FLOOD RISK ASSESSMENT UNDER THE CLIMATE CHANGE IN THE CASE OF PAMPANGA RIVER BASIN, PHILIPPINES

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ABSTRACT

The main objective of this study is to assess the flood risk in the Pampanga river basin that consists of the flood hazard, exposure, and risk in terms of potential flood fatalities and economic losses under the climate change. The Rainfall-Runoff-Inundation (RRI) model was calibrated using 2011 flood and validated with the 2009, 2012 and 2013 floods. The calibrated RRI model was applied to produce flood inundation maps based on 10-, 25, 50-, and 100-year return period of 24-hr rainfall. The rainfall data is the output of the downscaled and bias corrected MRI -AGCM3.2s for the current climate conditions (CCC) and two cases of future climate conditions with an outlier in the dataset (FCC-case1) and without an outlier (FCC-case2). For this study, the exposure assessment focuses on the affected population and the irrigated area. Based on the results, there is an increasing trend of flood hazard in the future climate conditions, therefore, the greater exposure of the people and the irrigated area keeping the population and irrigated area constant. The results of this study may be used as a basis for the climate change studies and an implementation of the flood risk management in the basin.

Keywords: Risk assessment, Pampanga river basin, Rainfall-Runoff-Inundation model, climate change, MRI-AGCM3.2S

1. INTRODUCTION

The Pampanga river basin is the fourth largest basin in the Philippines located in the Central Luzon Region with an approximate area of 10,545 km² located in the Central Luzon Region. It encompasses the four (4) provinces; most part of Nueva Ecija, Pampanga and some part of Bulacan and Tarlac. Due to the topographical location of the country, the basin experiences floods every year causing a disruptive situation. Based on the flood data analysis summarized by Fano (2010) from 1970 to 2010, among the provinces in the Philippines, Nueva Ecija, Pampanga and Bulacan are on the top rank list considering the number of flood events while the Pampanga province include in the top list considering flood casualties.

On the other hand, not only flood hazard that causes a disruptive situation but also climate change. Although changes of climate are happening since the beginning, but since the mid-20th century, it shows a significant change most likely to be due to human activities. Linking climate change to disaster risk, firstly it will increase weather and climate hazards, and secondly, it will increase in the vulnerability of

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communities to natural hazards through ecosystem degradation and rapid, unplanned urban growth, causing an unbalanced supply of human needs (food and water) (UNISDR, 2008). Therefore, this study focus on the risk assessment imposed by flood under the climate change in the Pampanga basin.

2. THEORY AND METHODOLOGY

As mentioned, the formula that was applied in this study is based on the definition of Risk as the combination of hazard, exposure, and vulnerability (R= H x E x V). Flood was identified as hazard while the potential affected people and the inundated irrigated area was considered in the analysis of exposure. On the other hand, to quantify the vulnerability of the potential affected population was based on a formula that calculates the potential fatalities considering the demographic condition while the assessment of inundated irrigated area was based on the damaged curve. The methodological approached that was applied in this study was given in Figure 1.

The Rainfall-Runoff-Inundation Model was used to simulate the inundation in the Pampanga basin. It is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously. Applying the 2D diffusive wave model to calculate the flow on the slope and 1D diffusive wave model to calculate the channel flow. For physical representation of the model, lateral subsurface, infiltration and surface flow is simulated. Lateral subsurface flow is based on the discharge-hydraulic gradient relationship while the vertical infiltration is estimated based on the Green-Ampt model. Also, the effect of dam was considered in the model. The model calculation was based on a simple rule that that the storage volume will continue to be updated based on the simulated inflow and outflow. And the outflow will be equal to inflow until such time that it reaches the maximum discharge capacity, then it will be maintained at the maximum set discharge.

