River flood inundation mapping in the Bago River Basin, Myanmar

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Abstract:

Flood inundation maps were generated in the Bago River Basin, Myanmar. Although the design of our study was not new, it is one of very few to have analyzed a flood inundation area in Myanmar. Nine flood events were applied to calibrate and validate the results. The flood-inundated area was validated with satellite image for the year 2006. The flood inundation maps with different return periods were delineated. Considering the 50- and 100-year return period flood scenario, the highest depth of inundation may affect the urban area of Bago. The information derived from this study can contribute to assessments of potential flood damage for the local region and for other locations where data is limited.

KEYWORDS   flood inundation maps; Bago River Basin

INTRODUCTION

Although floods occur most years in monsoon-affected countries, many countries still lack flood hazard maps to prevent or mitigate the damage. This is particularly true of flood prone countries such as Myanmar. Various studies were conducted on the effects of Cyclone Nargis in 2008 (ADPC and DMH, 2008; Fritz *et al.*, 2009; UN-HABITAT, 2011). However, scientific investigation on river flood disasters is very limited in Myanmar, with only limited studies related to soil loss modeling and morphometric analysis (Hlaing *et al.*, 2008) and climate change scenario analysis (Htut *et al.*, 2014) in the Bago River Basin.

In order to address this issue, we developed hydrologic and hydrodynamic models and generated flood inundation maps focusing on the Bago River Basin. Although the design of our study is not new, it is one of very few to have analyzed the flood inundation area in Myanmar. Furthermore, our study is significant because a local climate and hydrological dataset, as well as a topographic dataset, were used to assess the possible flood inundation in the data-scarce country of Myanmar.

Numerical flood simulation models are a useful tool for quantitatively evaluating flooding, which enables researchers to qualitatively evaluate hazard and health risk caused by flooding; however, the approach has disadvantages relating to insufficient datasets in developing countries (Hashimoto *et al.*, 2014). In developing proper assessments and flood control measures to prepare for the next flood disaster, it is important to develop a solid understanding of the actual situation surrounding this flood, including the root causes of flood damage (Komori *et al.*, 2012).

GENERAL DESCRIPTION OF THE STUDY AREA

The Bago River Basin is a flood prone area in Myanmar. During 2011, two severe floods occurred in the Bago River Basin in July and August. Nearly all of the rivers and creeks were flooded and an adjacent paddy field area of 498 km² was inundated. Thousands of households and properties were also affected with the duration of inundation above five days for each event.

The Bago River originates from a central mountainous region named Bago Yoma and the largest portion of the river itself is within the Bago Region. A small portion of the river outlet is in Yangon Region where the Bago River joins the Yangon River and, from there, enters the Gulf of Mottama. The basin has a catchment area of 5,348 km², and the main river is about 331 km long. Annual total rainfall at Bago station is about 3,300 mm. Only two rain-gauge and water level stations, Bago and Zaung Tu, are located in the Bago River Basin. The location of the Bago River Basin is shown in Figure 1.

In the Bago River Basin, Zaung Tu dam for electricity and a diversion weir for irrigation use were constructed in 1996 and 1998, respectively. A levee running from Bago city to Tarwa was constructed at the left bank due to topographic conditions. For the purpose of flood control, three earthen dams, namely Kodukwe, Salu and Shwelaung, were constructed and completed in 2012. A flood diversion channel from Zaung Tu weir to Moeyongyi lake was also completed in 2012.

METHODOLOGY

In this study, Hydrologic Engineering System and River Analysis System developed by Hydrologic Engineering Center, US Army Corps of Engineers (HEC-HMS and HEC-RAS) were utilized as the hydrologic and hydrodynamic models using HEC-GeoHMS and HEC-GeoRAS for linking to a GIS environment. HEC-HMS is widely applied in many water resource studies with reliable outputs (He and Croley, 2007; García *et al.*, 2008; Chen *et al.*, 2009; Olang and Fürst, 2011; Alaghmand *et al.*, 2010, 2012; Joo *et al.*, 2014; Kawasaki *et al.*, 2013). Data were collected from various sources, mainly from the Myanmar government (Table I).

