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Analysis of Climate Variability and Trends in The Context of Climate Changes: Case Study in Terengganu

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Abstract: Uncertainty of climate extreme nowadays causes an alteration in the local climate trend and variability. Terengganu, Malaysia recorded series of extreme drought and flood events throughout a year affected by North-East monsoon which will change the next climate pattern. Thus, it will be affecting the long-term planning and sustainability that related to the water resources in the long-term. The objective of this study was to analyse the trend changes of rainfall and temperature at Kuala Terengganu, Malaysia due to climate changes impact. The trends changes were analysed using Man-Kendall and Sen's Slope. The climate projection result shows the annual mean temperature is expected to have decreasing trend until end of century. However, Mar to June are expected to bit higher than historical reach to 29°C by RCP8.5. Then it will be dropped to 24°C (-5% from historical) during Northeast monsoon. Consistent to the annual rainfall, it was expected to have increasing trend over time. The highest increasing trend was expected to occur on Nov to Dec more than 40% by RCP8.5.

Keywords: Climate change, climate trend, climate variability, Terengganu River basin, Man-Kendall, Sen's Slope

1. Introduction

Frequent occurrence of extreme hydro-meteorological events with higher intensity are implication from the climate changes. There are numerous elements that can influence climate changes including changes in solar radiation, volcanoes, and internal climate variability, as well as the impact of human activities. According to Intergovernmental Panel on Climate Change [1], the global warming is expected to reach 1.5°C in year 2030 to 2052 if the dispersion of greenhouse gases (GHGs) is keep increasing without control. For instance, the release of carbon dioxide has increase significantly might alter the intensity and frequency of rainfall in a certain area, making weather patterns in that particular area unpredictable [2]. Flood, drought, flash flood, landslide, wild bush fire, and soil erosion are all examples of how climate change can disrupt society and human activity.

Flood event especially in Eastern Malaysia can be categorised as 2 phenomena, flash flood and river flood. Flash flood occurs when receiving extreme heavy rainfall within a few minutes or hours (10-50 mm/hr). During this time, the existing drainage system fail to accommodate excessive rain water causes overflows to road surface, residential areas, town and etc. Meanwhile river flood occurs when the water level in the river rises due to heavy or nonstop rainfall and

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overflows onto the river bank and the surrounding area. The main cause of these phenomenon is heavy rainfall but it produces different impact to the society.

Flood disaster in Terengganu happened almost in every year affected by Northeast monsoon. Even it is normal phenomenon in Malaysia, however the concern is about the frequency of event and its impact. In year 2014, an extreme flood occurred in most of part in Terengganu causes 5550 peoples were lost their home [3]. The rainfall was exceeded 1200 mm/month which similar to annual rainfall. The government spent RM132 million to repair the aftermath flood damages to the road and infrastructure. In year 2020, the flood happened after receiving 190 mm of rainfall within 8hours which similar to normal monthly rainfall (200 mm/month) [4]. It was due to continuous heavy rainfall during high tide phenomenon causes flood at low-lying areas.

Today, the projection of local climate is very crucial in order to study the climate changes in trend and variability. Simultaneously, it is significant study to estimate future climate changes that may occur in the chosen area. Forecasting the future climate change can provide various benefits to others, such as assessing and planning structure construction and infrastructure that is compatible with climate change anticipated data. This can also benefit to local residents in terms of planning their economic activities, such as agriculture, tourism, recreation, and so on. For the governments, the anticipated data can be used to plan and assess the best method to minimize losses and significant negative impact caused by climate change in the research area, as well as for water resource management [5], [6].

Time series modelling is a relevant tool for predicting long and short-term patterns in rainfall and temperature in a selected area. This method can also be used for observing, predicting, and determining the best modelling to use in order to develop a pattern of rainfall and temperature based on time series data. It is also can analyse the potential hydrological impact of climate change in the local area using time series modelling research [7].

Man-Kendall and Sen’s Slope estimator are non-parametric equation to identify the trend changes in rainfall and temperature. The positive value shows the upward trend meanwhile the negative value shows the downward trend. [8] and [9] were applied these estimators in their respective areas and successfully to identify the trend changes in the long term. Therefore, the objectives of this paper are to generate the rainfall and temperature in the long term at Terengganu and also to analyse the trend changes of rainfall and temperature by using Man-Kendall and Sen’s Slope.

