Climate Change and Rainfall Projections in the Ayung Watershed, Bali, Indonesia using NCAR Model

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Abstract. *Rainfall in an area is not the same over a period of time and fluctuates between sometimes very high and sometimes very low. Changes in rainfall are often associated with climate change in a region. Rainfall patterns over a long period can be used as an indicator of climatic conditions in a region. Consequences of climate change have a bad impact on environment. Future rainfall predictions are very important and can be useful in planning the strategies for adapting to changes in rainfall that may occur. The Ayung watershed is the largest watershed on the island of Bali, Indonesia and is very vulnerable to changes in rainfall. Changes in rainfall patterns cause various bad impacts, high rainfall causes flooding and low rainfall has the potential for drought. This study aimed at climate change and rainfall projections in the Ayung watershed, Bali, Indonesia using the National Center of Atmospheric Research (NCAR) Models employing the rainfall data for 8 rainfall stations spread over the Ayung watershed during 2006 – 2018, derived from global climate models. Rainfall projections were carried out for a climate change scenario based on the IPCC fifth assessment report by adopting the Representative Carbon Pathway (RCP) approach. Climate projection results from NCAR were based on observed rainfall data in Ayung watershed for Representative Carbon Pathway (RCP) 6.0. The results of rainfall projection had good agreement with the observed rainfall. The rainfall projections can be made until 2030 which could be useful in strategy planning to overcome problems that will occur in the future due to changes in rainfall patterns.*

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1. Introduction

Rainfall in a region varies from time to time fluctuating year to year over decades. There are some periods of very high rainfall while some others of very low or no rainfall. Changes in frequency, intensity, and amount of rainfall are associated with climate change in the region which are related to global climatic conditions [1]. Climate change is a phenomenon associated with changes in temperature, humidity and rainfall that last a fairly long period, usually more than 10 years in a region or globally [2][3][4]. Thus, it can be seen that changes in rainfall patterns over a long period of time can be used as an indicator of climatic conditions in a region. The previous rainfall patterns can be used to make projections of future climatic conditions [5].

High rainfall causes flooding, while drought occurs when rainfall is very low. Flooding leads to great damages and losses and also disrupts the supply of clean water. Rainfall prediction is important for anticipating the bad impacts that are related to changes in rainfall intensity and frequency so that various plans can be carried out to mitigate the possible problems that may arise in the future. By knowing the past pattern of rainfall from precipitation records, future rainfall patterns can be predicted. Future scenarios based on rainfall predictions can be used in climate change adaptation and disaster management due to changing rainfall patterns. Rainfall predictions can be done by regional climate projections through climate modeling [6][7].

The future rainfall predictions can be done by using Community Climate System Model (CCSM) of the climate change model developed by NCAR. It has been reported that the CCSM produces very realistic simulations of observational data for monthly or annual averages. NCAR has an interactive web application which expands GIS mapping and graphing capabilities to visualize possible temperature and precipitation changes throughout the 21st century. The maps and graphs are generated from a large dataset of climate simulations that were prepared for the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). From this application it is easy to investigate climate changes around the globe and through time, inspect climate trends, variability and uncertainty, and download maps and data [8].

The study area for this research is Ayung watershed, the largest watershed area on the island of Bali in Indonesia with the Ayung river flowing in it. Studies on water resource management and land cover have been carried out in the Ayung watershed, but the projection of climate change in the Ayung watershed has never been done before [9]. This research is very important to do to know the impact of climate change on rainfall in the future because the watershed is very vulnerable to the negative impacts of changes in rainfall. Rainfall predictions in the Ayung watershed were done using the global climate model (GCM) developed by NCAR.

2. Methodology

2.1 Study Area

The study area for this research, the Ayung watershed, is located in the middle of the island of Bali, Indonesia at 8°12′26.08″ S – 8°39′47.38″ S latitude, and 115°11′1.68″ E – 115°16′12.9″ E longitude with the largest river Ayung River flowing through the watershed (Fig. 1). It is the largest watershed in the Bali Penida River Basin, with an area of 306.149 km^2 with the river length of 71.791 km [9]. The watershed consists of mountainous areas in the north (upstream) and lowlands in the south (downstream). The upstream part is dominated by forest and agricultural areas while the downstream region has predominantly residential areas. The summary of the study area is shown in Table 1.

