EVENT BASED FLOOD MODELING IN LOWER KELANI BASIN

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ABSTRACT

In this study a two dimensional flood simulation model FLO-2D is applied to model the floods in lower Kelani basin. The model was applied to simulate four flood events occurred in the basin during recent past, viz., in November 2005, April 2008, May 2008 and May 2010. Model calibration was carried out for the flood event occurred in November 2005, by comparing the discharge hydrograph at Nagalagam Street gauging station. The other three events were used for validation. Normalized Objective Function (NOF), Nash-Sutcliffe efficiency (R_{NS}^2) and percentage bias (δ_b) were used to evaluate the goodness of fit between the simulated and observed flows at Nagalagam Street gauging station. The considered parameters indicated that there is a good agreement between the observed and simulated flows. Inundation extents shown in ALOS/PALSAR HH data set and flood inundation maps published by the Disaster Management Center were used to compare the simulated inundation extents with the observed for the flood events in May 2008 and May 2010 respectively. Simulation results show sound matching with observed extents for the flood events. The calibrated model can be used to forecast flood inundation extents at the lower Kelani basin.

Key words: Flood inundation, FLO-2D, Kelani basin, Model

1. INTRODUCTION

Floods are the most damaging natural hazard of the world [1] and flooding in urban areas is an inevitable problem for many cities in Asia [2]. Sri Lanka, due to her climatological and geographical conditions, is open to several types of natural disasters such as floods, landslides, cyclones, droughts, wind storms, coastal erosions, and tsunamis. Among these, floods have been identified as the most frequent natural disaster affecting lives and properties in vulnerable areas. Recent records indicate that Sri Lanka has experienced large scale flooding in every 2 to 3 years and on average about 200,000 people were affected in every year [3].

Development of extreme low pressure conditions in the Bay of Bengal and two monsoon systems, Northeast (November-February) and Southwest (May-September) have direct impacts on the rainfall patterns in Sri Lanka. Anomalously high seasonal precipitation typically associated with La Nina phenomenon and cyclonic storms which originate from the Bay of Bengal are usually the main reasons for devastating floods in the Island.
Forecasting of floods and inundation extents in river basins is important to issue early warning and thereby to reduce flood damages to life and property. This study develops a two-dimensional flood inundation model that can be used to map flood inundation extents in Kelani River basin, in Sri Lanka. Kelani River basin is located in between Northern latitudes 6° 47' to 7° 05' and Eastern longitudes 79° 52' to 80° 13' with basin area of 2230 km^2. The upper part of the basin (up to Hanwella) is mountainous while the lower part (below Hanwella), has plain features. The basin receives about 2400 mm of average annual rainfall and the river carries a peak flow of about 800-1500 m^3/s during monsoon periods.

2. METHODOLOGY

Two-dimensional flood simulation model, FLO-2D was utilized to map, inundation areas. It is a two-dimensional flood routing model that distributes a flood hydrograph over a system of square grid elements. The model is capable of numerically routing a flood hydrograph while predicting the area of inundation and simulating flood wave attenuation [4]. The FLO-2D system consists of processor programs to facilitate graphical editing and mapping which simulate channel and floodplain details. The Grid Developer System (GDS) generates a grid system that represents the topography as a series of small tiles. FLO-2D moves the flood volume around on a series of tiles for overland flow or through stream segments for channel routing. Flood routing in two dimensions is accomplished through a numerical integration of the continuity equation and the equations of motion [5].

The GDS was used to generate 250 m x 250 m grids covering the lower basin area. The required topographic data was derived from the data obtained from the Department of Survey, Colombo; 1:10,000 map layers were used to develop Digital Elevation model (DEM) in Arc-GIS environment and land use data were used to assign Manning's coefficients over the basin. Manning's n values assigned according to land use pattern distribution are given in Table 1.

Channel and flood plain roughness coefficients were adjusted to fit the simulation results with observations by applying a trial and error procedure to calibrate the model.