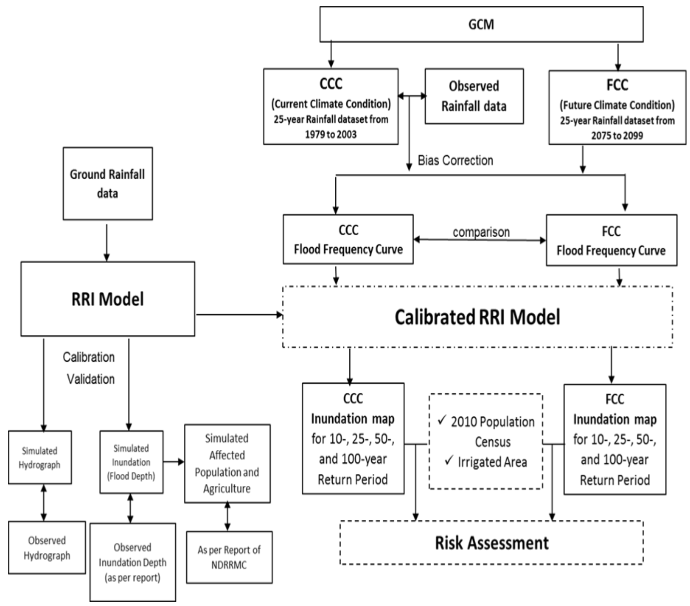

Figure 1. Methodological approach applied in this study.

For the Pampanga river basin, the RRI model was developed on a 500 m scale and applied to simulate the flood discharge and inundation areas of the past four flood events as part of the calibration (year 2011) and validation (year 2009, 2012, and 2013). As part of calibration, the hydrograph in Sapang Buho, Mayapyap, and San Isidro stations was compared to the observed. Also, the simulated result showing the extent of inundation areas was compared to the PAGASA post flood report for flood event of 2011 and to the MODIS for flood events of 2009, 2012 and 2013. Furthermore, to verify the formula and applied approach in quantifying the vulnerability in this study, the flood event of 2011 was used and the simulated result of the affected population and agriculture was compared to the report prepared by NDRRMC.

For the assessment of climate change impact, the precipitation data from MRI-AGCM3.2s was used as an input to the calibrated RRI. It is set of data of 7-days rainfall for 25 years considering the current climate condition (CCC) (1979-2003) and future climate condition (FCC) (2075-2099).The data set was dynamically downscaled from 20km to 5km resolution for better representation and bias corrected after it was found out that it was underestimated compared to the observed rainfall data set. The bias correction was based on a simple approach that is introducing a correction coefficients after comparing the data set of current and observed rainfall. These correction coefficient were applied to both climate conditions for 10-, 25-, 50-, and 100-year return period of 24-hour rainfall. An inundation maps were produced applying these conditions and cases to the calibrated RRI for the above mentioned return periods.

Going forward to the risk assessment, the 2010 census data were used for analyzing the affected population and potential fatalities was calculated based on the equation developed by ICHARM under MEXT SOSEI Project (Okazumi, et al., 2014). For the evaluation of irrigated area, it considers three stages of crops – stage1 (vegetative), stage2 (reproductive), and stage3 (maturing) as shown in Figure 2 and the cropping calendar was given in Figure 3. Converting to monetary value of production of losses, the equations adopted was based on the Manual on Damage Assessment Reporting System of Agriculture (2013) and the parameters was based on the latest available data from the Bureau of Agriculture Statistics ("Philippine Statistics Authority." n.d.).

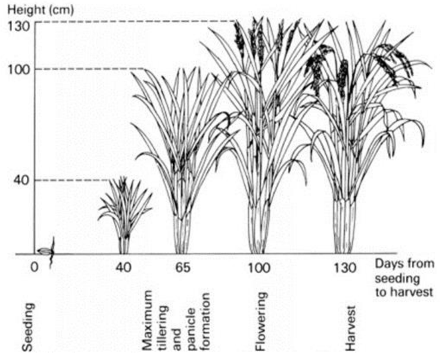

Figure 2. Growth stages of palay. Source: A Farmer's Primer on Growing Upland Rice, 1988

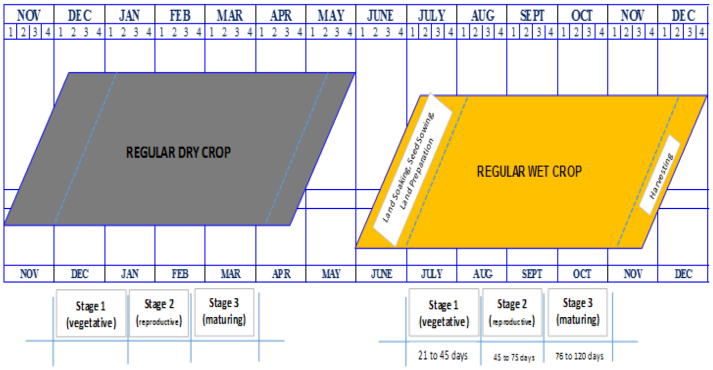

Figure 3. Regular cropping calendar showing the three stages of palay for a given days and months

