INVESTIGATION ON THE EFFECT OF REPRESENTATIVE CONCENTRATION PATHWAYS (RCPs) TO THE CLIMATE RESEARCH: CASE STUDY AT MALAYSIA

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Abstract

This study assesses the role of RCPs as an important development of climate research. RCP presents the specific radiation forcing as possible scenarios that would lead to the climate formulation known as RCP2.6, RCP4.5 and RCP8.5. In recent years, the climate research in Malaysia were generated using Fourth Assessment Report (AR4) under the A1B scenario. However, these scenarios had been revised and AR5 was introduced since 2014 to overcome the weakness in the AR4. Therefore, the main objective of this study was to identify the effect of RCPs on climate generation and the best RCPs for each state in Malaysia based on a statistical climate model. The Statistical Downscaling Model (SDSM) was used as a climate driver to downscale the long-term local climates concerning the potential emission changes in the local weather. Results showed that 4 out of 10 states agreed that the RCP2.6 had a good correlation to the local climate with higher R (> 0.8) and lower %MAE (< 23%). This finding proved that RCPs play a main role in the long-term climate assessment.

Keywords Statistical downscaling, RCPs, climate forecasting, AR5

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Faculty of Civil Engineering Technology, UMP Research Series: Water, Energy, and Environment, Vol. 1, [insert doi here later]

Introduction

Nowadays, climate change has become a significant global issue on the earth. Since the rapid growth of pre-industrial era, an anthropogenic greenhouse gas emission (GHGs) has increased drastically. These issues are driven largely by economic, population growth and land development (Yeh and Liao, 2014). According to Intergovernmental Panel on Climate Change (IPCC, 2014), the global temperature is expected to rise approximately 1.4 ^{o}C to 5.8^{o}C at the end of the century. The increment of GHGs concentrations such as carbon dioxide, methane and nitrous oxide in the atmospheric system is the dominant cause of warming since the mid-20th century. It encourages unexpected magnitudes of effective rainfall and significant impact due to numerous anthropogenic activities (Wafaa and Bastawesy, 2020).

Malaysia is not an exception to the climate change impact. The irregular pattern of climate and unpredicted disaster events in the last two decades have proved the present of climate changes. Tukimat et. al. (2017) investigated the impact of climate change on the irrigation water demand at the paddy field area. The increment of 0.2^{o}C in local temperature and 4% per decade of rainfall in the region causes the irrigation water demand to be reduced by 0.9% per decade. Even though it is good for water sustainability, however, it might affect the capability of the reservoir storage, due to rises in rainfall intensity. Meanwhile, Tang (2019) revealed that the continuous rise of temperature and mean sea level are highly contributing to extreme weather events. Hassan and Harun (2017) studied at Kurau River to assess the climate change impact on the sustainability of the dam in the long term. The function of the dam is to supply sufficient water to the industrial demand and domestic at Kerian District and Larut Matang District. Thus, the mitigation of climate change in Malaysia must be revised and strengthened, to control the impact of climate change.

Therefore, the climate model has been introduced to downscale the coarse resolution from the climate drivers such as atmosphere, oceans and land surface. There were 2 types of downscaling, known as statistical downscaling and dynamical downscaling. Tang et al. (2016) stated that both models produced different projected rainfall, as they might be affected by the large uncertainties. Meanwhile, Shah et al. (2018) claimed the Regional Climate Model (RegCM) produced better skills in predicting wintertime precipitation. In Malaysia, the Providing Regional Climate for Impacts Studies (PRECIS) modelling has been used to simulate regional and local climate over Malaysia (Tiwari et al., 2018).

Each climate model has their own capability and limitation. The SDSM is one of the statistical downscalings to downscale the GCMs model using statistical equation. This model applied a simpler mathematical equation, making it easier to understand the relationship pattern between predictor and local climate (known as predictand). Besides, the simulated outputs were published in the finer resolution, which does not require high computation demand like dynamical downscaling. Thus, it requires low cost but is still capable to provide reliable simulated results likes dynamical downscaling. A large number of research have been done to compare the performance of SDSM model with other model (Khazaei et al., 2020; Wangsoh et al., 2017; Tukimat and Harun, 2015). Meanwhile, Dong et al. (2020) combined the SDSM with Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) to generate the long-term climate at Xiangjiang River Basin. However, the accuracy of the climate simulation still depends on the RCPs selection. Therefore, the objective of this study is to identify the best RCPs for Malaysia.

