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Original Research Article

# Island-wide coastal vulnerability assessment of Sri Lanka reveals that sand dunes, planted trees and natural vegetation may play a role as potential barriers against ocean surges

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## ABSTRACT

Since the Indian Ocean tsunami on 26 December 2004, there have been continuous efforts to upgrade the (tsunami) early warning systems as well as their accessibility in local and regional places in South and Southeast Asia. Meanwhile, the protection offered by coastal vegetation like mangroves to the people, property and physical landscape was also recognized and prioritized by both public and private authorities at various governance levels. As more than 90% of the Sri Lankan coastline is vulnerable to water-related impacts and existing bioshields like mangroves are potentially able to protect less than one-third of it, if at all they are in good condition, an attempt was made to build knowledge on the other potential natural barriers along the coast. In this context, a *ca.* 2 km belt of the entire coast was digitized, classified and assessed for vulnerability in relation to the existing land-use/cover. First, a visually interpreted land-use/cover map comprising 16 classes was developed using Google Earth imagery (Landsat-5, 2003). Second, based on the Global Digital Elevation Model data from the ASTER satellite, the land-use/cover map was further re-classified for elevation demarcation into waterless, run-up and flooded areas. And finally, both vulnerable and less vulnerable areas were identified by taking into account the average wave heights that the 2004 tsunami reached in the country (North: 5.5 m, South: 7 m, East: 5 m and West: 3.75 m). Among the selected areas studied, Jaffna and Kaluvanchikudy-Komari are found to be vulnerable and, Trincomalee, Yala and Puttalam are less vulnerable. While vulnerability was largely associated with the conditions devoid of natural barriers, the less vulnerable areas had mangroves, *Casuarina*, dense vegetation and/or sand dunes as land cover, all of which might prove effective against ocean surges. However, these land cover types should never be considered as providing full protection against the type of threats that can be expected. As the present study provides only baseline information on island-wide vulnerability of areas to water-related impacts, further

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investigation and validation along similar research lines are needed to establish a blueprint for future preparedness.

## 1. Introduction

Although history has documented >2000 tsunami events since 2000 B.C. in >12,900 locations (Dunbar et al., 2008), the 26 December 2004 Indian Ocean tsunami was proven to be the most deadly in the contemporary period and created far reaching spatial and temporal impacts on terrestrial as well as marine habitats (Tang et al., 2006; Subba Rao et al., 2007; Rachmalia et al., 2011; Samarakoon et al., 2013; Andrade et al., 2014). Because of the massive death toll and property loss (e.g. IUCN, 2005a; UNEP & MENR, 2005; Chatenoux and Peduzzi, 2007; Matsumaru et al., 2012; Mishra et al., 2014), coastal communities in Southeast and central South Asia are not only fearing tsunamis but also other water-related impacts such as cyclones, sea-level rise and combinations of these, with coastal erosion as a damage-facilitating process. Although tsunami science has much progressed during the last decade, disaster mitigation remains challenging but evident from other tsunami catastrophes in the past ten years (e.g. Japan tsunami on 11 March 2011) (Oskin, 2014, 2015).

Physical structures being damaged or removed by the force of ocean surges and the debris it carries can result in the physical removal of plants and animals (Subba Rao et al., 2007; Andrade et al., 2014). In some cases this happened irrespective of the presence of coastal forests like mangrove and other land cover types (e.g. sand dunes) having the potential to act as protective buffers for coastal zone (e.g. Cochard et al., 2008; O'Connell, 2008; Das and Vincent, 2009; Tanaka et al., 2009; Mukherjee et al., 2010; Feagin et al., 2010; Zhang et al., 2012). In fact, loss and degradation of the coastal protective features due to physical infrastructure as well as agriculture and aquaculture development is still ongoing in many locations (Dahdouh-Guebas et al., 2005a; Pattanaik and Prasad, 2011; Nfotabong-Atheull et al., 2011; Satyanarayana et al., 2012; Bao et al., 2013; Dat and Yoshino, 2013; Ha et al., 2014; Santos et al., 2014; Nguyen, 2014). Therefore it could not be ascertained so far that forests like mangroves were in a healthy state adequate to fulfill their potential coastal protection function (Dahdouh-Guebas et al., 2005a,b). The current state of these ecosystems is often not well documented, raising uncertainty about their coastal protection ability and urging for a precautionary principle to reduce harmful types of exploitation or even destruction (Dahdouh-Guebas et al., 2005b). The justification in this precautionary principle also lies in the reports of other instances, in which mangroves were considered to have contributed to mitigating the effects of the 2004 tsunami on human population, physical landscape and private/government property (Williams, 2005; Dahdouh-Guebas, 2006; Dahdouh-Guebas and Koedam, 2006; Quartel et al., 2007; Ellison, 2008; Das and Vincent, 2009; Teh et al., 2009). Besides mangrove assemblages, also seagrass beds, coral reefs and sand dunes have been recognized for their functionality of reducing coastal vulnerability against ocean surges (Chatenoux and Peduzzi, 2007; O'Connell, 2008).

The coastal landforms in Sri Lanka comprise estuaries, lagoons, beaches, rocky shores, sand dunes, salt marshes and mangroves (Dahdouh-Guebas and Jayatissa, 2009), with an occasional hill or cliff right at the ocean front. The 2004 tsunami hit the entire East and Southwestern coast of the island, where its impact varied according to factors such as offshore bathymetry, beach slope, local topography, distance to the coastline, etc (Liu et al., 2005; Dahdouh-Guebas et al., 2005b; Wijetunge, 2006; Patnaik et al., 2012). Besides the loss of lives and property, coastal water bodies filled with debris, beach erosion, uprooted vegetation, and salinization of drinking water and agricultural fields, were some of the aftermath environmental consequences (IUCN, 2005b,c; UNEP & MENR, 2005). It has been postulated that different coastal plant species were affected differently. Coconut palms for instance were fairly resistant to the energy of the waves as well as to subsequent salinization, whereas *Casuarina* trees taller than 6 m were broken, yet survived (IUCN, 2005a; Mascarenhas & Jayakumar, 2008). In the case of mangroves, although frontal trees were uprooted, the back mangrove remained more or less unaffected in mangrove forests that were in a fair state (Dahdouh-Guebas et al., 2005b; UNEP & MENR, 2005). The local tsunami witnesses indeed specified that the mangrove forests protected several lives and properties located behind the vegetation (Dahdouh-Guebas et al., 2005b; Dahdouh-Guebas and Koedam, 2006; Tanaka et al., 2011; Sandilyan and Kathiresan, 2015). However, there are also studies challenging the role of mangroves in tsunami protection (e.g. Kerr et al., 2006; Kerr and Baird, 2007; Baird and Kerr, 2008; Satheeshkumar et al., 2012), whereas an overview of missing evidence was provided by Cochard et al. (2008) and Dahdouh-Guebas and Jayatissa (2009).

In Sri Lanka, more than 90% of the coastline is vulnerable to water-related impacts, while existing bioshields like mangroves could only protect less than one-third of it (Feagin et al., 2010). Hence, other potential barriers in the vicinity are to be investigated. In this study, we aim at identifying vegetation types and other physical barriers located up to 2 km inland from the coast using remote sensing and ground-truth. Subsequently, we identify vulnerable and less vulnerable areas along the coastline by using a GIS-based risk assessment incomplete yet pioneering data, which should foster the precautionary principle and draw attention to conservation and restoration of the coastal vegetation.