Cluster 4: Global Change and Sustainable Development

Assessment of Changes in the Water Resources Budget and Hydrological Regime of the Pampanga River Basin (Philippines) due to Climate Change

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ABSTRACT

Southeast Asia is already experiencing changes in its climate. Heat waves, droughts, floods, and tropical cyclones in the region have been more intense and frequent, causing extensive damage to properties, assets, and human life. In the Philippines, climate change is manifested by the dramatic increase in the number of extreme floods, rising from just under 20 during 1960—1969 to nearly 120 by 2000—2008. This study aims to contribute to the efforts to strengthen the climate change adaptive capacity of the Philippines by assessing the changes in the water resources budget and hydrological regime of the Pampanga river basin, which is one of the most important river basins in the country. The Coupled Model Intercomparison Project Phase 5 (CMIP5) tool under the Data Integration and Analysis System (DIAS) was used to generate data used in the analyses. The results show that the projected total annual water budget of the Pampanga river basin for the years 2046-2065 is larger than present. This increase will likely be concentrated to occur in the wet season (June-November). The models project a wetter wet season and a moderately drier dry season. Results also show that the number of extreme rainfall events is very likely to increase as well as the number of no-rain days. Adaptive measures and climate change policies can be planned and executed given the results of this study.

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ASSESSMENT OF CHANGES IN WATER RESOURCES OF THE PAMPANGA RIVER BASIN DUE TO CLIMATE CHANGE

1.0   INTRODUCTION
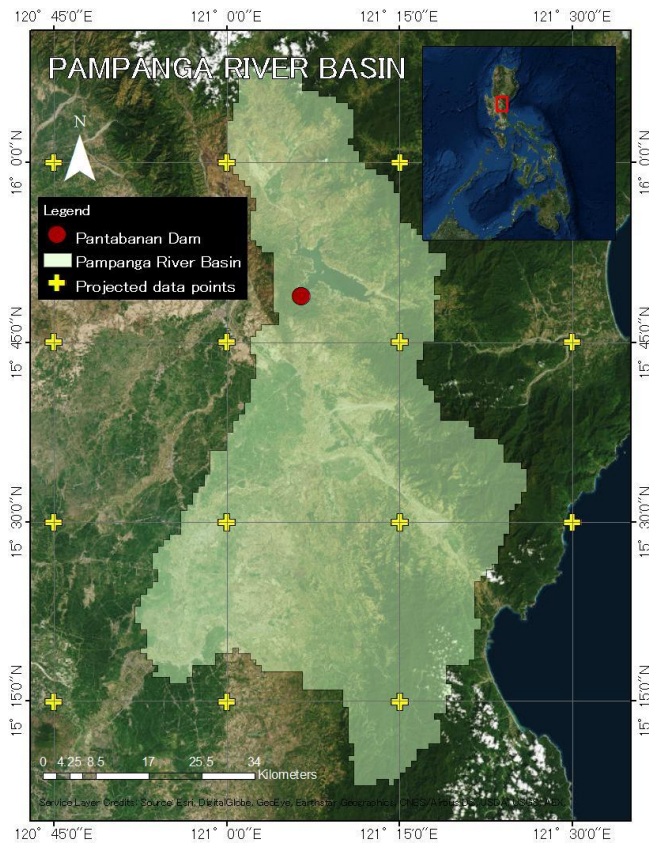
The study focuses on the Pampanga river basin located in the island of Luzon in the Philippines. The study area is bounded by the region (15°00'N, 120°45'E to 16°15'N, 121°30'E) as shown in Fig. 1. Pampanga river basin is the fourth largest in the Philippines. The study area covers about 3,700 km^2 which includes parts of Pampanga, Bulacan, and Nueva Ecija. The total length of the main river, the Pampanga River, is about 260 kilometers.

Figure 1. Pampanga River Basin

Climatology and Topography. On average, 5 tropical cyclones pass through the basin in a span of three years. The dry season lasts from the month of December up to May while June to November is the wet season. The months with the highest amount of rainfall are July, August, and September. The main river channel has a relatively low gradient, particularly at the middle and lower sections. The basin experiences at least one flooding in a year, with some areas remaining submerged during the wet season but relatively dry during dry season [6].

Economic Value.   The study area includes one of the most important dams in the Philippines: the Pantabangan dam. This dam is critical to the irrigation water supply of the surrounding agricultural lands. The Pantabangan dam and reservoir located at the northern part of the basin (see Fig. 1) serve to provide irrigation to about 102,000 ha of land in the provinces of Bulacan, Pampanga and Nueva Ecija. It also supplies water to the country's capital, Metro Manila, for domestic and industrial use. The Luzon grid is partly supplied by the hydroelectric power generated by the dam. Pantabangan dam is also used to reduce flooding in the downstream villages [3].

Water Resources Management. The current system of water resources management of the dam relies on the data provided by the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). The management implements an end-to-end approach which begins with PAGASA providing local climate forecasts by downscaling regional climate forecasts. A hydrological model is then used to forecast seasonal water inflow given the local climate forecasts and other hydrological variables. With this information, the reservoir operators optimize the reservoir yield and make decisions regarding the amount of water to be released for various purposes. The final step is the assessment of the impact which feeds back data to PAGASA to further improve the process.

Climate Change. A changing climate could have drastic effects to the Pampanga river basin and to the country as a whole. Agriculture, particularly rice production, is critical to the Philippines' food security and economy. According to the World Bank, agriculture accounts for 11.3% of Philippines GDP as of 2014 [12]. Rice is also the most important crop in the country because it is a staple food of most Filipinos. Central Luzon is one of the largest producers of rice in the Philippines. This dependence on agriculture makes the region especially vulnerable to the ill effects of climate change. In the recent years, Southeast Asia is already experiencing changes in its climate. A study conducted by the Asian Development Bank notes that heat waves, droughts, floods, and tropical cyclones in the region have been more intense and frequent, causing extensive damage to property, assets, and human life. The number of extreme floods in the Philippines has risen dramatically, rising from just under 20 during 1960—1969 to nearly 120 by 2000—2008 [1]. Climate change projections based on the most pessimistic scenario would result to a decline of 50% of the rice yield potential of the countries in the Southeast Asia region [1].