The model was calibrated and validated for the flow at Nagalagam Street discharge gauging station. In order to, derive these corresponding results surface detention and dynamic wave stability coefficient were set to 0.015 m and 1.0 respectively. Infiltration was calculated according to the Green Ampt loss method. This method employs initial loss, initial saturation, capillary suction head, hydraulic conductivity and soil porosity. The values of initial loss and initial saturation were set to 1 mm and 95% respectively. According to world-soil-database [6] the major portion about 70% of the soil in lower Kelani basin is loam. According to Maidment [7], the corresponding values of capillary suction head, hydraulic conductivity and soil porosity of loam soil is 90 mm, 13.2 mm/s and 0.463 respectively and they were allocated accordingly.

Table 1: Manning's roughness coefficients (Chow et.al, [8])

Land use type	Manning's n value
Roads and builtup areas	0.015
Gardens	0.035
Marsh and water bodies	0.010
Paddy	0.018
Agricultural crops	0.035

Simulated hourly discharge was compared with observed hourly values and numerically analyzed the goodness of fit by considering Normalized Objective Function (NOF), Nash – Sutcliffe efficiency (R_{NS}^2), and percentage bias values (δ_b). Past studies showed that these parameters were successfully used for analyze goodness of fit (e.g. Ehret, et al. [9], Chu, et al. [10], and D. N. Moriasi [11]).

$$NOF = \frac{1}{\bar{O}}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - S_i)^2} \qquad (1)$$

$$R_{NS}^2 = 1 - \frac{\sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad (2)$$

$$\delta_b = \left|\frac{\sum_{i=1}^{n}(S_i - O_i)}{\sum_{i=1}^{n} O_i}\right| \times 100\% \qquad (3)$$

Moreover, in order to justify the inundation extents, ALOS/PALSAR satellite, HH data set (operating at C band, incidence angle of 34^0, 12.5 m pixel size and approximate ground resolution of 25 m) and flood inundation maps published by the Disaster Management Center (DMC) were used to compare the simulated inundation extents with the observed for May 2008 and May 2010 flood events respectively.

For ALOS/PALSAR satellite data, two types of images are required to demarcate the flood inundated areas, as dry day image (3rd March 2008) and image taken during the flood event (3rd June 2008) covering the study area. The processing was carried out in ERDAS IMAGINE 9.2 image processing software environment.

Initially the noise reduction was done by applying filtering. The regions where there is a sharp change in the pixel values of dry day and wet day were selected and analyzed their statistics to determine a threshold value and classified in to two categories as flooded and non flooded areas to compare with the simulation results.

The DMC dataset directly provides the inundated areas and here also image was classified in to two categories as flooded and non flooded areas to compare with the simulation results.

3. RESULTS

The model was calibrated for the extreme event occurred in November 2005, by comparing the flow at Nagalagam Street discharge gauging station and validation was carried out for the events occurred in April 2008, May 2008 and May 2010. Figure 1 indicates the relationship of the simulated results with the observed flow at Nagalagam Street for November 2005 flood event which was used for model calibration.

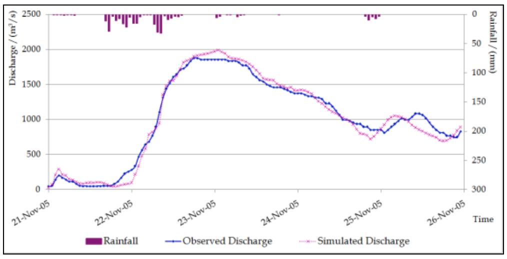

Figure 1: Time series of observed and simulated flow at Nagalagam Street during 2005 flood

Simulated hourly discharge was compared with observed hourly values and numerically analyzed the goodness of fit by considering (NOF), (R_{NS}^2), and (δ_b) values. The values of NOF, R_{NS}^2 and δ_b, for the event are 0.09, 0.98 and 6.98% respectively.

