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# A conceptual framework for evaluating tsunami resilience

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**Abstract.** As many coastal towns in the northeast coast of Japan were destroyed by tsunami accompanied with the Great East Japan Earthquake, a few of them were survived or little damaged with no or less casualties due to some reasons. Yoshihama in Iwate prefecture is one of such little damaged communities and is known as “Lucky Beach.” There were such “lucky” and “unlucky” regions in Indonesia and Sri Lanka too, which were affected by Indian Ocean Tsunami. Identification of reasons for vulnerability or resilience is the primary consideration of this article. It presents pragmatic conceptual framework for evaluating resilience, based on author’s first-hand experience on above both tsunamis. Integral resilience of a given area has been considered after dividing into three phases namely, onsite resilience, instantaneous survivability, and recovery potentiality of the area. The author assumes that capacity of each phase depends on socioeconomic, infrastructural and geographical factors of the area considered. The paper moves forward, arguing appropriateness of the framework by giving examples collected from Japan, Indonesia and Sri Lanka. The framework will be useful for evaluating resilience of coastal townships and also planning resilient townships, specifically focusing on tsunami.

## 1. Introduction

News about large disasters becomes frequent in recent years. In Asia the largest two such tsunamis happened within seven years, challenging the knowledge on disasters. The Indian Ocean Tsunami (IOT) caused by magnitude 9.1 earthquake occurred on 26th December 2004. It affected more than 15 countries; Indonesia and Sri Lanka were the most seriously affected countries. Around 127,720 people were killed and 93,285 were still missing, 139,195 houses were destroyed, 85,000 houses were damaged and 635,384 people were displaced in Indonesia. In Sri Lanka, around 35,399 people were killed, 114,069 housing were destroyed or damaged and 480,000 people were displaced [1,2]. Around six years later, on 11th March, 2011 the Great East Japan Earthquake and Tsunami (GEJET) caused by magnitude 9.0 earthquake hit Japan. Around 18,703 people were killed and 2,674 people were missing, 126,574 houses were fully destroyed, and more than 450,000 people had to be evacuated [3].

Among various stories and studies regarding damage and lost caused by both tsunami disasters, there are some stories about survived or little damaged coastal areas due to some reasons. These “lucky beaches” exist in Indonesia, Sri Lanka and Japan. In Indonesia several coastal areas such as Lhok Pawoh & Ladang Tuha Villages in South Aceh District and Moawo & Pasar Lahewa Villages in Nias Island, were survived or no casualties. Lhok Pawoh and Ladang Tuha Villages were protected by geographical factors, while social factors contributed for lifesaving of Moawo and Pasar Lahewa Villages’ residents [1,4]. In Sri Lanka, some areas such as Galle Fort were survived due to infrastructural factors, while the surroundings were severely damaged. In Japan, Yoshihama in Iwate