The procedure for developing the flood inundation maps consisted of four steps: (i) extraction of geospatial data, (ii) development of design flood hydrographs, (iii) computation
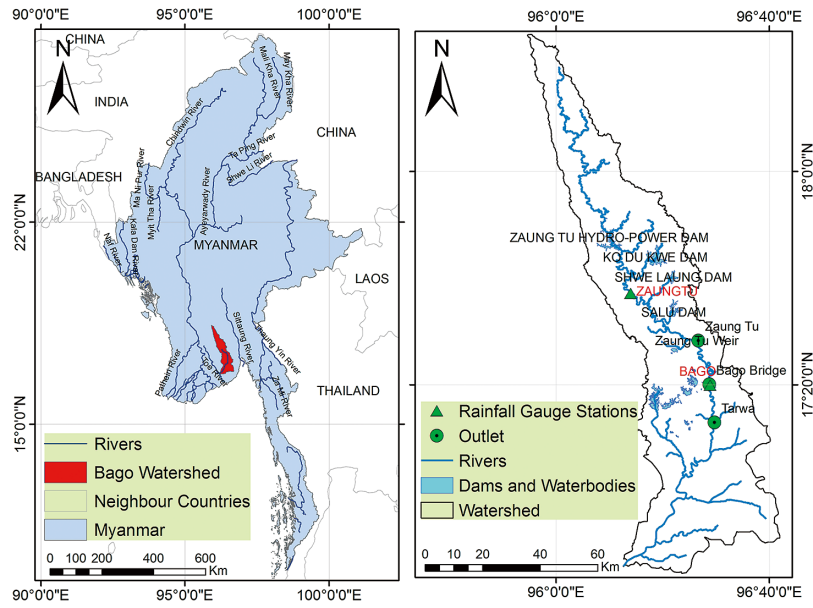
Figure 1. Location of the Bago River Basin, Myanmar

Table I. Data source

Used dataset	Sources
Daily precipitation [1967–2013]	Department of Meteorology and Hydrology
Daily water level [1987–2013]	
Rating curve for Bago and Zaung Tu	
Daily reservoir outflow [2011–2014]	Department of Hydropower
Channel surveyed elevation data and map [2013]	Directorate of Water Resources and Improvement of River Systems
48 river cross sections [2014]	Irrigation Department
Edited 10m- Digital Elevation Model	Khaing (2014)
Land cover map [2009]	The European Space Agency GlobCover
Soil map [2003]	FAO-UNESCO The Digitized Soil Map of the World
PALSAR image of Advanced Land Observing Satellite (ALOS) [2006]	Japan Aerospace Exploration Agency (JAXA)

of water surface profiles and (iv) floodplain mapping and visualization. The overall methodology is shown in Figure 2.

The flood events were applied to the HEC-HMS model using calibration and validation approaches. The design flow hydrographs were generated by HEC-HMS. Water surface profiles were generated by HEC-RAS. The flood inundation map was generated for the 50 km reach of the Bago River. Two statistical criteria were used to evaluate the calibrated model performance, namely Pearson's coefficient of determination (R^2) and Nash and Sutcliffe model efficiency (NSE). Flood inundation maps were developed for different return periods – 2, 10, 50 and 100 year as future scenarios.

Hydrological modeling

Hydrological modeling in this study was conducted up to the Tarwa outlet across a catchment study area of 2,800 km². HEC-HMS was used for hydrological modeling. Soil Conservation Service (SCS) curve number and SCS unit

hydrographs were selected for the loss and transform methods, respectively. Recession and lag methods were assigned for the base-flow and routing methods, respectively. Flood inundation mainly occurred in the lower part of the Bago River Basin. The lack of rainfall data in upper part of the Bago River Basin did not seriously affect flood estimation of Bago station. Zaung Tu and Bago rain gauge stations are located in middle part of the Bago River Basin. Rainfall data for the middle part of the Bago River Basin dominated the Bago flood estimation; more rain gauge stations will lead to better results in terms of model calibration.