Watershed	Ayung Watershed
Area	306.149 km^2
Main river	Ayung river
Length of the river	71.791 km
Latitude	8°12′26.08″ S – 8°39′47.38″ S
Longitude	115°11′1.68″ E – 115°16′12.9″ E

Table 1 The data of study area

Indonesia is divided into three rainfall regions, A, B and C with their distinct characteristics. Region A is located in southern Indonesia from south Sumatera, Java, Bali to Nusa Tenggara Islands, southern Kalimantan, Sulawesi and part of Irian Jaya. Region B is located in northwest Indonesia from northern Sumatra to north western Kalimantan. Region C encompasses Maluku and northern Sulawesi.

Region A has one peak and one trough and experiences strong influences of two monsoons, namely the wet northwest (NW) monsoon from November to March (NDJFM) and the dry southeast (SE) monsoon from May to September (MJJAS). Region B has two peaks, in October–November (ON) and in March to May (MAM). Those two peaks are associated with the southward and northward movement of the inter-tropical convergence zone (ITCZ). Region C has one peak in June to July (JJ) and one trough (November–February). The JJ peak in Region C is about 300 mm/month, whereas the peaks in Regions A and B are 320 mm/month and 310 mm/month respectively. The minimum rainfall in Region A is the lowest and reaches a mean below 100 mm/month. Thus, Region A is the driest region during the dry season in July–September and the wettest region in December. The homogeneous pattern in Region A indicates the wide extent of the dry season, which reaches all Java, Bali and the Nusa Tenggara Islands, Sumatera and part of Kalimantan [10]. The Ayung watershed is located in Region A.

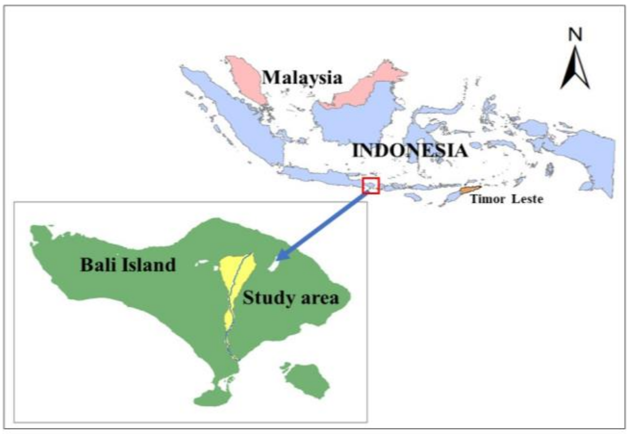


Fig. 1 Study Area [9]

2.2 Data Collection

Rainfall data for this study for the period 2006 - 2018 were obtained from global climate modeling, which was developed at the National Center of Atmospheric Research of USA [11] with a resolution of 1 degree as a data source to predict rainfall based on climate projections in the Ayung watershed (Fig. 2).

Another data source was observed rainfall records during the period 2006 – 2018 from 8 rainfall stations (Sading, Mambal, Tegalalang, Tampaksiring, Bedugul, Pengotan, Gitgit and Kedisan) spread over the Ayung watershed (Figure 2). Coordinates of the location for all stations are shown in Table 2.

