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Analysis on Evapotranspiration Changes in Sungai Perlis River Basin Effecting by the Climate Changes

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Abstract: This study investigated future (2025–2100) changes in evapotranspiration (*ET*) in Perlis River basin, under a high emissions scenario, comparing the most recent state-of-the-art climate models using Hargreaves-Samani (*HS*) method. Four global climate models (GCMs) of CMIP6 namely CMCC-CM2, IPSL-CM6A, MIROC6 and MRI-ESM2 were selected. The results revealed good results in the selected CMIP6 models in replicating historical temperature and evapotranspiration over the basin. The selected models projected a 1.1–2.5°C more rise in temperature by the end of the century. The future projection of evapotranspiration is projected to decrease towards the end of century. It is proved that the HS method considers *ET* has a positive correlation with the temperature, i.e., the higher the temperature the higher the *ET*. In conclusion, the *HS* method is suitable for estimating *ET* in the study area and projecting the changing pattern of ET under climate change scenarios.

Keywords: CMIP6; Hargreaves-Samani; Perlis River Basin; Evaporation; Projection

1. Introduction

Evapotranspiration (*ET*) is one of the important components in water balance system. Accurate estimation of *ET* is essential for water availability and budgeting, and planning. It has been anticipated that impact of climate change on water resources will be through evapotranspiration. It is also reported that climate change will cause a steady rise of temperature and changes in rainfall pattern. Higher temperature will induce higher evapotranspiration which in turn will affect the hydrological system and water resources [1]. Thus, quantifying the changes in *ET* due to climate change is very important for the management of long-term water resources.

A number of studies have been carried out in projecting future temperature and evaporation in Malaysia [2]; [3]. Meanwhile [4] investigated changes in projected rainfall and temperature over Malaysia by the end of the 21st century based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) A2, A1B and B2 emission scenarios. The future projection of temperature indicated extensive warming over the entire country by the end of the 21st century. The projected temperature increment ranged from 2.5 to 3.9°C, 2.7 to 4.2°C and 1.7 to 3.1°C for A2, A1B and B2 scenarios, respectively. [2] Adib *et al.* (2020) investigated 10 CMIP5 GCMs for future temperature projections (2021–2080) in the north part of Peninsular Malaysia. Future projections showed an increase in both maximum and minimum temperatures under the three RCP scenarios, with a maximum increase of 2.5°C under RCP8.5 scenario. [5] assessed temperature patterns in the Kelantan

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River basin, using the latest CMIP model. Their key finding was that the models projecting increases in maximum and minimum temperatures by 0.8°C and 0.9°C, respectively.

There are few methods have been developed to estimate the *ET* such as Penman-Monteith [6], Hargreaves Samani [7], Thornthwaite, Blaney and Criddle, Priestley-Taylor, Makkink and Turc methods [8]. Nevertheless, there are only few methods such as the Penman-Monteith method which are reliable and very close to field observation. However, these methods are data-hungry and require extensive climatic-variables for reliable estimation of *ET*. This poses a problem in making accurate future *ET* projection for data scarce region. Most meteorological stations only measure temperature and rainfall while other meteorological parameters that are required for *ET* estimation are rarely measured. Another challenge often encountered in application of these methods is in projecting *ET* due to climate change. Normally, the general circulation models (GCMs) predict future changes only for a few parameters. The problems mentioned above can be overcome by using simple *ET* method which can estimate *ET* from few readily available meteorological data. According to [7], a PET method requires only daily mean maximum, mean minimum temperature and extraterrestrial solar radiation. The Hargreaves-Samani (HS) method has been widely used for its simplicity to evaluate and to calibrate its parameters [9]. Previous studies have provided calibration and adaptation of this method for a wide range of climatological conditions indicating that the HS method it is as precise and accurate as the FAO-PM method [9]; [10].

