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HYDROLOGICAL MODELLING FOR EVALUATING CLIMATE CHANGE IMPACTS ON STREAMFLOW REGIME IN THE BERNAM RIVER BASIN MALAYSIA

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ABSTRACT

The complexity of hydrological models has been a setback in their evaluation particularly for long-term simulations. Deficit and constant loss (DCL) method has been introduced in Hydrologic Engineering Center's Hydraulic Modeling System (HEC-HMS) model for continuous based simulations. However, studies on climate change impacts using the method are still very few. This study used the method to evaluate potential impacts of climate change on streamflow at Bernam Basin, Malaysia for 2010-2039, 2040-2069 and 2070-2099 to the baseline period (1976-2005) under two RCP scenarios (RCPs 4.5 and 8.5). The model efficiency during evaluation is found satisfactory. Compared with the baseline period, the predicted streamflow decreased in all future periods during main and off-seasons. However, the changes have become more pronounced during the off-season with a significant decrease of 9.14% under the worst-case scenario (RCP8.5). Therefore, the Basin would likely experience tremendous pressure in the late century due to low streamflow, particularly in off-season months.

Keywords: *Climate change; deficit and constant loss method; flow regime; HEC-HMS; hydrological model*

INTRODUCTION

The global climate system is expected to experience severe warming in the future (Ismail et al., 2020a). Climate change brings a severe impact on water resources, which affects water availability; disturb the ecosystem and food security (Yilmaz and Shabib, 2019). Water scarcity is a major issue globally (Elleuch et al., 2019; Paudel et al., 2018). Changes in rainfall and temperature patterns threaten water resources and consequently affects agricultural production and increase the vulnerability in agro-hydrological watersheds. Temperature and rainfall variations are the most commonly identified issues influencing predicted changes in climate during the coming century (Chien et al., 2013). The patterns of the changes varied significantly across the places in the world (Ismail et al., 2020c; Lian et al., 2015). Water for irrigation is susceptible to climate change that affects agricultural production (Schlenker et al., 2007). As pressure on the world's freshwater resources increase, many river basins will face both increasing freshwater scarcity and increasing pollution. Therefore, adaptation strategies under the new realities of climate change are the most important challenges in the 21st century for global water and food security.

There have been global issues on the water availability, and its consistent quantification in individual river basins and also at the global scale (Chien et al., 2013). This has consequently affected the performance of irrigation in agro-hydrological watersheds. The largest portion of human accessible water withdrawal and water consumption from rivers, lakes and aquifers is used mostly for irrigation. The water use by irrigation has been estimated to reach about 2,500 km^3 $year^{-1}$ globally, and this represents almost 70% of total human water use (Rost et al., 2008). In Malaysia, the sector has the greatest annual water withdrawals, with more than 80% of the country's water demands accounted for rice irrigation use (Amin et al., 2011). However, future streamflows are projected to decrease with the impact of climate change (Chien et al., 2013; Dlamini et al., 2017).

Hydrological models have been extensively used for hydrological studies globally. They are reliable tools to assess the hydrological effects of environmental change (Li et al., 2009). Modelling of the IPCC scenarios has shown their impact on the hydrological responses in catchments and plant growth (Purkey et al., 2007; Sardans and Penuelas, 2004). However, the complexity of some of these models have been a major setback, which consequently affects their performance (Ali et al., 2018; Khorram and Vahedi, 2018). This is as a result of the difficulty in calibration processes, particularly for long term simulations due to the complexity of the relationships between most hydrological variables (Huo and Li, 2013). For instance, out of the 65% of the physical-based modelling studies in Malaysia, 60% applied the HEC-HMS model due to its least input parameters followed by the SWAT model with 20% (Abdulkareem et al., 2018). Though there are no specific criteria for choosing the best model for a specific location (Ali et al., 2018). Since climate change study is a continuous based simulation, with predictions for a long period that involves various parameters, choosing a suitable model with simple structure, minimum input data requirements and reasonable precision is essential.