Table 1 shows the goodness of fit according to NOF, R_{NS}^2 and δ_b for validation period.

Table 2: Goodness of fit for validation

Event	NOF	R_{NS}^2	δ_b
April 2008	0.14	0.97	10.37%
May 2008	0.11	0.91	8.92%
May 2010	0.23	0.85	18.56%

According to Table 2, there is a good agreement between the simulated and observed Nagalagam Street discharge. Then the simulated inundation extents were compared with observed for May 2008 event and May 2010 event. The observed and simulated inundated extents for both events are shown in Figure 2 and 3.

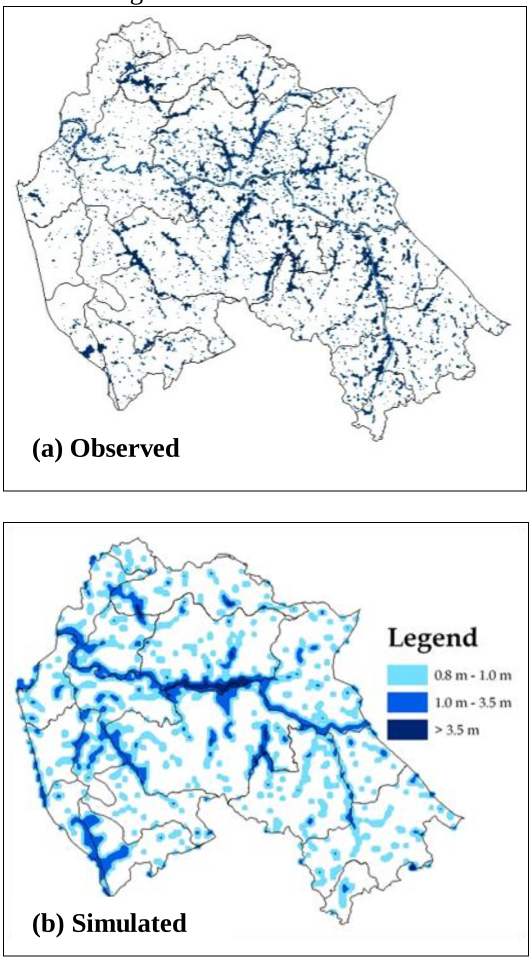

Figure 2: Inundation extent of May 2008 flood

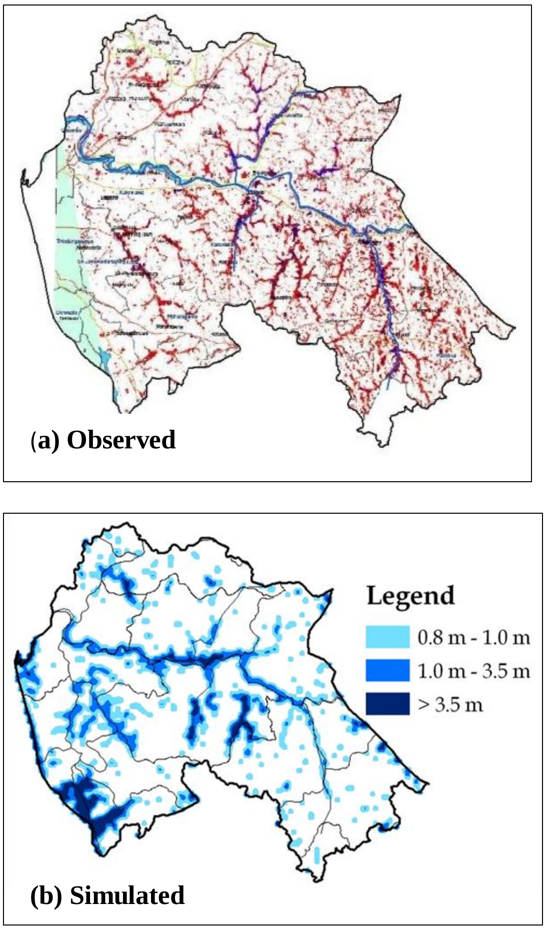

Figure 3: Inundation extent of May 2010 flood

The inundation extents were compared by considering the fraction of the domain classified correctly by the model, which was successfully utilized in past studies (e.g. Aronica, et al., [12], Horritt, [13] and Nandalal, [14]) and the following equation was used.

