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12th International Conference on Hydroscience & Engineering
Hydro-Science & Engineering for Environmental Resilience
November 6-10, 2016, Tainan, Taiwan.

Afforestation as a Buffer against Storm Surge Flooding along the Bangladesh Coast

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ABSTRACT

The geographical location and climatic condition of Bangladesh are responsible for cyclone and other natural disasters. In coastal areas, afforestation is a proven cost-effective method to dissipate wave energy and reduce inundation during storm surges. In this study, hypothetical 1km wide afforestation is considered along the coast from shoreline. Here effectiveness of afforestation as a buffer against the storm surge inundation is calculated based on relative roughness of the lower part of the Sundarban. The Delft3D dashboard, flow model and distributive force model are applied to simulate the impact of coastal afforestation on inundation due to cyclone generated storm surge. From this study it has been found that around 30% velocity, 32 to 35 % thrust force and 11.41% inundated area are reduced due to coastal afforestation.

KEY WORDS: Afforestation; Buffer; Storm Surge; SIDR; Bangladesh Coast; Thrust Force

INTRODUCTION

Bangladesh very often becomes the landing ground of cyclones because of the funnel shaped coast of the Bay of Bengal. On an average, a severe cyclone strikes the country every three years (GoB, 2008) and more than 14 severe cyclones are generated in the Bay of Bengal in every ten years (IWM, 2002). Approximately one sixth of tropical cyclones that develop in the Bay of Bengal make landfall on the Bangladesh coast (Islam, Bala, Hussain, Hossain, Rahman, 2011). Cyclones in this region cause damage when it is associated with storm surge. This is because of the geographical location i.e. low flat terrain, high density of population and poorly built houses. Inundation due to cyclone induced storm surges causes significant loss in the coastal livelihood (Gonnert, Dube, Murty, Seifert, 2001). In the past 500 years a total of seven tropical cyclones with fatalities of between 100,000 and 500,000 impacted mostly Bangladesh and neighboring Indian coastlines (Singh, Khan, Rahman, 2001; Webster, Holland, Curry, Chang, 2005). SIDR, a category 4 type cyclone that devastated the coastal zone of Bangladesh in 2007, was one of the most catastrophic natural disaster causing nearly 2,388 human casualties and $2,300 billion property damage (World Bank, 2010). As the cyclone made landfall in the east of Sundarban, the mangrove couldn't reduce the thrust with its full potential.

Coastal vegetation has been widely recognized as a natural method to reduce the energy of storm surges and tsunami waves (Rahman and Rahman, 2013). Afforestation can alter surface properties relevant to climate, generate favourable atmospheric circulations for precipitation, control ground water, and increase evaporation. Using afforestation to induce favourable climate has been discussed over many years (Abiodun, Salami, Matthew, Odedokun, 2013). This was evident during cyclone SIDR but couldn't play the desired role in reducing inundation area as the landfall location was not exactly at the Sundarban. This study mainly focused on the impact of afforestation due to storm surge flooding. In this study, a hypothetical 1km wide mangrove forest is considered along the coast from shoreline. The impact of this afforestation on storm surge inundation is studied by imposing a SIDR strength cyclone to make landfall on different locations along the Bangladesh coast.

STUDY AREA

The study area comprises south-western, south central coastal region including the estuarine system of the Ganges-Brahmaputra-Meghna (GBM) delta (Rabeya, Sakib, Rahman, Sumaiya, Haque, Rahman, Islam, 2016). The Ganges-Brahmaputra-Meghna (GBM) delta is one of the world's most significant deltas that comprises world's largest mangrove forest – the Sundarban. Some of the devastating cyclones which made landfall in this region are Bhola cyclone (1970), Chittagong cyclone (1991) and cyclone SIDR (2007). It is generally believed that Sundarban acts as a buffer against the cyclone wind and surge impacts (Sakib, Nihal, Haque, Rahman, Ali, 2015).