RCPs Description

In the year 2014, the IPCC introduced four new climate scenarios in the AR5, known as RCP2.5, RCP4.5, RCP6.0 and RCP8.5. Each RCP presented the specific radiation forcing as possible scenarios that would lead to the climate formulation. It describes the pathways of GHGs, atmospheric concentration, air pollution emission and land use. RCP2.6 has radiative forcing peaks at 3.1 W/m^2 mid-century, returning 2.6 W/m^2 by the year 2100. The emission pathways represent the scenarios in the literature leading to very low GHG concentration levels. Meanwhile, the RCP4.5 and RCP6.0 are two intermediate stabilisation pathways at approximately 4.5 W/m^2 and 6.0 W/m^2 after the year 2100 onward, respectively. The RCP8.5 is the highest pathway for which radiative forcing reaches greater than 8.5 W/m^2 by the year of 2100 and continues to rise for some amount of time. It is characterised by the increasing greenhouse gas emissions over time, the representative for scenarios in the literature leading to high greenhouse gas concentration levels. However, the best RCPs are chosen to capture the range for impact assessments if the full range of RCPs used is not possible. In this case study, only RCP2.5, RCP4.5 and RCP8.5 were considered in the analysis, as provided by Canadian Earth System Model (CanesM2).

Methodology

Figure 2 shows the flow of research. In this study, the climates trend was analysed using Statistical Downscaling Model (SDSM). There were 2 types of data required; rainfall (provided by Department of Irrigation and Drainage of each state, JPS state) and climate agents (NCEP and GCM data from IPCC). Only the data provided with less than 1% of missing data will be considered in the analysis. Therefore, the objective of this study is to obtain the best radiation level (RCPs) for each state in Malaysia, based on the statistical analyses (MAE and R) between the validated and historical records.

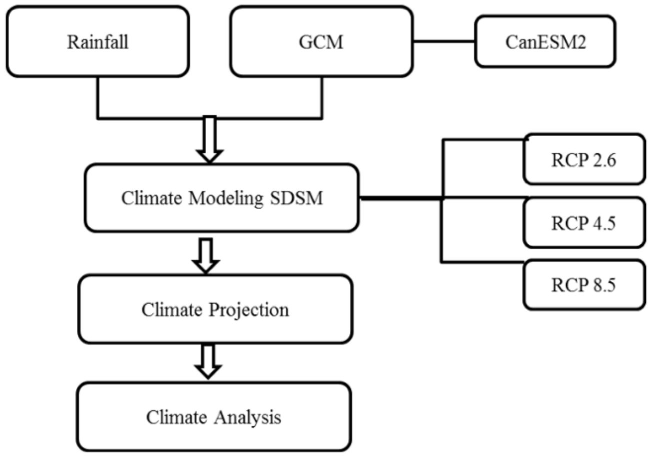


Figure 1: Flow of Study

Climate Simulation using Statistical Equation

SDSM was introduced by Wilby and Dawson (2007). SDSM is a software to downscale the Global Climate Model (GCMs) and it is coded in Visual Basic 6.0. It built up the relationship between the GCMs variables (predictors) and the local climate (predictands). The data of GCM will be downscaled using multiple linear regressions by daily predicator-predictand relationships. The predictor variable describes the daily information in the large-scale state of the atmosphere, while the predictand provides the condition at the site scale. This regression equation will be built using an ordinary Least Squares algorithm.

The local rainfall is classified as a conditional process, because the local weather is correlated with the occurrence of wet days. The fourth root transformation is applied to the original series, as the distribution of precipitation is skewed to convert it to the normal distribution and then used in the regression analysis. This process involved 2 steps; determine the rainfall occurrence in daily basis and then determine the estimated value of rainfall on each rainy day with considered estimated GHGs. From these steps, the predictor-predictand equations were developed using a multi-linear regression approach in generating the daily weather at the region for 100 years. The rainfall (y) on day t can be determined by Equation (1) and (2):

$$y_t = F^{-1}[\emptyset Z_t] \quad (1)$$

$$Z_t = \beta_0 + \Sigma\beta_j\widehat{u_t} + \beta_{t-1} + \varepsilon \quad (2)$$

Where F is the empirical function of y_t, $\emptyset$ is the normal cumulative distribution function, Z_t is the z-score on day t, β is the regression parameter, $\widehat{u_t}$ is the normalised predictor and ε is the variable parameter.

Site of the Study

This study covers 10 states in Malaysia, as shown in Figure 1. There were 10 rainfall stations considered, representing each state in Malaysia. The selection was limited to less than 1% of missing data to ensure the accuracy and reliability of the findings. Malaysia's climate was influenced by 4 seasons, known as North-East monsoon (NE) (Nov to Mar); South-West monsoon (SW) (May to Sept) and 2 inter-monsoons (Mar to May and Oct to Nov). Monsoon will influence the speed and direction of the wind that brings less or heavy rainfall in the region (Satari et al., 2015).

