Analysis of Future Precipitation, Evaporation and Temperature at Sembrong Dam using MRI-AGCM3.2s Climate Model

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ABSTRACT.
Climate change is one of the most important challenges faced by human society. Cases of more intense drought and flood are being predicted to occur more recently in the future. The Sembrong Dam is a major source of water supply for population in Kluang Johor. In recent years, only water quality of the dam has become a main concern. However, water quantity is also important to be assessed. The purpose of this study is to analyze the trend of current and projected monthly precipitation, evaporation and temperature data. These climate data may have significant changes in their trends due to climate change and would be useful to be assessed for preparation measures for the future. The projected climate data were extracted from MRI-AGCM3.2s which is developed by Japan Meteorological Agency. This climate model was found to be the most suitable model for this study based on its resolution, modeling period and scenarios. The modeled periods are from 1979 until 2003 for present and future is 2079 until 2099. Observe data were collected from Department of Irrigation and Drainage (DID) Malaysia. Data are selected from the station nearest to Sembrong Dam. To calibrate and validate the future monthly climate data, bias corrections were applied. Two methods were chosen, they are bias correction and change factor. After calibration, the corrected data were validated using observation data by comparing its seasonality distribution and using RMSE and correlation. Results of validation show an RMSE and R^2 value of 0.4 and 0.87. The future bias corrected data (year 2079-2099) were then used for the Mann-Kendall trend test. The results of Mann-Kendall test showed that there are no significant increasing and decreasing trend for future precipitation within the year 2079 to 2099.. There are similar trend for the future evaporation and temperature, almost all months have significant increasing trend lower than 0.01 level of significant. Prediction of the future precipitation and evaporation for end of century from years 2079-2099 at Sembrong Dam area were able to be estimated.
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Keywords: climate model, bias correction, change factor, correlation

1.0 INTRODUCTION

Recently the changes of the weather and intensity of extreme precipitation events have raise concern that human activity might have resulted to the alteration of the climate [7]. Sembrong Dam is a major source of water supply for the surrounding people living in the districts of Kluang and parts of Batu Pahat. The dam, which was previously built for flood mechanism in 1984 and managed by the Department of Irrigation and Drainage (DID), has been providing water for human consumption since 1990. In daily, the Dam covers some 775 ha and supplies some 55 million liters of treated water by Sembrong water treatment plant. However, climate change may affect the changes of precipitation, evaporation and other hydrological cycle processes. Thus, climate change analysis is important to predict the future estimation of trend and quantity of water at Sembrong Dam. Today, GCM is used to simulate future climate scenarios. There are several types of Global Climate Model. They are Atmospheric Global Climate Model (AGCM), Ocean Global Climate Model (OGCM), Couple Global Climate Model (CGCM) and Coupled Model Intercomparison Project Phase 5 (CMIP5).

1.1 Problem Statement

The Sembrong Dam is a major source of water supply for population and act as flood protection. However, in December 2006, Batu Pahat was affected by flood and it was reported that several downstream areas along Sembrong River were inundated. The flood may occur because of heavy rainfall due to climate change. Despite being the main source of water resources in the area, no information is available on the study on climate change. Therefore, there is a need to assess the future climate within Sembrong dam area. This includes estimating the trend of future rainfall, temperature and evaporation. Climate models are the most important tools available today for projection of climate change. There are varieties of GCM models and the output has discrepancies which needs bias correction to fit the climate data. Trend analysis may be used based on the idea that what has happened in the past gives traders an idea of what will happen in the future.

1.2 Objectives

Based on the identified problems, to analyze the trend of monthly precipitation, evaporation and temperature, there are several objectives to be achieved:

(i) To review and select the most suitable GCMs model for Sembrong Dam area.
(ii) To identify the best method for Bias Correction of the climate data.
(iii) To analyze the trend of future precipitation, temperature and evaporation at Sembrong area.

1.3 Scope of Study

There are various GCM models, however only MRI-AGCM3.2s is used for this study. Validation of the GCM model is based on comparison of seasonality against observed data and by statistical error analysis. Based on availability of GCM model, the, the size of the AGCMs grid cell used is 20km resolution. Downscaling and analysis in terms of spatial was not included in the study. The study focuses on bias correction of the future climate projections.. Secondly, the future scenario is focus on RCP8.5 because assumption of high population and relatively slow income growth with modest rates of technological and high greenhouse emission in that time of period.

