry out a vulnerability assessment it was imperative to list of all vulnerable parameters in the study area pertaining to its population, built environment, socio-economic aspects and environment. For each of these parameters a list of impact elements were identified. Impact elements are those characteristics of the parameter considered that could be mostly affected by the tsunami waves. Extensive field visit were undertaken and data on the impact.

Figure. 2 Field Photographs showing different types of houses in Karaikal

Element were collected from the local population.The position of major infrastructures, road networks etc were collected using ArcPAD GPS. Location of each household was mapped using an Arc PAD and questionnaire was used to collect data on the socio-economic of each house hold (Fig.1a,1b).

This work was carried out to assess the vulnerability of existing buildings at Karaikal to future tsunami. The PTVA-3 Model calculates a relative vulnerability index (RVI) for every inundated structure in Karikal by taking into consideration the structural vulnerability , the exposure vulnerability and the protection offered to the building both in terms of natural and man-made structures.

The houses in coastal Karaikal ranges from well built concrete houses to huts with thatched roofs (fig.2). Since the type of houses and the building material were the primary factors deciding the structural vulnerability of the building. Data was collected on the type of houses, material used, foundation type and roof details. The building vulnerability for each building was calculated by considering the contributions made by the following attributes.

a. *Type of house*- the houses were classified as concrete, tiled or huts or thatched houses and weightages were calculated depending on the vulnerability of each house type. Obviously, concrete houses were more resistant and therefore less vulnerable when compared to the huts or tiled houses.
b. *Foundation*- the houses in this area had a concrete foundation or simple mud foundation. Deep foundation can offers more resistance to scouring effect of water flow and can counter the impact of a wave on the walls of the building. During the 2004 tsunami, buildings with shallow or surface spread foundations suffered the heaviest levels of damage[7-9].

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

Where “T” is the type of house, “F” is foundation, “M” denotes the material used and “S” the number of story’s in the building. “w1” is the weighting coefficient of each attribute. It is obvious 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 undertaken using an evaluation matrix by means of Macbeth software, a specially designed platform for multi criteria analysis and decision making [10-11].

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[12]. In order to calculate the exposure vulnerability of the buildings two factors were selected namely the elevation of the house from the mean sea level and the distance of the houses from the shore. 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 generated using high resolution 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. Fig. 3 shows the exposure vulnerability of the buildings in Karaikal.

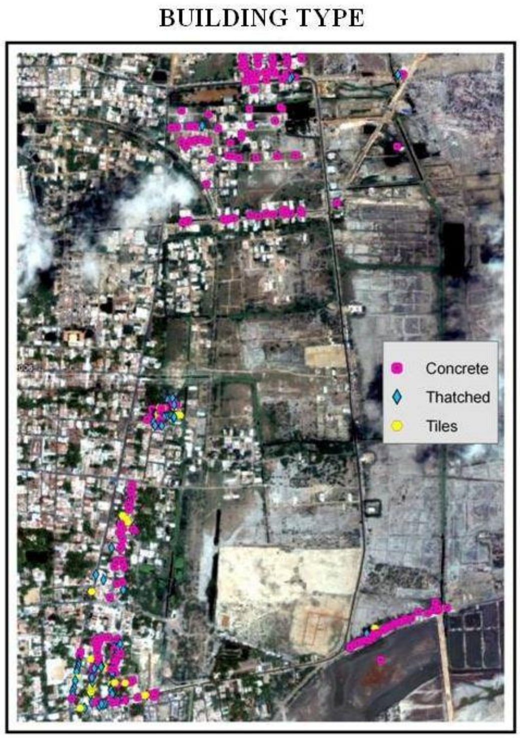

Figure.3. Different Building Types of houses in Karaikal

The water level at Karaikal due to the 2004 Sumatra tsunami was calculated using the numerical models. These models were constructed to predict the extent of inundation and run-up using a finite difference code TUNAMI N2 on nested grids derived from high resolution elevation and bathymetry datasets. To reproduce the correct wave dynamics during inundation, accurate 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 integrate the datasets obtained from various sources and computational grids were generated to form a seamless data for numerical model. A water level map was generated by overlying the numerical model outputs on Karaikal base map (Fig.4).