The time of concentration was 57 hours, with the model parameter set optimized using individual events. Six flood events between 2004 and 2008 were selected for the calibration process. In the calibration procedure, six parameters were adjusted, including initial abstraction, curve number, base-flow initial flow rate, recession constant, base-flow threshold ratio and SCS lag. Six different events were cali-
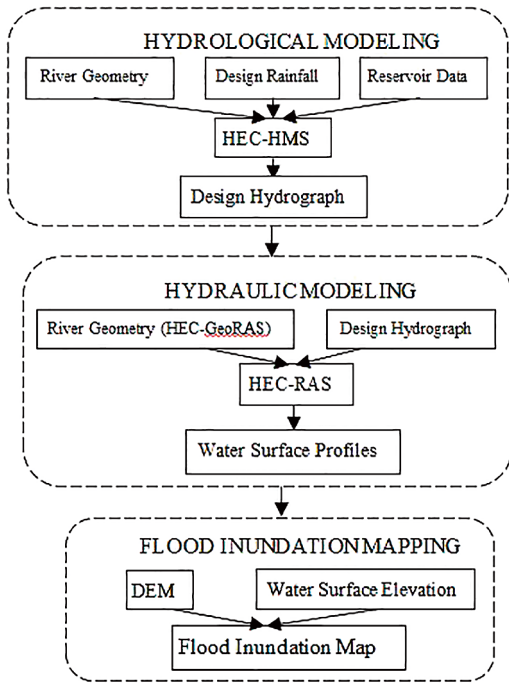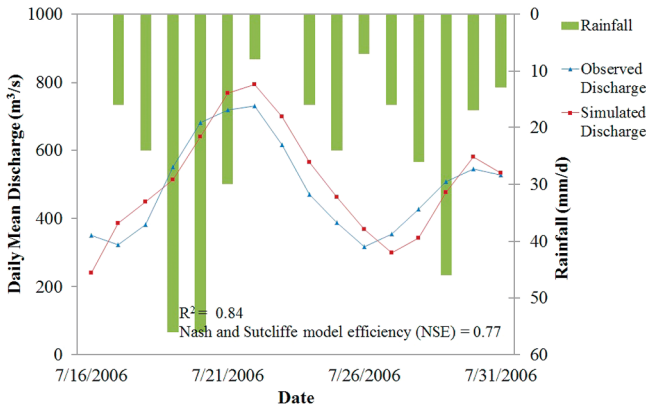
Figure 2. Overall methodology

Table II. Validation results of discharge at Bago station

Flood events	2009	2010	2011
NSE	0.82	0.78	0.66
R^2	0.52	0.91	0.73

Figure 4. Observed and simulated hydrographs in the validation process for the 2010 flood event at Bago station
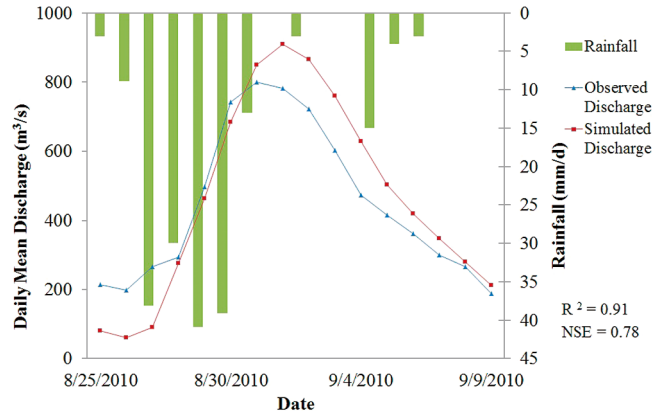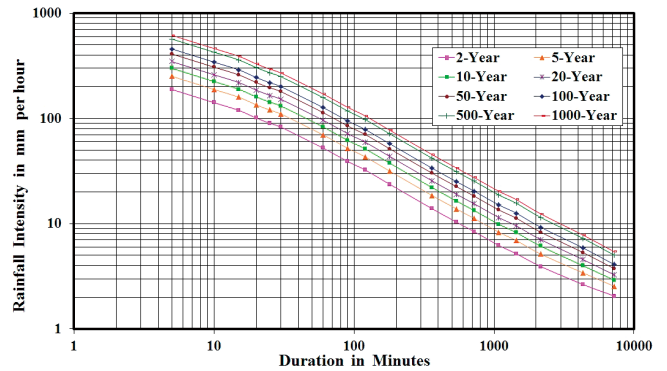

