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Mitigation of Climate Change Impact by the Scenario of RCP 2.6 and RCP 8.5

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ABSTRACT

This study aims to analyze the impact of climate change on hydrological characteristics and flood discharge in the Noelmina and Benanain River Basins, East Nusa Tenggara Province, under the Representative Concentration Pathway (RCP) 2.6 and RCP 8.5 scenarios. The hydrological modeling was conducted by using the HEC-HMS software, based on the CHIRPS satellite rainfall data and it is validated against ground station observations. The model was calibrated by using the Nash-Sutcliffe Efficiency (NSE) and correlation coefficient (R) to ensure simulation reliability. The simulation results indicate that climate change significantly affects flood discharge in both basins. Under the RCP 2.6 scenario, peak discharge tends to decrease due to the higher evapotranspiration, whereas under the RCP 8.5 scenario, peak discharge increases by approximately 10–30% compared to current conditions. These findings reveal that climate change may intensify the extreme flood risks and reduce water availability during dry seasons. Therefore, adaptive water resource management strategies are required, including the reservoir capacity enhancement, land conservation, and climate-based water management optimization for sustainable river basin development.

Keywords: Climate Change, HEC-HMS, RCP 2.6, RCP 8.5, Noelmina River Basin, Benanain River Basin, Flood Discharge

INTRODUCTION

The water resources are one of the most vulnerable sectors and most impacted by the climate change. The rainfall pattern change which is increasingly uncertain, by the tendency of temporal and spatial variability increasing, causes the significant uncertainty in the water supply. This phenomenon can trigger the increasing of the frequency and intensity of hydrometeorology disaster (BMKG, 2022), as flash flood in one side and widespread drought as well as prolonged in the other side. The sustainable water resources management in river region that is as an integrated ecological and economic unit, demanding the depth understanding about the projection of climate change impact in the future and the adaptation of strategic development (Muleta and Marcell, 2023) that not only effective however is also efficient, responsive, and can be adapted to the dynamics of environment that is continuously changed.

The global climate change has become as one of the challenges to be most urgent and multidimensional that is faced by human civilization on 21st century. This phenomenon is marked by the increasing of global average temperature, rainfall pattern moving, the increasing of the frequency and intensity of extreme weather events (Koutsovili et.al, 2021) (as hot wave, heavy rain, drought), the rising of sea water level, and the changes in global hydrology cycle, have triggered the fundamental moving in the natural and social systems in all over the world.

The increase in greenhouse gas concentrations in atmosphere, mainly carbon-dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2o) that most of it comes from the anthropogenic activity like burning of fossil fuels, deforestation, intensive agricultural practice, and industrial process are as the specific stimulation from this climate change (IPCC, 2021 and Myhre et.al, 2013). The impact of climate change goes beyond mere temperature changes; it fundamentally influences the natural ecosystem, biodiversity, food production, society health, stability of economy, and the most crucial is for human survival (Ismail et.al, 2020 and Dau et.al, 2021), the availability as well as management of vital natural resources, mainly water. Various studies have indicated that Indonesia will experience the increase of average temperature, the significant change of rainfall pattern (with the potency of rainfall increase in several regions and the decrease in the other region, as well as the moving of rainy and dry seasons), the increase of flood event frequency and drought, as well as the increase of sea water level that can threaten the coastal areas (Aldrin et.al, 2018).

The province of Nusa Tenggara Timur (NTT) that is the Noelmina and Benanain watersheds' location which are as the biggest watershed in Timor Island and as one of the river regions in NTT province that faces high vulnerability due to the climate change. This region is generally characterized by dry tropical climate with long and intense dry season, as well as the strong dependence on the water resources which is limited for rained agricultural demand and household consumption. The change of rainfall pattern that is projected will be increasingly extreme in the intensity as well as duration. It is potential to aggravate existing ones, as lack of clean water, harvest failure due to the drought, and the increase in flood risk (Wichels and Ranganathan, 2020) in the certain areas when there is high rainfall.