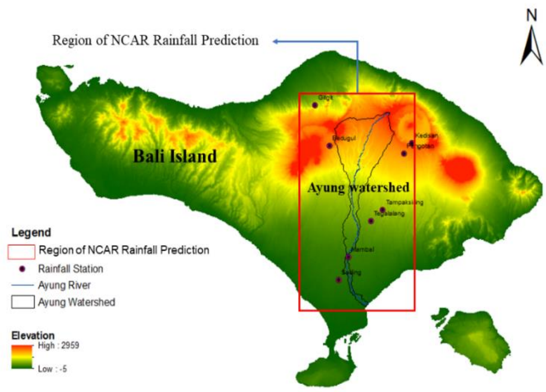


Fig. 2 Rainfall stations positions and selected area for NCAR rainfall prediction [9]

Station Name	Latitude	Longitude	Elevation (m)
Kedisan	8°16'49.02" S	115°22'54.6" E	1062
Mambal	8°35'19" S	115°11'28" E	146
Pengotan	8°18'15.72" S	115°21'40.26" E	1173
Tegalalang	8°27'44.46" S	115°16'40.62" E	353
Tampaksiring	8°26'9.18" S	115°18'24" E	493
Bedugul	8°17'5.36" S	115°10'24.97" E	1244
Sading	8°35'58.92" S	115°11'40.86" E	109
Gitgit	8°11'20.9" S	115°08'15.0" E	710

Table 2 Coordinates of rainfall stations at Ayung Watershed

2.3 Climate Projection and Rainfall Prediction

Projections of future climate conditions in the Ayung watershed may be helpful in understanding the various future climate scenarios that could be used to predict future rainfall [12]. These climate change projections make use of global climate models outputs. Climate models are based on the quantitative approach to the processes that occur in the atmosphere, to represent them by mathematical equations to explain the interaction processes of various climatic constituents, namely the hydrosphere, lithosphere, atmosphere, and biosphere. Human interactions and activities lead to changes in the balance of climate conditions globally [13].

The NCAR Community Climate System Model (CCSM) projections model is a model that allows researchers to conduct fundamental research on the earth's past, present and future climatic conditions. This model consists of four separate models, namely modeling the earth's atmosphere, oceans, resistant surface and sea ice [10]. With this model, it is expected that the climate in the Ayung watershed can be predicted in the future, including rainfall predictions. Considering the impact of human activities on climate change, scenarios have been prepared that can affect the balance of the energy system based on the various factors influencing atmospheric conditions from energy use and the resulting emissions.

The simulated rainfall data for this study was obtained from NCAR Community Climate System Model (CCSM). The Community Climate Model (CCM) was created by NCAR in 1983 and can be used freely for modeling the global atmosphere. This model has also had steadily improved until 2003 and is widely used around the world to understand climate over a relatively long period of time, in a period of 10 years or more. In general, it has been reported that the CCSM produces very realistic simulations of observational data for monthly or annual averages [14].

The data used for rainfall projection was monthly rainfall for the period 2006 - 2018 with the climate change scenario adopting the Representative Carbon Pathway (RCP) approach which is presented in the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) that predicts climate conditions based on greenhouse gas concentrations. The various Representative Carbon Pathway (RCP) approaches are shown according to the level of radiation emissions (increasing the greenhouse effect), namely Representative Carbon Pathway (RCP) 2.6, Representative Carbon Pathway (RCP) 4.5, Representative Carbon Pathway (RCP) 6.0 and Representative Carbon Pathway (RCP) 8.0 [8].

Representative Carbon Pathway (RCP) 2.6 is a low pathway predicting that radiation emission would peak at about 3 W/m^2 before 2100 and then decreasing. Representative Carbon Pathway (RCP) 4.5 and Representative Carbon Pathway (RCP) 6.0 are two intermediate pathways radiative predicting that forcing level is stabilized at 4.5 W/m^2 and 6 W/m^2, respectively after 2100. Representative Carbon Pathway (RCP) 8.0 is a high pathway in which radiative forcing level reaches 8.5 W/m^2 by 2100 [15]. Based on the GCM model by NCAR, the projected rainfall data for each Representative Carbon Pathway (RCP) for the period 2006 - 2018 were compared with the observed rainfall data for the same period.