It is important to understand the future water availability in the basin in the context of global climate change. However, before water availability can be estimated, it is first necessary to analyse the future climate scenarios. The objective of this present study was to predict the climate change impacts on evapotranspiration in Perlis River basin. Historic and future climate projection data were used as a basis for analysing changes in the pattern of those climate parameters.

1.1 Study Area

The current study was conducted in the Perlis River basin which is located on the northwest coast of Peninsular Malaysia with a total catchment area of 724 km^2 (Figure 1). The study area experiences humid tropical climate throughout the year with the range of temperature between 23°C to 32°C. The trend of rainfall regime in Peninsular Malaysia is mainly affected by two distinct monsoons which are the Northeast Monsoon (NEM) from October to March and the Southwest Monsoon (SWM) from May to September. The NEM is more pronounced due to the sudden surge in rainfall amounts while the SWM is associated with the relatively dry period [11]. The Perlis river is formed from many tributaries including Arau, Timah, Jarum, Tasoh, Korok, Repoh, Kechor and Temenggong rivers. The highlands of Perlis river basin are generally covered with thick tropical forest growth. Low lying plains have been cleared at various places for rubber plantations, sugar-cane and paddy cultivation. Timah-Tasoh dam is the only dam in this basin and has a catchment area of 191 km^2 and is drained by two main rivers namely Timah river and Tasoh river with contributing area of 51 km^2 and 140 km^2, respectively. Water supply and irrigation needs come from this Timah-Tasoh dam. Temperature data (1985–2014) from Chuping station near the study area was used for future climate data downscaling and bias correction (Table 1).

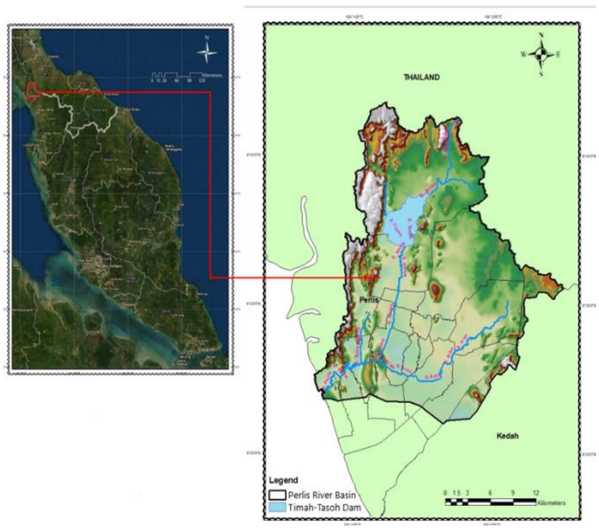

Fig. 1 – Perlis River Basin

Table 1 – Description of Temperature Station

No	Station Name	Coordinate		Data Availability
		Latitude (°N)	Longitude (°E)	
1	Chuping	06 29 00	100 16 00	1979-2021

Data from the evaporation station as described in Table 1 was used to analyse the climate pattern within the catchment. Based on temperature data at Chuping MMD station, the daily temperature ranges between 23°C to 31°C. The humidity is around 80% all year round. The highest temperature was recorded in April while the lowest temperatures was recorded in December. From Figure 2, the mean monthly evaporation ranges from 92 mm (November) to 156 mm (March) with mean annual evaporation 1400 mm/year, equivalent to a daily mean of 3.85 mm/day.

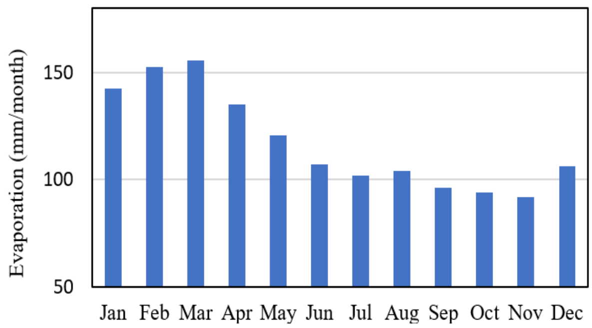

Fig. 2 – Historical Monthly Evaporation (1979-2021)