This research especially will focus to the analysis of climate change impact in the Noelmina and Benanain watersheds by using two different climate scenarios from Intergovernmental Panel on Climate Change (IPCC) that is Representative Concentration Pathway (RCP) 2.6 and RCP 8.5. The scenario of RCP 2.6 presents the emission track that is very ambitious and the aim is to limit the safe boundary threshold of global warming. On the contrary, the RCP 8.5 illustrates the high emission scenario and without effective mitigation policy that is projected will produce the significant global warming. However, this research intends to give the substantial scientific contribution in the effort to achieve the sustainable water resources management in the vulnerable areas as Noelmina and Benanain, as well as becomes a model that can be adopted by the other regions in Indonesia that face the similar challenges.

MATERIALS AND METHODS

Research Location

Noelmina watershed (Figure 1) is in the Timor Island, Nusa Tenggara Timur Province and stretching from the mountainous in the center of island until the estuary in Timor Sea near the regions of Kupang and Timor Tengah Selatan. The upstream system is sourced in the mountainous area (including the Mutis Mountain) and the main river is through the administrative areas of some regency in the Timor south-west. The Noelmia watershed area is 2,000 km^2 and it is included in the management of BPDAS Benanain-Noelmina.

Benanain watershed (Figure 2) is in the Timor Island, Nusa Tenggara Timur Province and in the south-east island that the upstream is in the mountainous zone and the estuary is in the Timor Sea. Administratively, this watershed is stretching through some regency in the region including the area surrounding Kupang and Timor Tengah Selatan, so the management involves the regional institution and the Big Institution of NT II-River Region.

Method of Data Collecting

The method of data collecting is generally classified into 2 as follows:

a. Primary data, the primary data is data that are obtained from observation or direct review in the field. The primary data is also obtained from the interview with hydrology staff of BMKG, the manager of hydrology data in the watersheds on Noelmania and Benanain river regions, BPS, society, and the related side that can give the information about climate change, the development of Kolhua Dam, the availability of raw water source, water demand, scope of water service as well as number of populations.
b. Secondary data, the secondary data is data that are obtained from the related institution that are BMKG of Kupang, Big Institution of Nusa Tenggara II River Region, BPDAS Benanain-Noelmina, BPS of Noelmina and Benanin River Regions that includes CHIRPS satellite rainfall data, ground station rainfall data, discharge data in Noelmina and Benanain watershed, data of population number, administrative map, Noelmina and Benanin watersheds, map of water resources potency in Noelmina and Benanain watershed, and coverage data of water service.