Observed rainfall data are necessary for the studies related to hydrology in a watershed with various hydrological components in it [16]. Availability of rainfall data plays an important role in planning and predicting hydrological conditions in a watershed in the future [17]. There are several methods that can be used to obtain areal rainfall in a watershed and one of them is the arithmetic mean method that has been generally used [18]. Areal rainfall estimation is very important in solving various hydrological problems [19]. Monthly rainfall data from 8 observation stations in the Ayung watershed were averaged using the arithmetic average method to obtain regional rainfall for the period 2006 - 2018.

2.4 Model Evaluation

The evaluation of the NCAR model on the observed rainfall was carried out through two statistical parameters the coefficient of determination (R^2) [20] and the root mean square error (RMSE) [21]. Based on the statistical comparison between simulated and observed rainfall values, an appropriate Representative Carbon Pathway (RCP) projection matching with observed data from 2006 - 2018 was obtained. After obtaining the appropriate Representative Carbon Pathway (RCP) projection, rainfall forecasting was carried out until 2030.

3. Results and discussions

3.1 Rainfall Analysis

Rainfall analysis in the Ayung watershed was carried out to obtain rainfall patterns for the period 2006 – 2018 using the observed rainfall data from 8 rainfall stations. Areal rainfall data for the Ayung watershed were obtained by averaging the rainfall data from all observation stations using the arithmetic mean method. The results of rainfall analysis from 8 rainfall stations in the Ayung watershed show that the rainfall has a monsoonal pattern and shows the trend of decreasing rainfall during 2006-2018 (Fig. 3).

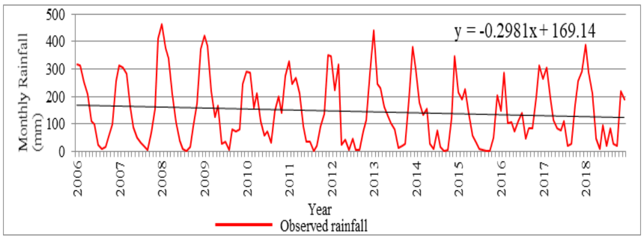


Fig. 3 Rainfall pattern in Ayung Watershed for the period 2006 – 2018

The monsoonal rainfall pattern is characterized by one peak of the rainy season and has a clear difference between the rainy season and the dry season. The monthly rainfall trend based on the average of monthly accumulated rainfall in the Ayung watershed during period 2006 - 2018 is shown in Fig. 4 below.

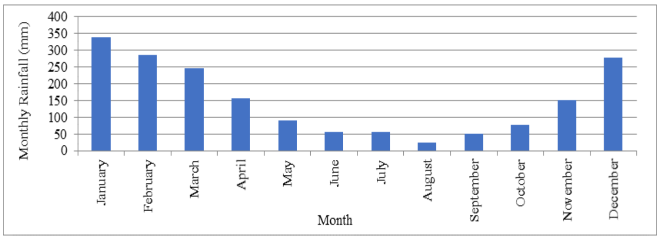


Fig. 4 Average monthly accumulated rainfall in the Ayung watershed during the period 2006 - 2018

It can be seen that the highest average rainfall in the Ayung watershed during the period 2006-2018 was in January followed by in February and December, while the dry season was during the months of June, July, August and September. March, April and May represent the transition from the rainy season to the dry season. October and November are the months of transition from dry to rainy season.

3.2 NCAR Climate Projection and Rainfall Prediction

For the climate projection in the Ayung watershed, the rainfall trend for each Representative Carbon Pathway (RCP) scenarios were considered and compared with the observed rainfall during the period 2006 – 2018 as shown in Fig. 5 – Fig. 8.

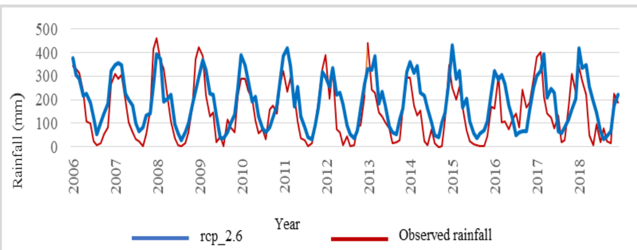


Fig. 5 Rainfall projection with RCP 2.6 compared with the observed rainfall in the Ayung watershed during the period 2006 – 2018

