STORM SURGE INUNDATION ANALYSIS OF CYCLONE NARGIS EVENT

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ABSTRACT

Flooding has always been one of the major hazards in Myanmar. Cyclone Nargis was a strong tropical cyclone that caused the worst natural disaster in the recorded history of Myanmar. The Cyclone Nargis made landfall in the country on 2nd May 2008, causing catastrophic destruction and at least 138,000 fatalities along its way. The most of the fatalities in the affected area were made by the storm surge flooding in low land coastal area. Flood inundation map may be useful tools which may aid in mitigating and managing the flood hazard as non-structural measure. This map should be generated by using a numerical simulation model which is capable of estimating inundation processes. Flood inundation models may be useful predictive tools which may aid in mitigating and managing the flood hazard. In recent years, a simple two-dimensional hydraulic model has been successfully applied to solve the several floodplain problems. The research undertaken within this thesis indicates the applicability of such modelling techniques for the determination of flood extents for storm surge flooding at coastal area. This model is based on two-dimensional raster storage cell approach and uses the simplified hydraulic treatments based on a dimensional analysis of one dimensional shallow water equations. Model inputs included floodplain friction, time-series water surface elevations, hourly rainfall data and digital elevation models (DEMs). For the whole delta area, the model domain is simulated under two conditions by using DEM with 15sec (~500m) resolution. The first condition is only considered the flooding caused by storm surge and the results are compared with observed data. It is obvious that some inundated areas cannot be predicted under this condition. Therefore, the second condition is considered the flooding caused by both storm surge effect and rainfall-runoff effect. This result has the close agreement with satellite inundation map. To provide the required information for structural measures, one area is selected from delta region, and levees are ideally constructed within study area. And then it is simulated under this condition by using 3sec (~90m) resolution DEM. This result indicates that the areas below the elevation 6 m are covered with levees or embankments by which this island can be prevented from such flooding.

Key words: *storm surge, simplified two-dimensional model, DEM, friction parameter, Cyclone Nargis*

INTRODUCTION

Myanmar, borders with the Bay of Bengal and Andaman Sea, with its 2400 km long coastline is potentially threatened by the waves, cyclones and associated storm surge. Storm surge is simply water that is pushed toward the shore by the force of the winds swirling around the storm. This advancing surge combines with the normal tides to create the cyclone storm tide, which can increase the mean water level up to 5 m or more. This rise in water level can cause severe flooding in coastal areas, particularly when the storm tide coincides with the normal high tide. Cyclone Nargis was a strong tropical cyclone that caused the worst natural disaster in the recorded history of Myanmar. This severe cyclone made landfall in Ayeyarwady Delta on 2nd May 2008, causing catastrophic destruction and at least 138,000 fatalities along its way. The most of the fatalities in the affected area were made by the storm surge flooding in low land coastal area. After the cyclone Nargis hit, the inland inundation in the Ayeyarwady delta area could be known from satellite images by comparison of wet land area before and after the cyclone as shown in Figure 1.

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However, only the locations of flood could be found by the images, not the inundation level of flooded water by the storm surge. Moreover, some locations shown in the satellite images did not clearly indicate if inundated or not, because the land could not be measured accurately by the satellite images when the area was covered by dense canopies of forest. The aim of this study is to get the inundation level of flood over the affected area and understand more about the mechanism of the storm surges flooding induced by Cyclone Nagris in Ayeyarwady Delta through numerical simulation.