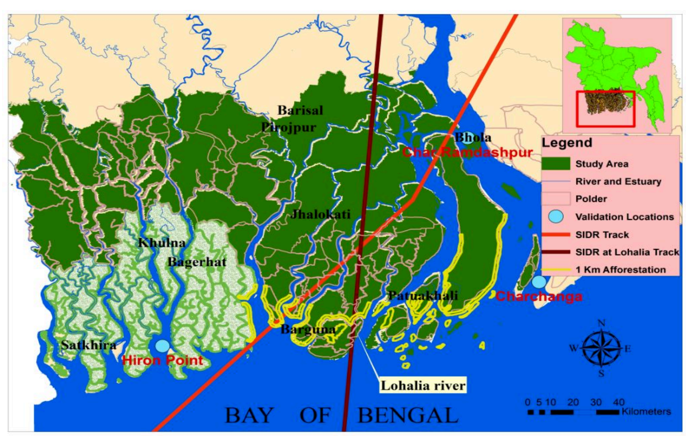

Fig. 1 Study area showing hypothetical afforestation, cyclone track and model validation locations

The lower southern part of Sundarban (35% of the total Sundarban area) is considered as densely populated with the plant habitats and thus is the most effective in reducing the thrust of a cyclone and the resulting inundation (Sakib, Nihal, Haque, Rahman, Ali, 2015). In the study area, 1km hypothetical afforestation is considered (Fig. 1). A hypothetical cyclone with the strength of SIDR is generated and allowed to make landfall in different locations of the coast. Fig. 1 shows the study area with a 1km wide hypothetical afforestation. The figure also shows the cyclone track and model validation locations.

MODEL DESCRIPTION

In this study, 2 models are applied – a storm surge model and a distributive force model. For storm surge model, Delft 3D flow model coupled with Delft Dashboard is applied. To calculate force exerted by the cyclone wind and cyclone generated storm surge, a distributive force model is applied (Akter, Haque, Rahman, Alim, 2017).Time series of discharge is specified as the upstream boundary condition, with a time series of water level for the downstream boundary condition. Discharge data is used from the measurement of Bangladesh Water Development Board (BWDB) for the year 2007. For downstream water level boundaries, tides are generated by using GCOMS (Kay, Caesar, Wolf, Bricheno, Nicholls, Islam, Haque, Pardanes, Lowe, 2015) data for the year 2007. SIDR track was collected from Indian Meteorological Department (IMD) (http://www.rsmcnewdelhi.imd.gov.in). Cross sectional data for each of the estuarine systems of the GBM delta are measured under the ESPA delta project (http://www.espadelta.net). The domain of the measurements covers the entire study area. Open access General Bathymetric chart of the Oceans (GEBCO) data is used as the bathymetry of the Bay of Bengal. The inland ground elevation data is collected from Centre for Environmental and Geographic Information Services (CEGIS), Bangladesh.

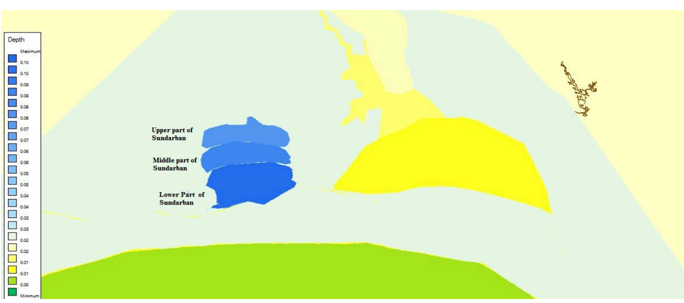

Fig. 2(a) Model Domain (Before Afforestation)

The Sundarban itself was divided into three regions (Fig. 2(a)). The lower part (35% of the total Sundarban area) was considered as densely populated with the plant habitats and thus is most effective in reducing the thrust of a cyclone and the resulting inundation. These impacts slowly diminish when middle (35% of the total Sundarban area) and upper (30% of the total Sundarban area) parts were considered (Sakib, Nihal, Haque, Rahman, Ali, 2015). In Fig. 2(a), the entire coast except Sundarban is ineffective as a buffer against the storm surge inundation. In Fig. 2(b), the coast is effective to act as a buffer against the storm surge inundation. In this study, effectiveness of afforestation as a buffer against the storm surge inundation is calculated based on relative roughness of the lower part of the Sundarban. In addition to SIDR, one hypothetical cyclone with strength similar to SIDR but different landfall location is considered.