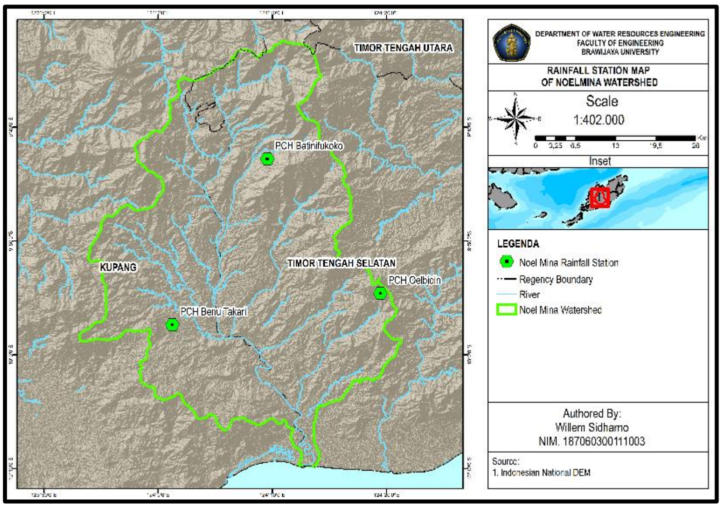

Figure 1. Map of Research Location and Rainfall Station

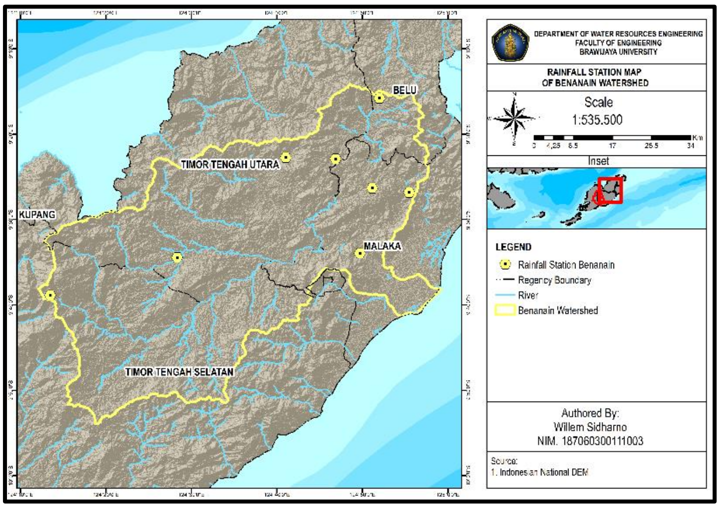

Figure 2. Map of Research Location and Rainfall Station in Benanain Waterhed

Hydrology Modeling by Using HEC-HMS Software

Design flood can be calculated by using software, one of them is HEC-HMS (Hasan et.al, 2024). The software is developed by the United States Army Corps of Engineers (USACE) Hydraulic Engineering Centre (HEC) that is HEC-HMS. This application of HEC-HMS is domain/ freeware public application that is developed by US ARMY. This application can be directly download on the website: http://www.hec.usace.army.mil. The explanation is as follows: (Figure 3 presents the flow chart of research).

a. ***The Main Part:*** in the analysis of design flood by using hydrology modelling of HEC-HMS, it formerly must be known the main part of hydrology modelling that is Basin Models (Watershed Model), Meteorologic Models (Rainfall Model), Control Specifications (Boundary of modelling time), Time Series Data (Distribution of rainfall data). To obtain the result of hydrology modelling by using HEC-HMS 4.2, it must be through three stages that are data input, running program, and running output.

b. ***Watershed Model (Basin Model):*** in the modelling of watershed/ basin, it is necessary to be attended the parameter of watershed area. For this modelling is selected the analysis method by using SCS and Snyder (DPU Dirjem Pengairan, 1999).

c. ***Rainfall Model (Meteorology Model):*** this rainfall modelling intends to analyze the design flood that is dropped on the watershed that has been prepared in the previous stage. The design rainfall intensity that is used in the modelling is design maximum rainfall depth that has been analyzed by using the distribution method due to the planned return period.

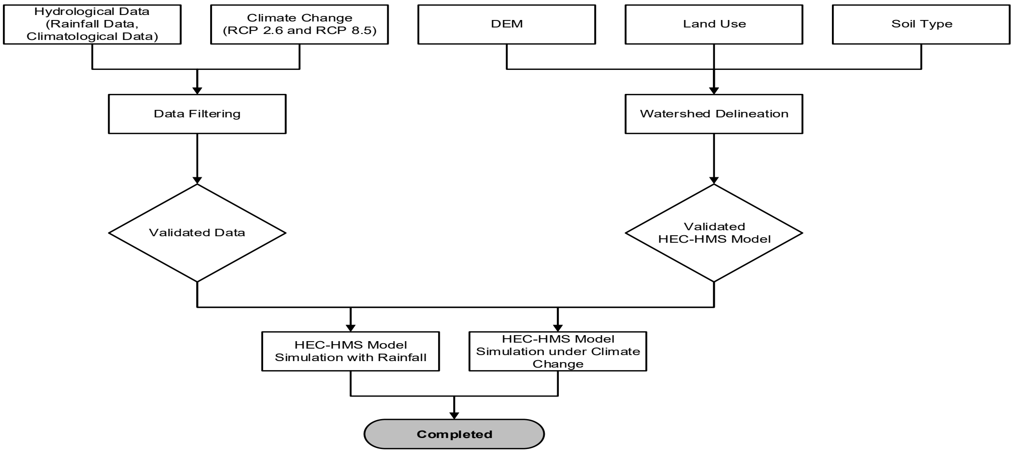

Figure 3. Flow Chart of Research

d. The boundary of modelling time (Control Specification): the modeling control is the time duration in the modeling running. By carrying out this modeling control, it will be obtained the time which the discharge will experience the drastic change due to the direct run-off. In determination of this modelling control, that must be paid attention is for every return period of modeling, it must be carrying out the control. This modeling control consists of when the model simulation is started and when is ended.

