RRI MODEL-BASED FLOOD EVACUATION TIMELINE OF CITY AND MUNICIPALITY LGUs IN PAMPANGA RIVER BASIN, PHILIPPINES

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ABSTRACT

The Pampanga River Basin (PRB) in the Philippines experiences frequent flooding due to typhoons and monsoons putting millions of people's lives at risk every year. Flood evacuation timeline is an action plan which indicates "who does what and when" and is important to reduce casualties due to floods by moving people at risk to safer locations effectively and efficiently. This research aims to develop a scenario-based flood evacuation timeline for cities and municipalities with high flood-risk based on flood simulation by Rainfall-Runoff-Inundation (RRI) model. Simulated floods caused by past weather disturbance with different rainfall patterns and recurrence intervals revealed that the rainfall of 2004 Typhoon Yoyong brought flood with the fastest propagation speed while the rainfall of 1998 Typhoon Loleng with 20-year return period brought flood with average propagation speed. This study used these rainfall as input to the RRI model to develop the flood evacuation timeline of the midstream municipality of Cabiao, Nueva Ecija based on the identified flood risks and flood scenarios. The results of this study can be useful for local government units (LGUs) to efficiently prepare and respond during flood disasters.

Keywords: evacuation, timeline, RRI model

INTRODUCTION

In recent years, the total occurrence of reported natural disasters globally has increased steadily and about 80% of these disasters are extreme weather-related events, such as storms, floods, and droughts (CRED, 2019). The Philippines, an archipelagic country located in the western Pacific Ocean is prone to storm and flood-related disasters because of its geophysical location and socio-economic conditions. The Pampanga River Basin (PRB) is the 4th largest basin in the country with an area of 10,434 km^2 and a population of 6,801,655 (PSA, 2015). It is estimated that 2,421 km^2 or 23.2% of PRB is flood-prone (PRFWCC, 2017). The basin

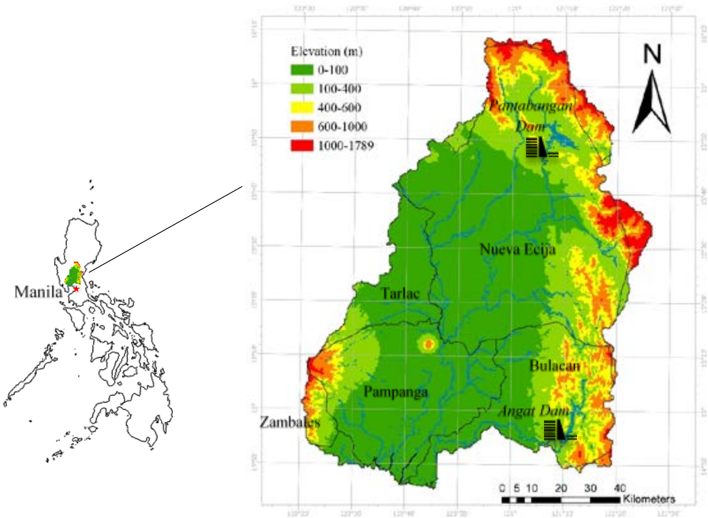

Figure 1. Location map and digital elevation model of Pampanga River Basin

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experiences frequent flooding due to seasonal monsoons and tropical cyclones (NWRB and JICA, 2011) putting millions of people's lives at risk every year.

Since flood remains a serious threat to human lives, it is important to mitigate flood disasters. This study aims to develop a scenario-based flood evacuation timeline which indicates "who does what and when" and is pre-determined to ensure well-coordinated actions of different disaster management bodies under a common disaster scenario and disaster timeframe (JICA, 2016). Rainfall-Runoff-Inundation (RRI) model is a two-dimensional (2D) model that can simultaneously simulate rainfall-runoff and flood inundation (Sayama, 2017). This study utilizes the RRI model to identify future flood risk and flood scenario for the development of flood evacuation timeline.

METHODOLOGY

The methodology used in this study is divided into five main parts as shown in Figure 2.