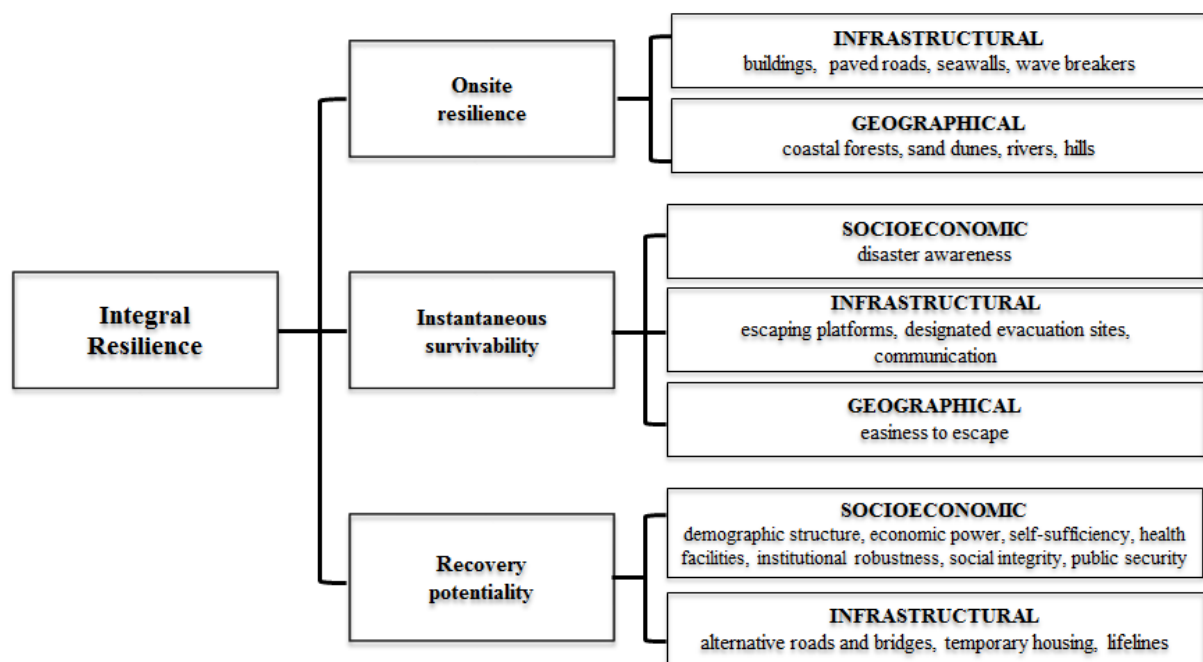


prefecture reported a little damage because of social and geographical factors [5]. These facts lead to the question, why some areas were survived or a little damaged while other areas were not?

The main purpose of this article is to propose a general conceptual framework, which can be used to assess and analyse the vulnerability or resilience of townships when facing tsunami. It will analyse some factors that contribute to the fate of "lucky beach," "unlucky beach" or other relevant coastal areas.

## 2. The Conceptual Framework

UNISDR defines resilience as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions [6]. Accordingly, the proposed framework assumes that an "ideal resilient region" should fulfil three requisites namely onsite resilience, instantaneous survivability, and recovery potentiality. The level of fulfilment in a given requisite can basically be evaluated by socioeconomic, infrastructural, and geographical capital of the region in question (see figure 1). Onsite resilience is the "hereditary" ability of a given place to withstand tsunami even before tsunami comes. Instantaneous survivability is the ability to survive during the climax of the disaster. Recovery potentiality is the ability to recover soon after the disaster, even though the region was destroyed by tsunami.



**Figure 1.** The conceptual framework.

### 2.1. Socioeconomic factor

The proposed framework hypothesizes that the resilience is partially a socially constructed ability. Priority 3 of Sendai Framework for Disaster Risk Reduction encourages enhancement of social resilience through investing in disaster risk prevention and reduction [7]. It encourages a broader and a more people-centred preventive approach to disaster risk.

Many authors have investigated on measuring socioeconomic factors of vulnerability or resilience. Some of the very relevant and comprehensive research works will be introduced here. Resilience index proposed by Kusumastuti et al. [8] considered that social resilience is a function of demographic characteristics and access to resources, while community resilience is related to the attributes of the area that promote population wellness, quality of life, and emotional health; and economic resilience is

related to the economic vitality of the community. Furthermore, institutional resilience is related to the efforts of local government to raise the awareness and preparedness of the residents toward disaster. The socioeconomic vulnerability index (SeVI) proposed by Ahsan and Warner [9] has used a Composite Indicator Framework method, which consists of three main dimensions: adaptive capacity, sensitivity and exposure. These dimensions were further divided into five domains: demographic, social, economic, physical, and exposure to natural hazards. Socioeconomic factors in Ahsan and Warner [9] study have been evaluated through population density and growth, male/female ratio, percentage of illiterate households, participation for elections and volunteering, percentage of unemployed households and households below poverty line etc. Antwi et al. [10] measured the socioeconomic index through 6 indicators, namely population density, livelihood diversification, vulnerable groups, knowledge on climate, migration rate, and access to social service. In the same study political/governance index has been measured using 5 indicators namely, politically influential persons, stakeholder organizations, number of assembly members, and local participation in district activities.

Based on above previous literature the socioeconomic factor of our framework will be considered some quantitative dimensions such as demographic structure, economic power, self-sufficiency, and health facilities, which can be often gathered by census organizations, both government and private. Qualitative dimensions such as institutional robustness, social integrity, public security and disaster awareness can be collected through field surveys.