3. RESULTS AND DISCUSSIONS

In the flood hazard assessment, a Rainfall-Runoff-Inundation (RRI) model was developed on a 500 m scale and applied to simulate the flood discharge and inundation areas of the past four major floods as part of the calibration (year 2011) and validation (year 2009, 2012 and 2013). For calibration of the model, the hydrograph in Sapang Buho, Mayapyap, and San Isidro stations was compared to the observed and applying the Nash-Sutcliffe Efficiency test, the value was 0.63, 0.51, and 0.68 respectively which is in an acceptable range. For validation, the MODIS image was compared to the simulated inundation extended. Additionally, 2011 flood was simulated to validate the affected people and irrigated area as part of risk assessment and the result was compared to the NDRRMC report. The result shows that there are 1,192,067 people affected in 953 barangays while the report shows that there are 1,471,228 affected people in 1,041 barangays. The result shows a good agreement between the simulated and reported data. While the affected irrigated area analyzing the province of Nueva Ecija, the simulation resulted to have a loss of 53 million USD compared to the reported value which is 85 million USD. The difference can be accounted brought by wind because the above mentioned flood event was due to typhoon. For assessing the impact of climate change, the MRI-AGCM3.2S precipitation data were used in the calibrated RRI model to produce flood inundation maps with precipitation of 10-, 25-, 50-, and 100-year return period. The MRI-AGCM3.2S data were dynamically downscaled from 20km to 5km. Although it was downscaled for better representation, there are still uncertainties because of the model limitations, shortcomings, errors, and biases. In this case, Figure 4 shows that the MRI-AGCM3.2S was underestimated as to compare to the ground rainfall. For this study, a simple correction approach was applied that is introducing a correction coefficient based on the difference between the observed and the data set of current climate condition. The correction coefficient will be applied to every return period for current and future climate conditions data set. Also, the evaluation of the possible outlier in the data set was carried out and found out that the data set under the future climate condition, there is a possibility of an outlier after applying the normal probability plot in the data set under future climate condition (Figure 5 & Figure 6).

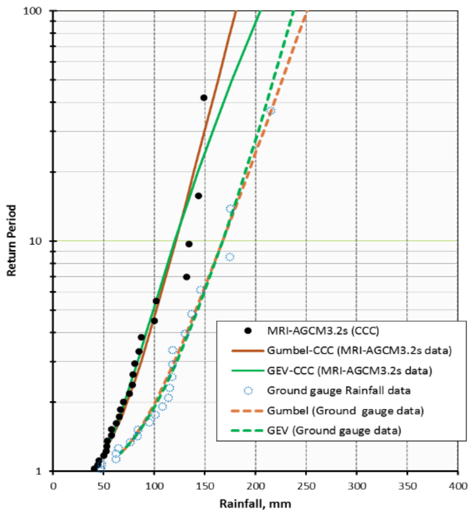

Figure 4. Probability analysis comparing the ground rainfall and the MRI-AGCM3.2S CCC.

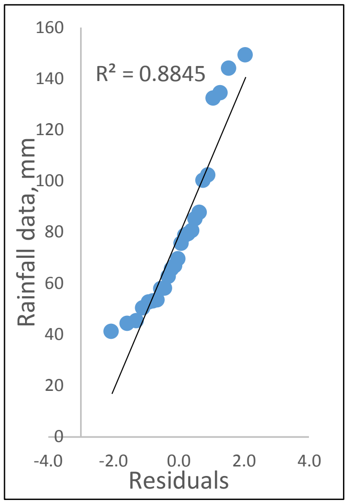

Figure 5. Normal probability for data set under CC.

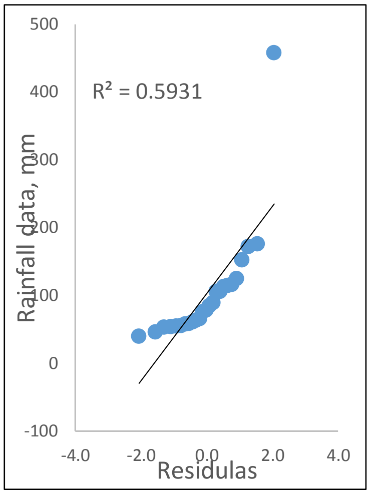

Figure 6. Normal probability for data set under FCC.