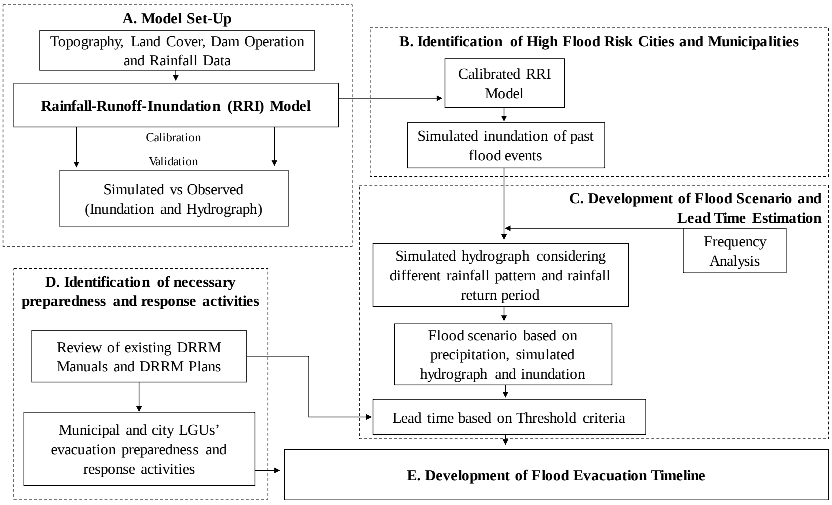

Figure 2. Methodology adopted in this study

A. Model Set-up

The schematic diagram of the RRI model used in this study is shown in Figure 3 (Sayama, 2017). Input files used to set-up the model is summarized in Table 1.

The model is calibrated and validated using the data of past major floods that affected the basin. The flood brought by 2011 Typhoons Pedring and Quiel is used for calibration and the flood brought by Typhoon Lando in 2015 is used for validation. Calibration and validation of the model include comparison between simulated and observed inundation, comparison between the estimated and reported affected population, and comparison of simulated and observed discharges at Sapang Buho, Mayapyap and San Isidro stations using model efficiency criteria (e.g. coefficient of determination r^2, Nash-Sutcliffe Efficiency E_{NS}, and index of agreement D).

B. Identification of High Flood-Risk Cities and Municipalities

Cities and municipalities with high flood-risk are identified by using the calibrated model to develop inundation maps of floods brought by 2009 Typhoon Pepeng, 2011 Typhoons Pedring and Quiel and 2015 Typhoon Lando. These inundation maps are overlaid with the population map to estimate the population that experienced more than 0.5 m-flood. The identified cities and municipalities are used as case studies.

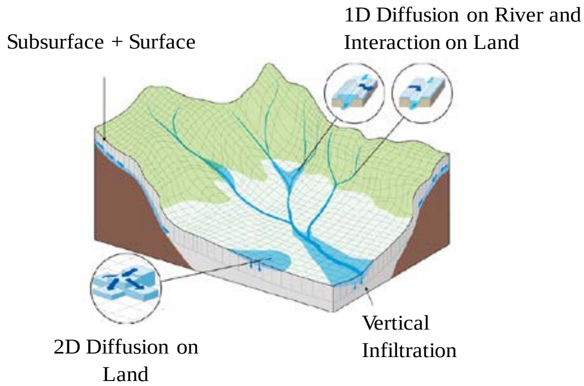

Figure 3. Schematic diagram of the RRI model

C. Development of Flooding Scenario and Lead Time Estimation

Future flood scenarios are identified by simulating floods considering different rainfall patterns and recurrence intervals. This study used the rainfall patterns of 12 weather disturbances that caused flooding in PRB which include the 1998 Typhoon Kadiang, 1998 Typhoon Loleng, 2004 Typhoon Marce, 2004 Typhoon Yoyong, 2009 Typhoon Ondoy, 2009 Typhoon Pepeng, 2011 Typhoon Falcon, 2012 Southwest Monsoon, 2013 Typhoon Maring, 2015 Typhoon Lando, and 2015 Typhoon Nona. For the recurrence interval, the 24-hr maximum rainfall of 2-, 5-, 10-, 20-, 50-, 100-, 200-, 500-, and 1000-year rainfall return period are computed using frequency analysis. Flood warning water levels equivalent to a specified percentage of the river capacity are used in this study. These water levels were converted to river discharge using the latest available rating equations found in PRFFWC manual (PRFFWC, 2017). The flood propagation speed is estimated by calculating time intervals between warning levels from the simulated hydrograph as shown in Figure 4. It is assumed that the flood with shorter time intervals between warning levels propagates faster. The rainfall that will bring flood with fastest and the average flood propagation speed are used to develop flood scenarios. The lead time is estimated based on several factors, which include rainfall intensity, river discharge, and area and depth of inundation. It depends on predefined threshold criteria such as heavy rainfall, overtopping water level of the river, inundation depth of more than the average first floor height of houses.