Figure 3. Observed and simulated hydrographs after the calibration process for the 2006 flood event at Bago station

Figure 5. Intensity-duration-frequency curve

brated by the optimization trial option using the peak weighted root mean square error objective function. The model performance of two flood events in 2007 and 2008 were outside the acceptable range (Model efficiency was less than 0.6). Therefore, optimized model parameter sets from four flood events were averaged to estimate single optimal model parameters. The calibration result for the 2006 flood event is shown in Figure 3. There was a close relationship between the observed and simulated flow, as indicated by an R^2 of 0.84.

Three flood events between 2009 and 2011 were used for validation. Validation results are shown in Table II. R^2 and NSE values were 0.9 and 0.78, respectively, for 2010 flood event. These indicate a close and good correlation between the observed and simulated flow. The validation result of 2010 flood event is shown in Figure 4. Design storms with different return periods were estimated from an

intensity-duration-frequency curve shown in Figure 5. Then design floods with different return periods were generated in HEC-HMS.

Hydraulic modeling

HEC-RAS was used for hydraulic modeling using a river cross-section dataset, Manning's n values, and flow data including flow rates, flow change locations, and boundary conditions. The 1D HEC-RAS model can be adequately calibrated using hydrometric data, and can then be used to make adequate predictions of flood extent when water free surfaces are extrapolated onto a high resolution DEM (Horritt and Bates, 2002). Hydraulic modeling in this study was conducted for a 50 km reach starting from Zaung Tu weir to Tarwa outlet using the 48 cross-sections measurement dataset (500 m to 1,500 m interval). Boundary conditions at the Zaung Tu Weir, the upstream end of the river system, were assigned to define flow hydrograph. The Bago station was assigned to define uniform lateral inflow hydrograph. The Tarwa station, at the downstream end of the river system, was assigned to define the normal depth and assume the fric-
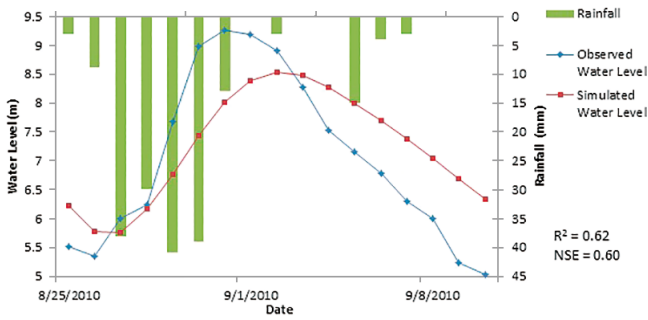
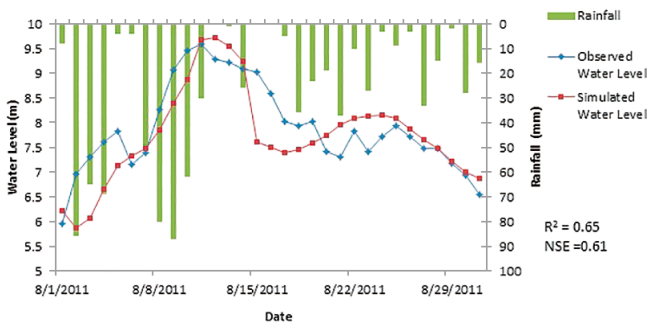Figure 6. Validation result for the 2010 flood event at Bago station