Figure 2: Geographical area of the study

Malaysia Meteorological Department (MMD) reported that wind speed can reach up to 30 knots during NE monsoon and bring heavy rainfall that can cause flood, especially in the Eastern part of Malaysia. However, less than 15 knots of wind speed during SW monsoon contribute to the dry season and less rainfall. The pattern of rainfall in Malaysia is non-uniformly distribution with average annual rainfall is 2400mm per year. The least and heaviest rainfall are focused on Feb and December, respectively. The average temperature is 27^{o}C with 80% of relative humidity.

Results and discussion

List of Predictors for Climate Simulation

Table 1 shows that 5 out of 26 predictors were selected for each weather station. These 26 predictors comprise climate attributes such as air temperature, solar radiation, cloud cover, wind speed, vapour pressure and precipitation. The selection of predictors is important to calibrate the model, as it will be used to develop the predictand – predictor relationship.

Table 1: List of Predictors for each station

	mslp	p500	p850	shum	temp	p_f	r500	r850	rhum	p5_zh	p5_u	p8_u	p_u	p_z	p8_f
Perlis (6503001)		/	/		/		/		/						
Pulau Pinang (5204048)			/		/		/		/						
Melaka (2223023)				/	/	/	/	/							
Negeri Sembilan (2418034)	/			/		/	/	/							
Johor (1437116)	/			/	/			/	/						
Pahang (3931014)				/				/			/		/	/	
Terengganu (5230042)							/	/					/	/	/
Kelantan (5923001)		/					/	/			/	/			
Sabah (5361002)		/			/			/		/	/				
Sarawak (2219001)		/	/		/		/	/							

Before performing the calibration process, predictor variables from NCEP data were selected through a screening process using the explained variances (P-value) and correlation (R) among predictand – predictor association.

The result revealed that different atmospheric variables are affecting the formation of local rainfall. However, even though each station requires different predictors due to the locations and earth surface, most of the stations in Malaysia agreed that relative humidity at 500hpa (r500) and 850hpa (r850), and mean temperature at 2m height (temp) were good influence to the climate formation. Relative humidity refers to the amount of water vapour in the air and the existence of the relative humidity depends on the monsoon. It is significant with Malaysia's climate that is influenced by South West Monsoon, North East Monsoon and two inter-monsoons. Besides, Tu and Lu (2020) agreed that the existing water vapour and air temperature strongly influenced the formation of rainfall.

As proved, Table 2 shows the performances of predictors in the local climate formation based on calibrated and validated results. The result shows all successful stations produced higher R with low %MAE. The highest percentage of mean absolute error (%MAE) occurred during the validated result at Sabah, with 22.2% affected by a weak relationship to the divergence at 500hPa (p5_zh). It is related to the collision between stronger and weaker wind, which leads to rising air. However, the correlation was still high up to 0.81, which is considered acceptable for this case.

Table 2: Performance of predictors to local climate

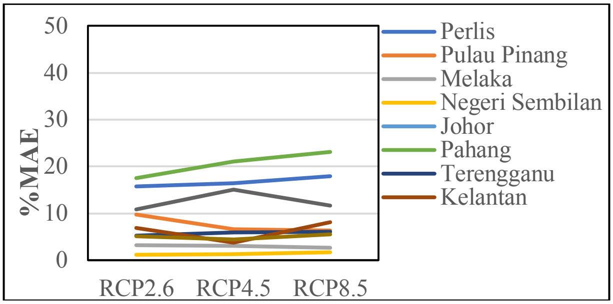
		R	% MAE
Perlis	Calibrated	0.93	17.1
	Validated	0.93	18.3
Pulau Pinang	Calibrated	0.91	12
	Validated	0.91	13.9
Melaka	Calibrated	0.92	11.5
	Validated	0.96	10.7

		R	% MAE
Negeri Sembilan	Calibrated	0.91	11.5
	Validated	0.89	12.6
Johor	Calibrated	0.87	13.2
	Validated	0.89	11.6
Pahang	Calibrated	0.93	2.5
	Validated	0.8	17.7
Terengganu	Calibrated	0.96	7.6
	Validated	0.95	8.1
Kelantan	Calibrated	0.96	7.0
	Validated	0.93	6.8
Sabah	Calibrated	0.95	2.4
	Validated	0.81	22.2
Sarawak	Calibrated	0.94	2.7
	Validated	0.82	17.1