e. Distribution of Rainfall Data (Time Series Data: the rainfall data that is used for analyzing the rainfall with various return periods is annual maximum daily rainfall. It causes the result of rainfall is per-24 hours.

f. The Data Output of HEC-HMS: after all of the program input has been explained, the next stage is carrying out the program running. After program running, in each outlet of watersheds will be known as follows: outflow (flood hydrograph), incremental precipitation (rainfall distribution), excess precipitation (distribution of rainfall that becomes as run-off), precipitation loss (distribution of rainfall that enters into land), direct run-off.

g. Calibration of HEC-HMS result: coefficient of Nash and Sutcliffe (NSE) is as the efficiency size that illustrates the suitability degree of model result to the data variation of observation result. The efficiency value of NSE that is introduced by Nash and Sutcliffe (Nash and Sutcliffe, 1970) is defined as follows:

$$NSE = 1 - \frac{\sum_{i-1}^{n} [Q_o - Q_s]^2}{\sum_{i-1}^{n} [Q_o - \overline{Q_o}]^2}$$

where: Qo= observed discharge (m^3/s); Qs= simulation discharge (m^3/s); Qo= average observation discharge (m^3/s). The criteria of correlation coefficient (R) are between -1 until +1. The mark of (+/-) shows the direction of relation (positive/ negative), and the size of value shows the strength of relation. For the significant test of R, it is usually used the t-test (there is compared the R calculated and R table or it can use the t-test for correlation). Table 1 presents the criteria of correlation coefficient.

Table 1. Criteria of Correlation Coefficient

Value of R	Interpretation
0 – 0.19	Very low
0.20 – 0.39	Low
0.40 – 0.59	Moderate
0.60 – 0.79	Strong
0.80 - 1	Very strong

RESULTS AND DISCUSSION

Frequency Analysis of Rainfall

Distribution of hourly design rainfall is differentiated from maximum rainfall by using PSA 007 method (Analysis Standard Procedure). This method is used for estimating the rainfall data on the various time duration (1 until 6 hours) based on the daily design rainfall that has been obtained before from the result of probability distribution analysis. By using the coefficient of run-off (C) that is 0.45, there obtains the value of effective rainfall (Rn).

Table 2. Frequency of Hourly Rainfall in Noelmina Watershed

Time	Return period (year)					
	2	**5**	**10**	**25**	**50**	**100**
1	2.10	3.32	4.17	5.60	6.97	8.68
2	4.73	7.01	8.81	11.82	14.72	19.29
3	13.41	17.71	20.87	26.74	32.53	39.55
4	3.94	5.53	7.42	10.57	13.94	17.36
5	1.05	1.84	2.78	3.73	4.65	5.79
6	1.05	1.48	2.32	3.73	4.65	5.79

Table 3. Frequency of Hourly Rainfall in Benanain Watershed

Time	Return period (year)					
	2	**5**	**10**	**25**	**50**	**100**
1	2.30	3.51	4.09	4.77	5.24	5.69
2	5.17	7.42	8.63	10.06	11.06	12.63
3	14.66	18.74	20.43	22.77	24.45	25.90
4	4.31	5.86	7.27	9.00	10.48	11.37
5	1.15	1.95	2.72	3.18	3.49	3.79
6	1.15	1.56	2.27	3.18	3.49	3.79

Simulation of HEC-HMS

Simulation of Actual Design Flood

The simulation of actual design rainfall in the Noelmina and Bananain watersheds is carried out by using the software of HEC-HMS and the results are show in Figure 4 and 5.