Research Motivation. This study aims to strengthen the climate change adaptive capacity of the Philippines by assessing the changes in the water resources budget and hydrological regime due to climate change of one of its major river basins, the Pampanga river basin. The results of this research can be used to enhance existing policies for climate change adaptation both in the national and local government units. Specifically, the integrated water management of the Pampanga river basin can be improved with the additional data generated by this research. Downscaled climate change projections for the target area can help improve the flood control and prevention schemes, irrigation management, and water demand management.

2.0   METHODOLOGY

The Coupled Model Intercomparison Project Phase 5 (CMIP5) tool under the Data Integration and Analysis System (DIAS) was used to generate data for this study. Collected climate data for the years

ASSESSMENT OF CHANGES IN WATER RESOURCES OF THE PAMPANGA RIVER BASIN DUE TO CLIMATE CHANGE

1979-2005 was used as a benchmark for the past and present climate. Selected Global Climate Models (GCM) under CMIP5 were used to project future climate for the years 2046-2065 with RCP8.5 emission scenario, which is the pathway with the highest greenhouse gas emissions [7]. Point analyses were conducted to compare the past and future precipitation data including the annual total rainfall budget, monthly means, and rainfall extremes. Spatial analyses were also conducted to compare the 50-year and 200-year return period intensity rainfall of the past versus the future data. Specific details are discussed in the following sections.

2.1 Data Integration and Analysis System (DIAS)

DIAS was designed to coordinate cutting-edge information for science and technology and various research fields related to the Earth's environment. Its main objective is to function as a data infrastructure that can integrate Earth observation data, numerical model outputs, and socioeconomic data. With this system, new knowledge can be generated towards the goal of solving the Earth's environmental problems and generating socioeconomic benefits. DIAS was launched as part of the Earth Observation and Ocean Exploration System, which is one of five National Key Technologies defined by the Third Basic Program for Science and Technology of Japan [9].

2.2 Coupled Model Intercomparison Project 5 (CMIP5)

CMIP5 is the fifth phase of the Coupled Model Intercomparison Project. CMIP5 provides a set of coordinated climate model experiments from climate modeling groups around the world. CMIP5 can be used to examine climate predictability and explore the ability of models to predict climate on decadal time scales [11]. This functionality of CMIP5 is used in this study to project the future climate in the Pampanga river basin for the years 2046-2065 with RCP8.5 emission scenario. This emission scenario, with the highest greenhouse gas emissions, can be characterized by high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas (GHG) emissions in absence of climate change policies [7]. The World Meteorological Organization describes RCP8.5 as rising radiative forcing pathway leading to 8.5 W/m^2 in 2100 [13]. RCP8.5 can be regarded as the most pessimistic scenario for future climate of the target area.

2.2.1 Model Selection

Four GCM's under CMIP5 were selected to be used for the purposes of this study. Initially, the 15 models listed in Table 1 were considered for selection. The models were ranked according to how well they perform for the target area of the Pampanga river basin. This was done by comparing the

model results for the years 1979-2005 to the available actual data. Six meteorological elements were used for the evaluation. These elements are rainfall, air temperature, geopotential height, outgoing longwave radiation, zonal wind, and meridional wind. The correlation coefficient and root-mean-square error (RMSE) for each month and for each variable were used as criteria to rank the models.

Table 1. Table of models considered

Model Name		
ACCESS1.0	BCC-CSM1.1	CESM1(BGC)
CNRM-CM5	CanESM2	FGOALS-g2
GFDL-CM3	GISS-E2-R-CC	HadGEM2-ES
IPSL-CM5A-MR	MIROC-ESM	MIROC5
MPI-ESM-MR	MRI-CGCM3	NorESM1-M

Finally, the 4 GCM's that suited best for the Pampanga river basin were determined. Table 2 lists the final models that are used in this study. The selected models with their ensemble members were used to project precipitation data for the future years 2046-2065. Ensemble members are closely related simulations by a single model. Each member is named as $r < N > i < M > p < L >$, where N, M and L are integers used to distinguish between different initial conditions, initialization method, and perturbation physics [8].

Table 2. Selected models

Model Name (No. of Ensemble members)	
CNRM-CM5 (1)	CanESM2 (5)
GFDL-CM3 (1)	MPI-ESM-MR (1)

2.2.2 Bias Correction

Monthly precipitation data were computed for several points inside and near the target area. The location of these data points are plotted over the basin map in Fig. 1. The resulting data were corrected for bias using the APHRODITE bias correction tool available with CMIP5. APHRODITE stands for Asian Precipitation Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources. It is a daily precipitation dataset with high-resolution grids for Asia. The data are obtained from a rain gauge observation network in different countries [10]. Bias correction is needed because of the limitations of GCM's. Generally, GCM rainfall output has low extreme heavy rainfall rate, has incorrect distribution of moderate intensity rain, and has small number of no-rain days [2]. The models were bias-corrected so that they would best fit with the past data as given by