Figure 7. Validation result for the 2011 flood event at Bago station
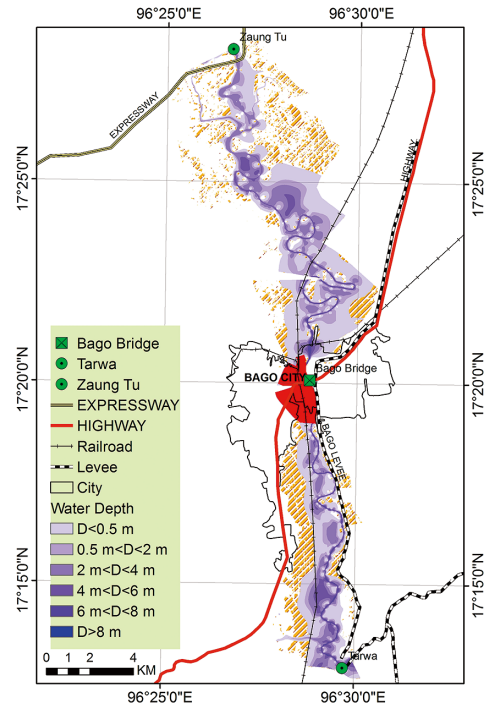

Figure 8. Comparison of the 2006 flood inundation map with an ALOS PALSAR image

Table III. Comparison of predicted flood inundation area for 2006 July flood event

	Simulated by the model	Observed by the ALOS image	Over-lapped area	Over-estimated by simulation	Under-estimated by simulation
Flood area (km^2)	51.0	42.9	41.0	4.0	11.5
Percentage (%)	119.0	100.0	95.6	9.3	26.8

tion slope of downstream.

The simulated flow data with time series of flood event were used for calibrating the model. Normal depths were defined as a boundary condition. The unsteady flow condition was adopted to run this model and a friction slope of 0.0003 was applied. The calibration process was undertaken for 3 different flood events between 2004 and 2006. The model was validated with the two different flood events of 2010 and 2011. Validation results for 2010 flood event and 2011 flood event are shown in Figures 6 and 7, respectively. The validation result of 2011 was better than the 2010 result. Satisfactory performance was indicated by the NSE value (0.6).

RESULTS AND DISCUSSION

The simulated flood inundation maps for the 2006 flood event were validated by comparing the actual flood area derived by ALOS PALSAR images taken on 22nd July during the flood event and that derived using the model (Figure 8). Comparison of the predicted flood inundation area for the July 2006 flood event is shown in Table III.

Flooding around the center of Bago City was over-estimated by the model. However, there is a possibility that the ALOS PALSAR images couldn't detect the flood in the city center appropriately because local authorities and residents reported serious flood damages in the city center. Validation of results for the 2011 flood event was undertaken by comparing the model output with field data. Simulated flood inundation depth and area for 2011 flood event are shown in Figure 9. The inundation urban area simulated by the model and observed flooded urban area for the 2011 flood event are 5.2 km^2 and 4.9 km^2, respectively (a difference of 6.1%).

The degree of flood hazard was classified according to $D < 0.5$ m, 0.5 m $< D < 2$ m, 2 m $< D < 4$ m, 4 m $< D < 6$ m, 6 m $< D < 8$ m, and $D > 8$ m. The inundation area with classified hazard depths according to 2-, 10-, 50-, and 100-year return periods are shown in Table IV. An increase in the rainfall event return period between 10-year to 100-year events caused a 13% increase in the river flood inundated area. Figure 10 illustrates the generated river flood extent and water depth distribution maps for the 100-year return period.