Simulation of Design Flood Due to the Climate Change RCP 2.6

The simulation of design flood due to the climate change condition of RCP 2.6 in the Noelmina and Benanain watersheds that is carried out by using the software of HEC-HMS are presented in Figure 6 and 7.

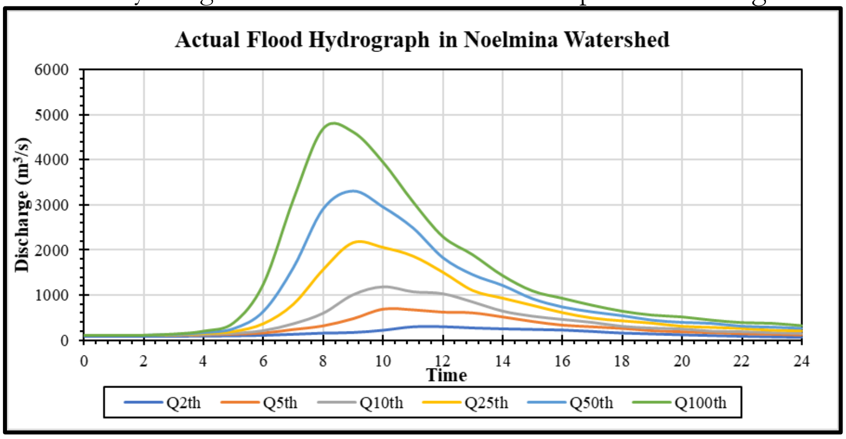

Figure 4. Actual Flood Hydrograph in Noelmina Watershed

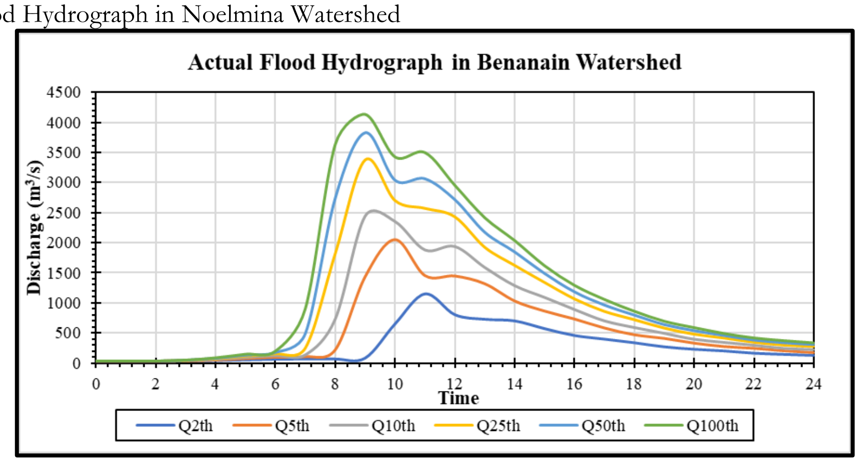

Figure 5. Actual Flood Hydrograph in Benanain Watershed

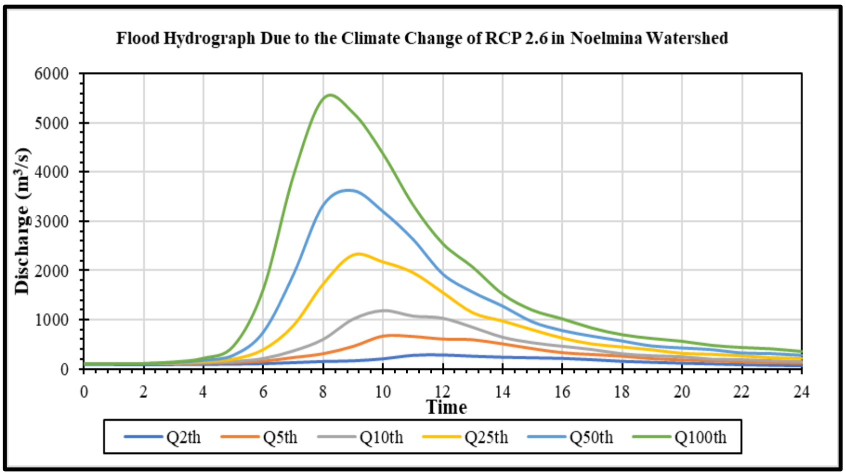

Figure 6. Flood Hydrograph Due to the Climate Change of RCP 2.6 in Noelmina Watershed

