Damage response of coral reefs during the 2004 Indian Ocean tsunami

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1. Abstract

The Republic of Maldives forms the central part of the Chagos-Maldives-Laccadives submarine ridge and extends on 860 km long and 80 to 120 km wide. It consists of 1,192 low-lying coral reef islands gathered into 20 atolls. The archipelago of 4,513 km² is the seventh largest reef system in the world and offers one of the greatest coral diversity of the Central Indian Ocean. The Maldives also have the lowest land elevation among the four exiting atoll countries (Kiribati, Marshall Islands and Tuvalu) and about 80 % of the islands do not exceed 1 m above the mean sea water level (MSWL). Hence, the archipelago is very vulnerable to large waves events and especially tsunami attacks (Gunn et al., 2005; Riyaz et al., 2010). The 2004 IOT was the only record of tsunami in the Maldives. The economic consequences of the tsunami have been substantial with a budget deficit of 80 million USD due to the immediate reconstruction and a drop-in tourism income the following year (Mohamed et al., 2016). The maximum tsunami height recorded was about 4 m on Vilufushi Island, Thaa atoll. In total, 82 people died and around 2,000 houses were damaged. Casualties and damage to houses/infrastructures were mostly concentrated in the southern part of the Maldives. Compared to the destructive impact of the tsunami in Sri Lanka, most of islands reported no victims and a few damages only. Such contrast can be explained by (i) the fact that Sri Lanka acted as a buffer and reduced the hydrodynamic force of the tsunami, at least for the northern part of the Maldivian archipelago, (ii) the tsunami did not hit the Maldives at high tide and (iii) the shallow bathymetry combined with the presence of offshore coral reefs and deep channels separating atolls attenuated the tsunami waves amplitude (Fritz et al., 2006; Goffredo et al., 2007). In addition of acting as a natural defense during the IOT, coral reefs represent a central resource for the archipelago's economy, mainly based on tourism and fishery industries. According to the Maldives Bureau of Statistics (2022), tourism represented about 21.4 % of the Gross Domestic Product (GDP) while fisheries accounted for 4.1 % with more than 70 % of the total fish catch exported abroad (mainly tuna). They also have major ecological functions within the ecosystem (maintenance of habitats, biodiversity…) and between ecosystems such as mangroves and seagrass beds (biological support though "mobile links", organic production export…) (Moberg and Folke, 1999). To protected such a resource, the Maldivian government established about 70 Marine Protected Areas (MPAs), of a few hectares, where recreational diving and bait fishing only are allowed (Mohamed, 2007). After the IOT, field surveys reported damage to living corals and the reefs, varying in extent and intensity. Given their ecological and economic importance, there is an urgent need to better understand how tsunamis such as the 2004 IOT damaged such a marine environment. There is a relatively poor understanding of tsunami hydrodynamic disturbances on coral reef communities. To overcome this lack of knowledge, we use fragility curves, originally expressed as the relationship between damage probability on structures or human lives and hydrodynamic features of tsunami inundation (Koshimura et al., 2009a). This "vulnerability tool" has been widely applied to buildings or infrastructures (Charvet et al., 2014; Koshimura et al., 2009b; Lahcene et al., 2021; Shoji and Nakamura, 2017; Suppasri et al., 2011), marine vessels or ports (Chua et al., 2021; Muhari et al., 2015; Suppasri et al., 2014) as well as aquaculture rafts and eelgrass (Suppasri et al., 2018).

2. Objectives

In this study, we first reproduce the flow depth, the flow velocity and the hydrodynamic force of the tsunami, using TUNAMI-N2 model, with the finest resolution of 10 m to grasp the local variations of the IOT characteristics. The coral cover is considered in the tsunami numerical modelling through the Manning's roughness coefficient. The calibration and validation of the 2004 IOT model stand on tsunami water level marks (e.g., inundation at buildings, debris in trees…) recorded during field surveys (Fritz et al., 2006; Fujima et al., 2005; Kan et al., 2007). We then develop the tsunami fragility curves for living corals and reefs in the Maldives. Finally, we produce a vulnerability map based on the IOT to (i) identify areas where coral reef system is the most vulnerable to be damaged by a tsunami and (ii) discuss tsunami impact on the Marine Protected Areas (MPAs) and on the Maldivian economy. For the first time, we investigate the vulnerability of such environment to tsunami attacks. Such a study has implications for the development of long-term reef monitoring and planning to strengthen the resilience of reef resources after large wave events.

3. References

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