APHRODITE. The correction for each model was then applied to its predicted future precipitation. Figures 2 and 3 show examples of bias correction of ranked past extreme rainfall data and past monthly precipitation for the point (15°30'N, 121°15'E).
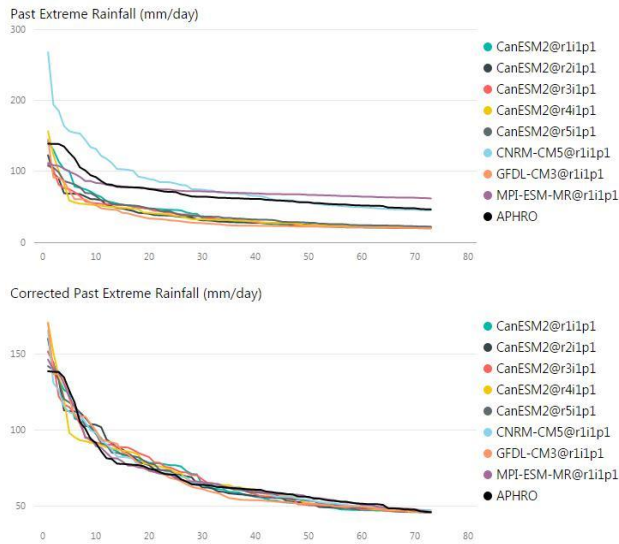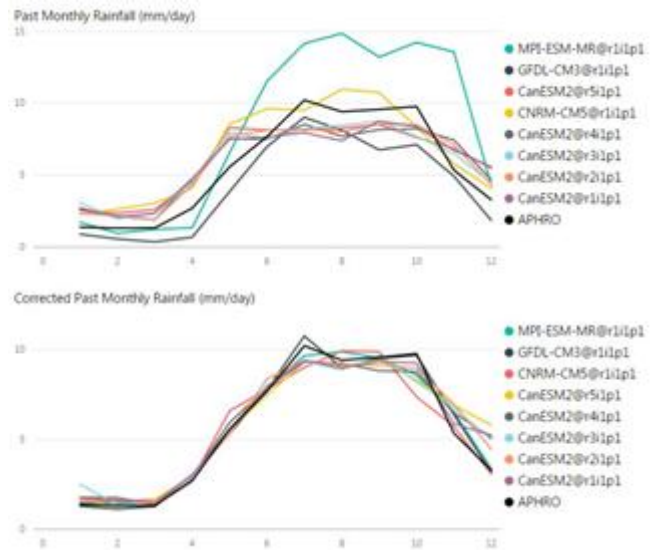

Figure 2. Extreme Rainfall Correction (Past)

Figure 3. Monthly Rainfall Correction (Past)

2.3 Point Analysis and Spatial Analysis

Analysis was done on 3 point datasets (16°00'N-121°00'E, 15°45'N-121°15'E, 15°30'N-121°15'E) using the bias corrected projected future precipitation. The changes in annual total rainfall budget, monthly rainfall, return period intensities, and number of extreme rainfall and no rainfall days were assessed for each point. Spatial analysis using a GIS tool was also conducted to assess the changes in 50-year and 200-year rainfall intensities. This is done by interpolating precipitation data from all the points. Ordinary Kriging was the method used for interpolating the rainfall data because it has been shown that this method produces lower error compared to other common methods for a mountainous region in a tropical setting [4] such as the Philippines.

3.0   RESULTS AND DISCUSSION

3.1 Point Analysis

The following points were considered for point analysis: (16°00'N-121°00'E, 15°45'N-121°15'E, 15°30'N-121°15'E). These points were chosen as representative of the upstream, mid-portion, and downstream parts of the main river.

3.1.1 Upstream Point: 16°00'N-121°00'E

Figure 4 shows the trends of monthly precipitation as given by the models at the upstream point. Generally, all the models predict an increase in monthly rainfall. The top four models that gave the highest increase in rainfall were chosen and tabulated. Tables 3 shows the change in monthly precipitation from past to future in absolute values and percentages respectively. All the models project that the wet season (June-November) will experience increase in rainfall while the dry season (December-May) will become moderately drier or stay the same. Looking at the total annual change in rainfall at Table 3, the models project an average increase of between 6.5 -15.8 mm/day of rainfall.

Figure 5 shows the rainfall intensities for different return periods for the upstream point. Most models overestimate the past data and there is a disagreement for the future projection. Because of this, no definite conclusion can be derived from this set of data.

Table 4 summarizes the number of no-rain days and number of extreme rain days given by the models for the past and future. Extreme rainfall is defined here as rainfall exceeding 90 mm/day, which is expected to cause serious flooding in low lying areas necessitating immediate evacuation. This is given by the Philippines' weather bureau's (Philippine Atmospheric, Geophysical and Astronomical Services Administration) rainfall warning levels [5]. Table 4 shows that the upstream point will experience an increase in the number of no-rain days, the number of extreme rainfall events will also increase dramatically with 3 models projecting more than double of the past number.
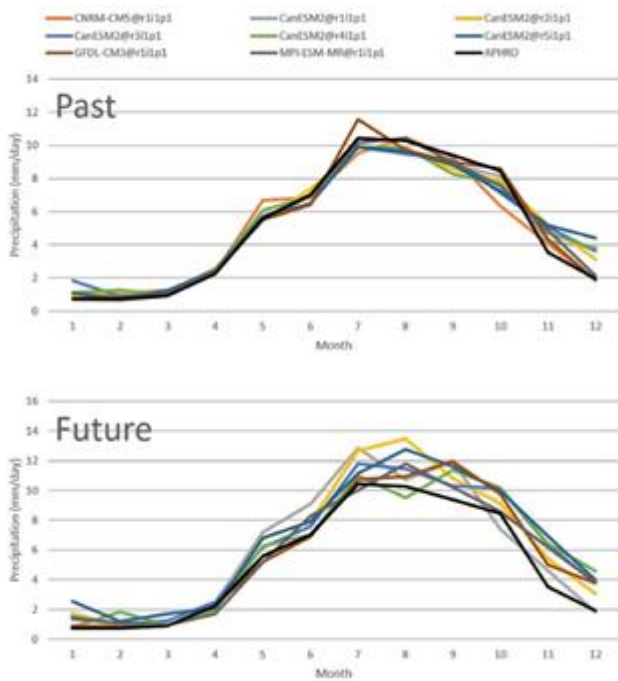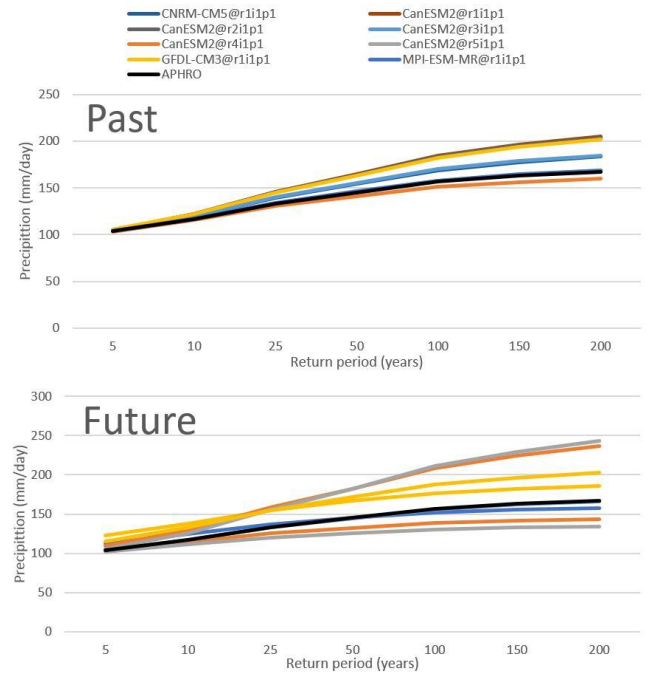
Figure 4. Monthly Rainfall Data for Upstream