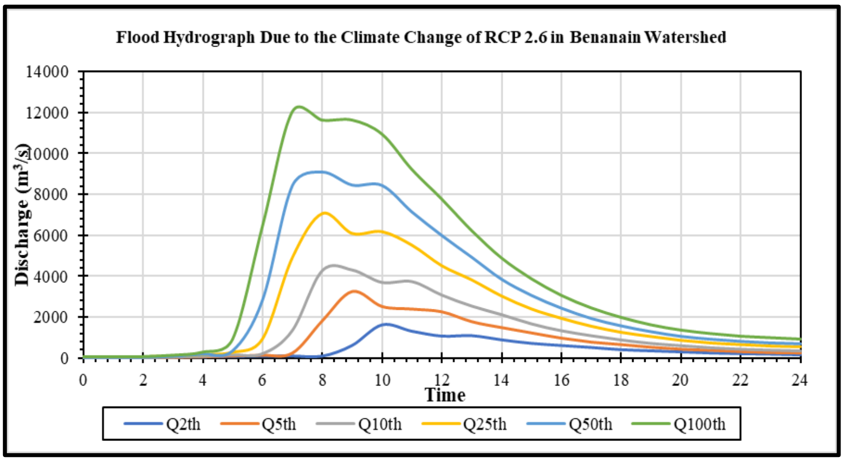

Figure 7. Flood Hydrograph Due to the Climate Change of RCP 2.6 in Benanain Watershed

Simulation of Design Flood Due to the Climate Change of RCP 8.5

The simulation of design flood due to the climate change condition of RCP 8.5 in the Noelmina and Benanian watersheds are presented in Figure 8 and 9.

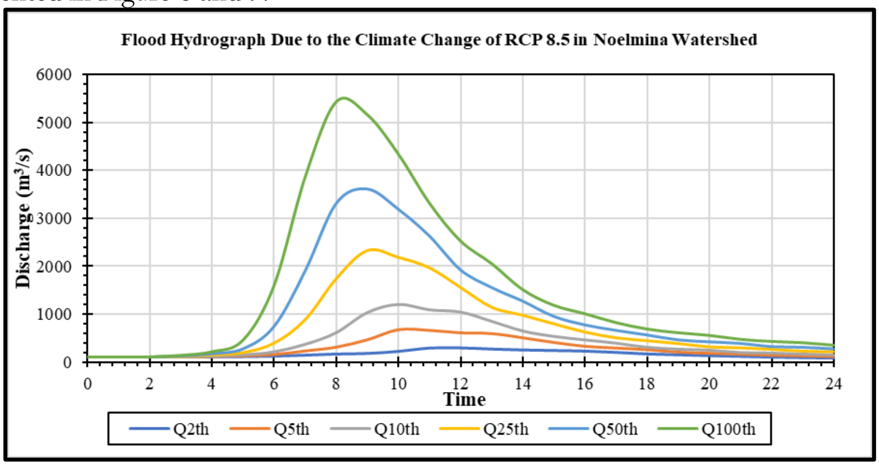

Figure 8. Flood Hydrograph Due to the Climate Change of RCP 8.5 in Noelmina Watershed