2.0 LITERATURE REVIEW

2.1 Review of GCM Models

Climate models are important tools utilized to advance our understanding of current and past climate. In general, Atmospheric General Circulation Models (AGCMs) is a kind of Global Climate Model (GCM) which is widely used for future climate projections. GCMs have been used for a range of applications, including investigating interactions between processes of the climate system and providing projections of future climate states under scenarios that might be used in the climate system. The most widely recognized application is the projection of future climate under scenarios of increasing atmospheric carbon dioxide, (CO_2). The AR4 scenarios have become old and therefore, IPCC developed a new set of new emission scenario referred to as representative concentration pathways (RCPs). Table 1 show several models that can be used in this study based on the model's advantages. However the best model selected is based on the availability of the present period which is from the years 1983 to 2003, scenario and model resolution.

Table 1: Comparison of a few Global Climate Models available for analysis.

GCM				
Name	**Version**	**Resolution**	**Scenario**	**Period**
(a) KAKUSHIN	MRI-AGCM 3.1S (AS)	20 km	Present SRES A1B SRES A1B	1979-2003 2016-2039 2075-2099
(b) SOUSEI	MRI-AGCM 3.2S (YS)	20 km 60 km	Present RCP8.5	1979-2003 2075-2099
(c) MoE adapt	CMIP3 MME CMIP5 MME	15 km + 5 km 20 km + 5 km	RCP2.6 RCP4.5 RCP6.0 RCP8.5	1980-1999 2016-2035 2076-2095
(d) NAHRIM	RegHCM-PM	9 km	SRES A1B	1984-1993 2025-2034 2041-2050
(e) JMA Vol. 8	MRI-AGCM 3.2S (YS)	20 km	Present SRES A1B SRES A1B	1979-2003 2016-2039 2075-2099

2.2 MRI-AGCM 3.2s

The model used for determining the future climate data is MRI-AGCM3.2s. MRI-AGCM3.2s is developed by the Japan Meteorological Agency (JMA) and Meteorological Research Institute (MRI) (Mizuta et al. 2006). The model simulation of the present period is suitable with the available observation data. The model has 20 km resolution climate projections and scenario used is RCP8.5 due to the scenario having the highest carbon dioxide emission in the end of century.

Table 2: Time period for present and future data of MRI-AGCM 3.2s

Model	Time Period	Reason
MRI-GCM3.2s	1979-2003 2079-2099	The release of carbon oxygen is very high in this time range (industrial expansion). Representing the end of the century.

3.0 METHODS

3.1 Area of Study

Sembrong Lake is located in the districts of Air Hitam and Kluang within the range of **2°01'35''N 1°58'29''N** latitude and **103°09'32''E 103°12'57''E** longitude. Table 3 shows the details of the study area. Table 4 shows the list of rainfall stations near the Sembrong area. From the table, the nearest station was selected for further analysis to determine the observed data and the coordinate for the MRI-AGCM3.2s extraction.

Table 3: Description of the Sembrong Dam Area

Background of project of Sembrong Dam	
Location	Batu Pahat, Johor
Reservoir Area	8.5 km^2
Catchment Area	130 km^2
Observed data taken	Department of Irrigation and Drainage
Model GCM used	MRI-AGCM 3.2s
Method used	Bias Correction

Table 4: Rainfall stations near Sembrong Dam.

Station ID	Name of Station	Location	Latitude	Longitude
1931003	Empangan Sg. Sembrong di Air Hitam	Air Hitam	01° 58' 25"	103° 10' 45"
2031069	Ldg. Yong Peng di Batu Pahat	Batu Pahat	02° 04' 15"	103° 09' 10"
2132154	Ldg. Ulu Paloh di Kluang	Kluang	02° 06' 20"	103° 15' 30"
2133157	Ldg. Pamol Kluang	Kluang	02° 06' 40"	103° 20' 40"
2032071	Ldg. Kian Hoe di Kluang	Kluang	02° 01' 35"	103° 16' 15"
2033152	Ldg. Mengkibol di Kluang	Kluang	02° 00' 25"	103° 18' 00"
1933151	Ldg. Lambak di Kluang	Kluang	01° 58' 05"	103° 19' 35"

3.2 Selection of Data Station

The observed stations selected is the nearest and having the least missing data. Table 5 shows details of the selected stations for the precipitation and evaporation stations. Future data is presented using the MRI-AGCM 3.2s with the coordinate of latitude and longitude as follow.

