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Numerical modeling of storm surge attenuation by mangroves in protected area of mangroves of Qheshm Island

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ABSTRACT

With the experience of storm surges along Persian Gulf of Iran it is needed to simulate storms in coastal areas and study the protection techniques in order to protect communities and industrial facilities in coastal areas. Mangrove forests play a unique role in attenuating storm surge during tropical cyclones. MIKE21 FM is an applicable software for simulating cyclones within coastal environments. A hydrodynamic model is used to analyze the attenuating role of the protected area of mangroves between Gheshm Island and Khamir Port mangroves under a realistic conditions by updating the calibrated Manning's coefficient based on the land cover data to incorporate the mangrove effect with modifying bottom friction and characteristics of cyclone Gonu 2007 which is the strongest cyclone recorded in the Arabian Sea and Persian Gulf. In this research we measured the maximum surge levels in both scenarios (in situ conditions and the condition which mangrove forest is neglected); maximum storm tide reduction by mangroves (MSTRM) by mangroves and maximum storm tide reduction rate by mangroves (MSTRRM). Also inundation maps are presented aiming to measure the areas rescued from inundation and the areas inundated caused by mangroves. The simulations shows that the minimum and maximum storm tide reduction rate by mangroves are 5.32% and 34.88% respectively.

1. Introduction

Storm surge is an abnormal rise of water in ocean or movements of sea water onto coastal lands ranging from 1 to 9 m depending on size of the storm, wind intensity and topographic location (Chen et al., 2008); they are generated by high winds, wave setup, low pressure weather system and interaction with tidal conditions (Zhao and Chen, 2013); and also a serious threat to human lives and properties in coastal areas that can cause high destructive effects in these areas specially in populated low lying ones.

Recently numerical simulations and field measurements suggest that natural vegetation, coastal wetlands and mangrove forests have the potential to reduce surges; However they may cause local increase in storm surge as the vegetation and forests lead the water toward another area (Wamsley et al., 2010).

Cruz and Santos (2013) analyzed a mangrove planting zone that mitigates typhoon – induced coastal erosion. Zhang et al. (2012) studied the role of mangroves in attenuating storm surges along the Gulf Coast of South Florida. Cao et al. (2015) presented a mathematical method that resulted in vegetation - induced wave dissipation during storms. Sheng et al. (2012) used numerical model to estimate vegetation canopies effects as natural barriers on storm surges and waves. Loder et al. (2009) studied the sensitivity of hurricane surge to morphological parameters of a coastal wetlands through a coupled hydrodynamic and wave model simulation. Möller (2006) studied the wave height dissipation caused by saltmarsh vegetation in a UK coastal saltmarsh under a digital photographic method. Jadhav and Chen (2012) studied wave dissipation over salt marsh vegetation during tropical cyclone under a field investigation and their results shows that incident waves attenuated exponentially over the vegetation. Möller et al. (2014) represented a research considering the effectiveness of marshes in protecting the coastline by wave attenuating during extreme events. Riffe et al. (2011) studied the dissipation of waves thorough natural salt marshes via two dissipation models in Skagit Bay of Washington. Mazda et al. (1997) investigated wave reduction by mangroves as a coastal protection in the Tong King delta of Japan. Lövstedt and Larson (2010) investigated vegetation-wave-damping in shallow lakes under field measurements and mathematical modeling. Gedan et al. (2011) research found that coastal wetland vegetation is an effective natural buffer for shorelines during storm surges and against erosion. Shepard et al. (2011) reviewed the conditions that coastal marshes protect coasts by flood water and wave attenuation and shoreline stabilization.

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Fig. 1. Geographical location of protected area of mangroves and satellite image by NASA of the study area.

It is important to model and investigate the defensive effect of mangroves during tropical cyclones to reduce the damage to property and loss of lives in the future. Numerical analysis based on configuration of vegetation, bathymetry and storm parameters can be effective for examining the storm surge attenuation by mangroves. Few studies have been conducted to investigate mangrove effects under the real conditions of land cover and tropical cyclone characteristics; in many researches the effect of coastal land cover is neglected by using a constant Manning's coefficient, while different types of land cover have different effects on wind stress and bottom friction force (Lui et al., 2013; McIvor et al., 2012); also physics of storm surge and surge is too complicated to be simulated with a constant rate (Wamsley et al., 2010).

In this study we investigated the effects of mangroves on attenuating storm surge during tropical cyclone Gonu 2007 occurred in Arabian Sea and Persian Gulf based on variations of actual mangrove cover and storm parameters. Cyclone Gonu is simulated by the MIKE21 flow model FM numerical model; the data used in this research is obtained from several verified datasets and also compared with local measurements.

MIKE21 developed by the DHI (Danish Institute of Technology) is a 2D hydrodynamic software. The model is applied and developed to calculate wind and wave induced currents such to simulate storm surges. It is able to perform simulations based different driving effects such as momentum dispersion, wind shear stress and also flooding and drying can be included if the model in located in an area with tidal flats. It works on the basis of full non-linear equations of continuity and conservation of momentum, Alternating Direction Implicit finite difference solution of second-order accuracy and Smagorinsky eddy formulations.

For investigating the reduction height, minimum and maximum reduction rates of height, area that mangrove rescued from inundation and also the area that mangrove caused inundation because of leading water toward them numerous runs were made under two basic scenarios:

1 The scenario that mangroves were neglected
2 The scenario that mangrove effect is considered in the model by calibrating the Land Cover data to study area and updating Manning's coefficient in the model

2. Case study

In 2002 the total global area of mangrove forests distributed in 118 countries, tropical and subtropical regions was 137,760 km^2. Mangroves are mostly occur between 30′ N and 30′ S in the inter-tidal regions (Giril et al., 2011).

Mangrove forests along Iran coasts occur between 25′ 19′ and 27′ 84'.in 2002, 93.37 km^2 of Iranian shorelines was estimated to be covered with mangrove forests. The area between Khamir port and Qheshm Island with 67.5 km^2 is largest mangrove forest in Persian Gulf (Zahed et al., 2011). (Fig. 1 and Fig. 2)

Because of large spatial scale of storm surges, accurate results would not be found in small scale projects investigating coastal wetland effects on storm surges. The simulation covers Oman Sea, Persian Gulf and whole southern coasts of Iran in order to attain a comprehensive modelling study (Lapetina and Sheng, 2014).