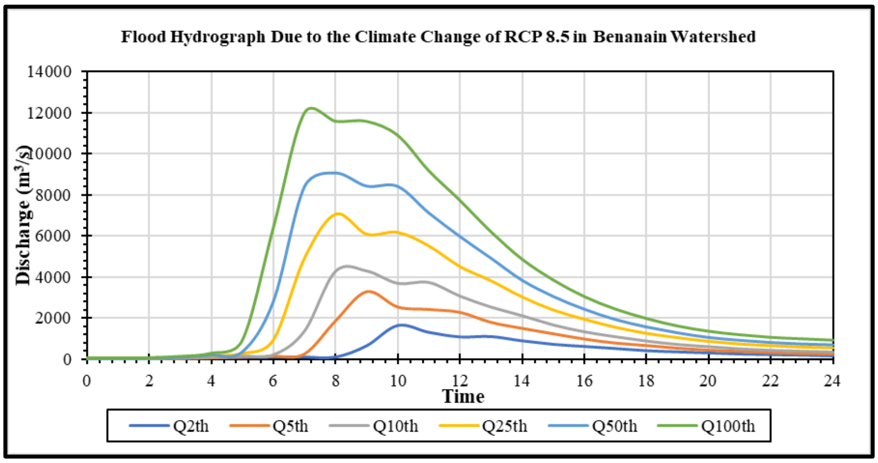

Figure 9. Flood Hydrograph Due to the Climate Change of RCP 8.5 in Benanain Watershed

Simulation of Actual Dependable Discharge

The simulation of dependable discharge due to the actual discharge condition, climate change discharge of RCP 2.6, and climate change discharge of RCP 8.5 in the Noelmina and Bananian watersheds are carried out by using the software of HEC-HMS and the results are presented in Figure 10 and 11.