HEC-HMS is a hydrologic modelling software developed by the US Army Corps of Engineers Hydrologic Engineering Centre (HEC) for simulating precipitation-runoff processes of watershed systems. It uses deterministic mathematical modelling to compute various components of the hydrologic cycle (USACE-HEC, 2016). Among the advantages of the model over other hydrologic models are the various options in methods selection, to compute different hydrological responses for watershed development. The hydrologic model, together with loss methods for runoff computations (also included in the model), provides a basis for the evaluation of climate change impacts. These methods are soil moisture accounting (SMA) and DCL methods, which are the most applicable methods for continuous simulation in the program. The SMA method has been widely used to compute continuous simulations in HEC-HMS (Roy et al., 2013; Yimer et al., 2009). However, the major challenge with this method, despite its wider acceptance by the researchers is, numerous input parameters, which make the simulation tedious and consequently, affect the accuracy of the model output.

Previous studies have extensively applied the HEC-HMS model to examine the impacts of future climate projections on water resources (Chu and Steinman, 2009; Kabiri et al., 2015). The DCL method uses one layer to account for continuous changes in moisture. The method is simple and performed well in both event and continuously based simulations (Babel M.S., 2014; Meenu et al., 2013). In addition, it requires lesser-input parameters compare to SMA and can easily be obtained from the land use and soil grids, using GIS extension of HEC-HMS. Nevertheless, despite its simplicity, accuracy in simulation of long-term events, studies on climate change impacts using the method are still very few (Babel M.S., 2014; Meenu et al., 2013). The most recent studies (Ismail et al., 2020b; Mahmood and Jia, 2016; Mahmood et al., 2016) recorded success when the impact of climate change on water resources was assessed using the method. In addition, many hydrological studies (Alansi et al., 2009; Dlamini et al., 2017) were carried out in the study area using different models. Thus, the need to test the suitability of the HEC-HMS model as different hydrological models perform best in certain hydrological catchments. Therefore, the aim of this case study is to know the applicability of the DCL method in HEC-HMS in assessing the impact of climate change on hydrological responses in the Upper Bernam River Basin in Malaysia.

METHODOLOGY

Study area

The Bernam River Basin is an agro-hydrological watershed situated at the boundary between the States of Perak and Selangor, Malaysia (Figure 1). The mean elevation is about 950 m above sea level. The river flow routes through sections of a large forest complex, oil palm, rubber and paddy farms; and covers a basin area of about 1097 km^2 stretching about 127 km before discharging into the state of Malacca.

Figure 1: Upper Bernam River Basin (UBRB), Malaysia

The climate of the area is a humid tropic that is largely characterized by two predominant rainfall seasons, the dry season (January–June) and the wet season (July–December) (Deni et al., 2010). The average annual rainfall in the region is about 2,000 mm, and its distribution is mostly between October and January and only to a limited extent over April–May. However, the distribution of rainfall is unpredictable between January and –August. The mean maximum and minimum temperatures are 31.5 °C and 22.3 °C, respectively.

Hydrologic modelling system for Bernam River Basin

HEC-HMS was applied for simulating precipitation-runoff processes of Bernam River Basin. HEC-HMS requires spatial and hydro-climatic data for hydrological simulation. The spatial data include digital elevation model (DEM), soil and land use maps of the area while the hydro-climatic data are rainfall, temperature (minimum and maximum), relative humidity, wind speed and solar radiation.

Spatial data

The spatial data used are Digital Elevation Model (DEM), soil and land use maps. HEC-GeoHMS and Arc-Hydro tool coupled with ArcGIS Program used to process spatial data. Theses data were used to generate various components of the hydrological catcheent.

Historical climate data

Climate data from 1976 to 2006 include rainfall, temperature (minimum and maximum), wind speed, humidity and solar radiation were used for calibration and validation of the HEC-HMS model. Daily archives of these data were obtained from the Department of Irrigation and Drainage (DID), Malaysia. Daily streamflow of the Bernam river at gauging station SKC Bridge was also collected.