Figure 5. Return Period and Intensities for Upstream

Table 3. Table of change for upstream point: mm/day and percentage

	Model Name							
	CNRM		Can@r1		Can@r4		Can@r5	
Month	mm/day	%	mm/day	%	mm/day	%	mm/day	%
1	0.76	90.05	0.68	62.5	1.43	126.33	0	-16.65
2	-0.17	-16.27	-0.22	-20.02	-0.03	-2.39	0.14	18.62
3	-0.34	-26.77	-0.18	-16.41	0.76	78.92	-0.31	-25.08
4	0.09	3.87	-0.35	-13.64	-0.38	-15.48	-0.21	-8.42
5	0.5	7.47	1.06	18.5	0.72	11.82	-0.49	-8.61
6	2.25	32.85	0.95	13.76	1.01	14.64	0.44	6.79
7	3.32	34.88	2.7	27.05	1.29	13.07	0.85	8.59
8	0.26	2.49	3.91	40.76	2.91	29.52	1.33	13.8
9	2.66	28.65	2.04	23.22	3.33	40.22	3.12	35.22
10	1.07	16.83	0.99	12.15	2.28	29.56	2.49	34.33
11	0.53	12.98	1.25	30	2.23	47.15	-0.2	-3.86
12	-0.02	-1.07	-0.77	-20.02	0.23	6.1	-0.62	-14.08
Total	10.91		12.06		15.78		6.54	

Table 4. Table of 0 or Extreme Rainfall count for upstream point

P/F	Model Name			
	CNRM	Can@r1	Can@r4	Can@r5
P(0)	1104	1144	1122	1148
P(Ext)	11	11	5	10
F(0)	1142	1176	1017	1160
F(Ext)	34	20	25	11

3.1.2 Middle Point: 15°45'N - 121°15'E

Figure 6 shows the trends of monthly precipitation as given by the models at the middle point. Generally, all the models predict an increase in monthly rainfall, same case as the up-stream point. The top four models that gave the highest increase in rainfall were chosen and tabulated. Table 5 shows the change in monthly precipitation from past to future in absolute values and percentages, respectively. Again same with the upstream point, all the models project that the wet season (June-November) will experience increase in rainfall while the dry season (December-May) will become moderately drier or stay the same. Looking at the total annual change in rainfall at Table 5, the models project an average increase of between 6.9-17.1 mm/day of rainfall.

Figure 7 shows the rainfall intensities for different return periods for the middle point. The trends are very similar with the upstream point, Fig. 5. And following the same reasoning, no conclusion can be derived from this set of data.

Table 6 summarizes the number of no-rain days and number of extreme rain days given by the models for the past and future. Table 6 shows that the middle point will also experience an increase in the number of no-rain days, the number of extreme rainfall events will also increase dramatically with 3 models projecting more than double of the past number.
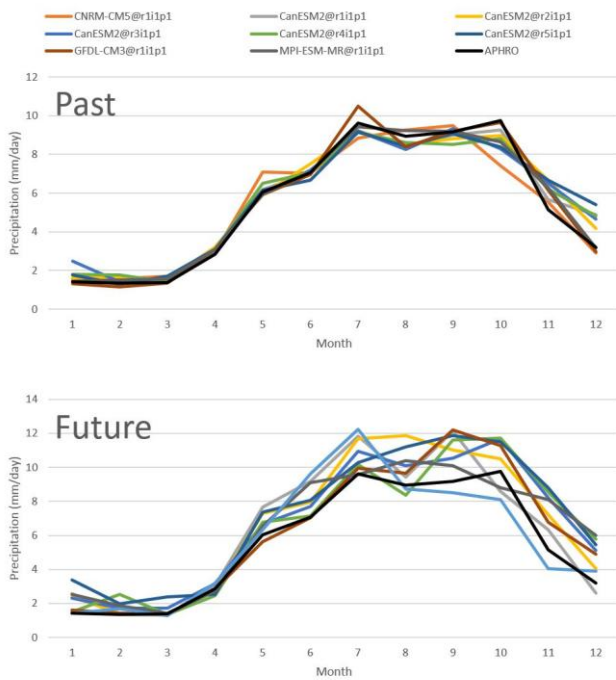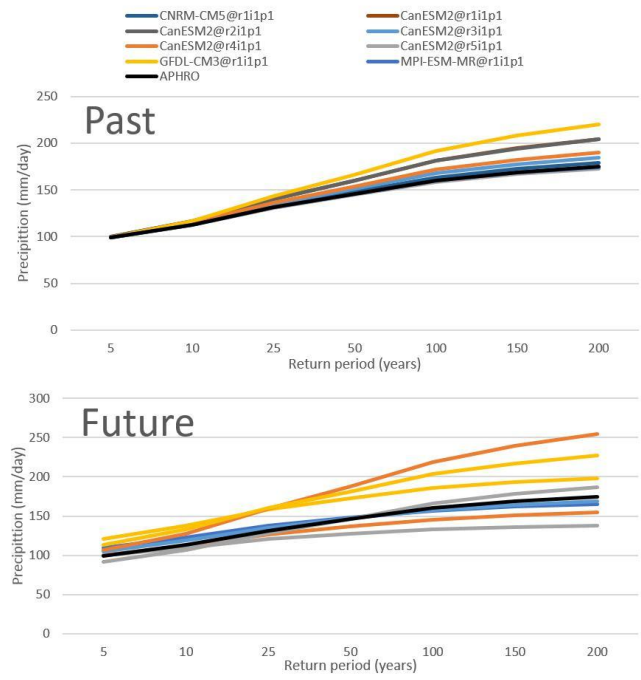
Figure 6. Monthly Rainfall Data for Middle Point