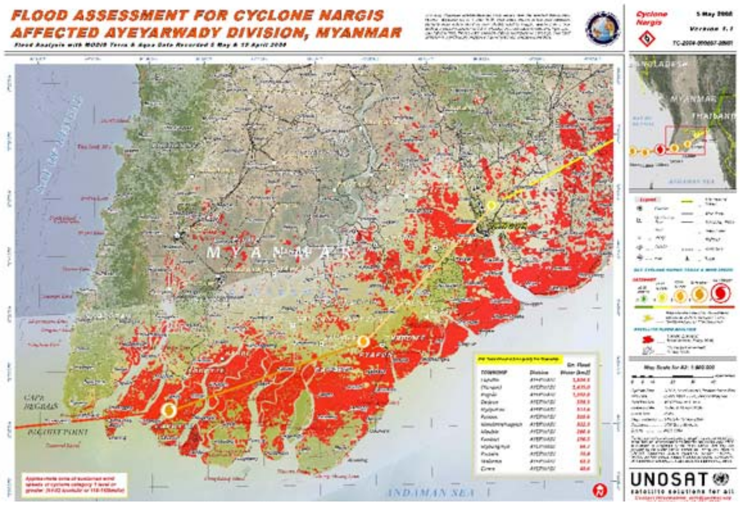

Figure 1. Flood inundated area detected from satellite

STUDY AREA

Ayeyarwady Division is located at the southern end of the central plain of Myanmar. Moreover Ayeyarwady division is mostly in delta region and cross by many rivers as the Ayeyarwady River which constitute the most important river system in Myanmar. The Ayeyarwady Delta is a large delta with wetlands and mangrove forests, which provides partial protection from storm waves. The delta front is wide with shoals in some places, thus slowing down the speed of tsunami; however, most part is opened to the storm surge. According to the natural condition, Ayeyarwady Delta has the highest vulnerability to the storm surge as it occupies lowest altitude, and high water volume because of numerous tributaries, several open or bell shape river mouths and very shallow slope.

On 2 and 3 May 2008, Cyclone Nargis struck the coast of Myanmar and moved inland across the Ayeyarwady Delta and Southern Yangon Division, causing many deaths, destroying livelihoods, and disrupting economic activities and social conditions. During the Cyclone Nargis, the sea level was raised by interaction of wind, surge and tide, and then propagated to inland along the tributaries of Ayeyarwady River which caused the extreme flooding in low land coastal areas. The highest surge in Pyinsalu (Laputta Township) of 7.01 m occupied 90 percent of land for several hours. Assessment data show that some 2.4 million people were severely affected by the cyclone, out of an estimated 7.35 million people living in the affected townships. As of June 24, 2008, the official death toll stood at 84,537 with 53,836 people still missing and 19,359 injured. Moreover, the disaster caused widespread destruction to home and critical infrastructure, including roads, jetties, water and sanitation systems, fuel supplies and electricity. The devastating impacts of Cyclone Nargis on the environment and livelihood based on local communities have increased people’s vulnerability to future natural hazards. Deforestation and forest degradation are as a result of Nargis.

MODEL DEVELOPMENT

Governing Equation: Often the full two-dimensional Saint Venant description of shallow water flow is unnecessary and various simplification that neglect different terms of the momentum equation have been proposed. A complete set of governing equations for simplified two-dimensional flood modeling comprises one of the simplified forms of the momentum equation, and a continuity equation. Continuity (or the law of conservation of mass) relates the volume in a given computational cell to the flows into and out of it during a time step. The continuity equation can be written as;

$$\frac{\partial V^{i,j}}{\partial t} = Q_x^{i-1,j} - Q_x^{i,j} + Q_y^{i,j-1} - Q_y^{i,j} \tag{1}$$

where V is the volume in cell (i, j), t is the time and $Q_x^{i-1,j}, Q_x^{i,j}, Q_y^{i,j-1}$ and $Q_y^{i,j}$ describe the volumetric flow rates (either positive or negative) between adjacent flood plain cells in the x and y Cartesian direction respectively. The continuity equation for the cell (i, j) can therefore be written as;

$$\frac{dh^{i,j}}{dt} = \frac{Q_x^{i-1,j} - Q_x^{i,j} + Q_y^{i,j-1} - Q_y^{i,j}}{\Delta x \Delta y} \tag{2}$$

where Δx and Δy are the grid cell dimensions. In this study, the above differential equation is solved by using the Adaptive Stepsize Control Runge-Kutta method. Each floodplain cell is thus treated as an individual storage element, and a simplified momentum equation is used to calculate the inter-cell fluxes. To date the momentum equation has typically been based on either empirical hydraulic relationship, such as Manning's equation;