Furthermore, three tests were applied to validate the possibility of this outlier. These tests are the Interquartile Range (IQR), the Dixon's test (Q test), and the Grubb's test, which the first test indicates that there is no outlier in the data set while the other two tests shows an opposite result. Since, it is hard to validate which is which to consider, this study analyzed both the cases – with (case 1) and without (case 2) an outlier. As a result, there is an increasing trend of precipitation in the study area. But comparing the two cases – with (case 1) and without an outlier (case2), we can say that we there is a big impact of climate change in case1 (Figure 7) as to compare to case2 (Figure 8).

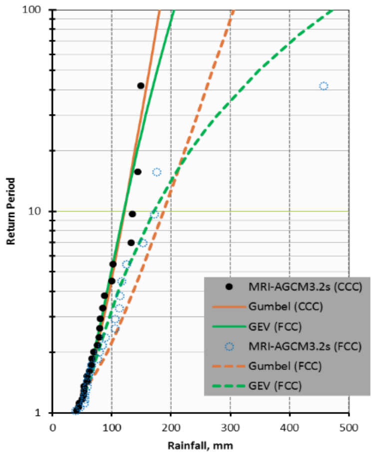

Figure 7. Frequency analysis of CCC and FCC-case1.

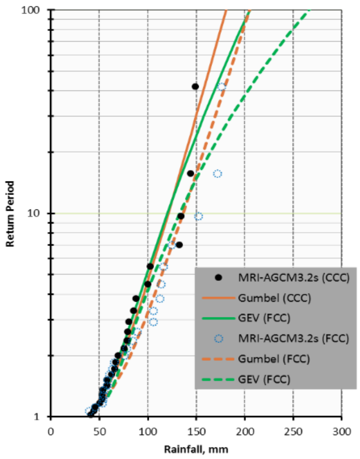

Figure 8. Frequency analysis of CCC and FCC-case2.

In the flood exposure and risk assessment, the result of the inundation area was based on 10-, 25-, 50-, and 100-year return period. As an example, a 50-yr return period inundation map under CCC and FCC case1 was given in Figure 9. Based on this inundation maps, out of 5.6 million people within the basin (2010 Census), 46-56% are affected by 10- and 100-year floods under CCC while 57-67% and 49-59% are affected under FCC of case 1 and case 2, respectively given in Table 1. Additionally, the municipality of Calumpit in Bulacan province, Cabanatuan City in Nueva Ecija, and San Fernando City in Pampanga were identified as the hotspot municipality/city and the flood risk in terms of potential fatalities was calculated given in Table 2.

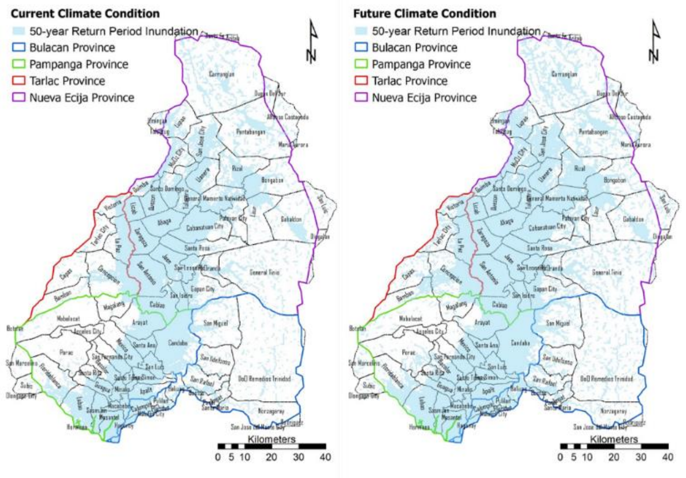

Figure 9. Inundation map of CCC and FCC-case1 for 50-year return period.

Table 1. Summary of affected population.