Figure 7. Return Period and Intensities for Middle Point

Table 5. Table of change for middle point: mm/day and percentage

| | Model Name | | | | | | | |
| | Can2@r1 | | Can@r3 | | Can@r4 | | Can@r5 | |
Month	mm/day	%	mm/day	%	mm/day	%	mm/day	%
1	0.64	36.41	-0.97	-39.07	1.58	87.88	-0.16	-9.1
2	-0.18	-11.22	1.14	81.55	0.22	12.5	0.14	10.84
3	-0.19	-12.36	-0.19	-12.21	0.99	70.56	-0.33	-19.5
4	-0.39	-12.25	-0.57	-18.81	-0.54	-17.55	-0.28	-9.01
5	1.12	18.13	0.76	12.66	0.85	13.03	-0.5	-8.15
6	0.89	12.59	-0.03	-0.42	0.99	14.03	0.37	5.55
7	2.44	26.4	0.99	10.77	1.16	12.7	0.79	8.62
8	3.49	41.67	0.08	0.97	2.6	30.17	1.22	14.48
9	2.02	22.44	2.3	24.68	3.35	39.35	3.1	34.13
10	1.23	13.27	3.44	41.51	2.68	30.39	2.89	34.48
11	1.55	27.33	2.06	31.68	2.6	41.77	0.13	1.95
12	-0.84	-17.16	1.11	23.86	0.65	13.52	-0.51	-9.46
Total	11.78		10.12		17.13		6.86	

Table 6. Table of 0 or Extreme Rainfall count for middle point

P/F	Model Name			
	Can2@r1	Can@r3	Can@r4	Can@r5
P(0)	736	716	739	723
P(Ext)	9	7	5	9
F(0)	788	724	684	735
F(Ext)	20	18	25	10

3.1.3 Downstream Point: 15°30'N - 121°15'E

Figure 8 shows the trends of monthly precipitation as given by the models at the downstream point. The pattern seen in the previous 2 points is seen as well in the downstream point; all the models predict an increase in monthly rainfall. The top four models that gave the highest increase in rainfall were chosen and tabulated. Table 7 shows the change in monthly precipitation from past to future in absolute values and percentages respectively. Similar with the upstream and middle portion points, all the models project that the wet season (June-November) will experience increase in rainfall while the dry season (December-May) will become moderately drier or stay the same. Looking at the total annual change in rainfall at Table 7, the models project an average increase of between 10.3-17.8 mm/day of rainfall.

Figure 9 shows the rainfall intensities for different return periods for the downstream point. The trends are very similar with the upstream point and middle point, Figs. 5 and 7. And following the same reasoning, no conclusion can be derived from this set of data.

Table 8 summarizes the number of no-rain days and number of extreme rain days given by the models for the past and future. According to Table 8, 2 models project increase in the number of no-rain days, while the other 2 project a decrease. Nothing can be concluded from the projected number of no-rain days at the downstream point. However, the number of extreme rainfall events will increase dramatically with 2 models projecting around double of the past number and another one predicting more than double.
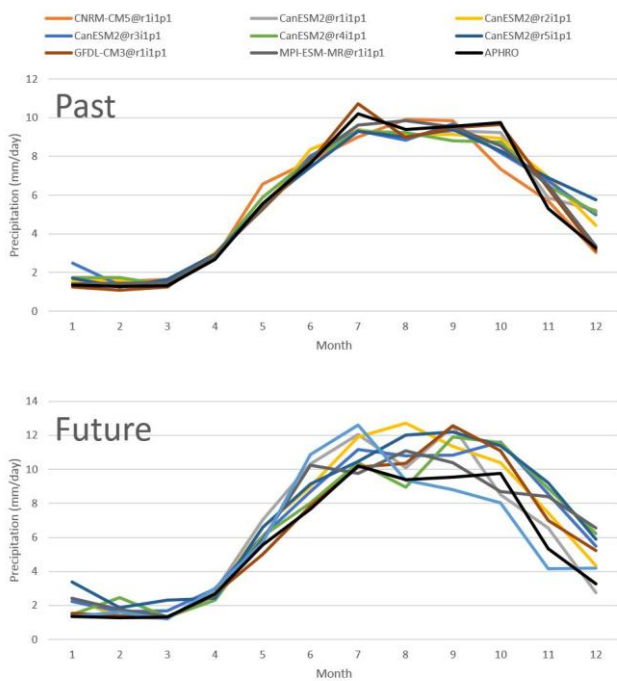
Figure 8. Monthly Rainfall Data for Downstream Point
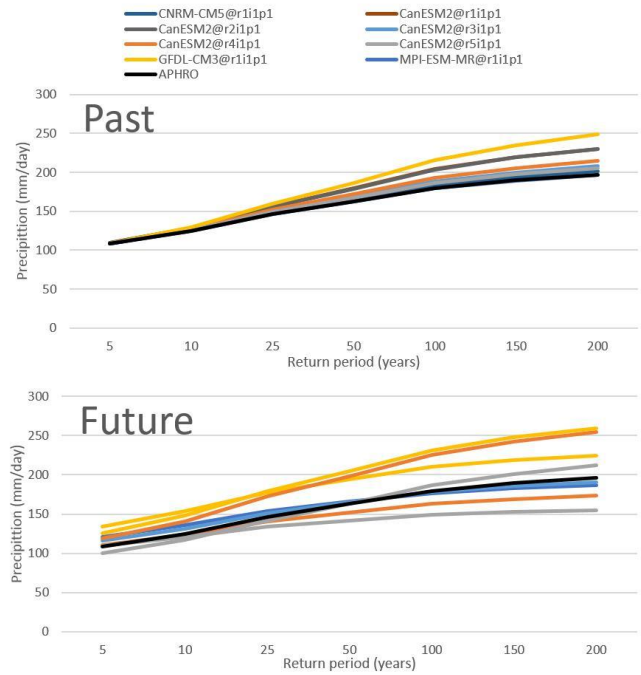

