Flood Simulation in Yangon City with Rainfall-Runoff Inundation (RRI) Model

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1. INTRODUCTION

Flood and storm are the major cause of disasters in Myanmar according to a global disaster database. Flooding is one of the most disastrous phenomena in the world. When flood occurs, flood awareness increases which subsequently lead strategic prevention measures. The main causes of flood are heavy rainfall and climate changes. Flooding occurs when the watershed system receives heavy rainfall or continual rainfall events and, the water flow rate exceeds the channel capacity. In this research, flood inundation models for Yangon City developed using the Rainfall-Runoff Inundation (RRI) model[1)3)]. Yangon City is situated in the center of a large region called Lower Myanmar, which embraces the lowlands of the coastal area of the country. This city lies at the junction of the Bago River and Hlaing River. Yangon is prone to three types of flood characteristics. They are Pluvial flood, Fluvial flood, and Coastal flood. Among these flood characteristics, Flooding in Yangon is typically fluvial and pluvial. It frequently happens in each rainy season. Fluvial flooding in Yangon occurs when the water levels in the surrounding river or canal are higher than areas within the city. Pluvial flooding can also occur during the low tides at some locations due to the discharge capacity of the drainage system and blocking by solid waste. Flooding up to a depth of 0.5 meters and lasting from 3 to 5 hours occurs 6 to 10 times per year.

The Yangon city is at risk of flooding, with extreme events occurring at least 5 times per year when heavy monsoon rainfall coincides with high tides. During 2014, severe floods happened in the Yangon area in June and July because of continuous heavy rainfall. The 2014 flood event in Yangon is different from the past floods. Nearly all the rivers and creeks were overflowed, and the inundation duration lasted above seven days. In addition, based on records from 1947-2008, there has been a 3.2% annual probability of Yangon being affected by a tropical cyclone and a 6.7% probability of storm surge in nearby coastal areas. Flooding in Yangon thus takes many forms, from nuisance water to flood disaster. Severe flooding in the city occurred in 1973, 1974, 1976, 1988, 1991, 1997, 2002, 2004, 2007, and 2014.The 2014 flood caused by heavy rainfall affected 14 of the Yangon region’s townships and affected many infrastructures and people with enormous financial losses.

Available model to simulate rainfall-runoff and flood inundation is highly required. Many flooding inundations models have been adopted in many parts of the world and are evidenced by their successfully application to river basins[4)-6)]. The rainfall-runoff-inundation (RRI) model[1)] is one of such model that can applied to evaluate river discharges and flooding-inundation depths in flood prone areas such as the Bago River Basin and accompanying counterparts.

In this paper, the study area included part of Bago River Basin, specifically covering the downstream part of the river including the Yangon City with aim of studying the rainfall and runoff characteristics of flood in Yangon City. Previously, other researchers applied RRI model for this Bago River basin covering both upstream and downstream part of the Bago River[(7)]. In detail description, these researchers analyzed the performance RRI model whether or not it can be applied for a flat river basin and checked the model performance by comparing with satellite base data from UNOSAT (United Nations Satellite Centre). However, the basin area in the current study differs compared to previous study. In addition, the effect of parameters in the model on the discharge hydrograph was not revealed for the basin. In this paper, the applicability of RRI model to a flat river basin was discussed to understand the runoff characteristics of flood in Yangon for the future.

The objective of this study include:

- To understand the rainfall and runoff characteristics of 2014 flood in Yangon
- To clarify the RRI parameters, of lateral saturated hydraulic conductivity (k_a) values and depth of soil layer (soil depth) for flat large river basin in Yangon

2. METHODOLOGY

The RRI model was applied for flood inundation analysis and calculated peak inundation depth, flood duration data set, and river discharge hydrograph can be expected from simulation results.