Fig. 2(b) Model Domain (After Afforestation)

MODEL CALIBRATION AND VALIDATION

The storm surge model is calibrated and validated by using measured hourly tidal water level data during cyclone SIDR. Calibration and validation locations are shown in Fig. 1. Roughness and wind drag coefficients are used as the calibration parameters. Performances of the model during the calibration exercises are evaluated by computing the model reliability (Haque, Sumaiya, Salehin, Rahman, 2017). Using this indicator, the maximum model reliability of the storm surge model for the 'most acceptable model parameters' is obtained approximately 60%. The calibrated model is then validated where measured hourly tidal water level data was available during the time of landfall of the cyclone. The calibration and validation performances of the model are shown in Fig. 3.

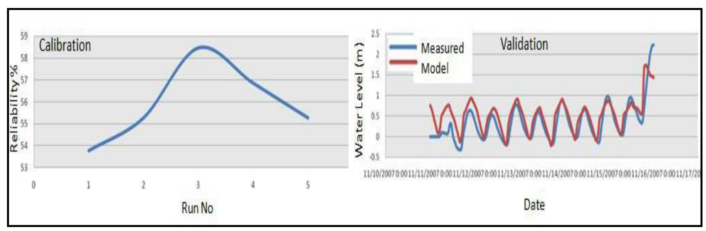

Fig. 3 Storm Surge Model Calibration and Validation

RESULTS

Inundation

SIDR Actual Case (Before and After Afforestation)

For SIDR actual case when no afforestation is considered along the coast, significant inundation takes place in the lower and upper south central coast (Figs. 4~5). Although the landfall of cyclone SIDR was close to the Sundarban, its effectiveness to reduce the impacts of cyclone and storm surge was not noticeable in this particular case. The reason is – landfall location of SIDR was in the east of Sundarban, whereas, the maximum sustained wind speed of SIDR was in the further east (right side of the track due to northern hemisphere). So, Sundarban did not have the scope to play its role. In a previous study, it was found that Sundarban as a buffer against storm surge is effective when landfall location of a cyclone is exactly at Sundarban (Sakib, Nihal, Haque, Rahman, Ali, 2015). After introducing 1 km wide afforestation, reduction of inundation area and inundated depth is noticeable. No inundation is found in the lower central region where effectiveness of afforestation is the maximum.

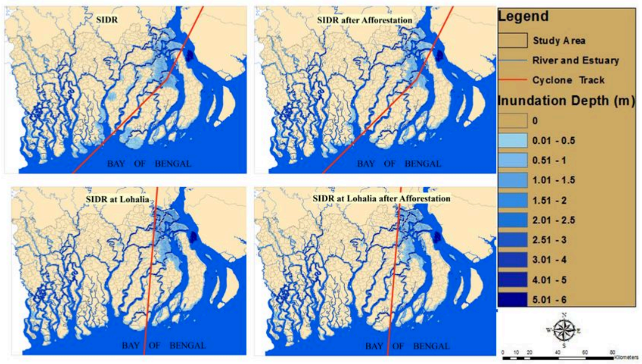

Fig. 4 Areal extent of inundation due to SIDR and SIDR at Lohalia before and after afforestation

SIDR Landfall at Lohalia (Before and After Afforestation)

Without afforestation when a cyclone similar to the strength of SIDR made landfall at the mouth of Lohalia river (Fig. 1), there is significant inundation in the upper central coast of the region (Figs. 4~5). Introduction of afforestation for the same cyclone reduces the extent of inundation (Figs. 4~5).