$$Q_x^{i,j} = \frac{h_{flow}^{5/3}}{n} \left(\frac{h^{i-1,j} - h^{i,j}}{\Delta x}\right)^{\frac{1}{2}} \Delta y \tag{3}$$

where n is the Manning's coefficient and the flow depth, h_{flow}, represents the depth through which water can flow two cells. Significant advances in flood inundation modeling have been made in the recent years through the use of simplified 2D hydraulic numerical models. These models have been used to estimate the inundation processes not only for rainfall runoff simulation but also for coastal flooding cases throughout the world.

Data Preparation: Two of the principle properties of the floodplain which affect the movement of the flood wave are friction caused by land cover and surface relief. Generally, five kinds of data are required: (1) topographic data or DEM to construct model grid (2) time-series storm surge level to provide as downstream boundary condition (3) hourly rainfall data to calculate surface flow (4) friction parameters for study area, and (5) some validation data. Floodplain topography is the principal variable that affects the movement of the flood wave. DEMs data are downloaded from USGS (U.S. Geological Survey) website. 15sec resolution DEM is used to simulate for large area and which is shown in Figure (2). It was difficult to obtain the recorded storm surge level data which is derived by using interpolation method based on observed peak surge height and known time history function. Figure (3) presents the time-series storm surge level during Cyclone Nargis event. Floodplain land cover causes friction that affects the movement of the flood wave. Given a lack of detail land cover information of study area, average various friction parameters have been used in this study. The range of Manning's n value from 0.04 to 0.1 is used over the whole domain until to get the best results. Amounts and arrival times of rainfall associated with cyclones are highly unpredictable. Cyclone may dump as much as 12 in (300 mm) of

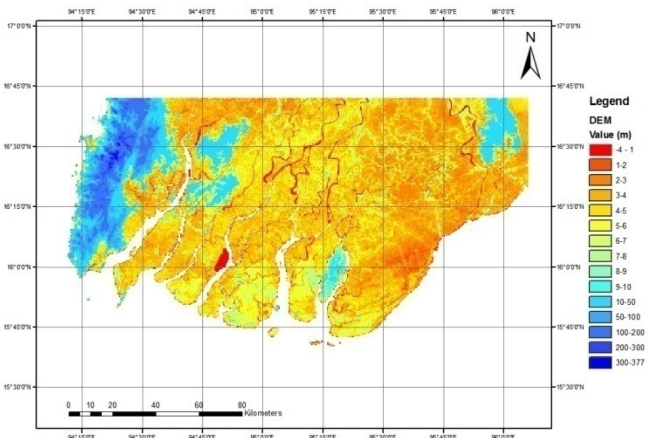

Figure 2. DEM of Ayeyarwady Delta

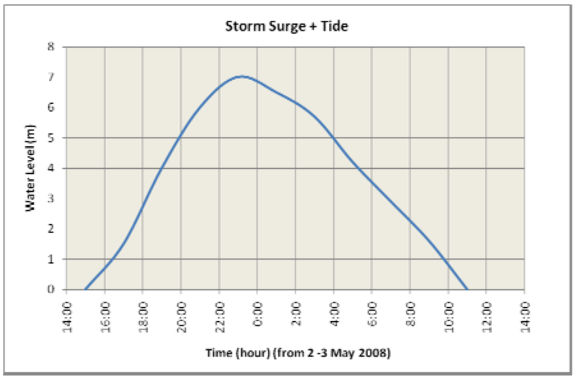

Figure 3. Time-series storm surge + tide level

rainfall in 24 hours over large areas, and higher rainfall densities in localized areas. As a result, watersheds can quickly surge water into the rivers that drain them. This can increase the water level near the head of tidal estuaries as storm-driven waters surging in from the ocean meet rainfall flowing from the estuary. In this study, hourly rainfall data is downloaded from GSMaP website and the amount of rainfall is 105 mm for total 20 hours. Fortran Program is used to simulate the storm surge flooding at study area. The solution domain in the program is discretized into uniform grid elements. The computational procedure for overland flow involves calculating the discharge across each of the boundaries in the eight potential flow directions and begins with a linear estimate of flow depth at the grid element boundary. The updated water level for each time step is determined by dividing the rate of change of discharge per flow area for each boundary.