(1) Rainfall-Runoff-Flood (RRI) model

Rainfall-Runoff-Flood (RRI) model is a two- dimensional model capable of simultaneously synchronizing rainfall-runoff and flooding. The model type is distributed, hydrological model. The model handles slopes and river channels separately. The RRI model can simulate flood inundation depth and area during floods as well as river water level and discharge volume during normal flows. Rainfall data, topographic data, flow accumulation, flow direction, and river discharge data are essentially needed for RRI simulation. A one-dimensional analysis method is generally used for predicting flood flow of river roads in rainfall runoff analysis. In order to properly consider the rainfall distribution and the action of the topography, a distributed runoff model is used. In recent years, rainfall runoff flood analysis (RRI: Rainfall-Runoff-Inundation) model has been developed. The RRI model is a highly versatile model that can analyze the

Key Words : RRI model, Yangon Basin model, Lateral Saturated Hydraulic Conductivity , Soil depth
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process of rainfall runoff, flooding, and flooding in an integrated manner, and is expected to be applied to flood prediction of rivers using rainfall as input conditions. Continuous equation (1) of watershed slopes are shown.

$$\frac{\partial z_s}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=r-f \qquad (1)$$

where, z_s = water level, q_x, q_y, = x, y unit width flow rate in the direction, r =rainfall intensity, f = vertical penetration intensity. The unit width flow rate of equation (1) is divided into surface flow and penetrating flow.

Equation of motion in the depth x_i direction of the surface flow is shown in equation (2).

$$\frac{\partial u_i h}{\partial t}+\frac{\partial u u_i h}{\partial x}+\frac{\partial v u_i h}{\partial y}=-gh\frac{\partial z_s}{\partial x_i}-\frac{\tau_{0i}}{\rho} \qquad (2)$$

where, u, v = the velocity of the surface flow in the x, *and* y directions, *and* g = gravitational acceleration.

In the RRI mode, a diffusion wave is assumed for surface flow, in which the convection terms in equation (2) is ignored and, equation (3) is used to calculated the surface flow flux[2),3)].

$$u_i h=\frac{1}{n}h^{\frac{5}{3}}\frac{\partial z_s}{\partial x_i}\frac{1}{\sqrt[4]{\left(\frac{\partial z_s}{\partial x}\right)^2+\left(\frac{\partial z_s}{\partial y}\right)^2}} \qquad (3)$$

where, the flow velocity of the surface flow in the direction of u_i: x_i, h = the water depth of the surface flow, n = the roughness coefficient of Manning.

3. RRI MODEL CALIBRATION AND VALIDATION

The RRI model is developed to simulate the water flow mechanism between slope grid cells and river grid cells[1)]. It is calibrated the known rainfall data and the observed river discharge data. Model calibration is adjusting selected model parameters values and other variables in the model to match the model outputs with the observed values. The calibration procedure consists of a combination of manual and automated calibrations. If the simulation result and observed value are very different, the parameter set is rejected, and if the model output is like the observed value, the model parameter set is acceptable. In this study, finding acceptable parameters are manually calibrated by trial and error. Historical rainfall data is used in the calibration of the model and checks past flood occurrences. The RRI model was set up for calibration based on 2014 flood events.

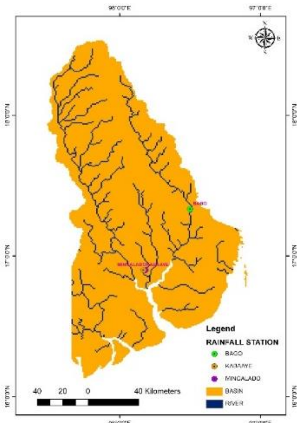

Fig.1 Location Map of Yangon Basin Model

The calibration process was performed for one flood event of 2014 for different soil depth and different lateral saturated hydraulic conductivity (k_a) values in the Bago River basin using a daily flow basis. A total 20 numerical runs were conducted using the daily flow basis. And then, the simulation period from the 7th of June to the 23rd of August was selected, because according to the accumulative rainfall graph, the graph starts increasing rainfall data from early June to August even the rainy season starts from May to October. These parameters used which gives the satisfactory output to measured data and those coefficients are close to those expected from study basin area.