Considering the 50- and 100-year return period flood scenarios, the highest depth of inundation may affect the Bago City urban areas and around Bago Bridge. The largest flood
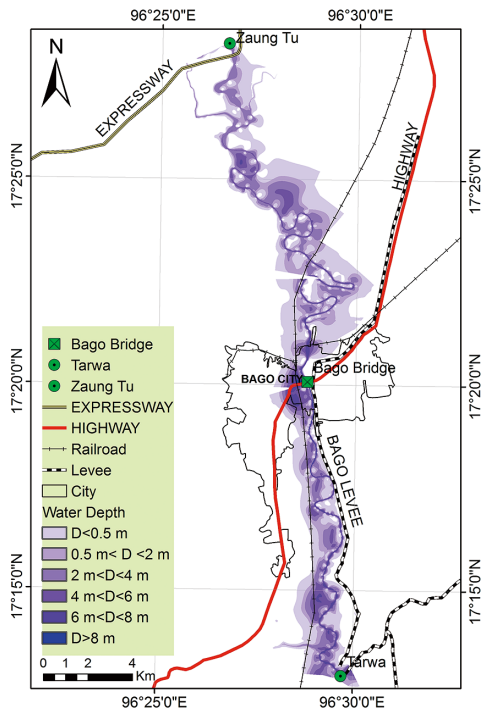
Figure 9. Simulated flood inundation depth and area for the 2011 flood event
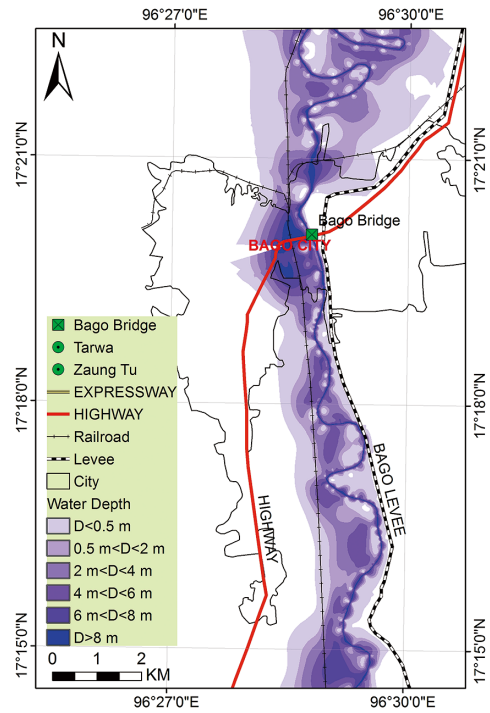

Figure 10. Flood inundation area for a 100-year return period event

Table IV. Flood inundation area with classified water depths in various return periods (Zaung Tu weir to Tarwa outlet reach)

Water depth (m)	Total inundation areas							
	2 year flood		10 year flood		50 year flood		100 year flood	
	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%
$D < 0.5$ m	26.45	49.58	25.65	45.09	24.9	39.27	24.7	38.53
0.5 m $< D < 2$ m	10.64	19.94	10.93	19.22	10.77	16.99	10.72	16.72
2 m $< D < 4$ m	11.26	21.11	12.4	21.80	14.06	22.18	14.17	22.10
4 m $< D < 6$ m	3.85	7.22	5.70	10.02	9.70	15.30	10.19	15.89
6 m $< D < 8$ m	1.10	2.06	20	3.52	3.16	4.98	3.41	5.32
$D > 8$ m	0.05	0.09	0.20	0.35	0.81	1.28	0.92	1.44
Total	53.35	100.00	56.88	100.00	63.40	100.00	64.11	100.00

extent can reach the rural areas located near the upper areas of Bago City. These large floods can also affect the downstream rural areas including the paddy fields.

CONCLUSIONS

Flood inundation maps of the Bago River Basin were developed and the result validated by comparing with ALOS PALSAR images from the 2006 flood event. The analysis undertaken demonstrated that the model is currently at the limit of predictive ability for flood inundation, but the results of calibration and validation indicated acceptable results in terms of simulating flood events. The results of the hydrologic model could be further improved by installing a dense network of gauged stations. For a given topography and flow condition, all elements of geometric description including the number of cross-sections, spacing, location and structural details (bridge/culverts) play a key role in describing the inundation extent. For more accurate hydraulic model result, more cross-sections with closer intervals need to be measured. Further study and analysis could consider new dams, which were constructed in 2012 in the Bago River Basin.

From a disaster reduction viewpoint, we believe the information derived from this study can contribute to assessments of potential flood damage for the local region, as well as other locations where data is limited, such as is generally the case in Myanmar. Such an analysis would also be helpful in formulating and directing post-event relief efforts.

ACKNOWLEDGEMENTS

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