RESULTS AND ANALYSIS

Simulation Results of Ayeyarwady Delta: The model domain includes the 80311 number of grid cells and covers the area of 16500 km^2. In order to simulate the large area, 15sec resolution DEM is used for this study. First, the simulation does not include the rainfall-runoff effect and only consider the storm surge effect. The model is run for a total 20 hours starting from 15:00 hours (2 May 2008) to 11:00 hours (3 May 2008) based on Myanmar Standard Time (MST). These results cannot be accepted when they are compared with the satellite image and available observed data. It is obvious that the flooding was caused due to not only storm surge but also rainfall-runoff effect. Therefore, the model domain is simulated by considering both storm surge and rainfall-runoff effect. To aid in the determination and understanding of any variations in flood inundation extent, flood extent maps with different time periods can be seen in Figures 4 (a, b, c, d). The study area has been begun to inundate 3 hours after starting time of simulation and then inundated areas are extended with successive time. Most of the areas within study domain are inundated 9 hours after starting time. According to the simulation results, Laputta, Bogale, Phyapon, and Dadye Townships were severely affected by tidal surge.

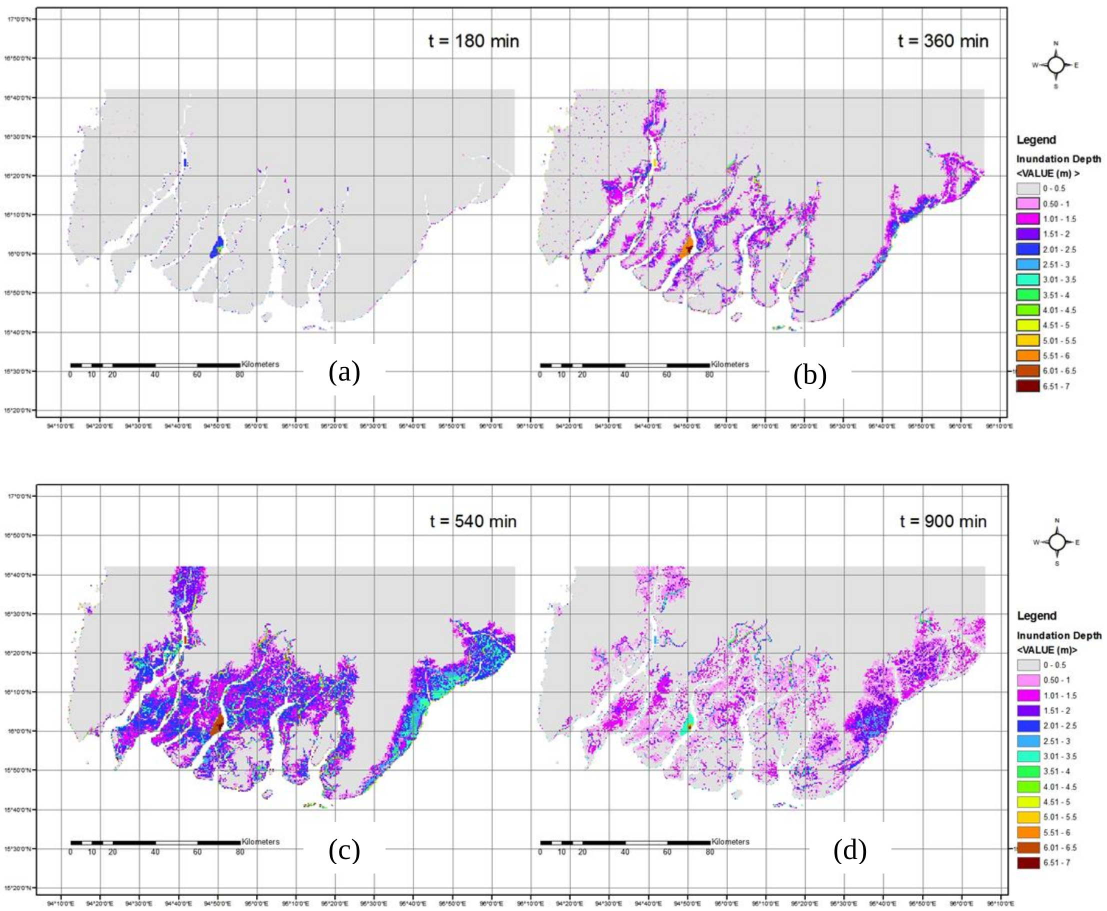

Figure 4. (a, b, c, d) Flood inundated area and inundation depth with different time periods

Figures 4 (a, b, c, d) simply show the inundation extent and flood depth with different time respectively, and the difference is noticeable as Figure 4 (d) which is closed to the end of simulation period and water has begun to recede. Figure 5 shows the maximum inundation depths and maximum flood