Table 1. Input data used to set-up the RRI model

Input Data	Description	Source/Organization
Topographic Data	450x450m grid-sized Digital Elevation Model (DEM)	National Mapping and Resource Information Authority (NAMRIA)
Land Cover	2015 Reclassified Land Cover Map	NAMRIA
Dam Operation Rules	Operation rules of Pantabangan Dam	National Irrigation Authority (NIA)
Rainfall Data	Ground gauge rainfall data	Pampanga River Basin Flood Forecasting and Warning Center (PRFFWC)

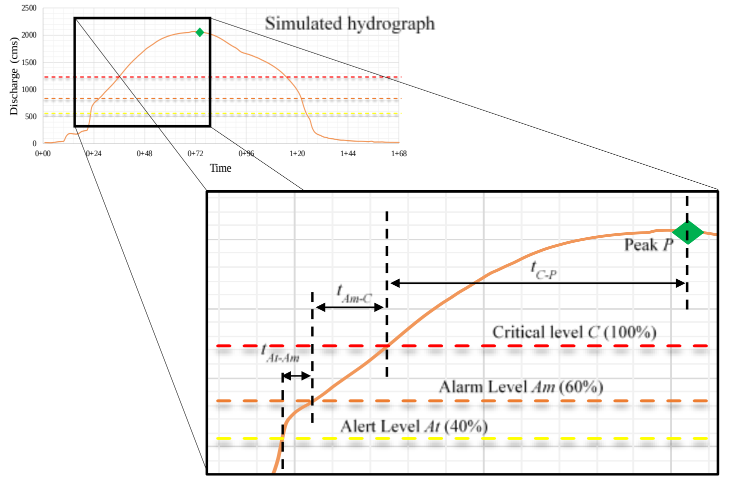

Figure 4. Estimation of time intervals between warning levels

D. Identification of Necessary Preparedness and Response Activities

Necessary evacuation preparedness and response activities of LGUs integrated into the timeline are based on existing disaster risk reduction and management manuals and plans, specifically the disaster preparedness manual of LGUs for typhoon (LGA and DILG, 2018).

E. Development of Flood Evacuation Timeline

The flood evacuation timeline of the identified high-risk cities and municipalities is developed based on the simulated flood risks and flooding scenarios of the identified rainfall.

RESULTS AND DISCUSSION

A. Model Set-up – Calibration and Validation

Figure 5 shows the comparison between the reported (PRFFWC, 2011) and the simulated inundation and river discharge using the calibrated model brought by 2011 Typhoons Pedring and Quiel. It can be observed from both maps that inundation of more than one meter happened in the midstream and downstream of the basin. Moreover, using map overlay analysis the estimated number of affected barangays (villages) of the flood with a depth above 0.1 meter is 1,785, compared to the PRFFWC's report of 1,722. Also, observed and simulated hydrographs in Sapang Buho, Mayapyap, and San Isidro stations were compared using model efficiency criteria. Table 2 shows that all model efficiency criteria are within the acceptable range. Based on these results, the model has managed to simulate the flood brought by 2011 Typhoons Pedring and Quiel. The calibrated RRI model was

Table 2. Model efficiency criteria results of calibration

Efficiency Criteria	Sapang Buho	Mayapyap	San Isidro	Acceptable Range
NSE	0.58	0.66	0.68	0 – 1.0
r^2	0.84	0.68	0.88	≥0.50
d	0.89	0.87	0.94	≥0.50

validated by comparing the observed and simulated hydrographs in Sapang Buho and San Isidro stations brought by 2015 Typhoon Lando.