Performances of RCPs with Local Climate

Under CanESM2 model, three different scenarios, RCP2.6, RCP4.5 and RCP8.5, were carried out to find out the future rainfall under various carbon emissions. To determine the best RCPs for each station, the statistical analyses were tested. Figure 3 shows the %MAE and R between historical with climate forecasting using different RCPs. By using the same equation produced by NCEP data, the predictors were replaced by RCPs that consider the long-term radiation level to validate the accuracy of the projected result. At this stage, the lowest %MAE with a higher R-value was considered the best RCP for that particular region. For example, the %MAE of Pahang was expected to increase when the level of radiation increased. By RCP2.6, the %MAE was 17% but increased up to 22% by RCP8.5.

Consistency of R-value starts to reduce with an increment of RCP. Therefore, RCP2.6 is the best radiation level for Pahang state. But not all patterns of RCP are similar to Pahang state. An example is at Kelantan, whereby the %MAE dropped at RCP4.5. It showed that the predicted rainfall by RCP4.5 was closer to the historical data and was selected as the best RCP for Kelantan.



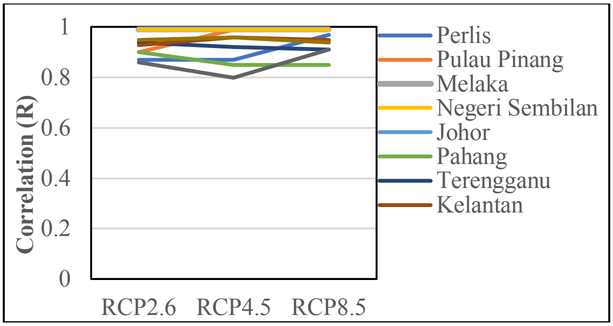


Figure 3: Statistical analyses between RCPs and historical

Table 3 shows the summary of the best RCP for each state in Malaysia. There were 4 states (Perlis, Negeri Sembilan, Pahang and Terengganu) that prefer to use RCP2.6 but other 3 states (Pulau Pinang, Melaka and Johor) prefer to use RCP8.5. Meanwhile, Kelantan, Sabah and Sarawak preferred RCP4.5 as their radiation level. Based on this finding, it is proven that each state has different radiation levels based on location, topography, society, economy and development. The selection of RCPs was very significant in the climate monitoring and analysis to control the accuracy of the projected result.

Table 3: Summary of the best RCPs

	RCP2.6	RCP4.5	RCP8.5
Perlis	/		
Pulau Pinang			/
Melaka			/
Negeri Sembilan	/		
Johor			/
Pahang	/		
Terengganu	/		
Kelantan		/	
Sabah		/	
Sarawak		/	

Conclusion

This study investigates the best RCPs for Malaysia to forecast the long-term climate trend in the context of the climate changes. There were 10 rainfall stations that had been considered, representing 10 states in Malaysia based on 1% of missing data. It is very significant to control the quality and accuracy of the findings. The SDSM reacts as a climate model to develop the predictor-predictand relationship using the statistical equation. The predictors were provided by 2 groups; 1) NCEP that was used to calibrate the equation and then 2) CanesM2 – AR5 to validate the accuracy of the equation while considering the RCPs level. Referring to the performances of R and P-values in the screening process, the appropriate predictors were chosen for each station. Different stations preferred different types of atmospheric variables, as climate influencers and different atmospheric variables affect the formation of local rainfall. However, most of the stations agreed that mean temperature at 2m height, relative humidity at 500hPa, and 850hPa have better influences on climate formation than other atmospheric variables. As proved, each equation successfully produces higher R (> 0.8) with lower %MAE (< 22.3%) in the calibrated and validated results.

According to the RCPs selection, the lowest %MAE and highest R were considered the best RCPs, and successfully reduced the gap between simulated and historical data. The findings varied because of different locations, topography, society, type of economy and development. Nevertheless, 4 out of 10 states agreed that RCP2.5 is an appropriate level of radiation forcing and GHGs at these regions, which is classified as a low impact of the climate changes. This finding was very significant in monitoring and assessing the long-term climate trend and changes to the water sustainability.

Acknowledgement

The authors would like to thank the Ministry of Higher Education for providing financial support under Fundamental research grant No. FRGS/1/2019/TK01/UMP/02/1 (University reference RDU1901141) and Universiti Malaysia Pahang for additional financial support under Internal Research grant RDU1803156, Malaysian Meteorological Department (MMD), and Drainage and Irrigation Department (DID).

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