2. Methodology

2.1 Missing Data Treatment using IDW

Missing data from the station was gap-filled using Inverse Distance Weighted (IDW) method. This is to ensure the data provided is complete, homogeneous, and reliable before performing the climatic analysis. The IDW method which estimates missing value based on observed values at nearby station is shown in Equation (1).

$$V_o = \frac{\sum_{i=1}^{n}({}^{v_i}/_{D_i})}{\sum_{i=1}^{n}({}^{1}/_{D_i})} \quad (1)$$

where V_o is the assessed value of the missing data, V_i is the value of same parameter at i^{th} nearest station, D_i is the distance between the station with missing data and the i^{th} nearest station.

2.2 Statistical Downscaling Method

For the climate projection, the possible future changes in the temperature and evaporation of study area were comprehensively assessed using the latest scenario, SSPs. These new socioeconomic pathway scenarios incorporate the socioeconomic changes along with greenhouse gas emissions to project future climate. The future climates were analysed for temperature and evaporation changes under two future SSP scenarios, namely a medium forcing scenario SSP2-4.5 and a strong forcing scenario SSP5-8.5. These two pathways represent respectively a middle of the road pathway (SSP2) and a pathway with fossil-fueled development (SSP5). The monthly temperature simulations of CMIP6 GCMs for the period of 1985–2014 were used to assess their performances. The data were downloaded from https://esgf-node.llnl.gov/projects/ cmip6/. Four (4) selected models from the CMIP6 archive are listed in Table 2.

Table 2 IPCC's CMIP6 GCMs

Assessment Report (ARs)	Model	Modelling Institutions	Spatial Resolution
AR6 (SSP2-4.5 and SSP8.5)	MRI-ESM2-0	Meteorological Research Institute, Japan	1.1° × 1.1°
	MIROC6	Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Kanagawa	1.4063° × 1.4063°
	CMCC-CM2-SR5	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, Lecce Italy	1.25° × 0.9375°
	IPSL-CM6A-LR	Institute Pierre Simon Laplace, Paris	2.5° × 2.5°

2.3 Bias Correction using Linear Scaling

The statistical downscaled future climate change data required a bias correction to remove the biases between the downscaled with the observed data. In this study, linear scaling model was used. The bias correction was carried out using the historical dataset generated from the downscaled GCMs model and the observed data from the selected ground stations. This results in more consistent values with the observation over the historical period. The bias correction was applied on each of the 12 months temperature data with separate calibration for each station. The linear scaling model equation is given as follows:

$$BC = \frac{P_{obs(avg)}}{P_{sim(avg)}} \quad (2)$$

where P_{obs} refers to average of monthly observed data, P_{sim} refers to average of data from CMCC-CM2, IPSL-CM6A, MIROC6 and MRI-ESM2.

2.4 Estimation of ET by Hargrieves-Samani Equation

The future climate change evapotranspiration was not directly simulated from the GCM but computed from the future climate change temperature using the Hargreaves-Samani equation. They developed an alternative approach to estimate ET_O where only mean maximum and mean minimum air temperature and extraterrestrial radiation are required. This equation is derived through regression of temperature reduction coefficient and relative humidity factor. The equation is expressed as:

$$ET_O = 0.0023(T_{max} - T_{min})^{0.5}(T_{mean} + 17.8)(R_a \times 0.408) \quad (2)$$

where T_{max}, T_{mean}, and T_{min} are refer to the temperature reading at condition of maximum, mean and minimum, respectively meanwhile $R_a$is the extra-terrestrial radiation (MJ.m^{-2}), and 0.408 is a factor to convert MJ m^{-2} to mm.