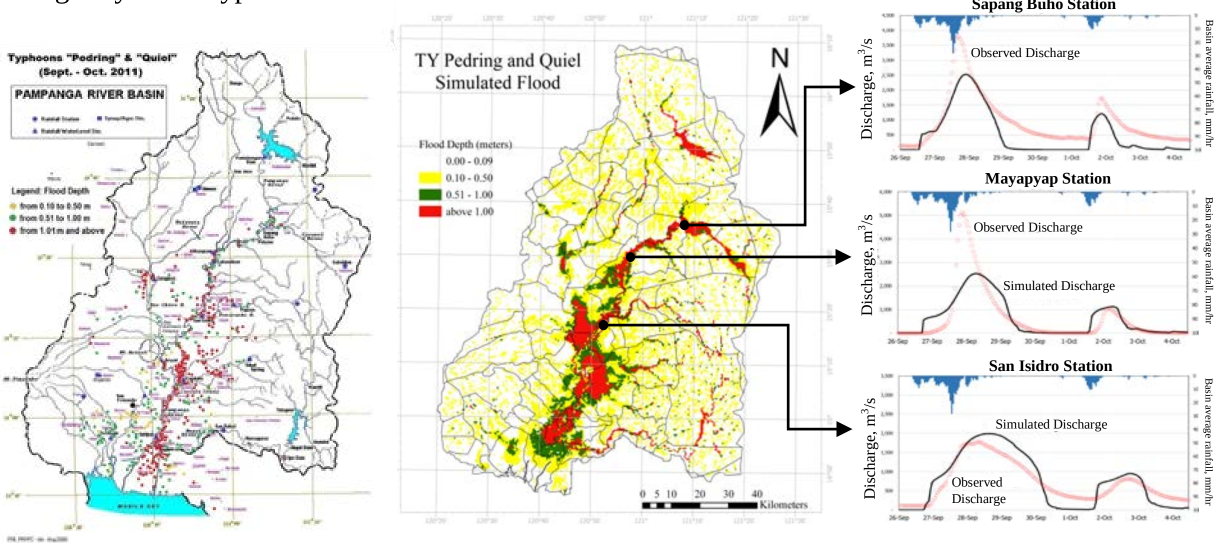

Figure 5. Comparison between the reported and simulated inundation (left and center) and river discharge (right)

B. Identification of High-Flood Risk Cities and Municipalities

Using the calibrated model, the flood brought by 2009 Typhoon Pepeng, 2011 Typhoons Pedring and Quiel and 2015 Typhoon Lando were simulated to produce inundation maps. These maps were overlaid with the population map and revealed that many cities and municipalities located downstream of the basin experienced more than 0.5 meter-flood, but because of high concentration of population in midstream cities and municipalities, these areas recorded higher number of affected population, specifically the municipalities of Jaen, Cabiao, San Isidro and Cabanatuan City in the province of Nueva Ecija and the municipalities of Candaba and Arayat in Pampanga. The municipality of Cabiao, Nueva Ecija was used as case study and the warning levels at San Isidro Station were used to estimate flood propagation speed.

C. Development of Flooding Scenario and Lead Time Estimation

The rainfall patterns of past weather disturbances mentioned in the methodology were converted to different recurrence intervals and used as input to the RRI model to simulate hydrographs at San Isidro Station. From the simulated hydrographs, time intervals between warning levels were calculated. Shown in Figure 6 is the average time intervals between warning levels brought by different rainfall with different recurrence intervals, where $t_{At\text{-}Am}$, $t_{Am\text{-}C}$, and $t_{C\text{-}P}$ corresponds to the time interval between Alert to Alarm, Alarm to Critical and Critical to Peak level respectively. From this graph, it can be observed that the rainfall pattern of 2004 Typhoon Yoyong brought the shortest time intervals between warning levels, thus bringing flood that will propagate the fastest. In case the rainfall pattern like Typhoon