2. Study Area

Terengganu, Malaysia is located in the eastern part of Peninsular Malaysia. Terengganu is bordered by Kelantan at northwest and Pahang at southwest. At the east of the Terengganu is the South China Sea which is one of the main influences of the climate variability and trend of Terengganu. The total area of Terengganu is 13,035 km^2. There are eight (8) districts located in Terengganu, which are Besut, Dungun, Hulu Terengganu, Kemaman, Kuala Terengganu, Marang, Setiu and Kuala Nerus. Terengganu River Basin is approximately about 5000 km^2 which is located at the north of the tropical coastal region (4°40’ - 5°20’N, 102° 30’ - 103°09’E).

Terengganu has temperature between 25.6°C and 27.8°C and also annual rainfall of 3300 mm. Terengganu also receives high volume of precipitation during the Northeast Monsoon season or also being known as the wet season from November to January every year. Table 1 shows the list of stations had been considered in this study.

Table 1 - List of stations

Station ID	Station Name	Latitude	Longitude
4131001	Kg. Ban Ho	04 08 00	103 10 30
3933001	Hulu Jabor, Kemaman	03 55 05	103 18 30
4734079	Sek. Men. Sultan Omar	04 45 45	103 25 10
4929001	Kg. Embong Sekayu	04 57 10	102 58 00
5331048	Setor JPS Kuala Terengganu	05 19 45	103 08 00
5428001	Kg. Batu Hampar	05 26 50	102 48 55
5524001	Kg. La	05 31 50	102 29 00
5331047	Stn Kajicuaca Kuala Terengganu	05 19 05	103 08 10

3. Methodology of Study

Fig. 1 shows the flowchart of the study. Rainfall data from seven (7) stations for 30 years’ length (1988-2017) have been collected from Drainage and Irrigation Department (DID) Malaysia and temperature data from one (1) station has been collected from Malaysia Meteorological Department (MMD). The process of missing data treatment and screening process has proceeded using Linear Scaling Method. This is to make sure that all the data are reliable, valid, and fit with the chosen method for the next step. Next, calibration has been undergone for the fifteen (15) years (1988-2002) and validation for the next fifteen (15) years (2003-2017) by using Statistical Downscaling Model (SDSM) on the strength of the ability of SDSM as a climate agent to forecast the changes of climates trend [10]. The selection of predictors has been carried on for the assessment of the relationship between correlation values of predictors and historical data.

Furthermore, the projection of rainfall and temperature have proceeded with three (3) interval years which are Δ2030 (2020-2039), Δ2050 (2040-2069), and Δ2080 (2070-2099) by using SDSM with GCM-CanesM2. The projection of future climate is very crucial in order to do the analysis of trends and patterns of climate changes in Terengganu. The analysis of trends and variability has been undergone by using Man-Kendall Test and Sen's Slope Test.