3. Results and Discussions

The CMCC-CM2, IPSL-CM6A, MIROC6 and MRI-ESM2 adopted Shared Socioeconomic Pathways (SSPs) scenarios as in the IPCC 6th Assessment Report (AR6) were used to examine the potential changes of rainfall and temperature characteristics over the Perlis river basin. The changes were computed for two future time slices (2025–2050 and 2051–2100) relative to the reference period (1985–2014) under two (2) SSPs (SSP2–4.5 and SSP5–8.5). The further analysis was proceeded which to analyse the temperature climate – bias correction analyses process. After the bias correction was applied to the downscaled data from GCMs, the performances of the CMCC-CM2, IPSL-CM6A, MIROC6 and MRI-ESM2 were first examined and plotted as shown in Figure 3.

This figure compares the monthly temperature between the historical (1985–2014) and the simulated GCMs ensembles. In this study, the GCMs were compared based on average of 30 years length of records data. It is noted that the simulated rainfall and patterns generally resemble those in the historical observations with a minimum of 5% inaccuracy. It is noted that the simulated temperature and patterns generally resemble those in the observations. Except for January and February, MIROC6 mostly gave higher temperature compared to historical pattern. IPSL-CM6A and MRI-ESM2 showed lower temperature patterns for all months compared to other GCMs and historical trends.

Generally, for comparison to the historical period, the calculated errors in the simulated mean monthly temperature from CCMC-CM2, IPSL-CM6A, MIROC6 and MRI-ESM2 were -0.3%. -2.4%, -2.2% and +2.5%, respectively. The CCMC-CM2 was able to successfully produced the least error among the GCMs, followed by MIROC6, IPSL-CM6A and MRI-ESM2.

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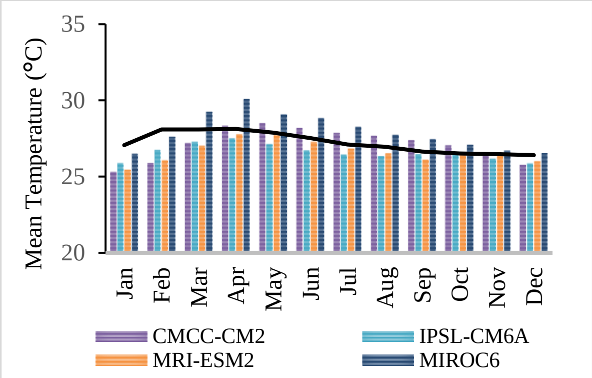

Fig. 3 - Comparison of monthly temperature performances from simulated GCMs from AR6 (CMCC-CM2, IPSL-CM6A, MRI-ESM2 & MIROC6 year 1985-2014) with historical data (1985-2014)

Monthly distribution of climate parameters in the study area for *ET* estimation is given in Table 3. The extraterrestrial radiation (MJ.m^{-2}) values were adopted from Hydrological Procedure No. 17, "Estimating Potential Evapotranspiration Using the Penman Procedure" published by Department of Irrigation and Drainage (DID), Malaysia.

Table 3 Average monthly parameters used for estimating ET at the study area

Parameter	Max Temp (°C)	Min Temp (°C)	Mean Temp (°C)	Extraterrestrial Radiation (MJ.m−2)
J	29.4	24.5	27.1	785
F	31.5	23.9	28.1	826
M	33.8	25.9	28.1	873
A	34.3	27.2	28.5	896
M	32	27	27.9	845
J	31.5	26.1	27.5	856
J	30.7	26.6	27.1	837
A	30	26.2	26.9	848
S	29.9	25.8	26.6	888
O	29.5	25.5	26.5	835
N	29.1	25.1	26.5	818
D	29	24.9	26.4	762

Figure 4 presents the comparison of the monthly simulated evapotranspiration between the historical observation (1985-2014) and the GCMs produced data over the Perlis River basin area. It is noted that the calculated evaporation using all GCMs generally resembles those in the observed evaporation rate. Hence, the models can be further used for projection.