inundated area caused by Cyclone Nargis. Storm surge rolled over the low lying areas which were flooded with up to 2 to 5 meters of salt water. Further amplifying the storm surge's height was the fact that Nargis was moving slowly, since there was more time for the surge to propagate inland.

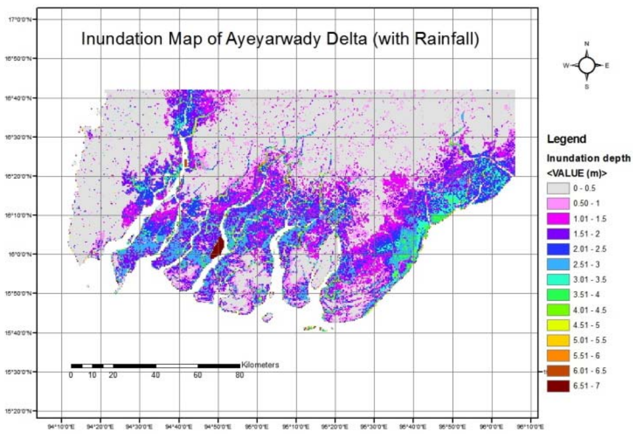

Figure 5. Simulated flood inundation depth and area

Validation of Results: For the model validation, the predictions of inundation extent and depths should be compared with observed data. However, local information was difficult to obtain due to the negative impact of Nargis flooding. Therefore, available satellite image is used to compare with simulation result. The simulated inundation extent has close agreement with observed satellite image (Figure 1 and Figure 5). In particular, in some areas, small difference is made to predicted inundation extent for the range of friction coefficient. In addition to the spatial extent of inundation, measurement of depth on floodplain would be ideal for validating the predicted movement of flood wave. The depth of flooding is an important fact to be considered when assessing the amount of damage caused to property. Therefore, the simulated inundation depths are also compared with the available observed data which are shown in Figure 6. It can be seen that the observed inundation depths are larger than simulated results. The differences between them are around 0.5 m. One of the possible reasons for this may be due to average topography data, and which estimated slopes may be difference from the actual situation of study domain. To that end, the data used in the new generation of simple flood inundation models are critical to the prediction of inundation extent.