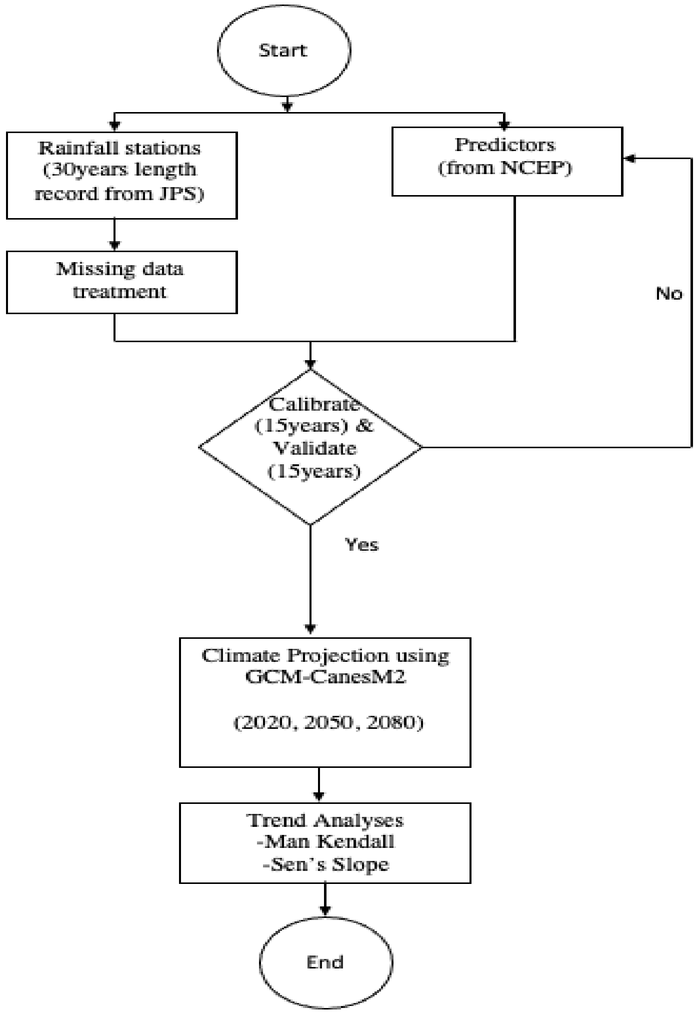

Fig. 1 - Flowchart of the study

3.1 Statistical Downscaling Model

Statistical downscaling models are being used to investigate the relationship between large-scale atmospheric variables and local or regional climate variables that can be extracted from the data obtained and applied to the large-scale field simulated by the climate model. As compared to dynamic downscaling models, statistical downscaling models have the benefit of being able to approach fines spatial scale and also being able to use parameters that cannot get from Regional Climate Modelling (RCM) [11]. Statistical downscaling models are also able to extract the link between atmospheric data from Global Climate Models (GCM) and the surface variable to be fit into the new GCM projection because statistical downscaling models are based on the assumption that data does not change over time and statistical downscaling models are capable to construct high-resolution simulations and can be applied into a large number of GCMs projection [12].

The climate projection has been carried out by using SDSM with GCM-CanesM2 on the strength of SDSM that able to recognize the differences in future and long-term climate projections, which correlate to the dispersion of GHGs and the emission of aerosol to the atmosphere system, and anticipated dissemination of greenhouse gases and radiation into the atmosphere [13].

3.2 Man-Kendall Estimator

Man-Kendall test is the statistical test that has been used to quantify the significance of trends in hydro-meteorological time series [14], analyse the trend of rainfall [15] especially for the long-term rainfall, and solve the problem regarding the missing data, the requirement of few assumptions and data distribution can be independence [16].

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(X_j - X_i\right) \tag{1}$$

where n is the number of data points, X_i and X_j are the data values in the time series i and j ($j > i$). The *sgn* values stated in Eq. (1) is to specify the trend of the data either increasing or decreasing. If *sgn* value is negative, it shows the trend of the data is decreasing, if *sgn* value is positive, it shows the trend of the data is increasing, if *sgn* value is zero, it shows the trend of data is no trend.

3.3 Sen's Slope Estimator

Sen's Slope test is a non-parametric procedure that has been used for estimating the slope of trend in a sample of n pairs of data and estimating the magnitude of trend [15]. In a previous study [16], Sen's Slope test has been used to estimate the trend precipitation and at the same time, the seasonal cycle and length of the time series data have been ignored. Sen's Slope is not dependent on the distribution assumption, serial correlation, and seasonal cycle.

$$Q_i = \frac{X_j - X_k}{j - k} \quad for\ i = 1,..,.,n \tag{2}$$

where X_j and X_k are the data values at time ($j > k$) and n is the number of time periods. The Q_i values stated in Eq. (2) is to specify the magnitude of data either increasing or decreasing. If the Q_i value is positive, it shows the magnitude is increasing, and if the Q_i value is negative, it shows the magnitude is decreasing.

4. Results and Discussions

Table 2 shows the list of predictors that been used for climate projection. Different stations have different types of predictors that influence the current climate. The parameter of a predictor which is able to produce the best scatter plot and the minimum of P-value are highly correlated and will be chosen for the climate predictor [13]. Based on the results, mean sea level pressure (mslp), geopotential height at 850hPa (p850) and specific humidity at 850hPa (s850) were the most significant variables for this study area. Besides, zonal velocity at 100hPa (p1_u) and 500hPa (p_5u), vorticity at 500hPa (p5_z) and 850hPa (p8_z), geostrophic airflow velocity at 500hPa (p5_f), and divergence at 850hPa (p8_zh) were also contributed to the formation of rainfall. Most of the parameters were related to the wind in term of direction and velocity. It is significant to the site study because its location near to the coastal. Consequently, the wind associated with this geopotential height transport the moisture to this region and influencing the formation of rainfall.