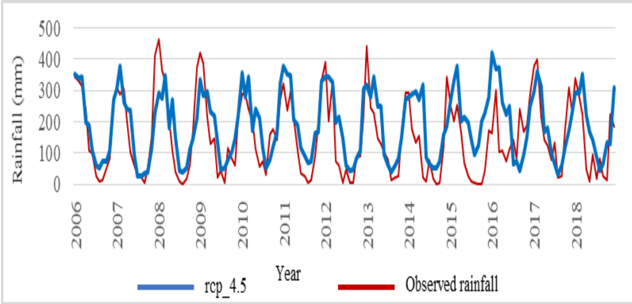


Fig. 6 Rainfall projection with RCP 4.5 compared with the observed rainfall in the Ayung watershed during the period 2006 – 2018

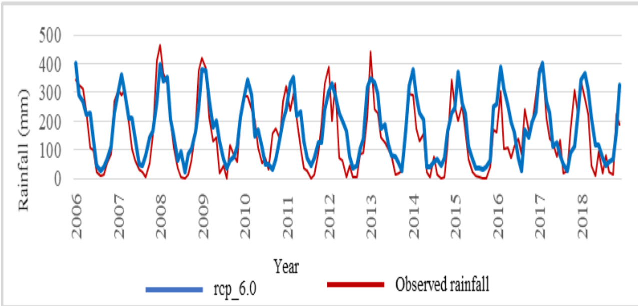


Fig. 7 Rainfall projection with RCP 6.0 compared with the observed rainfall in the Ayung watershed during the period 2006 – 2018

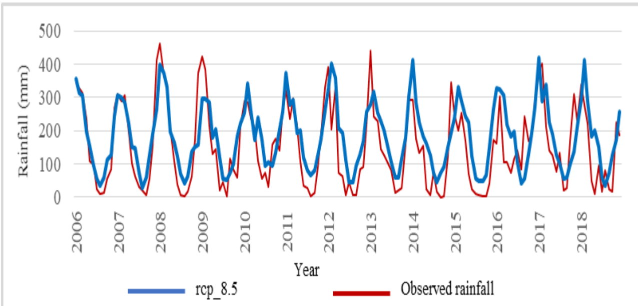
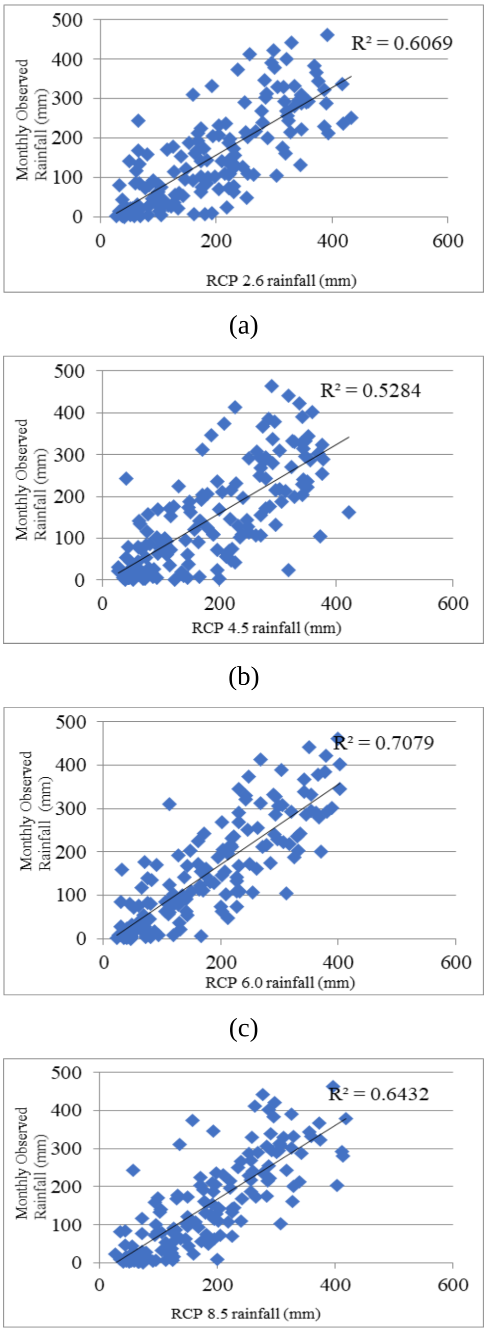