Table 5: Precipitation and evaporation stations nearest to Sembrong Dam.

Station no. and name	Type of data	Period of data Obtained	Latitude	longitude
1931003	Rainfall (observed)	January 1983-December 2003	01° 58' 25"	103° 10' 45"
2033301	Evaporation (observed)	January 1983-December 2003	02° 01' 10"	103° 19' 30"
MRI-AGCM 3.2s	Rainfall and Evaporation	Present: January 1983-December 2003 Future: January 2079-December 2099	01° 58' 05"	103° 7' 30"

3.3 Calibration, Validation and Error Analysis methods

There are biases between the AGCM and reality which should be corrected. There are four methods for calibrating the MRI-AGCM data. The data from the year 1983 to 1992 was used for the calibration, while data from year 1992 to 2003 was used for validation.

(a) Bias correction (SH and BC) (b) Change factor (DEL and CF)

Figure 1: Type of calibration method.

Based on figure (a) and (b), the method of bias correction and change factor can be written as follows:

$T_{SH}(t) = T_{RAW}(t) + (\overline{O_{REF}} - \overline{T_{REF}})$ (eq. 1)

$T_{BC}(t) = \overline{O_{REF}} + \frac{\sigma_{O,REF}}{\sigma_{T,REF}} (T_{RAW}(t) - \overline{T_{REF}})$ (eq. 2)

$T_{DEL}(t) = O_{REF}(t) + (\overline{T_{RAW}} - \overline{T_{REF}})$ (eq. 3)

$T_{CF}(t) = \overline{T_{RAW}} + \frac{\sigma_{T,RAW}}{\sigma_{T,REF}} (O_{REF}(t) - \overline{T_{REF}})$ (eq. 4)

Where, O_{REF} = observations in the historical reference period, T_{REF} = GCM output from the historical reference period, T_{RAW} = raw GCM output for the historical or future period, T_{SH} = T_{BC} = bias corrected GCM output and T_{CF} = T_{DEL} =change factor GCM output. $\sigma_{T,REF}$ and $\sigma_{O,REF}$ represent the standard deviation of the daily GCM output and observation in the reference period respectively. $\sigma_{T,RAW}$ represents the standard deviation of the model output.

(a) Bias Correction methods

The bias correction (BC) methodology may be described using Figure 1 (a). SH and BC corrects the projected raw daily GCM output using the differences in the mean and variability between observations and the GCM in a particular reference period. Equation (1), T_{SH} assumes the variability in observations and GCM is the same, while equation (2), T_{BC} considers correcting the variability of the projected raw data based on observed data.

(b) Change Factor methods

The change factor (CF) methodology may be described using Figure 1 (b). DEL and CF conducts the corrections by utilizing the observed reference data using the differences in the mean and variability between the reference and the projected GCM model. Equation (3), T_{DEL} assumes the variability to have similar magnitude in the future and reference periods .Equation (4), T_{CF} consider the changes in variance to determine the corrected data.

(c) Error Analyses

Correlation and Root Mean Square Error was used to validate the relationship between observed and calibrated data after the bias correction.

$$R^2 = \left[\frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{([N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2])}}\right]^2 \quad (5)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \quad (6)$$

Table 6: Correlation and RMSE requirements.

Correlation	RMSE
Strong relationship ≥ 7 0.4 ≤ Moderate < 0.7 Weak relationship < 0.4	Less error ≈ 0

3.4 Mann-Kendall test using MAKESENS Excel Template

Mann-Kendell trend test is used for detecting and estimating trends in the time series of average monthly values of precipitation, evaporation and temperature. The procedure is based on the nonparametric Mann-Kendall test. The Mann-Kendall test is applicable to the detection of a monotonic trend of a time series with no seasonal or other cycle. For the four tested significance levels the following symbols are used:

*** if trend at α = 0.001 level of significance
** if trend at α = 0.01 level of significance
* if trend at α = 0.05 level of significance
+ if trend at α = 0.1 level of significance
If the cell is blank, the significance level is greater than 0.1