$$F = \frac{S_{obs} \cap S_{mod}}{S_{obs} \cup S_{mod}} \times 100 \qquad (4)$$

S_{obs} and S_{mod} are set of domain sub regions (cells or pixels) observed as inundated and predicted as inundated respectively and F is the measure of fit. If the simulated extents exactly overlap with the observed extents F value is 100% and if no simulated extent overlaps with observed extents F value is 0. The F values are 79% and 73% for May 2008 and May 2010 events respectively.

4. CONCLUSION

An event based two dimensional flood simulation model was developed to map flood inundation extents in lower Kelani basin. The model predictions were in good agreement with the observation for past flood events.

The model can be applied to create inundation maps corresponding to rainfalls of return periods. For a given rainfall forecast, flood inundation maps can be created using the model output in advance to issue early warning and to carry out the evacuation as may be necessary to minimize the flood damages.

5. REFERENCES

[1]. H. N. Hashmi, Q. T. M. Siddiqui, M. A. Kamal, H. R. Mughal and A. R. Ghumman, "Assessment of inundation extent for flash flood management", African Journal of Agricultural Research, Vol. 7(8), pp. 1346-1357, 2012

[2]. C. Apirumanekul and O. Mark, "Modelling of Urban Flooding in Dhaka City", in: Proceedings of 4th DHI Software Conference, pp. 101-108, 2001

[3]. M. M. Ariyabandu and P. Hulangamuwa "Corporate Social Responsibility and Natural Disaster Reduction in Sri Lanka", Report, 2002

[4]. Tetra Tech, Inc., Surface Water Group, "Development of the Middle Rio Grande FLO-2D Flood Routing Model Cochiti Dam to Elephant Butte Reservoir", 2004

[5]. J. S. O'Brien, C. Jorgensen and R. Garcia, "FLO-2D Reference manual", 2009

[6]. FAO, CAS, IIASA, ISRIC, and JRC, "Harmonized world soil database viewer", http://www.iiasa.ac.at/, 2009

[7]. D. R. Maidment, "Handbook of Hydrology", 1993

[8]. V. T. Chow, D. R. Maidment and L. W. Mays, "Applied Hydrology", book, 1988

[9]. U. Ehret and E. Zehe "Series distance – an intuitive metric to quantify hydrograph similarity in terms of occurrence, amplitude and timing of hydrological events", Journal of Hydrology and Earth System Sciences Vol. 15, pp. 877–896, 2011

[10]. X. Chu and S. Alan, "Event and Continuous Hydrologic Modeling with HEC-HMS", Journal of Irrigation and Drainage Engineering, Vol. 135 (1), pp. 119-124, 2009

[11]. D. N. Moriasi, J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, T. L. Veith "Model evaluation guidelines for systematic quantification of accuracy in watershed simulations", Journal of American Society of Agricultural and Biological Engineers, Vol. 50(3), pp. 885−900, 2007

[12]. G. Aronica, P. D. Bates and M. S. Horritt, "Assessing the uncertainty in distributed model predictions using observed binary pattern information within GLUE", Hydrological Processes Journal, Vol. 16(1), 2002

[13]. M.S. Horritt, "A methodology for the validation of uncertain flood inundation models", Journal of Hydrology, Vol. 326, 2006

[14]. H.K.Nandalal,Flood risk management incorporating stakeholder participation and climate variability, Thesis, University of Peradeniya, 2011