## *2.2. Infrastructural factor*

Experience of past major tsunamis has proven that infrastructures such as seawalls and large buildings protected the coastal communities from tsunamis. At least those structures reduce the impact of tsunami. One of such examples is Dutch fort of Galle city in Sri Lanka. Built on a promontory, with walls to withstand cannon fire, the ramparts and bastions surrounding the 350-year old Dutch fort of Galle acted as a wave breaker against 2004 Indian Ocean tsunami, saving the old part from devastation. The coral, stone and stucco wall form its bastions and ramparts served to protect the approximately 400 buildings inside it on the 26th December 2004 when the tsunami broke through the lower gates of the Fort. The waves flowed out again very quickly and left no major structural damage, while surrounding of the fort was inundated above 3.5 m and destroyed the new part of the city.

The role of existing buildings on disaster mitigation is paid attention after the Great East Japan Earthquake (GEJE). Many authors have investigated damage conditions of buildings and justified the reasons for survival or failure [11,12,13]. GEJE fully destroyed around 126,000 buildings, and the number of half-destroyed buildings was counted as 272,000. However, some large buildings survived and had sometimes served to reduce the impact of tsunami while giving the temporary shelter to the affected inhabitants. One of the examples is a group of buildings in Sendai sewage purification centre in Miyagi Prefecture. All of those buildings were located at a distance of 325-637 m from the coastline and at altitudes between 2.2 and 3.1 m. On March 11, 2011, tsunami attacked the premises and ran up to 14.7 m [14,15]. None of the buildings were destroyed or submerged. Despite of close proximity to the sea, these reinforced concrete buildings survived and they were praised by the neighbours for protecting their lives. These structures could be used as escaping platforms and designated evacuation sites too.

Infrastructural factor of the proposed framework can be evaluated by field surveys connected with GIS on existing artificial structures such as reinforced concrete buildings, dams, seawalls etc.

## *2.3. Geographical factor*

The geographical factor weighs the role of coastal forests, sand dunes, rivers and hills to reduce the impact caused by tsunami. It is well known that moving from low-lying valleys to higher lands saves the damages by tsunami. On the other hand if an area is located on higher lands, it is geographically resilience. One of the very clear examples is Yoshihama in Iwate Prefecture, Japan. Despite of 18-meter high wave rampaged from the Pacific Ocean into the valley, just four houses were lost and one person died on March 11, 2011. Yoshihama became a safer place because of mass relocation to high

ground after having experience of tsunami in 1896 and 1933, in which Yoshihama experienced 204 and 17 fatalities respectively [5].

Researchers are split over the opinions about coastal forests. Some of them believe uprooted trees made more harms than benefits at the event of GEJE, because of huge power of waves [11]. However, others determined that homestead grooves (*igune*) in Sendai Plain protected nearby houses by reducing the impact of tsunami, as well as stopping the flowing debris, damaging the houses [16]. Ujiie et al. [17] have conducted interviews in 53 households with homestead grooves to investigate the function of these groves against the tsunami. Of the households surveyed, 64.2 per cent believed that the homestead grooves protected their homes from the tsunami; 18.9 per cent indicated that the homestead grooves did not protect their homes from the tsunami; and 7.5 per cent indicated that the homestead grooves unfortunately increased the damage done to their homes by tsunami. The 64.2 per cent households who had a positive image on homestead grooves insisted three merits of homestead grooves. Firstly, their opinion was that homestead grooves protected their homes from debris, uprooted trees and vehicles washed out by the tsunami. Secondly, homestead grooves, especially to the east of houses (seaward), decreased the impact of the tsunami so that their homes could not be washed out. Thirdly, they mentioned that homestead grooves, especially to the west of houses (landward), protected their belongings in their houses and soil erosion [14,18].

Sand dunes and mangroves have been studied by Tanaka et al. [19] on the role of coastal vegetation in tsunami protection based on field observations carried out after the Indian Ocean tsunami on December 26, 2004, in Sri Lanka. The study has concluded that combination of the sand dune followed by vegetation toward landside played an important role in retarding tsunami. In particular, if a mangrove forest is located behind a sand dune, it could trap most of the debris and prevent the buildings behind the forest from being damaged.

Based on these information we can anticipate that if an area has coastal forests, sand dunes, and hills, it is resilient. These features can be mapped using GIS and transformed to numbers.