Fig. 8 Rainfall projection with RCP 8.5 compared with the observed rainfall in the Ayung watershed during the period 2006 – 2018

It can be seen that the projection results the rainfall pattern of each Representative Carbon Pathway (RCP) projection can approach the observed rainfall pattern from 2016-2018. Furthermore, the comparison between simulated and observed rainfall for each Representative Carbon Pathway (RCP) are shown in the scatter plots in Fig. 9.

Various statistical parameters indicating the correlation between observed and projected average monthly rainfalls for the period 2006-2018, for each Representative Carbon Pathway (RCP) are summarized in Table 3.



(a)

(b)

(c)

(d)

Fig. 9 Rainfall projections with different scenarios compared with the observed rainfall in the Ayung watershed during the period 2006 – 2018 (a) RCP 2.6, (b) RCP 4.5. (c) RCP 6.0 and (d) RCP 8.5

Climate projection Scenario	R^2	RMSE
RCP_2.6	0.609	87.87
RCP_4.5	0.528	93.40
RCP_6.0	0.708	70.74
RCP_8.5	0.643	79.37

Table 3 Correlation between observed and projected average monthly rainfalls for the period 2006-2018, for each Representative Carbon Pathway (RCP)

Thus it can be seen that the appropriate climate projection for the Ayung watershed is Representative Carbon Pathway (RCP) 6.0. This means that the climatic conditions in the Ayung watershed are at an intermediate level with radiation emissions of 6 Watt / m2. Rainfall projections in the Ayung watershed until 2030, using Representative Carbon Pathway (RCP) 6.0, are shown in Fig. 10. A summary of the changes occurring in rainfall in Ayung Watershed during 2006-2030 is shown in Table 4.

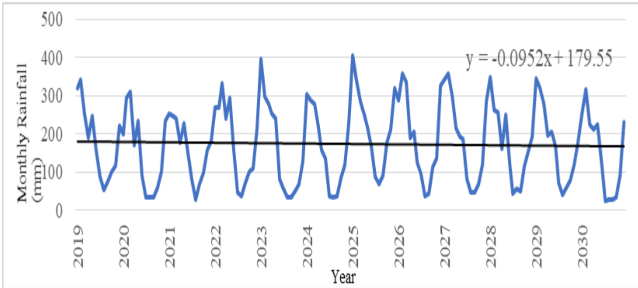


Fig. 10 Rainfall predictions in the Ayung watershed from 2019 to 2030 with Representative Carbon Pathway (RCP) 6.0

Year	Changes in rainfall (%)
2006 - 2007	3.16%
2007 - 2008	10.31%
2008 - 2009	-14.19%
2009 - 2010	10.47%
2020 - 2011	-8.22%
2011 - 2012	-18.72%
2012 - 2013	24.30%
2013 - 2014	-28.41%
2014 - 2015	-10.83%
2015 - 2016	64.07%
2016 - 2017	13.03%
2017 - 2018	-30.88%
2018 - 2019	42.39%
2019 - 2020	-15.96%
2020 - 2021	6.79%
2021 - 2022	12.22%
2022 - 2023	-8.79%
2023 - 2024	5.82%
2024 - 2025	23.03%
2025 - 2026	-10.63%
2026 - 2027	-2.22%
2027 - 2028	-8.22%
2028 - 2029	1.81%
2029 - 2030	-10.30%

Table 4 Changes in rainfall in the Ayung Watershed between 2006 and 2030

It can be seen that the trend of rainfall from 2019-2030 shows a decline, thus having a potential for causing water shortages or drought in the future. From Table 4, it can be seen that there was the maximum decrease in rainfall (30.88 %) during 2017 - 2018. While the future decrease in rainfall was predicted to occur during 2025-2026 (10.63 %).