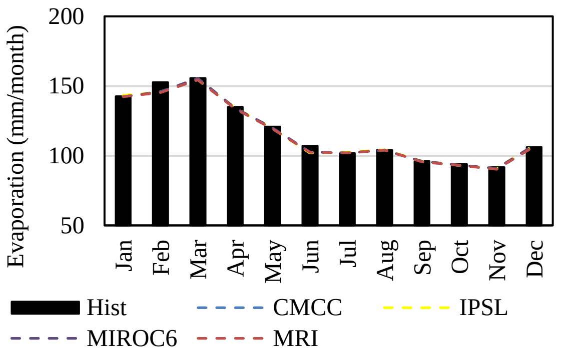

Fig. 4 – Comparison of monthly evaporation performances from simulated GCMs from AR6 (CMCC-CM2, IPSL-CM6A, MRI-ESM2 & MIROC6 year 1985-2014) with historical data (1985-2014)

Generating the Temperature and PET until 2100

The projection for both SSPs was considered during two time slices: 2025–2050 and 2051–2100 relative to a baseline period to compare changes in the future. The variation of the simulated mean monthly temperature, of all the GCMs is shown by shaded gray color as in Figure 5. Whereas the thick black line in each plot represents the historical data. Generally, it can be seen that the GCMs projected higher monthly temperature especially during the second half of the period (2051–2100). The future mean temperature ranged from 26.0 to 28.4°C with the lowest projected in February and the highest in April, respectively. While the projected annual mean temperature ranged from 29.1 to 32.5°C. The study reveals that average temperature of the study area will continue to rise by +1.2°C per decade.

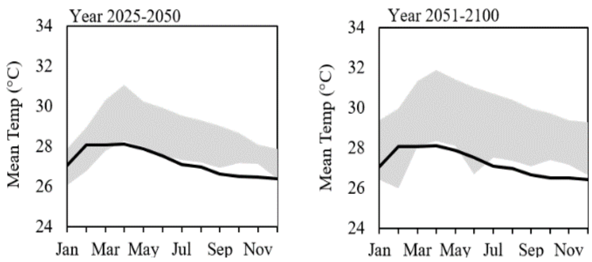

Fig. 5 - Comparison average monthly temperature between historical data (1985-2014) with GCMs projection from AR6 (CMCC-CM2, IPSL-CM6A, MRI-ESM2 & MIROC6) for the year of 2025-2100

The time series of the projected annual mean temperature for the period 2050–2100 based on the SSP2–4.5 and SSP5–8.5 scenarios generated from all the GCMs are shown in Figure 6. This figure indicates that the overall trend for the temperature is increasing during this century. The smallest increase under scenario SSP2–4.5 and the greatest under scenario SSP5–8.5. Temperature is expected to increase as the radiative forcing increases. For instance, maximum temperature is expected to increase higher under the SSP5–8.5 compared to the SSP2–4.5.

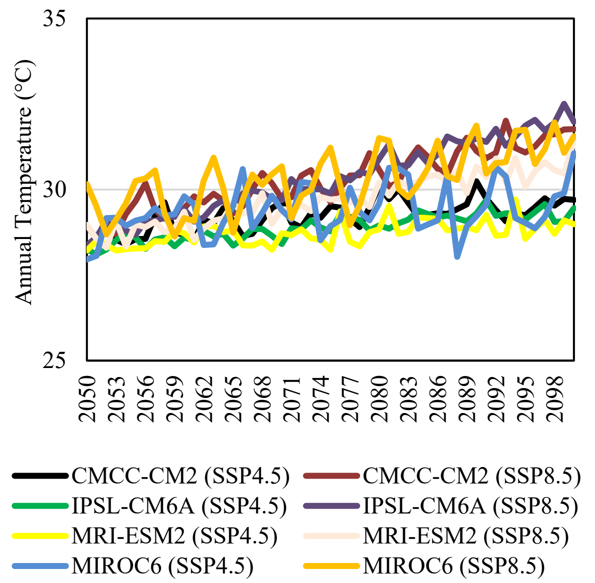

Fig. 6 - Long term trend of annual temperature for GCMs AR6 (CMCC-CM2, IPSL-CM6A, MRI-ESM2 & MIROC6) for the year of 2050-2100