The Mann-Kendall test is applicable in cases when the data values *xi* of a time series can be assumed to obey the model

$$x = f(t_i) + \varepsilon_i \quad (7)$$

Where *f(t)* is a continuous monotonic increasing or decreasing function of time and the residuals ε*i* can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. The Mann-Kendall test statistic *S* is calculated using the formula:

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (8)$$

Where *xj* and *xk* are the annual values in years *j* and *k*, *j* > *k*, respectively, and

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases}.$$

4.0 RESULT AND DISCUSSION

4.1 Analysis of Bias Correction methods.

The most suitable GCM to be used for estimating future precipitation and evaporation for this study is MRI-AGCM 3.2S. Although there is no downscaling and spatial analysis conducted, the grids of 20 km considering scenario RCP8.5 is sufficient enough to predict the precipitation by applying bias correction method. The correlation and RMSE was used to validate the data between precipitation and evaporation. Table 7 and Table 8 show the results of the corrected data by applying equation (1) to (4). In order for the calculations of the bias correction method to be correct, the corrected data must follow the following rules in equation (9) and (10).

$$\overline{T_{SH}} = \overline{T_{DEL}} = \overline{T_{RAW}} - \overline{T_{REF}} + \overline{O_{REF}} \quad \text{(eqn. 9)} \qquad V(T_{CF}) = V(T_{BC}) = \frac{\sigma^2_{OREF} \, X \, \sigma^2_{TRAW}}{\sigma^2_{TREF}} \quad \text{(eqn. 10)}$$

Table 7: Validation of the bias correction methods using DEL and SH.

Month	$\overline{T_{BC}}$			$\overline{T_{DEL}}$		
	Precp (mm)	Evap (mm)	Temp (˚c)	Precp (mm)	Evap (mm)	Temp (˚c)
Jan	192	168	29	192	168	29
Feb	91	186	30	91	186	30
Mar	210	220	30	210	220	30
Apr	194	189	30	194	189	30
May	130	192	30	130	192	30
Jun	123	185	30	123	185	30
Jul	118	177	29	118	177	29
Aug	155	174	29	155	174	29
Sept	147	174	29	147	174	29
Oct	196	175	29	196	175	29
Nov	213	165	29	213	165	29
Dec	260	154	28	260	154	28

Table 8: Validation of the bias correction methods using T_{CF} and T_{BC}.

Month	$V(T_{CF})$			$V(T_{BC})$		
	Precp (mm)	Evap (mm)	Temp (˚c)	Precp (mm)	Evap (mm)	Temp (˚c)
Jan	95536	3371	1	95528	3105	1
Feb	16073	2482	1	16003	2492	1
Mar	16457	10313	1	18236	10586	1
Apr	6442	10689	1	6044	13863	1
May	7224	4484	1	6734	6238	1
Jun	4451	1517	0	4535	2056	0
Jul	7331	1637	0	7614	1999	0
Aug	8437	935	0	8719	1066	0
Sept	116222	1419	0	116897	1814	0
Oct	26209	2880	1	26468	3767	1
Nov	1776	488	0	1766	766	0
Dec	19759	925	1	20069	1046	1

Table 7 shows the corrected similarity of precipitation, evaporation and temperature that the mean of T_{SH} is the same as T_{DEL}. The results in Table 8 show the similarity of precipitation, evaporation and temperature that produce different realization of the variability. The expected variance for T_{CF} is almost near value with T_{BC}. These shows that the model equations used for Bias correction method is correct.

4.2 Calibration and Validation of the Climate Data

4.2.1 Comparison between Observed and Bias Corrected GCM Data Based on Seasonality

Figure 2 shows a comparison between the bias-corrected and observed data of monthly average of the years 1992 to 2003. Based on the result, all four methods have similar seasonal pattern against observation data. It is seen that all the bias corrected data of precipitation, evaporation and temperature has strong relationship with the observed data, except for the precipitation of method 2 and 4. In March the method overestimate the precipitation value. Correlation and RMSE result will distinctively determine the best fit method of bias correction in the next section.