4. Conclusions

Based on observed rainfall data recorded at 8 stations around the study area during the period 2006-2018, Ayung watershed in Bali appears to have a monsoonal pattern because there is a clear difference between the rainy season and the dry season. The rainy season is in December, January and February while, the dry season is in June, July, August and September.

Based on the correlation between observed and NCAR climate forecasting model simulated rainfall in Ayung watershed during the period 2006-2018, the climate scenario seems to be close to Representative Carbon Pathway (RCP) 6.0 i.e. the greenhouse gas emissions are at an intermediate level with 6 W / m^2. This means that the consumption or use of fossil fuels in the Bali island is still quite high.

In accordance with the predictions from the NCAR model for the period 2019 – 2030, there would be a decrease in maximum rainfall in the region, which may cause a decrease in water supply in the future.

NCAR climate forecasting using observational rainfall is very helpful for projecting how the climate will change in the future in the Ayung watershed.

References

[1] K.E. Trenberth, "The Impact of Climate Change and Variability on Heavy Precipitation, Floods, and Droughts," *Encyclopaedia of Hydrological Sciences*, 2006.

[2] H.A. Rahman, "Global Climate Change and Its Effects on Human Habitat and Environment in Malaysia," *Malaysian Journal of Environmental Management*, vo.10, no. 2, pp. 17-32, 2009.

[3] K. L. Ebi, L. O. Mearns, and B. Nyenzi, "Weather and Climate: Changing Human Exposures, Climate Change and Health: Risks and Responses," *World Health Organization: Geneva*, 2003.

[4] L. Bernstein, P. Bosch, O. Canziani, Z. Chen, R. Christ, O. Davidson, W. Hare, S. Huq, D. Karoly, V. Kattsov, Z. Kundzewicz, J. Liu, U. Lohmann, M. Manning, T. Matsuno, B. Menne, B. Metz, M. Mirza, N. Nicholls, L. Nurse, R. Pachauri, J. Palutikof, M. Parry, D. Qin, N. Ravindranath, A. Reisinger, J. Ren, K. Riahi, C. Rosenzweig, M. Rusticucci, S. Schneider, Y. Sokona, S. Solomon, P. Stott, R. Stouffer, T. Sugiyama, R. Swart, D. Tirpak, C. Vogel and G. Yohe, "Climate change 2007: Synthesis Report: An Assessment of the Intergovernmental Panel on Climate Change," *IPCC*, 2007.

[5] K. Ghumman, Alotaibi, A. Haider, H. Ghazaw, Yousry and M. Shafiquzzaman, "Future Predictions of Rainfall and Temperature Using GCM and ANN for Arid Regions: A Case Study for the Qassim Region, Saudi Arabia," *Water*, vol. 10, no. 9, pp. 1-23, 2018.

[6] UCAR, "A New Way to Start a Climate Model Run", https://news.ucar.edu/124917/ncar-based-climate-model-joins-seasonal-forecasting-effort. [Accessed: 20 March 2021].

[7] S. Saengsawang, P. Pankhao, C. Kaprom and N. Sriwongsitanon, "Projections of Future Rainfall for the Upper Ping River Basin Using Regression-based Downscaling," *Advances in Climate Change Research*, vol. 8, no. 4, pp. 256-267, 2017.

[8] R. Moss, M. Babiker, S. Brinkman, E. Calvo, T. Carter, J. Edmonds, I. Elgizouli, S. Emori, L. Erda, K. Hibbard, R. Jones, M. Kainuma, J. Kelleher, J. F. Lamarque, M. Manning, B. Matthews, J. Meehl, L. Meyer, J. Mitchell, N. Nakicenovic, B. O'Neill, R. Pichs, K. Riahi, S. Rose, P. Runci, R. Stouffer, D. V. Vuuren, J. Weyant, T. Wilbanks, J. v. P. Ypersele and M. Zurek, "Towards New Scenarios For Analysis Of Emissions, Climate Change, Impacts, And Response Strategies, " *Intergovernmental Panel on Climate Change: Geneva*, pp. 132, 2008.