Meanwhile for temperature, zonal velocity at 100hPa (p1_u) and 850hPa (p8_u), meridional velocity at 100hPa (p1_v), geopotential height at 500hPa (p500), and near surface air temperature (temp) were selected to form the local mean temperature. The air temperature is very important variable to monitor the relative humidity, evaporation rate, and wind speed and direction and influence the rainfall pattern.

Table 2 - List of predictor variables

Predictors	**mslp**	**p5_u**	**p5_z**	**p5_f**	**p8_z**	**p8_zh**	**p850**	**s850**	**p1_u**	**p1_v**	**p500**	**p8_u**	**temp**
Kg. Ban Ho	/	/	/				/	/					
Hulu Jabor		/	/	/			/	/					
Kg. Embong Sekayu	/	/			/	/		/					
Kg. La	/				/		/	/	/				
Setor JPS KT	/				/	/	/	/					
SM Sultan Omar	/					/	/	/	/				
Kg Batu Hampar	/				/	/	/	/					
Mean Temperature									/	/	/	/	/

4.1 Calibration and Validation

During the screening factors, the best predictors with the best association with the predictand were chosen. Two (2) sets of historical data which are from 1988-2002 and 2003-2017, have been prepared as predictand files. These two (2) data sets will be calibrated and validated with the chosen climate predictors. To obtain a good result, 100 ensembles were utilised to calculate the average, which was then used to validate the model with observed data.

Fig. 2 shows performances of simulated results during calibration and validation processes for temperature. For temperature, the predictors selection was successfully to produce better simulated results with %error less than 3%. The variables for temperature were not too sensitive likes rainfall which require extra caution due to non-uniform pattern.

Fig. 3 shows the result of calibration and validation for seven (7) rainfall stations. The modelled rainfall resulting from SDSM for calibration and validation has been compared with the historical data. The validation process was carried out in order to obtain more precise and unbiased climate. The comparison between model rainfall data and historical data were made to monitor the accuracy of the results. From the calibration, seven (7) stations of rainfall were able to achieve average standard error (%error) less than 13%. The biggest error was in Nov which might affecting by the predictors. However, most of the stations were successfully to produce better simulated results during validation process with %error less than 10%. It proved that the list of predictors that have been chosen are able to produce a precise and unbiased climate projection.

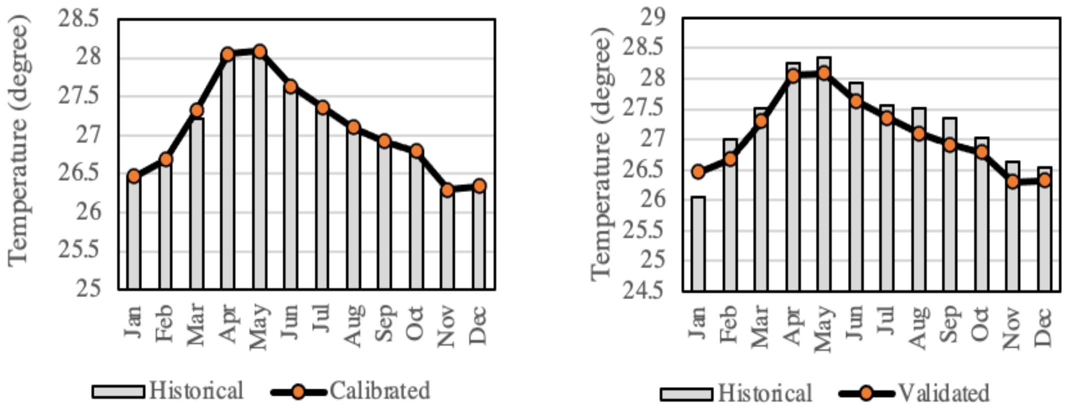

Fig. 2 - Calibrated and validated results for temperature stations

4.2 Climate Projection

The result of forecasting the long-term rainfall and temperature were presented in three (3) intervals period, which is ∆2030 (2020-2039), ∆2050 (2040-2059), and ∆2080 (2070-2099). This research was based on various recognised scenarios that encompass a variety of emission scenarios of CanesM2 predictors, which are divided into three levels of emission scenario RCP2.6, RCP 4.5, and RCP 8.5. Low emission scenarios are RCP 2.6, intermediate emission scenarios are RCP 4.5, and the high emission scenarios are RCP 8.5. The studies were repeated three different scenarios in order to have thorough grasp of future pattern alterations.