Downscaling of GCMs

To represent the impact of climate change on the watershed area, a statistical method “Delta change factor” method was applied to reduce the bias between the GCMs outputs and observations for high-resolution in future climate projections at station scale. A baseline period 1976-2005 was adopted and three future periods of 30-year time segments were defined as the 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099) for the study. The mean values of GCM simulated baseline and future climates were estimated using equations 1 and 2:

$$\overline{GCM_b} = \sum_{i=1}^{Nb} GCM_{bi}/N_b \quad (1)$$

$$\overline{GCM_f} = \sum_{i=1}^{Nf} GCM_{fi}/N_f \quad (2)$$

Where, $\overline{GCM_b}$ and $\overline{GCM_f}$, GCM_b and GCM_f are the mean values and values from the GCM baseline and GCM future climate scenario, respectively. N_b and N_f are the total number of values in the downscaling for baseline and future periods, respectively.

Subsequently, monthly additive (CF_{add}) and multiplicative Change Factor (CF_{mul}) changes between the baseline period and future period in the equivalent climate variable of interest were calculated for the GCM grid box using equations 3 and 4. Relative change factors were used in the case of rainfall (ΔP), derived from the ratio of projected-to-baseline averages, while absolute change factors were used for temperature (ΔT), by subtracting the GCMs averages representing baseline from the future.

$$CF_{Rain} = \left(\bar{P}_{GCM,fut,m} / \bar{P}_{GCM,base,m} \right) \quad (3)$$

$$CF_{Temp} = \left(\bar{T}_{GCM,fut,m} - \bar{T}_{GCM,base,m} \right) \quad (4)$$

Finally, local scaled future climate values were obtained by applying the Change Factors using equations 5 and 6. This involves superimposing the change factors suggested by the GCM-scenario combinations to the daily baseline time series to give perturbed climate series.

$$P_{adj,fut,d} = P_{obs,d} \times CF_{Rain} \quad (5)$$

$$T_{fut,d} = T_{obs,d} + CF_{Temp} \quad (6)$$

Where, P and T are the rainfall and temperature, respectively, the subscript; *adj,fut,d* denotes the downscaled future daily variable; *obs,d* denotes daily observations; CF denotes calculated additive and multiplicative change factors for rainfall and temperature; *GCM,fut,m* and *GCM,base,m* are the average monthly values of GCM output and baseline periods, respectively.

HEC-HMS model components

The HMS model components include basin models, meteorological models, control specifications and input data as illustrated in Figure 2. Point rainfall data was used using a specified hyetograph. Priestly-Taylor method was adopted in computing the potential evapotranspiration as mostly used in continuous simulation using HEC-HMS (Meenu et al., 2013). Dryness coefficient value of 1.2 is used in an environment with the humid condition to make small corrections based on the state of the soil moisture in HEC-HMS model (USACE-HEC, 2016). The starting date and time, ending date and time, and computation time step were set to run the simulation during calibration and validation periods.