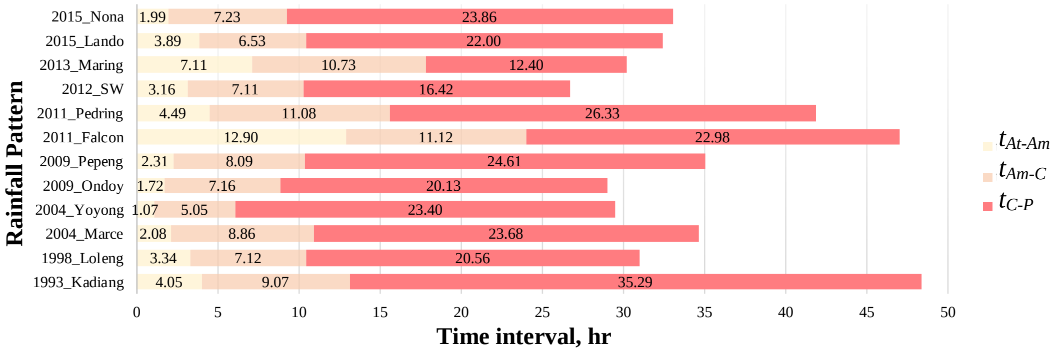

Figure 6. Average time intervals between warning levels by different rainfall patterns

Yoyong happens in the future, LGUs will have the shortest lead time to prepare and complete evacuation procedures. Thus, this study used the rainfall pattern of Typhoon Yoyong with 20-year return period as input to RRI model to develop flood evacuation timeline of Cabiao, Nueva Ecija based on the identified flood risk and flooding scenario.

Moreover, Table 3 shows the average time intervals brought by rainfall with different recurrence intervals. Figure 7 is the box and whisker plot of the same data to show the shape of the distribution, the central value, and the variability of time intervals. The rainfall pattern of Typhoon Loleng with 20-year return period brought flood with similar time intervals as the average. Thus, to consider the average flood propagation speed that needs evacuation, the rainfall pattern of Typhoon Loleng with 20-year rainfall return period was also used as input to the RRI model to develop flood evacuation timeline of Cabiao, Nueva Ecija based on the identified flood risks and flooding scenario.

Table 3. Average time intervals between warning levels of different rainfall return period

Return Period	Time interval, hr		
	$t_{At\text{-}Am}$	$t_{Am\text{-}C}$	$t_{C\text{-}P}$
2	7.16	11.86	15.00
5	5.59	11.21	18.21
10	4.59	9.90	21.38
20	4.19	9.15	22.87
50	3.85	8.39	24.38
100	3.70	7.97	24.65
200	3.54	7.58	25.25
500	3.36	7.11	25.77
1000	3.26	6.81	25.67
Mean	**4.36**	**8.89**	**22.58**

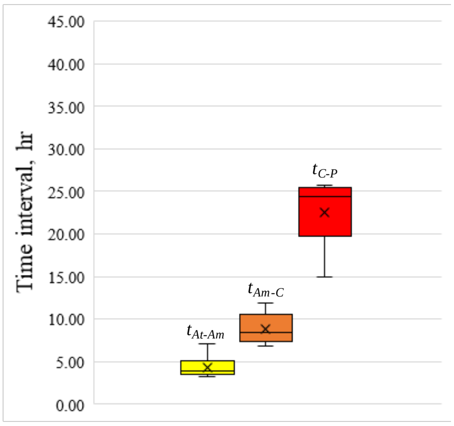

Figure 7. Distribution and variability of time intervals considering different rainfall return period

D. Development of Flood Evacuation Timeline of Municipality of Cabiao, Nueva Ecija

Based on the RRI model simulation of the identified rainfall, it was found out that the flood with 20-year return period using the rainfall pattern of Typhoon Yoyong brought inundation to 69.6 km^2 of Cabiao and a total of 45,494 people should be evacuated. On the other hand, the rainfall pattern of Typhoon Loleng with 20-year return period brought inundation to 70.4 km^2 and about 47,521 people or more than 60% of the population should be moved to higher places. Moreover, the rainfall pattern of Typhoon Yoyong brought faster flood that will last longer compared to that of Typhoon Loleng.

The flood evacuation timeline of the municipality of Cabiao, Nueva Ecija based on RRI model simulation of flood brought by Typhoon Loleng with 20-year return period is shown in Figure 8. This timeline shows specific actions the municipal Disaster Risk Reduction and Management (DRRM) Office, Barangay DRRM Committee and the residents should perform based on the rainfall intensity, simulated river discharge, and inundation.