Return Period	Climate Condition	Affected Population	% of affected population to the total population
10-year	CCC	2,585,716	46%
	FCC-Case 1	3,190,068	57%
	FCC-Case 2	2,759,170	49%
25-year	CCC	2,840,844	51%
	FCC-Case 1	3,477,558	62%
	FCC-Case 2	3,024,987	54%
50-year	CCC	3,013,317	54%
	FCC-Case 1	3,650,110	65%
	FCC-Case 2	3,174,095	56%
100-year	CCC	3,142,931	56%
	FCC-Case 1	3,768,634	67%
	FCC-Case 2	3,314,300	59%

Table 2. Hotspot municipality/city for each provinces with calculated potential fatalities.

Return Period	Climate Condition	Calumpit, Bulacan		Cabanatuan City, Nueva Ecija		San Fernando City, Pampanga	
		Affected Population	Fatalities	Affected Population	Fatalities	Affected Population	Fatalities
10-year	CCC	84,984	24	242,494	64	126,732	34
	FCC-case1	95,528	26	251,241	65	135,360	37
25-year	CCC	90,823	25	246,496	64	130,208	35
	FCC-case1	96,975	28	252,766	66	140,731	38
50-year	CCC	93,230	25	249,046	65	132,646	36
	FCC-case1	97,323	28	255,773	67	146,684	40
100-year	CCC	95,391	26	249,927	65	135,025	37
	FCC-case1	97,323	28	257,132	68	147,280	41

For 261,247 hectares of irrigated area in the basin, 44% to 72% of the area is affected by 10- and 100-year floods under CCC while 59-88% and 48-80% are affected under FCC given the three stages of crops, two cases and return period as mentioned (Table 3). In terms of monetary values, crop under stage 2 (reproductive) causes the highest monetary losses equivalent to 2,914 USD per hectare as to compare to other two stages. Lastly, the total 7-day inflow of the Angat dam increases by 24-35% and 9% comparing the CCC to FCC for case 1 and case 2 respectively, while the Pantabangan dam increases by 28-36% and 8-10% given the same conditions and cases.

Table 3. Summary of affected irrigated area for different stages of palay.

Return Period	Climate Condition	Stage 1 (Vegetative)		Stage 2 (Reproductive)		Stage 3 (Maturity)	
		Affected Agriculture, ha	% of affected irrigated area to the total irrigated area	Affected Agriculture, ha	% of affected irrigated area to the total irrigated area	Affected Agriculture, ha	% of affected irrigated area to the total irrigated area
10-year	CCC	153,606	59%	124,514	48%	113,648	44%
	FCC-Case 1	216,130	83%	183,662	70%	175,352	67%
	FCC-Case 2	173,463	66%	135,670	52%	125,012	48%
25-year	CCC	168,805	65%	141,177	54%	131,115	50%
	FCC-Case 1	224,153	86%	194,096	74%	186,715	71%
	FCC-Case 2	189,135	72%	152,518	58%	142,746	55%

Continuation…

Return Period	**Climate Condition**	**Stage 1 (Vegetative)**		**Stage 2 (Reproductive)**		**Stage 3 (Maturity)**	
		Affected Agriculture, ha	**% of affected irrigated area to the total irrigated area**	**Affected Agriculture, ha**	**% of affected irrigated area to the total irrigated area**	**Affected Agriculture, ha**	**% of affected irrigated area to the total irrigated area**
50-year	CCC	179,034	69%	151,982	58%	142,086	54%
	FCC-Case 1	224,153	86%	194,096	74%	186,715	71%
	FCC-Case 2	189,263	72%	164,317	63%	153,656	59%
100-year	CCC	187,469	72%	162,440	62%	150,810	58%
	FCC-Case 1	230,051	88%	203,374	78%	195,933	75%
	FCC-Case 2	207,737	80%	172,772	66%	163,452	63%

4. RECOMMENDATIONS

Although RRI has proven to be effective in use for the risk assessment in the Pampanga river basin, there are still some limitations of the model that need to improve for future works. One of those, is the RRI simulation of the dams, on which, it can be modified by a user depending on the operation rule. Also, the importance of the structural measures need to incorporate in the model like the levee, embankment, and diversion channels. Another thing, is the uncertainty of the AGCM-MRI3.2s data that has been used in this study. Although, a simple bias correction was applied, but for a better result and to reduce the uncertainty, it needs to consider other bias correction methods. Moreover, considering climate change impact, it is just necessary to review and analyze other GCM data. On the other hand, for the risk analysis under the future climate condition, it is more appropriate to use a projected population and review the possible future plans for expansion of the irrigated area.

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