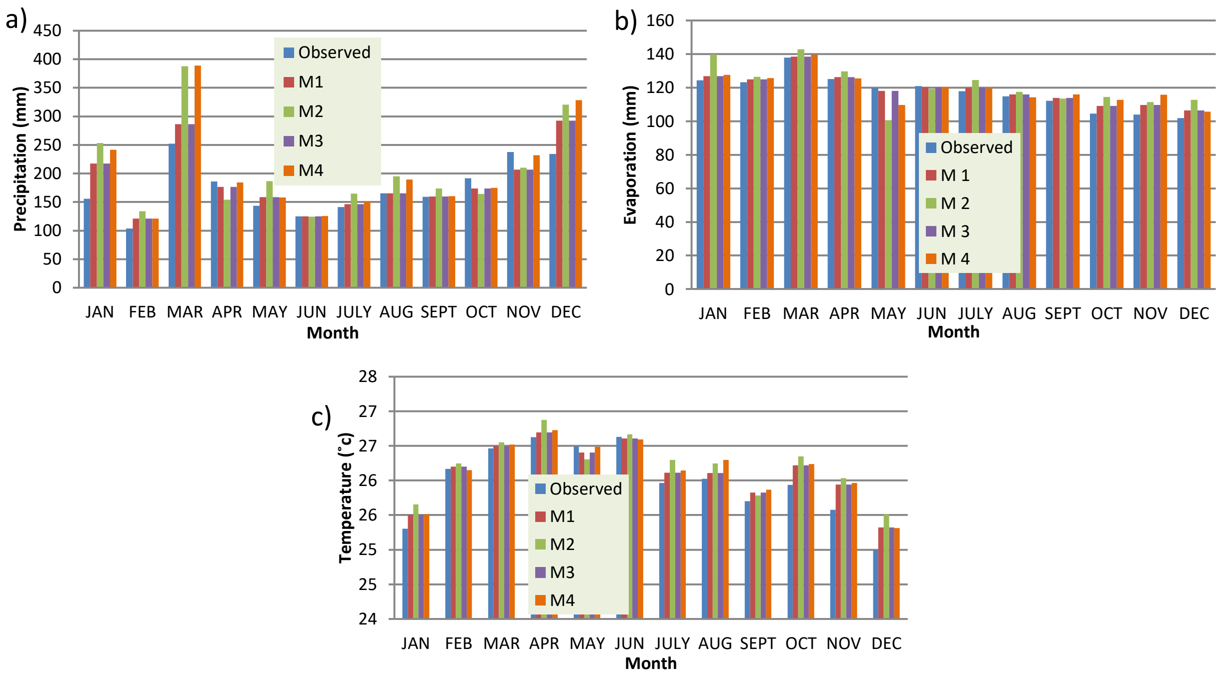

Figure 2: Seasonality Comparison of bias corrected (a) precipitation, (b) evaporation and (b) temperature.

4.2.2 Comparison between Observed and Bias Corrected GCM Data Based on Error analysis.

There are four calibration method considered in this study (refer 3.3). The calibrations were done using monthly average data from 1983-1992 while validations were done using data from 1993-2003. The climate data of precipitation, evaporation and temperature were used. The performances of validations were numerically assessed by using RMSE and correlation. Obtained RMSE and correlation, R^2 results of the climate data at Sembrong Dam are presented in Table 9.

Table 9: Validation of bias corrected and observation data based on RMSE and R^2.

Method	RMSE			R^2		
	Precipitation (m)	Evaporation (m)	Temperature (˚c)	Precipitation (m)	Evaporation (m)	Temperature (˚c)
1	0.40	0.06	1.16	0.87	1.00	1.00
2	0.61	0.09	1.20	0.73	0.95	1.00
3	0.39	0.07	2.07	0.87	1.00	1.00
4	0.52	0.08	2.10	0.80	0.98	1.00

The RMSE values for all calibration methods of the monthly average (1983-1992) GCM data were found to be allowable value when using both Bias Correction (eq 1 and eq. 2) and Change Factor (eq. 3 and eq. 4). The lowest RMSE values for all precipitation, temperature and evaporation is by using method 1. Results show that the correlations are very close to the observed data. It can be marked that method of bias correction (method 1) and change factor (method 3) are the best calibration method in reducing uncertainties associated with MRI-AGCM 3.2S due to both method have the least RMSE and highest R^2 values.