Fig. 4 shows the comparison of projected results for each interval year with historical. Based on the results, the projected rainfall is expected to have small difference increasing/decreasing in the future throughout end of century. By maintaining the monthly pattern, all RCPs agreed that Nov and Dec as the month that receiving the highest rainfall intensity due to Northeast monsoon. Meanwhile Jul as the least rainfall intensity due to monsoon transition. However, the annual rainfall is expected to decrease year by year at Kg Ban Ho, Hulu Jabor, Kg Embung Sekayu and SM Sultan Omar might have affected by the climate changes. As showed by RCP8.5 as the least of annual rainfall prediction (drop 12%) which contributed by the highest concentration in carbon dioxide release. Another 3stations there were Kg La, Kg Batu Hampar and JPS Kuala Terengganu expected to receive higher rainfall intensity (+20%) until end of century.

Meanwhile the mean temperature is expected to rise 1% than historical in Mar, Jun, Aug and Sept during Southwest monsoon. Then the temperature reading is expected to become lesser 4% than historical during Nov and Dec due to Northeast monsoon which consistent to rainfall pattern that having increasing trend during these months. Even all RCPs produce similar pattern in rainfall and temperature, however RCP8.5 is predicted to produce highest changes compared to other RCPs.

4.3 Trend Analyses

The analysis of trend and variability were proceeded by using Man-Kendall Test and Sen’s Slope Test. Every RCPs generate a distinct analysis value of trend analyses. Man-Kendall and Sen’s Slope highlight how crucial it is the selection of the best RCPs for each station in order to have a better outcome when analysing rainfall and temperature trends and variability.