### 3. Three Phases of Conceptual Framework

Numerous previous literature have proposed many conceptual models for evaluating resilience or vulnerability. Despite their differences, a number of common elements have been found: (a) the examination of vulnerability from a social-ecological perspective; (b) the importance of place-based studies; (c) the conceptualization of vulnerability as an equity or human rights issue and (d) the use of vulnerability assessments to identify hazard zones, thereby forming the basis for pre-impact and hazard mitigation planning [20]. The proposed framework in this paper, integral resilience of a given area has been considered, dividing into three phases (requisites) namely, onsite resilience, instantaneous survivability, and recovery potentiality of the area. It is a modification of previous models, which is built by introducing three requisites to be met for labelling a place as an ideal tsunami resilient area. Each phase (requisite) is dependent on two or three factors, which can be measured by different dimensions using obtainable independent variables. The framework assumes that an area uninhabited, but fully protected by infrastructural and geographical factors is the ideal, scoring the maximum in the integral resilience. On the other hand, existence of inhabitants gives a negative impact to the integral resilience. Therefore, socioeconomic factor which is totally dependent of human activity is not included in onsite resilience (see figure 1). The validity of this concept can be proved by social vulnerability score measured by Cutter et al. [21] for the Yellowstone National Park County in USA. The low social vulnerability score for Yellowstone National Park County is a result of its protected status with a very small population that has little ethnic, racial, or gender diversity.

As shown in figure 1, the dimensions to be considered under the socioeconomic, infrastructural, and geographical factors are varied according to the requisite. For example, while the geographical factor of onsite resilience will be evaluated by availability of coastal forests, sand dunes, rivers, and hills; geographical factor of instantaneous survivability is only a dependent of easiness to escape. This assumes that escaping is only the way remaining for saving life at the climax stage of a tsunami attack, which prevails in less than an hour. Recovery potentiality in figure 1 consists of two factors, socioeconomic and infrastructural. In recovery potentiality geographical factor is not important

anymore, because coastal forests, sand dunes, hills etc. are only needed to resist tsunami when it approaches, or provide an easy way to escape during a tsunami attack. Socioeconomic factor in recovery potentiality is one of the most important that can determine the recovery level of post-disaster phase. It could be evaluated by demographic structure, economic power, self-sufficiency, health facilities, institutional robustness, social integrity, and public security, while it assumes disaster awareness does not matter in this stage.

#### 4. Summary

This article forwarded a pragmatic conceptual framework for evaluating resilience, based on author's first-hand experience on tsunamis. The proposed model paid considerable attention on (a) dividing the disaster phenomena into three phases in relation to the temporality of tsunami, (b) defining which factors influence on a given phase and (c) selecting influential dimensions on each factor. One dimension has been carefully placed in only one phase to avoid double counting. The paper also provided some practical examples gathered through Indian Ocean tsunami and Great East Japan Earthquake in order to prove appropriateness of some dimensions. The next step is to apply the model into practical situations in order to verify the applicability of the model, and finally be instrumental in building resilient coastal townships.

