Mangroves as Protection from Storm Surges in a Changing Climate (WPS 7596)

Scientific literature to date emphasizes the role of mangroves in protecting adjacent coastal land from the impacts of inundation and erosion, both during natural disasters and through their longer-term influence on coastal dynamics. The flow of water through the mangrove forest is obstructed by the matrix of roots/ trunks of the mangrove trees, which creates bed resistance. Hence, mangroves can substantially reduce vulnerability and risk from wind waves and storm surges,[1] providing "natural protection."

The global scientific community has developed various models of the wave/storm surge attenuation processes. One of the main factors affecting wave height decline is cross-shore distance. Other factors include tree density, stem and root diameter, shore slope, bathymetry, spectral characteristics of incident waves, and tidal stage upon entering the forest. However, in a cross country study like the one presented in this paper, specifying location-specific bathymetry, mangrove species (their allometric characteristics: trunk width, root system and leaf area which determines the extent of bed resistance to the flow of water from storm surges), forest density, and forest width is beyond the scope of the analysis. Instead, the coastal protection services of mangroves was estimated using the algorithm described below:

1. The storm surge inundation zone protected by mangroves was derived from the inundation zone modeled for an extreme 100 year return period storm surge[2] with mangroves and a storm surge zone without mangroves (the counterfactual). The inundation area protected by mangroves (mangrove protection zone) was only calculated upstream of an area of mangroves greater than 3 arc seconds (90 sq. m).

$$SS\_PA = SS * wave_n - SS * wave_m$$

   Where *SS_PA* refers to the storm surge inundation area with protection, *SS* refers to the 1 in 100 surge height in meters, *wave* refers to the wave attenuation function, *n* refers to without mangrove and *m* refers to with mangrove.

2. For storm surge areas without mangroves, a linear distance decay of waves of 6.3 cm/km, where *d* is the distance in meters, was adapted from observational data summarized in McIvor et al. (2012) for salt marsh:

$$wave_n = \left(\frac{0.063m}{1000m}\right) * d$$

3. For areas with mangroves, using estimates from Zhang et al. (2012), the wave reduction was derived from the following:

$$wave_m = 80 * \exp(-0.3375 * d) + 16.75$$

4. The total of the cumulated wave reduction in meters calculated from step 2 and step 3 above and elevation above sea level[3] was subtracted from the storm surge wave height. If the result is positive, it is marked as an area of inundation.

5. The above mentioned computation was conducted for each grid cell.

6. Finally, the GIS modeling approach in ESRI ArcGIS used a cost-distance (path distance) function that accumulates the least-cost path planametrically across each cell (wave height) to adjust for direction and elevation.

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[1] *Storm surge* refers to the temporary increase in the height of the sea level due to extreme meteorological conditions: low atmospheric pressure and/or strong winds.

[2] It is a statistical measure of the average recurrence interval over a long period of time and is the inverse of the probability that the event will be exceeded in any one year. A 100 year storm surge has a 1% chance of occurring in any given year.

[3] Elevation data are from SRTM, and elevation of mangroves is modified as zero meter above sea level.

For this analysis, information was provided by Giri et al. (2010) on the extent and distribution of mangroves from the global mangrove databases of the USGS: Earth Resources Observation and Science Center. In this database, the status and distributions of mangroves were mapped using the 30-m resolution Global Land Survey (GLS) data for 2000 supplemented by Landsat archives. The GLS 2000 mosaics were prepared using images acquired from 1997 to 2000. Landsat imagery from the USGS archives was used if GLS data were cloudy. While mapping, each image was normalized for variation in solar angle and earth-sun distance by converting the digital number values to the top-of-the-atmosphere reflectance. The results were validated with other existing global, regional and local data sets (for details, see Giri et al. 2010). The USGS database includes a presence or absence grid cells showing the exact location, size, and shape of the mangroves.

In order to estimate coastal mangrove areas by country, vector coastline masks were extracted from SRTM version 2 Surface Water Body Data provided by NASA, and the country and region identifiers from the World Bank were used. Country boundaries along with mangrove data were used to estimate the extent of coastal mangrove forests, by country. This analysis was restricted to countries with previous exposure to tropical cyclones (UNEP/GRID 2009). A total of 46 countries met the criteria for inclusion in this study (for country coverage, see Box 1). While other countries have mangrove forests, the absence of cyclones makes their storm protection service less important.

Box 1:

- East Asia and Pacific (18): China; Fiji; Hong Kong SAR, China; Indonesia; Macao SAR, China; the Federated States of Micronesia; Myanmar; Palau; Papua New Guinea; Philippines; Samoa; Solomon Islands; Taiwan, China; Thailand; Timor-Leste; Tonga; Vanuatu; Vietnam.
- Latin America (20): Antigua and Barbuda, Belize, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Grenada, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, República Bolivariana de Venezuela.
- South Asia (4): Bangladesh, India, Pakistan, Sri Lanka.
- Sub-Saharan Africa (4): Comoros Islands, Madagascar, Mozambique, Seychelles.

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