Fig. 3 - Calibrated and validated results for rainfall stations

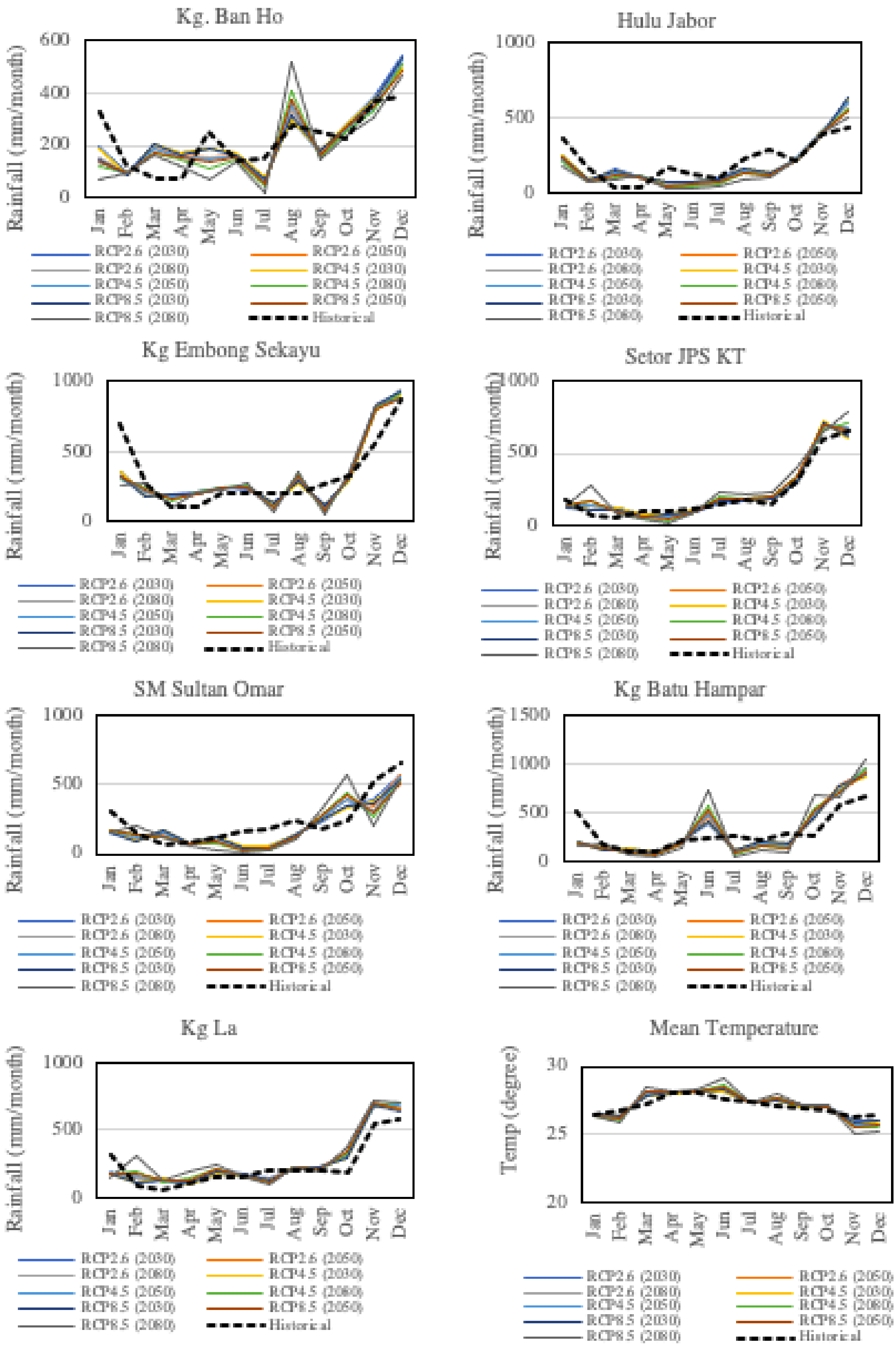

Fig. 4 - Comparison between projected rainfall and temperature with historical

Table 3 shows the trend analyses for rainfall by using Man-Kendall and Sen's Slope estimators. Based on this finding, Man-Kendall agreed that all the selected stations are having no trend while Sen's Slope shows the positive trend in the annual rainfall for all station. The highest value (+4.272) by RCP8.5 was in JPS Kuala Terengganu which expecting increasing trend in the future year followed by Kg La (+2.151) and Kg Batu Hampar (+3.283). Meanwhile other 4 stations were also estimated to have positive trend with higher increment in RCP2.6 and then the trend become lesser in RCP8.5.

To conclude, for the annual trend analyses, seven (7) selected station in Terengganu are expected be having an increasing trend for the annual rainfall.

Southwest monsoon is a rainfall season that occur in May until September every year and Terengganu is a state that slightly affected by the southwest monsoon season. Based on the result of trend analysis, Man-Kendall and Sen's Slope agreed that station Kg Ban Ho, and station Hulu Jabor are expected having a decreasing trend of rainfall during Southwest monsoon. Meanwhile, for the station Kg Embong Sekayu, station Setor JPS Kuala Terengganu, station Sek Men Sultan Omar, station Kg Batu Hampar, and station Kg La, both Man-Kendall and Sen's Slope are expected to have a increasing trend of rainfall during Southwest monsoon.

Northeast monsoon is a rainfall season that occur in Malaysia in October until March every year. During northeast monsoon, heavy rainfall and strong wind usually occur in the east side of Peninsular Malaysia including Terengganu. From our finding, both indicator of trend analysis, Man-Kendall test and Sen's Slope test agreed that station Kg Ban Ho, station Hulu Jabor, station Sek Men Sultan Omar, and station Kg Batu Hampar, rainfall is likely to decrease in the future during northeast monsoon. Meanwhile, for station Kg Embong Sekayu, station Setor JPS Kuala Terengganu and station Kg La, rainfall is estimated to increase during forecast period.

Fig. 5 shows the temperature trend using Man-Kendall and Sen's Slope estimators. Both analyses agreed that the annual trend of mean temperature are expected to decrease until end of century. However, Mar to June are expected to bit higher than historical reach to 29ºC by RCP8.5. Then it will be dropped to 24ºC (-5% from historical) during Northeast monsoon.