CONCLUSION AND RECOMMENDATIONS

The Pampanga River Basin (PRB) is considered as one of the important basins in the Philippines but also considered as one of the most flood-prone. The development of flood evacuation timeline is a mitigating measure to efficiently and effectively move people at risk during flood disaster. This study developed a scenario-based flood evacuation timeline for the municipality with high flood-risk in PRB based on flood simulation by Rainfall-Runoff-Inundation (RRI) model.

For the local government units (LGUs), this study provided methodology on how to develop a flood evacuation timeline specific to their city or municipality. This timeline can be a separate plan or can be integrated to their existing evacuations plans, but before implementation this should be reviewed and consulted with different disaster management bodies and other stakeholders. Moreover, the timeline should be improved and updated through exercises and actual disasters before approval.

For future studies, higher accuracy of flood simulation is recommended for higher reliability of flood evacuation timeline. Accuracy can be improved by prober calibration of the model using the latest available data.

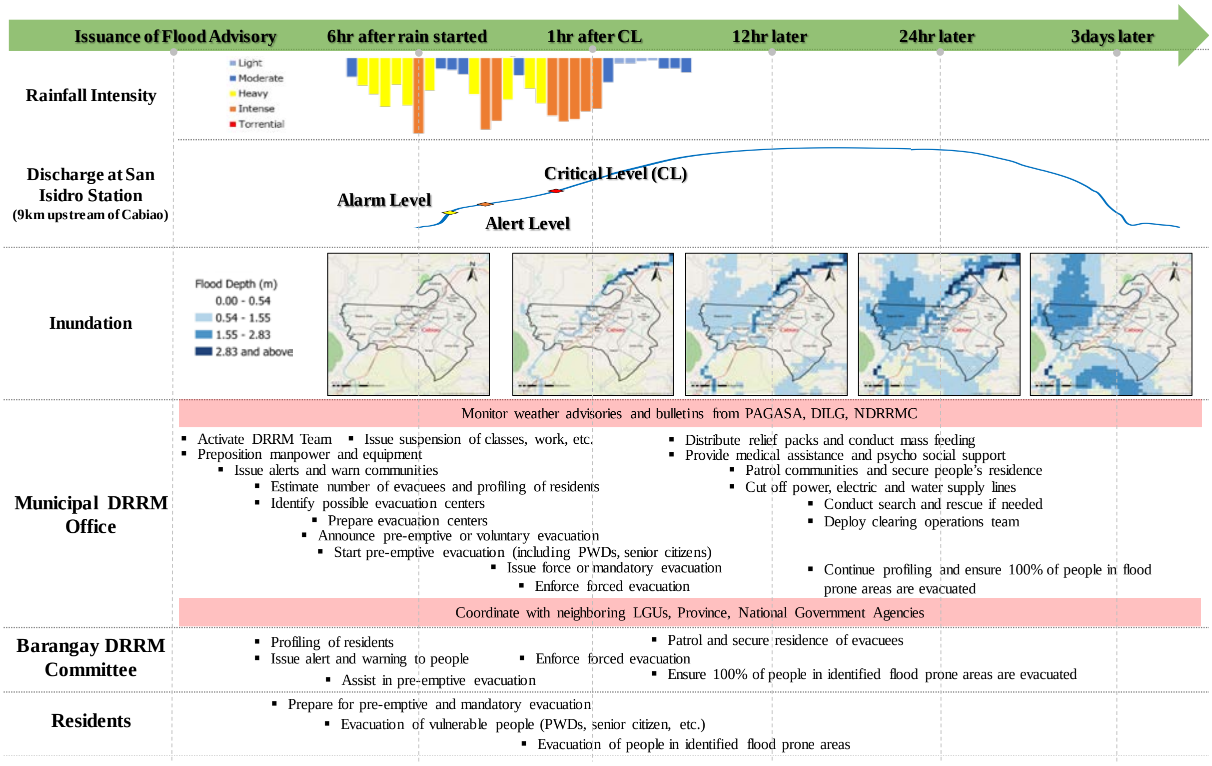

Figure 8. Flood evacuation timeline of Cabiao, Nueva Ecija based on rainfall pattern of Typhoon Loleng with 20-yr return period

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