Table 1 The value usage of parameters based on three land use

Calibration Parameters	Mountain	Flat Plain Area	Urban Area
Ns River	0.03	0.03	0.03
Ns slope	0.4	0.4	0.4
soil depth	1,1.5,2,2.5,3	1	0.5
φ	0.463	0.501	0.475
ksv	3.670d-6	1.000d-6	1.000d-7
Sf	8.890d-2	1.668d-1	3.163d-1
ka	0,0.05,0.1,0.2,	0	0

Table 2 Results of Efficiency Criteria and Error Computation

	2014			
Soil Depth(m)/ Ka(m/s)	0	0.05	0.1	0.2
1	0.854	0.775	0.757	0.740
1.5	0.939	0.876	0.854	0.833
2	0.944	0.898	0.877	0.856
2.5	0.939	0.904	0.888	0.869
3	0.932	0.904	0.891	0.873

In this study area, the initial water depth is set to be zero after dry season. The lateral saturated hydraulic conductivity parameter deals with the subsurface travel path to the discharge point in the basin. For example, when rainfall occurs, no water goes into the river if the k_a value is zero. When the k_a value is nonzero, large amount of water goes into the river.

Soil depth controls how much soil can be stored. When the soil is above the impermeable layer, such as bedrock is filled, infiltration stops and the flow increases. If the soil depth is high in the calculation, a large amount of water goes into the river. With k_a=0, only surface water surface goes into the river. On the other hand, if the large k_a values are used, the soil have storage space and then the water slowly move into the river that the discharge will be decreased. This is the effect of k_a and soil depth. Therefore, the depth of soil layer (soil depth) and lateral saturated hydraulic conductivity (k_a) are important parameters for fixing these calibration events.

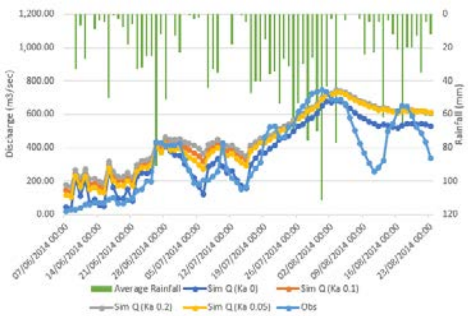

Fig.2 Simulated Hydrographs in different $k_a$value with calibrated soil depth for 2014 year

Table 3 shows the calibrated values for k_a and soil depth for a mountainous area in Japan[8),9)] and Myanmar. Calculated with the Nash Sutcliffe Efficiency value, which is indicated a close relation between the observed and simulated flow, the model performance is good. As a result, the best Nash Sutcliffe Efficiency value for 2014 event soil 2 (k_a 0) indicated a close correlation between the observed and simulated flows. In Japan's case, for the mountainous area, the values of lateral saturated hydraulic conductivity (k_a) ranged from 0.5 to 1 and the depth of soil layer (soil depth) value ranged from 0.5 to 1.3. In Myanmar's case, for the mountainous area, the lateral saturated hydraulic conductivity (k_a) value is 0 and the value for the depth of soil layer (soil depth) ranged from 2 to 3. So, the values of lateral saturated hydraulic conductivity (k_a) is smaller than of Japan's case and depth of soil layer (soil depth) is larger than of Japan's case.

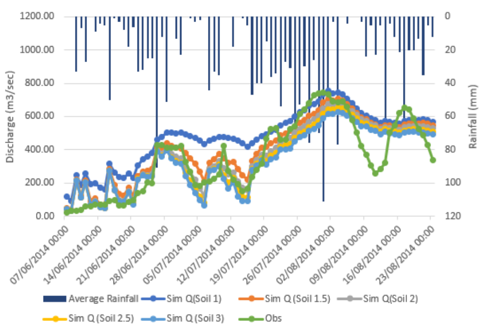

Fig.3 Simulated Hydrographs in different soil depth value with calibrated k_a for 2014 year

In the Japan's case[8),9)], when you use the large k_a value, the water can easily flow into the ground layer. When the gap between soil and the sediment materials size is large the water can easily flow into the ground layer. In Myanmar's case, the sediment materials size is not too large, hence the water cannot easily flow into the ground layer. This is the difference between of Japan and Myanmar.