Table 3 - Trend analyses based on Man-Kendall and Sen's Slope

No.	Station		RCP 2.6		RCP 4.5		RCP 8.5	
			MK	SS	MK	SS	MK	SS
1	Ban Ho	Annual	0.069	0.99	0.045	0.834	0.008	0.052
		SW monsoon	-1	-20.029	-1	-18.665	1	9.217
		NE monsoon	1	11.416	-1	-75.13	-1	167.437
2	Hulu Jabor	Annual	0.116	1.429	0.086	0.898	0.059	0.579
		SW monsoon	-1	-5.88	-1	-58.0064	-1	-126.059
		NE monsoon	1	47.223	-1	-84.23	-1	-118.128
3	Kg Embong Sekayu	Annual	0.15	2.219	0.173	2.393	0.156	2.686
		SW monsoon	1	9.727	-1	-5.024	-1	-20.583
		NE monsoon	1	38.503	-1	-13.142	-1	-10.21
4	JPS Kuala Terengganu	Annual	0.234	2.702	0.234	3.094	0.224	4.272
		SW monsoon	1	9.859	1	21.47	1	65.812
		NE monsoon	-1	-5.49	1	44.672	1	249.049
5	SM Sultan Omar	Annual	0.109	2.118	0.079	1.425	0.059	1.887
		SW monsoon	1	5.089	-1	-32.922	-1	-54.656
		NE monsoon	-1	-17.434	-1	-3.254	1	143.787
6	Batu Hampar	Annual	0.035	1.246	0.089	1.961	0.123	2.151
		SW monsoon	1	36.464	1	23.558	1	15.153
		NE monsoon	-1	-38.542	1	9.489	1	224.4552
7	Kg La	Annual	0.227	2.377	0.234	2.707	0.264	3.283
		SW monsoon	1	1.86	1	0.699	1	16.692
		NE monsoon	-1	-21.425	1	56.197	1	875.024

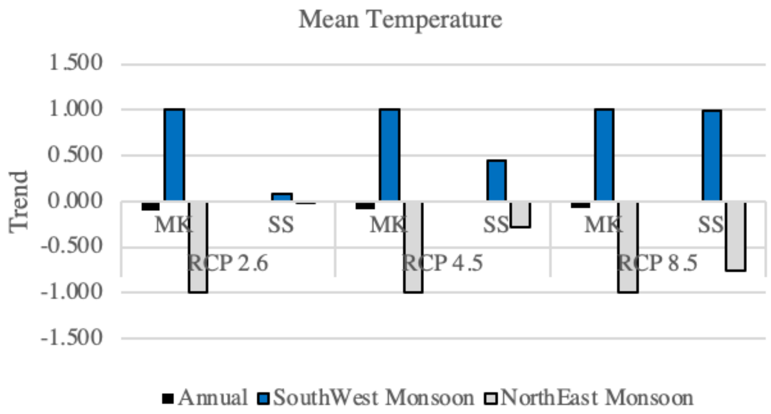

Fig. 5 - Trend analyses based on Man-Kendall (MK) and Sen's Slope (SS)

5. Conclusion

Due to anthropogenic climate change, these 3 variables in term of frequency, intensity, and length of rainfall events may rise or decrease. As a result of the sensitivity to climate change uncertainty, more emphasis should be paid to reducing the impacts and dangers associated with its occurrence. Calibration and validation processes were made by using SDSM which is to choose the most suitable NCEP climate predictors to every stations. The result of climate predictors for every stations may be varying due to the location of the rainfall and temperature stations. However, s850, mslp, and p850 were the most preference variables in all rainfall stations. These variables gave stronger correlation in the formation of local rainfall. As prove, simulated results for all stations were successfully to produce lesser %error (< 13%) during calibration and validation processes. Then, the long term rainfall and temperature pattern were simulated using GCM-CanesM2 for three (3) consecutive years; 2020-2039, 2040-2069 and 2070-2099 by using three (3) different RCPs; RCP 2.6, RCP 4.5 and RCP 8.5. Based on the results, 3 rainfall stations at Kg La, Kg Batu Hampar and JPS Kuala Terengganu are expecting to receive higher rainfall intensity (+20%) compared to historical data and the trend is expected to rise year by year. Meanwhile, another 4 stations at Kg Ban Ho, Hulu Jabor, Kg Embong Sekayu and SM Sultan Omar are expecting to receive lesser rainfall intensity (-19%) compared to historical with small increment at end of century. However, for the mean temperature is estimated to have decreasing trend until end of century.

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