[9] I. G. A. P. Eryani and N. Nurhamidah, "Sedimentation Management Strategy in River Estuary for Control the Water Damage in Downstream of Ayung River, " *International Journal on Advanced Science, Engineering and Information Technology*, vol. 10, no. 2, pp. 743-748, 2020.

[10] E. Aldrian and R. Dwi Susanto, "Identification of Three Dominant Rainfall Regions Within Indonesia and Their Relationship to Sea Surface Temperature," *International Journal of Climatology: A Journal of the Royal Meteorological Society*, vol. 23, no. 12, pp. 1435-1452, 2003.

[11] UCAR, "What is the CCSM?," https://gisclimatechange.ucar.edu/question/59. [Accessed: 19 March 2021].

[12] D. Jang, H. Park and J. Choi, 2016. "Development of Future Precipitation Forecasting Program Using Probability Forecast and Climate Change Scenario, *Procedia Engineering*, 154, 645-649, 2016.

[13] A. J. McMichael, R. E. Woodruff and S. Hales, "Climate Change and Human Health: Present and Future Risks," *The Lancet*, vol. 367, no. 9513, pp. 859-869, 2016.

[14] M. Blackmon, B. Boville, F. Bryan, R. Dickinson, P. Gent, J. Kiehl, R. Moritz, D. Randall, J. Shukla, S. Solomon, G. Bonan, S. Doney, I. Fung, J. Hack, E. Hunke, J. Hurrell, J. Kutzbach, J. Meehl, B. Otto-Bliesner, R. Saravanan, E. K. Schneider, L. Sloan, M. Spall, K.Taylor, J. Tribbia and W. Washington, "The Community Climate System Model," *Bulletin of the American Meteorological Society*, vol. 82, no. 11, pp. 2357-2376, 2001.

[15] S. Emori, K. Taylor, B. Hewitson, F. Zermoglio, M. Juckes, M. Lautenschlager and M. Stockhause, "CMIP5 data provided at the IPCC Data Distribution Centre, Fact Sheet of the Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) of the *Intergovernmental Panel on Climate Change (IPCC)*, " pp.1-8, 2016.

[16] W. Taesombat and N. Sriwongsitanon, "Areal Rainfall Estimation Using Spatial Interpolation Techniques," *Science Asia*, vol. 35, no. 3, pp. 268-275, 2009.

[17] S. Thorndahl, T. Einfalt, P. Willems, J. E. Jesper Ellerbæk Nielsen, M-C. t. Marie-Claire ten Veldhuis, K. Karsten Arnbjerg-Nielsen, M. R. Rasmussen and P. Molnar, "Weather Radar Rainfall Data in Urban Hydrology," *Hydrology and Earth System Sciences*, vol. 21, no. 3, pp. 1359-1380, 2017.

[18] F. Balany, "Different Ways of Calculating Catchment Rainfall: Cases in Indonesia," *Journal of the Civil Engineering Forum*, vol. 20, no. 1, pp. 1175-1182, 2011.

[19] T. Zhang, B. Li, J. Wang, M. Hu and L. Xu, "Estimation of Areal Mean Rainfall in Remote Areas Using B-SHADE Model," *Advances in Meteorology*, pp. 1-13, 2016.

[20] D. E. Reusser, T. Blume, B. Schaefli and E. Zehe, "Analysing the Temporal Dynamics of Model Performance for Hydrological Models," *Hydrol. Earth Syst. Sci*., vol. 13, no. 7, pp. 999-1018, 2008.

[21] T. Senjaya, D. Yudianto, X. Yuebo and W. K. Adidarma, "Application of TRMM in the Hydrological Analysis of Upper Bengawan Solo River Basin," *Journal of the Civil Engineering Forum*, vol. 6, no. 3, 2020.

Biographies

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