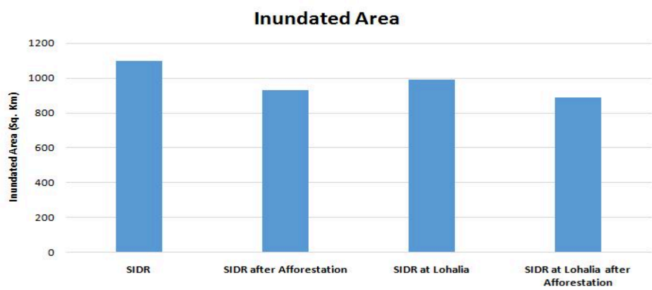

Fig. 5 Inundation area due to SIDR and SIDR at Lohalia before and after afforestation

Polder Overtopping

A polder is a low-lying tract of land enclosed by dikes that forms an artificial hydrological entity, meaning it has no connection with outside water other than through manually operated devices. Polders are at risk from flooding at all times, and care must be taken to protect the surrounding dikes. Dikes are typically built with locally available materials, and each material has its own risks: sand is prone to collapse owing to saturation by water; dry peat is lighter than water and potentially unable to retain water in very dry seasons. Initially polders helped protecting agricultural land from salinity during the dry season, while also allowing fertile silt to settle on the fields and flood plains during the monsoon. Dutch-style polders were deemed the optimal solution for the dual purpose of flood protection and providing food security through better water control, independent of local ecology. Polders have also some negative impacts like preventing the silt from the rivers from being deposited on the flood plains, resulting in high rates of sedimentation, congesting both rivers and canals and causing many of them to dry out over a period of decades. The sedimentation in the riverbeds raised water levels in the rivers higher than the land within the embankments and led to drainage congestion, which later became permanent water logging. The maximum, minimum and average polder heights in the study region are 5.75m, 4.5m and 4.79m respectively (Source: Bangladesh Water Development Board and Center for Environmental and Geographic Information Services data archives).

SIDR Actual Case (Before and After Afforestation)

For SIDR actual case several polders were overtopped in the lower central coastal region. After introducing 1 km wide afforestation, reduction of inundation depth is noticeable (Fig. 4). As a result, no polder overtopping incident occurred for SIDR actual case (Fig. 6).

SIDR Landfall at Lohalia (Before and After Afforestation)

When a hypothetical cyclone similar strength as SIDR made landfall at Lohalia, the region inside the polder was fully protected from surge water (Fig. 6) as the polder heights of the right side of the track are much higher than the polders which were overtopped during SIDR actual case. The scenario was similar i.e. no polders were overtopped after considering 1 km wide afforestation (Fig. 6). Fig. 6 depicts polder overtopping incident for both SIDR and a hypothetical cyclone, strength same as SIDR.

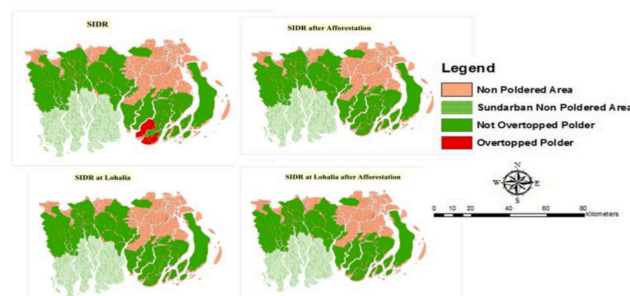

Fig. 6 Polder Overtopping Map for SIDR and Hypothetical Cyclone Strength Similar to SIDR (Before and After Afforestation)

Reduction of Velocity Magnitude

SIDR Actual Case (Before and After Afforestation)

For SIDR actual case when no hypothetical afforestation was considered, magnitude of velocity was noticeable in the encircled area (Fig. 7). The magnitude of velocity in the encircled area was 2 to 5 m/s (Fig. 7). On the other hand, after considering 1 km wide afforestation along the coast, reduction of velocity magnitude was found 30% for the same encircled area. The maximum magnitude of velocity lowered to 3.5 from 5 m/s in the encircled region.