Table 3 Different values usage for k_a and Soil Depth for a mountainous area in Japan and Myanmar

Important Parameter	Japan	Myanmar	Default Value in RRI model
Lateral saturated hydraulic conductivity (Ka)	0.5 to 1	0	0
Soil layer (Soil Depth)	0.5 to 1.3	2 to 3	1

4. CONCLUSION

In this study, the RRI model was applied to rainfall and flooding 2014 in Myanmar. The hydrographs are made with the demonstration of acceptable performance in simulating flood events and are closely related to meteorological hydrographs observed indicating usefulness of RRI model for flood inundation analysis. This study investigated the differences in values of lateral saturated hydraulic conductivity (k_a) and depth of soil layer (soil depth) between Myanmar and Japan. For the simulation for Japanese river basins, the k_a value ranges from 0.5 to 1 and soil depth ranges from 0.5 to 1.3. However, in terms of Myanmar river basin, k_a value is 0 and soil depth ranges from 2 to 3. The difference of these two parameters indicates the geographical features in Japan and Myanmar where sediment deposits deeply in large flat areas. More detail investigation on the difference in parameters and geographical features are required as future research avenues.

REFERENCES

1) Sayama, T. (2013). Rainfall-Runoff-Inundation (RRI) Model User's Manual. Tsukuba: International Center for Water Hazard and Risk Management (ICHARM).
2) Shimizu, R., Kaida, K., Matsuda, M., Uchida, T., Sayama, T., and Kawahara, Y.: Enhanced Rainfall-runoff－flood simulation with RRI model incorporating river vegetation resistance based on 2D numerical calculation results and slope direction surface flow flux, Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), Volume 77 Issue 1 Pages 84-91, 2021.
3) Shimizu, R., Uchida, T., Kawahara, Y., Yamashita, A., & Fukuda, T., (2021). High-Accuracy Prediction of Water Level in Rainfall-Runoff Analysis Coupled with Unsteady 2-D Calculation Results. Advances in River Engineering, Vol.27, pp.241-246, June 2021.
4) Bates, P.D., & De Roo,A.P.J. (2000). A simple raster-based model for flood inundation simulation. Journal of Hydrology 236: 54– 77. DOI: 10.1016/S0022-1694(00)00278-X.
5) Leandro, J., Chen, A.S., & Schumann, A. (2014). A 2D parallel diffusive wave model for floodplain inundation with variable time step (P-DWave). Journal of Hydrology 517: 250–259. DOI: 10.1016/j.jhydrol.2014.05.020.
6) Liu, L., Liu, Y., Wang, X., Yu, D., Liu, K., Huang, H., & Hu, G. (2015). Developing an effective 2-D urban flood inundation model for city emergency management based on cellular automata. Natural Hazards and Earth System Science 15: 381–391. DOI: 10.5194/nhess-15-381-2015
7) Bhagabati, S.S., Kawasaki, A. (2017). Consideration of the rainfall-runoff-inundation (RRI) model for flood mapping in a deltaic area of Myanmar, Hydrological Research Letters, Vol.11 Issue (3),155-160 (2017). DOI: 10.3178/hrl.11.155
8) Yagi, F., Uchida, T., & Kawahara, Y. (2020). Numerical Investigation of Three-Dimensional Flow Structures and Turbulence Energy Distributions in Bank Erosion Reaches During Large Flood Events, Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), Vol. 76, pp.404-413,2020. https://doi.org/10.2208/jscejhe.76.1_404
9) Nagai, H., Uchida, T., Kawahara, Y., Yagi, F., & Nakano, M. (2020). Evaluation Method of River Improvement in a Gravel Bed River-Case Study on The Nenotani River, Advances in River Engineering, Vol.26, 2020.