4.3 Mann-Kendall Trend Test and Present and Future Data Comparison

Table 10 shows comparison between the present and future trends of precipitation, evaporation and temperature. The results of Mann-Kendall test show there are no significant increasing and decreasing trend for future precipitation. However for present precipitation data, there are a significant decreasing trend with the significance level of lower than 0.05 only for the month of July, September and December. For the present and future evaporation and temperature similar trend are observe. Almost all months have significant increasing trend lower than 0.01 level of significance.

Table 10: Mann-Kendall trend statistics of present and future precipitation, evaporation and temperature.

Month	Precipitation		Evaporation		Temperature	
	Present (1983-2003)	Future (2079-2099)	Present (1983-2003)	Future (2079-2099)	Present (1983-2003)	Future (2079-2099)
Jan				**	+	**
Feb			+	*		*
Mar			*			
Apr			*	**		**
May			***	**	**	**
Jun			***	***		***
Jul	*			**	*	**
Aug	+			*		*
Sept	**		**	**	***	**
Oct				***	+	***
Nov	+			***	*	***
Dec	*			**	***	**

= Decreasing trend = Increasing trend

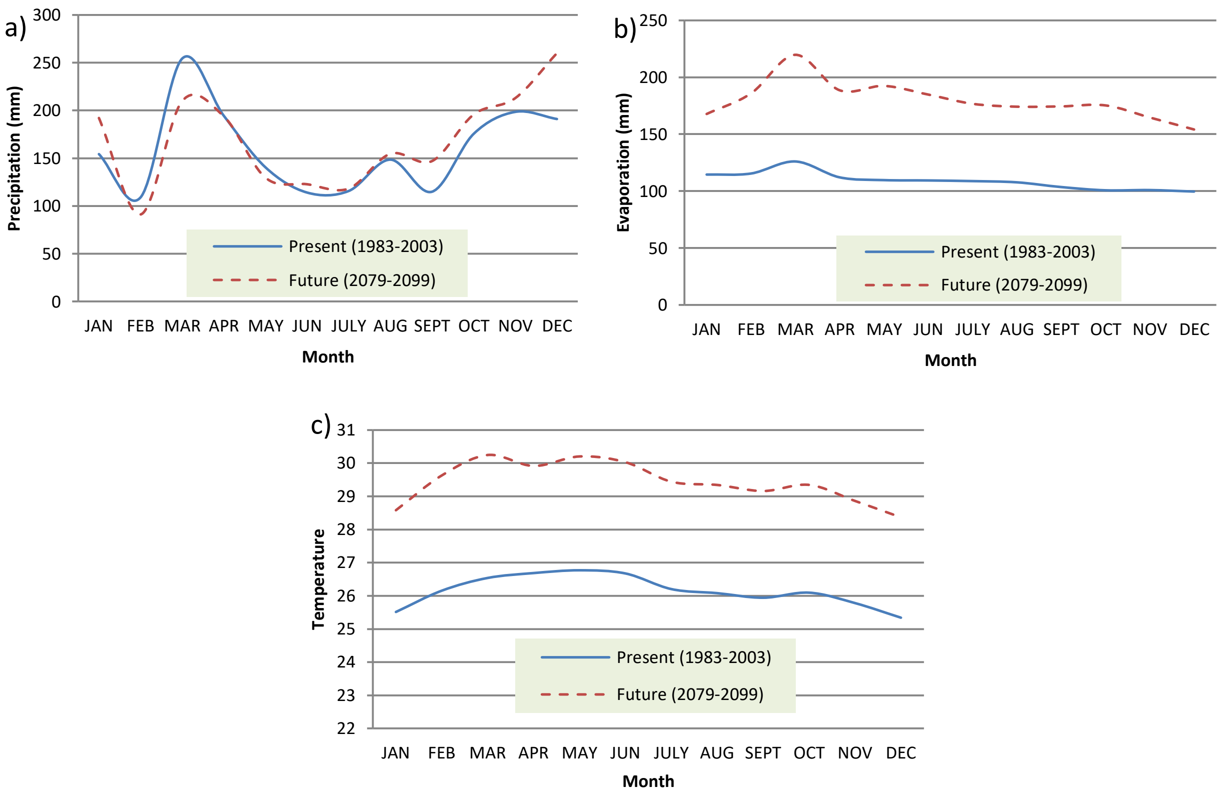

Figure 3: Seasonality Comparison of present and future (a) precipitation, (b) evaporation and (b) temperature

Based on figure 3, the future precipitation shows similar seasonality pattern with the present. November to march (North East monsoon) has high distribution of rainfall for both present and future. May to September has the least rainfall distribution. The temperature at Sembrong Dam shows an increasing temperature in the future. An increase of about 4˚C is predicted. This coincides with the global temperature which may rise by as much as 1˚C to 6˚C. (IPCC, 2007). Therefore, evaporation also shows an increasing value since the temperature increases.