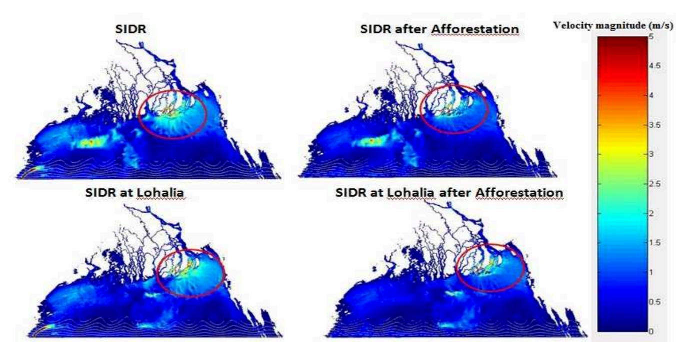

Fig. 7 Velocity Magnitude Map for SIDR and Hypothetical Cyclone Strength Similar to SIDR (Before and After Afforestation)

SIDR Landfall at Lohalia (Before and After Afforestation)

After landfall of a SIDR strength cyclone at Lohalia, the magnitude of velocity in the encircled area was found 2 to 5 m/s (Fig. 7). But this magnitude reduced to 3.5 from 5 m/s when same cyclone made landfall at 1 km wide afforested coast. So velocity reduction was 30%.

Thrust Force

SIDR Actual Case (Before and After Afforestation)

Coastal vegetation has been widely recognized as a natural method to reduce the thrust force of storm surges (Rahman, Rahman, 2013) which has also been proved after applying a distributive force model (Akter, Haque, Rahman, Alim, 2017) for this study. For SIDR actual case maximum thrust force was found 115 KN/m around cyclone landfall location (Fig. 8).Magnitude of thrust force had been reduced 34.78% after considering 1 km wide afforestation (Fig. 8).

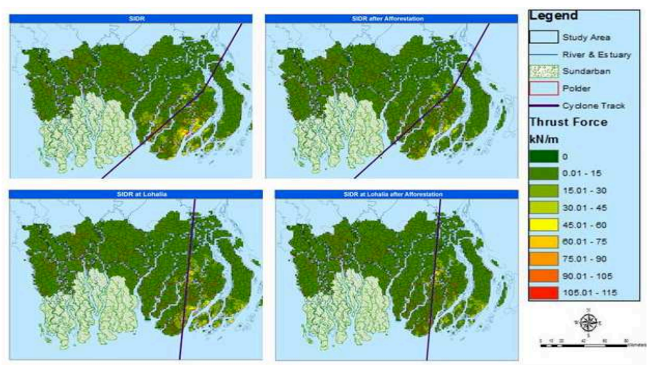

Fig. 8 Thrust Force Map for SIDR and Hypothetical Cyclone Strength Similar to SIDR (Before and After Afforestation)

SIDR Landfall at Lohalia (Before and After Afforestation)

After landfall of a hypothetical cyclone similar strength as SIDR at Lohalia, thrust force was found about 100 KN/m around landfall location (Fig. 8). But the value of thrust force reduced 32% when this cyclone made landfall at 1 km wide afforested coast (Fig. 8).

CONCLUSIONS

For both SIDR actual and a hypothetical cyclone similar strength as SIDR, one kilometer wide hypothetical afforestation reveals the following:

(1) Coastal afforestation plays an important role in decreasing inundation area, depth and velocity magnitude.
(2) Reduces polder overtopping incident
(3) Coastal afforestation works as a buffer in reducing thrust force

Bangladesh often suffers from cyclonic storm surges that cause severe damages to human life and property. So afforestation along the coast can play significant role as an adaptive measure by working as a buffer against the cyclone-generated storm surge flooding.

ACKNOWLEDGEMENTS

This work was carried out under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA), with financial support from the UK Government's Department for International Development (DFID) and the International Development Research Centre (IDRC), Canada. The views expressed in this work are those of the creators and do not necessarily represent those of DFID and IDRC or its Board of Governors. Website: www.deccma.com

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