Figure 7 presents the comparison of the monthly simulated evapotranspiration between the historical observation and the GCMs produced data over the Perlis River basin. It is noted that the calculated evaporation using all models for both SSPs generally resembles those in the observed evaporation rate. However, CMCC-CM2 model showed huge magnitude differences for both SSPs for the second time slice. Based on Figure 7, it can be seen that the projected annual evapotranspiration for both SSPs gradually increase towards year 2100. For SSP8.5, the projected annual evaporation is expected to reach 1700 mm. While for SSP4.5, the maximum annual values are 1600 mm. The average monthly evaporation varies from 90.9 mm (November) to 156 mm (March) with consistent pattern to the historical.

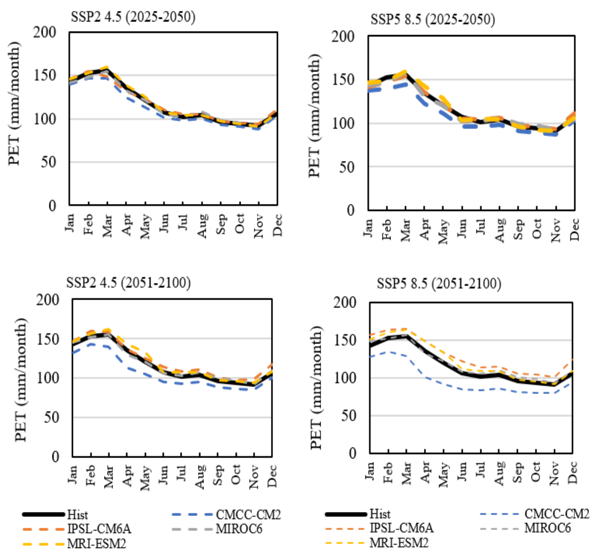

Fig. 7 - Comparison average monthly ET between historical data (1985-2014) with GCMs projection from AR6 (CMCC-CM2, IPSL-CM6A, MRI-ESM2 & MIROC6) for the year of 2025-2100

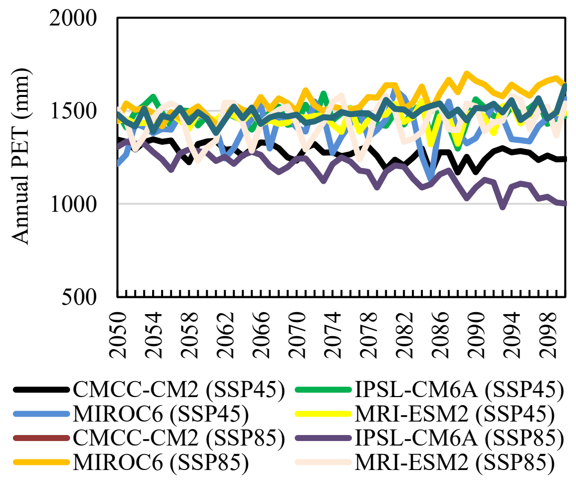

Fig. 7 - Long term trend of annual PET for GCMs AR6 (CMCC-CM2, IPSL-CM6A, MRI-ESM2 & MIROC6) for the year of 2050-2100

4. Conclusion

Assessment of ET especially in the context of climate change is very important. This study simulated the climate projection by using historical temperature and evaporation data from 1985 to 2014. The future climate change data for the basin were generated from the statistically downscaled Coupled Model Inter-comparison Project Phase 6 (CMIP6) for four selected models. The simulated temperature and evapotranspiration patterns generally resemble those in the historical observations. The GCMs revealed an increasing trend of the future mean temperature during 2025–2100 for all the SSPs. Under the SSP4.5 scenario, the projection results indicated a remarkable surface warming for all scenarios from +29.7°C to +31.1°C for the entire basin. Under the SSP5–8.5 scenario, the projected changes ranged from +31.4°C to +32.5°C. While for annual evapotranspiration, all of the GCM models agreed on greater projections with the consistent monthly pattern compared to the historical.

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