Figure 9. Return Period and Intensities for Downstream Point

Table 7. Table of change for downstream point: mm/day and percentage

	Model Name							
	Can@r1		Can@r3		Can@r4		GFDL	
Month	mm/day	%	mm/day	%	mm/day	%	mm/day	%
1	0.69	40.33	-1.02	-41.25	1.64	93.88	1.18	93.73
2	-0.19	-12.15	1.13	84.01	0.15	8.64	0.67	61.24
3	-0.2	-13.55	-0.19	-12.73	0.98	73.52	0.09	7.24
4	-0.38	-12.62	-0.52	-18.29	-0.46	-15.9	-0.35	-12.05
5	1.06	19.13	0.74	13.82	0.7	11.85	0.62	11.74
6	1.1	13.97	0.01	0.12	1.24	15.73	2.49	32.13
7	2.49	26.5	1.05	11.24	1.16	12.48	-0.98	-9.13
8	3.75	41.82	0.09	1.02	2.8	30.37	2.12	23.62
9	2.03	21.77	2.24	23.16	3.39	38.52	0.91	9.59
10	1.16	12.56	3.4	41.55	2.64	30.16	-0.98	-10.14
11	1.61	27.52	2.13	31.62	2.75	42.55	2.05	32.28
12	-0.87	-16.68	1.25	25.17	0.79	15.49	3.4	108.18
Total	12.25		10.31		17.78		11.22	

Table 8. Table of 0 or Extreme Rainfall count for downstream point

	Model Name			
P/F	Can@r1	Can@r3	Can@r4	GFDL
P(0)	774	731	745	639
P(Ext)	11	13	11	14
F(0)	828	747	689	570
F(Ext)	21	21	31	5

3.2 Spatial Analysis

Figures 5, 7, and 9 prove to be inconclusive to project the rainfall intensities given the return periods. However, it is still worthwhile to look at the extreme scenarios because this could potentially have drastic effects on the river basin. In this section, the past rainfall intensities and change in future intensity of the top 2 models that gave the highest projections are investigated. The 2 models that consistently projected the highest values are MPI-ESM-MR@r1i1p1 and CanESM2@r5i1p1. The results of these models for the 50-year and 200-year return periods are plotted over the river basin to reveal the spatial distributions.

3.2.1 Return Period: 50 years

Figures 10 and 12 show similar distributions of the 50-year return rainfall for the past, with the southeast end of the basin experiencing the most amounts of rainfall and gradually decreasing in the northwest direction. Figures 11 and 13 show the amount of precipitation change for a 50-year return event projected by the models. The models agree that the eastern portion of the basin will experience the biggest increase of about 40-70 mm/day, with the difference being that model CanESM2@r5i1p1 projects the increase to extend higher to the north. The results also show that the same area experiencing the highest amount of rainfall in the present will have the highest increase in the future.

3.2.2 Return Period: 200 years

Figures 14 and 16 also show similar distributions of the 200-year return rainfall for the past, with the southeast end of the basin still experiencing the most amounts of rainfall and gradually decreasing in the northwest direction. Figures 15 and 17 show the amount of precipitation change for a 200-year return event projected by the models. The models also agree that the eastern portion of the basin will experience the biggest increase of about 80-125 mm/day. Model CanESM2@r5i1p1 again projects a bigger area of high increase in rainfall intensity. The results also show that the same area experiencing the highest amount of rainfall in the present will have the highest increase in the future.
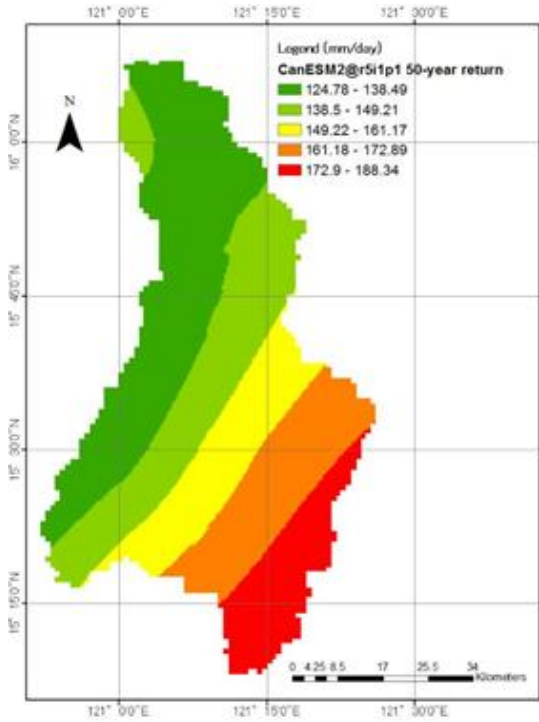
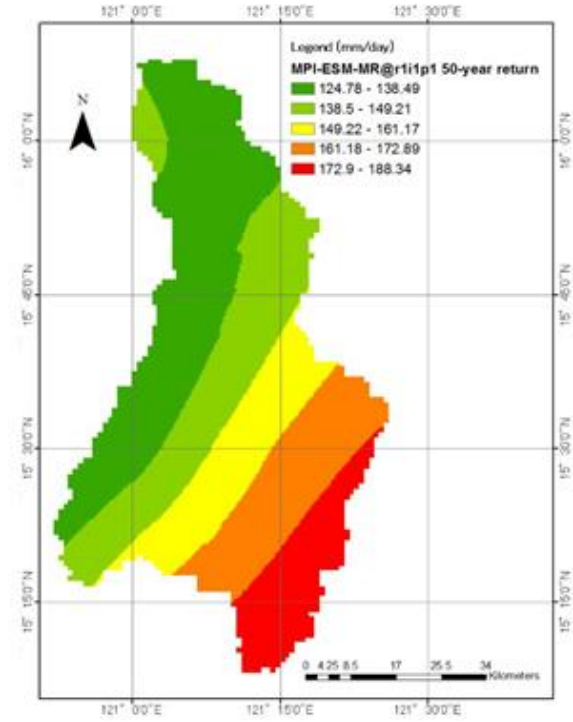Figure 10. CanESM2@r5i1p1 50-year return period (past)