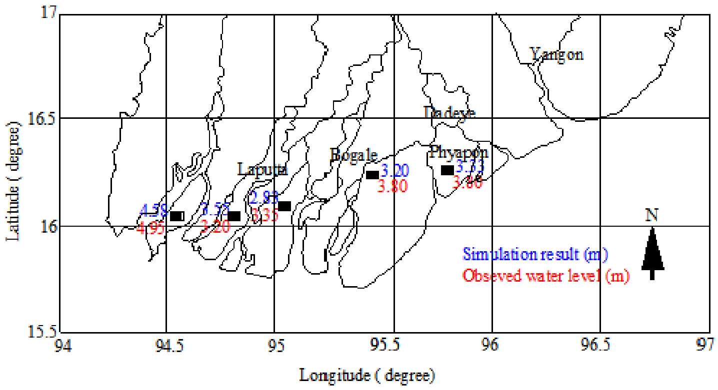

Figure 6. Comparison of inundation depths

Simulation Results of Ugaungpu Island: The embankments or levees should be constructed to prevent from such disaster at low-lying coastal areas. To provide the required information for structural measures, one area is selected from delta region, and levees are ideally constructed within study area, and then it is simulated including this counter-measure. Ugaungpu Island is located within Ayeyarwady Delta, and it was totally inundated during Cyclone Nargis. This selected area is simulated with and without levee in this section. DEM with 3ses

Figure 7. Simulation of Ugaungpu Island with different scenarios

(~ 90 m) resolution has been used for this duty. Figure 7 presents the three different conditions considering in simulation.

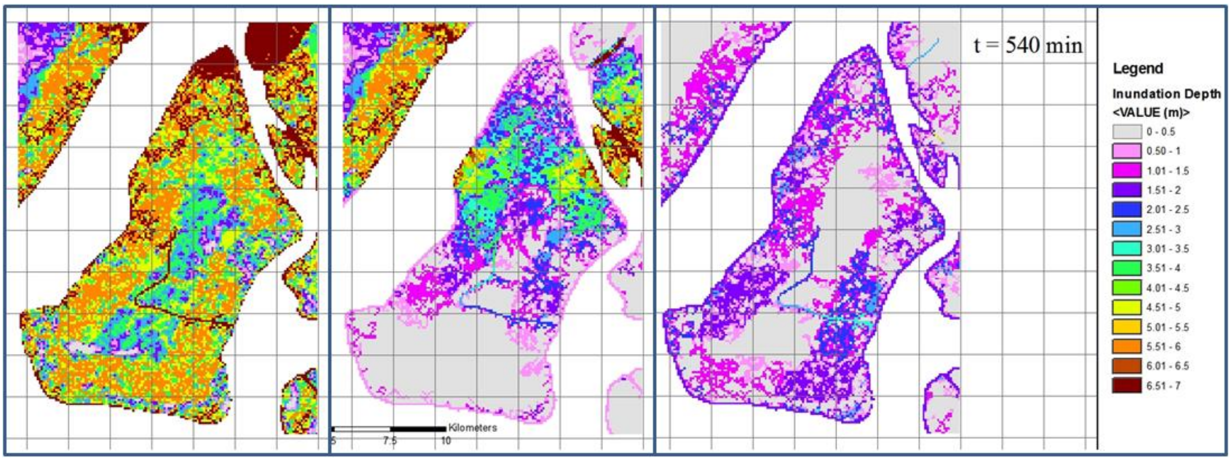

Figure 8. Simulation results of Ugaungpu Island with different scenarios

According to the results, this area is totally inundated 6 hours after running time if there are no levees. The inundation depths within this area are around 5 meters. When we use the discontinuous levee with 6 m height, some of the areas cannot be protected from flooding and also the inundation depths of unprotected areas are still high. Therefore, we try to investigate by using the continuous levee with 5 m height and the simulation results of different scenarios are shown in Figure 8. It is useful to assess the inundation extent on the study area by making reference with levee. The areas below the elevation of 6m (above mean sea level) are covered with levees or embankments by which this island can be prevented from such flooding.

CONCLUSION

According to the simulation results, Laputta, Bogale, Phyapon, and Dadye Townships were severely affected by tidal surge. Most of these areas were inundated 9 hours after starting time. Analysis of simulation results makes it obvious that the areas below the elevation of 7m are particularly vulnerable to flooding. Flood inundation simulation model can be used to find the required information for floodplain management such as inundated area, inundation depth and height of embankment. All the parameters employed in the model are physically based, and almost model input data can be acquired from open source data, and therefore it is possible to apply the model for flood hazard management in poor data environment.

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