#### 5. References

- [1] Danar O R and Pushpalal D 2014 Building community resilience: conceptual framework and its application in post tsunami resettlement *Elsevier Procedia Economic and Finance* **18** pp 489-96
- [2] International Recovery Platform 2016 Brief overview of the disaster by countries [http://www.recoveryplatform.org/countries\\_and\\_disasters/disaster/15/indian\\_ocean\\_tsunami\\_2004](http://www.recoveryplatform.org/countries_and_disasters/disaster/15/indian_ocean_tsunami_2004) (Accessed 31.10.2016)
- [3] Pushpalal D, Rhyner J, Hossini V 2014 *The Great Eastern Japan Earthquake, 11 MARCH 2011: Lessons Learned and Research Questions* (Bonn: United Nations University) p 10
- [4] Onrizal 2008 The stories of Tsunami Survivors (in Bahasa Indonesia). <http://onrizal.wordpress.com/2008/10/05/kisah-kampung-yang-selamat-dari-tsunami/> (Accessed 13.5.2014)
- [5] Corkill E 2011 Heights of survival. [http://www.japantimes.co.jp/life/2011/06/12/general/heights-of-survival/#.WAg1-un\\_pol](http://www.japantimes.co.jp/life/2011/06/12/general/heights-of-survival/#.WAg1-un_pol) (Accessed 31.10.2016)
- [6] UNISDR Terminology on Disaster Risk Reduction 2009 (Geneva: UNISDR) p 24
- [7] Sendai Framework for Disaster Risk Reduction 2015 (Geneva: UNISDR) p 18
- [8] Kusumastuti R D, Viverita, Husodo Z A, Suardi L, Danarsari D N 2014 Developing a resilience index towards natural disasters in Indonesia *International Journal of Disaster Risk Reduction* **10** pp 327-40
- [9] Ahsan M N and Warner J 2014 The socioeconomic vulnerability index: A pragmatic approach for assessing climate change led risks—A case study in the south-western coastal Bangladesh *International Journal of Disaster Risk Reduction* **8** pp 32-49
- [10] Antwi E K, Boakye-Danquah J, Owusu A B, Loh S K, Mensah R, Boafo Y A, Apronti P T 2015 Community vulnerability assessment index for flood prone savannah agro-ecological zone: A case study of Wa West District, Ghana *Weather and Climate Extremes* **10** pp 56-69
- [11] Suppasri A, Shuto N, Imamura F, Koshimura S, Mas E, Yalciner A C 2013 Lessons Learned from the 2011 Great East Japan Tsunami: Performance of Tsunami Countermeasures, Coastal Buildings, and Tsunami Evacuation in Japan *Pure Appl. Geophys.* **170** pp 993-1018
- [12] Matsutomi H, Yamaguchi E, Naoe K, Harada K 2012 Damage Conditions to Reinforced Concrete Buildings and Coastal Black Pine Trees in the 2011 Off the Pacific Coast of Tohoku Earthquake Tsunami (in Japanese). *Coastal Engineering Journal* **68(2)** pp. 351-55

- [13] Gokon H and Koshimura S 2012 Mapping of building damage of the 2011 Tohoku earthquake tsunami in Miyagi Prefecture *Coastal Engineering Journal* **54(1)** pp 1250006-1-12
- [14] Ogata K 2014 The Role of Obstructions in Disaster Risk Reduction: Focusing on the Great East Japan Earthquake, Master Thesis, Department of International Resources Policy, Graduate School of International Cultural Studies, Tohoku University pp 100-131
- [15] Pushpalal D and Ogata K 2014 The Role of Buildings in Disaster Risk Reduction: Focusing on the Great East Japan Earthquake *Elsevier Procedia Economic and Finance* **18** pp 483-88
- [16] Koganezawa T and Umikawa K 2012 The function of tsunami risk management on the coastal forest and wind break forest in Sendai coastal region (in Japanese) *Bulletin of Miyagi University of Education* **47** pp 1-9
- [17] Ujiie S and others 2013 Study on the damage situation of Igune from the salt of the tsunami and the disaster prevention function of Igune in the Sendai Plain – A case study from the Sangenjaya District, Tamaura area, Iwanuma, Miyagi Prefecture (in Japanese) *Journal of the City Planning Institute of Japan* **48(1)** pp 100-109
- [18] Ogata K and Pushpalal D 2014 Japanese Literature Survey of Ecosystem Services in Disaster Risk Reduction *The Great Eastern Japan Earthquake, 11 MARCH 2011: Lessons Learned and Research Questions* Eds. Pushpalal D, Rhyner J, Hossini V (Bonn: United Nations University) <http://collections.unu.edu/view/UNU:1904> pp 68-75
- [19] Tanaka N, Sasaki Y, Mowjood M I M 2006 Effects of Sand Dune and Vegetation in the Coastal Area of Sri Lanka at the Indian Ocean Tsunami *Advances in Geosciences Vol. 6: Hydrological Science* Eds. Namsik Park et al. World Scientific Publishing Company pp 149-59
- [20] Cutter S L, Barnes L, Berry M, Burton C, Evans E, Tate E, Webb J 2008 A place-based model for understanding community resilience to natural disasters *Global Environmental Change* **18** pp 598–606
- [21] Cutter S L, Boruff B J, Shirley W L 2003 Social Vulnerability to Environmental Hazards *Social Science Quarterly* **84(2)** pp 242-61

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