5.0 CONCLUSION

The physical basis and science of climate change at the regional level are of central importance for adaptation where the trend and future behavior of extreme events are critical to understand the impacts of climate change. In this study, MRI-AGCM 3.2S is used to project the future precipitations. The changes of precipitation and evaporation under four different methods of Bias Correction were assessed. Although, no downscaling was applied for the GCM data, Bias Correction may be use depending on the purpose of the impact study. The Bias Correction method used is found to capture the properties of observed precipitation, temperature and evaporation accurately. It shows less error and high correlation. The results of Mann-Kendall test showed that for future precipitation in the year of 2079-2099, there are no significant increasing and decreasing trend. There are similar trend for the future evaporation and temperature, almost all months have significant increasing trend lower than 0.01 level of significant. It is expected that the results obtained from this study will be helpful in impact assessment and adaptation in the study region.

REFERENCE

1. "Climate Change Scenarios." IPCC - Intergovernmental Panel on Climate Change, www.ipcc.ch/home_copyright.shtml.
2. Amneera, W. A., Najib, N. W. A. Z., Yusof, S. R. M., & Ragunathan, S. (2013). Water quality index of Perlis River, Malaysia. *International Journal on Civil and Environmental Engineering*, *13*(2), 1-6.
3. Awang, H., Daud, Z., Tan, L. W., Hatta, M., & Zainuri, M. (2015). Hydrology Properties at Sembrong Dam Reservoir in Johor. In *Applied Mechanics and Materials* (Vol. 773, pp. 1330-1334). Trans Tech Publications.
4. Gutowski Jr, W. J., Decker, S. G., Donavon, R. A., Pan, Z., Arritt, R. W., & Takle, E. S. (2003). Temporal–spatial scales of observed and simulated precipitation in central US climate. *Journal of Climate*, *16*(22), 3841-3847.
5. Nakicenovic, N., Alcamo, J., Grubler, A., Riahi, K., Roehrl, R. A., Rogner, H. H., & Victor, N. (2000). *Special Report on Emissions Scenarios (SRES), A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge University Press.
6. Ramirez-Villegas, J., Challinor, A. J., Thornton, P. K., & Jarvis, A. (2013). Implications of regional improvement in global climate models for agricultural impact research. *Environmental Research Letters*, *8*(2), 024018.
7. Semiromi, S. T., Moradi, H. R., Moghaddam, D. D., & Khodagholi, M. Future Climate Conditions and Trend Analysis of Precipitation and Temperature in Bar Watershed, Iran.
8. Suhaila, J., Deni, S. M., Zin, W. Z. W., & Jemain, A. A. (2010). Trends in peninsular Malaysia rainfall data during the southwest monsoon and northeast monsoon seasons: 1975–2004. *Sains Malaysiana*, *39*(4), 533-542.
9. Tabor, K., & Williams, J. W. (2010). Globally downscaled climate projections for assessing the conservation impacts of climate change. *Ecological Applications*, *20*(2), 554-565.
10. Thrasher, B., Maurer, E. P., McKellar, C., & Duffy, P. B. (2012). Bias correcting climate model simulated daily temperature extremes with quantile mapping. *Hydrology and Earth System Sciences*, *16*(9), 3309-3314.
11. Ushiyama, T., Hasegawa, A., Miyamoto, M., & Iwami, Y. (2016). Dynamic downscaling and bias correction of rainfall in the Pampanga River Basin, Philippines, for investigating flood risk changes due to global warming. *Hydrological Research Letters*, *10*(3), 106-112.
12. Williamson, G. S., & Williamson, D. L. (1987). *Circulation statistics from seasonal and perpetual January and July simulations with the NCAR Community Climate Model (CCM1): R15*. Climate and Global Dynamics Division, National Center for Atmospheric Research.