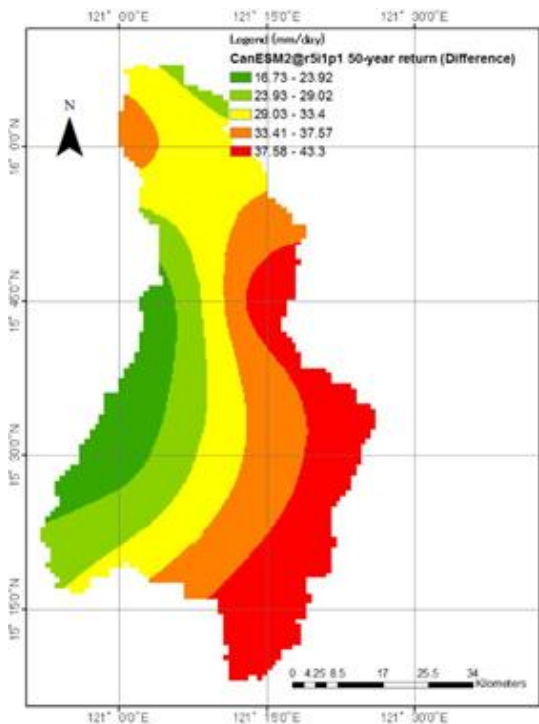Figure 12. MPI-ESM-MR@r1i1p1 50-year return period (past)

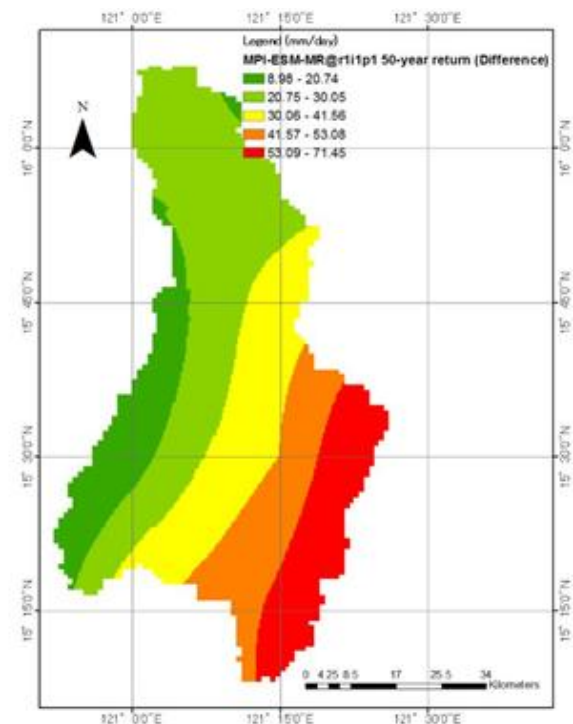Figure 11. CanESM2@r5i1p1 50-year return period (Difference)

Figure 13. MPI-ESM-MR@r1i1p1 50-year return period (Difference)
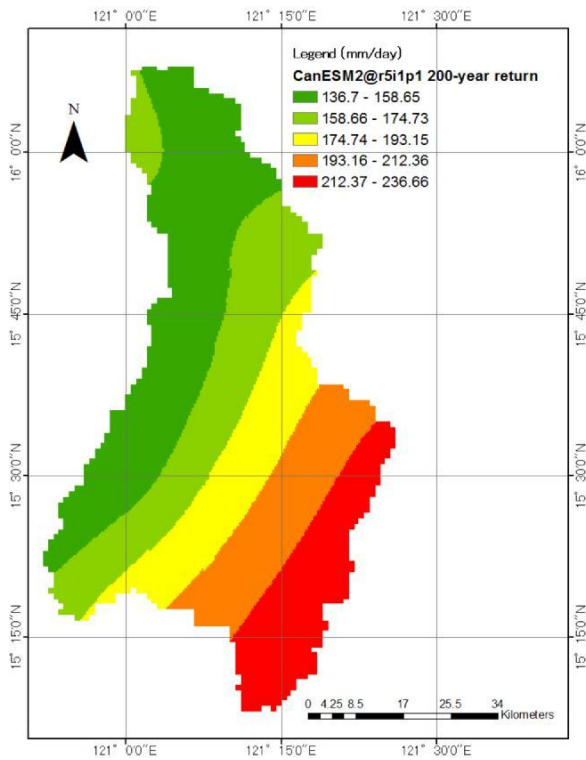
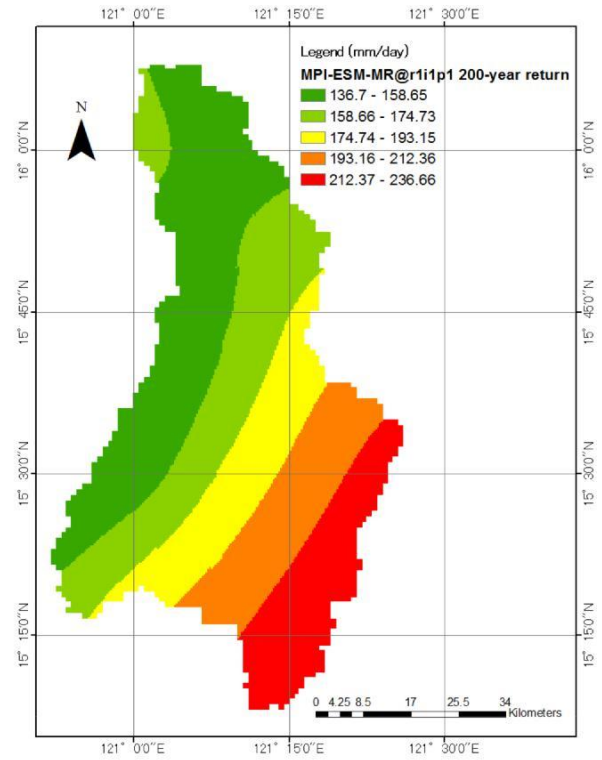Figure 14. CanESM2@r5i1p1 200-year return period (past)