Natural defenses such as mangroves, casuarinas, cashew and coconut plantation , sand dunes and man-made structures like sea walls offers resistance to the advancement of the tsunami wave thereby offering protection to the adjacent coastal areas.

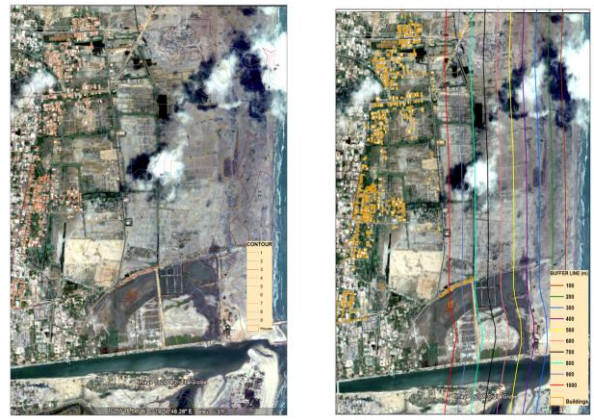

Figure. 4. Distance between the Elevation Contour and Buffer line from the Shoreline

Mangroves, casuarinas and coconut plantation withstood the tsunami waves as natural barriers and saved many lives and property in Tamil Nadu coast during the Indian Ocean tsunami (SDMRI report 2005). However no such coastal protection was found along Karaikal coast.

It is quite evident that all attributes involved in calculation of a building vulnerability or exposure cannot have equal weightages. For example, the type of houses and foundation were more important than the number of storey’s in terms of vulnerability calculation. To address concerns of subjective weighting of the attributes however, weights have been recalculated here via pair- wise matches between each of the attributes[6]. Comparisons between attributes were undertaken using an elevation matrix by means of the M-Macbeth software, a especially designed platform for multi criteria analysis and decision making[7,8].

MACBETH is the acronym of “Measuring Attractiveness through a Category Based Evaluation Technique”, which is the goal of Analytic Hierarchy Process. All attributes involved in the calculation of particular vulnerability components were compared and the software calculated the relative weight of each attribute. The same processes were repeated for the protection factors. Using this approach, weights for different attributes have been calculated, and the unavoidable subjective component of the decision making process have been reduced to minimum.

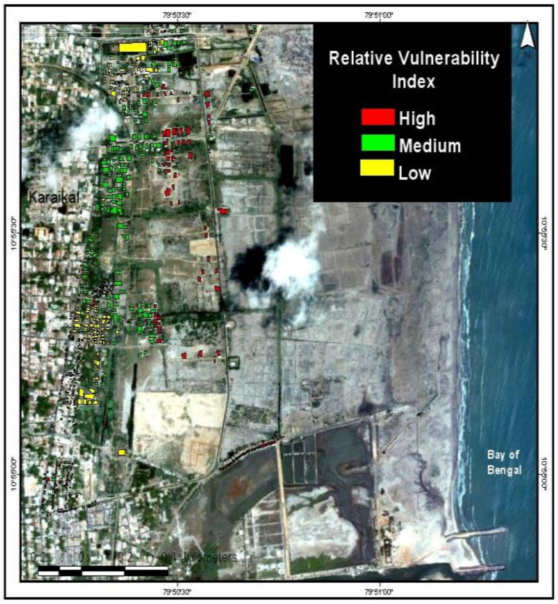

Figure.5. Relative Vulnerability Index for buildings at Karaikal calculated using PTVA model

Conclusion

The relative vulnerability index of the buildings were calculated based on the structural vulnerability, exposure and the protection parameters after assigning weightages to all attributes selected for calculating the individual vulnerabilities.

$$SV = (Bv). (Ex). (Prot)$$

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

Elevation and distance from the shore plays a crucial in deciding whether the house will be inundated or not. However, results clearly shows that have high building vulnerability even though they might be away from the shoreline are more vulnerable than the building with low building vulnerability and situated close to the shore (Fig.5). 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 building vulnerability, exposure vulnerability and protection factors offered to the building. This scientific analysis would be of immense use to the government departments who can plan their disaster mitigation strategies by first relocating the population in the building that have the highest RVI score.

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