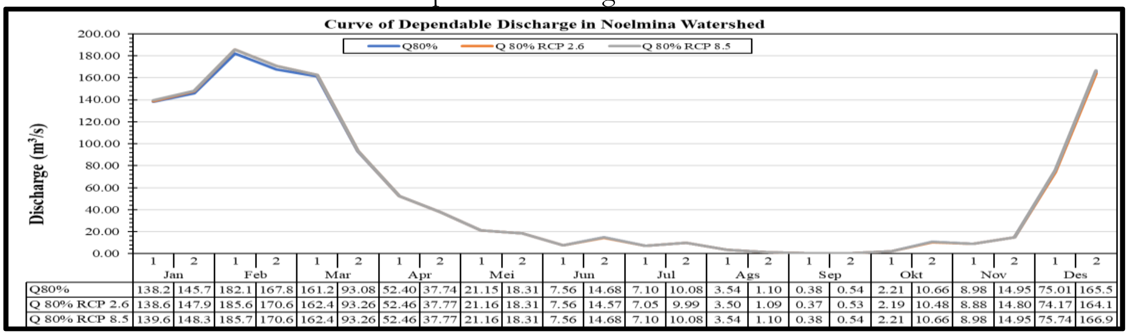

Figure 10. Curve of Dependable Discharge in Noelmina Watershed

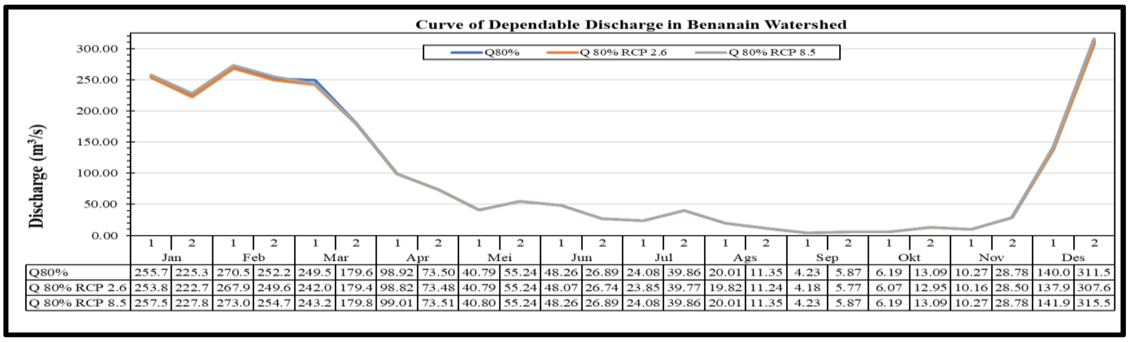

Figure 11. Curve of Dependable Discharge in Benanain Watershed

The Comparison of HEC-HMS Simulation Result

The simulation of design flood is carried out for the 3 main conditions as follows: a) actual condition (basic period) that represent the hydrology situation at this time; b) the scenario of RCP 2.6 climate change that illustrates the scenario of high mitigation with the increase of global temperature which is relatively low; c) the scenario of RCP 8.5 climate change that represents the extreme condition with the increase of temperature and emission of high greenhouse gas.

The hydrology model of HEC-HMS is used for simulating the hydrology response of watershed to the rainfall and evapotranspiration that is projected from the model result of regional climate (RCM)

Table 4. Simulation Result of Flood Discharge in Noelmina Watershed.

Return period	Scenario		
	Actual	**RCP 2.6**	**RCP 8.5**
Q 2 years	300.21	288.8	296.04
Q 5 years	688.25	665.24	682.38
Q 10 years	1187.81	1193.87	1211.13

Q 25 years	2169.81	2311.63	2323.7
Q 50 years	3302.09	3619.47	3614.5
Q 100 years	4698.82	5484.27	5440.69

Table 5. Simulation Result of Flood Discharge in Benanin Watershed

Return period	Scenario		
	Actual	RCP 2.6	RCP 8.5
Q 2 years	1156.58	1624.56	1651.30
Q 5 years	2049.93	3260.17	3277.73
Q 10 years	2446.25	4289.63	4296.96
Q 25 years	3369.34	7063.40	7063.40
Q 50 years	3824.21	9078.10	9063.92
Q 100 years	4139.94	12036.57	11994.06

The simulation result shows that there is the significant different between actual and projection flood discharge under both scenarios of climate change. On the basic period, the flood peak discharge shows the normal condition in accordance with the natural characteristic of watershed. However, on the scenario of RCP 2.6, the peak discharge is generally decreasing than the actual condition, mainly on the month with medium rainfall. It is allegedly by the increase of evapotranspiration due to the increase of moderate temperature; therefore, it reduces the surface run-off although the rainfall does not significantly change. On the contrary, on the scenario of RCP 8.5, the peak discharge shows the significant enough increasing than the actual condition. This increase is between 10 until 30% on the several peak events, mainly on the rainy season. It is along with the prediction of the increase of extreme rainfall intensity and the frequency of heavy rainfall event on the scenario of extreme climate.

The Implication to the Water Resources

This finding shows that the strategy of climate change mitigation and management of reservoir or dam is needed to be customized with the projection of hydrology in the future. The scenario of RCP 8.5 demands the available additional storage capacity or reservoir operation rule that is more adaptive for anticipating the increase of flood peak. Meanwhile, on the scenario of RCP 2.6, the focus of management is more directed to the efficiency of water use and conservation of water resources, remembering to the potency of discharge decreasing and water availability.

Overall, this simulation result confirms that the climate change is potential to change the hydrology characteristic of watershed significantly, from the magnitude side of peak discharge and seasonal flow pattern as well as the frequency of extreme flood event

CONCLUSION

Based on the analysis above, it can be concluded that the climate change has a significant impact to the water management of water resources in the Noelmina and Benanain watershed. The both scenario of RCP 2.6 and RCP 8.5 show that without the accurate step of mitigation, the negative impact of climate change will be getting worse, threaten the availability and quality of clean water. Therefore, there is needed a strategy of comprehensive mitigation that involves all of stakeholders including government, society, and public sector. The steps of mitigation as the development of green infrastructure and technology of efficient water management will be as the key in facing this challenge. In addition, there is also important to increase the society consciousness about the important of sustainable water resources management for determining the water availability in the future.

In the end, this research is hoped can give the base for the better decision making in the water resources management in the vulnerable region towards the climate change, as well as to give the contribution to the further research in this field.

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