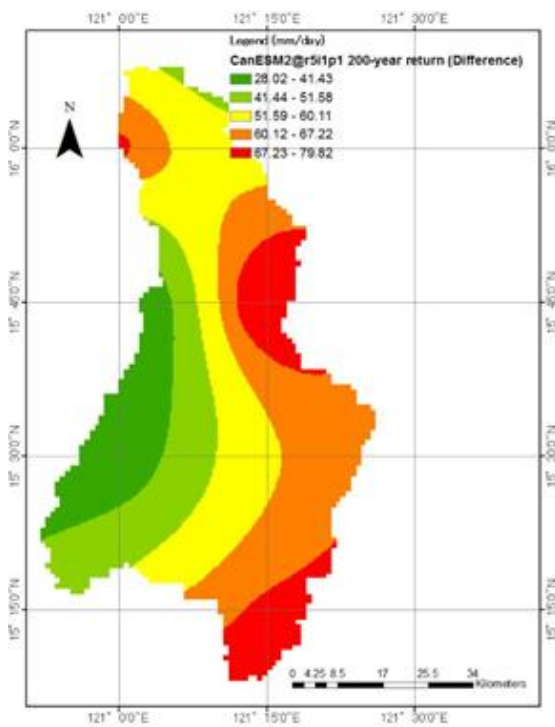Figure 16. MPI-ESM-MR@r1i1p1 200-year return period (past)

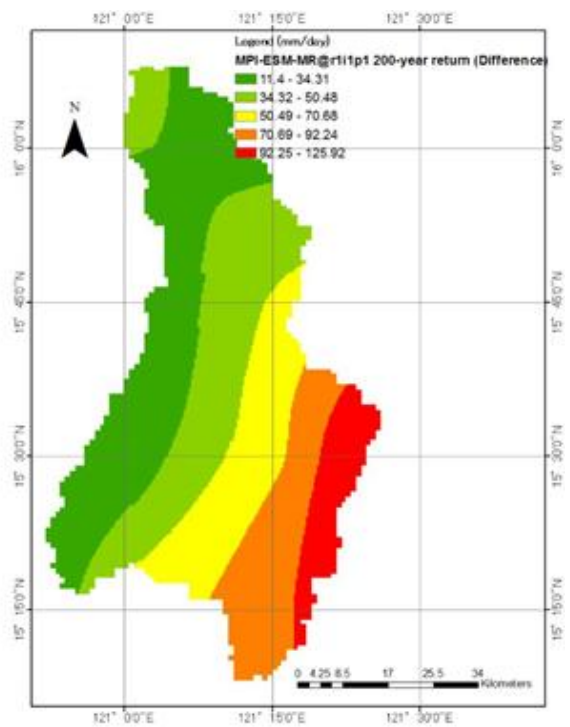Figure 15. CanESM2@r5i1p1 200-year return period (Difference)

Figure 17. MPI-ESM-MR@r1i1p1 200-year return period (Difference)

4.0   CONCLUSION

The results of the point analysis show that the upstream, middle, and downstream points of the main river of the Pampanga river basin will all experience an increase in their total annual water budget for the years 2046-2065. The average amount of increase will probably be in the range of 6.5-18 mm/day of rainfall. This increase, however, will likely be concentrated to occur in the wet season (June-November). The models generally project a wetter wet season and a moderately drier dry season. Another important result from the models is that they all project that the number of extreme rainfall events is very likely to increase while the number of no-rain days is also expected to increase. These changing trends are critical to various stakeholders such as the agriculture sector, the water resource managers, dam operators, national and local government units, and also the local residents. With this new information, several preparatory actions can be taken such as: improvement of the water resource management to accommodate for the increase in water supply, modification of current agricultural practices to optimize crop yield, and strengthening of disaster response capabilities and resilience of vulnerable people. Although the projection of the future 50-year and 200-year return rainfall is unsuccessful, preparation for the worst case scenario can still be beneficial. The results of the spatial analysis show that in the worst case, the models predict an increase of 40-70 mm/day for the 50-year return rainfall which in the present is at 120-190 mm/day and an increase of 80-125 mm/day for the 200-year return rainfall which in the present is at 140-240 mm/day. These values are well beyond the threshold value of 90 mm/day for serious flooding. Preparations and adaptation measures should be planned and executed as early as now. These results are all based on the projections using the RCP8.5 emission scenario which is the most pessimistic case. Taking measures to prepare for the worst case scenario should also go together with enacting climate change policies to dampen the ill-effects of climate change in our near future.

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