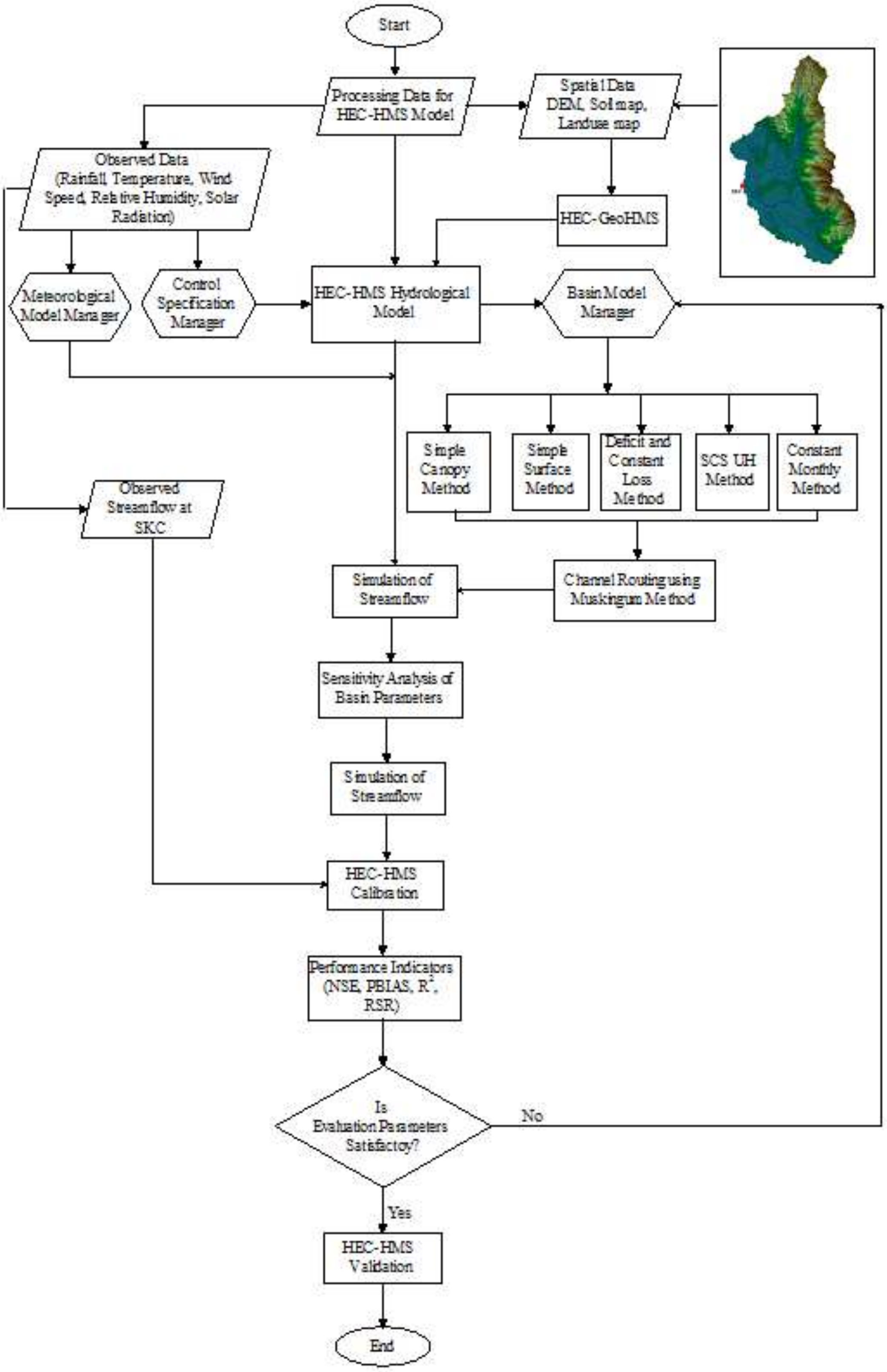


Figure 2: **HEC-HMS model for simulation of hydrologic response.**

HEC-HMS setup for the Bernam River Basin

HEC-HMS model components were used to simulate the hydrologic response in the Bernam watershed. The spatial data used to set up the basin model using HEC-GeoHMS and Arc-Hydro tools and estimated sub-basin areas, times of concentration, lag time and reach lengths of the watershed. The basin model represents the physical watershed, which consists of sub-basin, reach, junction, sink (outlet), diversion within the watershed. A newly introduced DCL method was adopted for this study (USACE-HEC, 2016) because of its simplicity, it requires few input parameters compared to

SMA and performed well in both event and continuous based simulations (Mahmood and Jia, 2016; Mahmood et al., 2016).

Model calibration and validation

Historical monthly discharge records were used for evaluating the performance of the HEC-HMS model. Manual and automatic calibration techniques were applied to optimize model parameters. Flow discharge data for 18 years (1981-1998) was used for model calibration and 8 years (1999-2006) for validation.

Simulation of future impacts of climate change

The perturbed future rainfall and temperature data were used as input variables for modelling future streamflow scenarios of the basin using the validated hydrologic model. For long-term analysis, data was prepared following the 'period change' approach, to analyze the change from a defined baseline period. The flow simulation was performed for each RCP scenario for 30-year time segments centered on the three future periods. The validated model was re-run with the downscaled climatic variables for the baseline and the future periods. Consequently, changes in streamflow for River at the scheme were analyzed with respect to observed and projected future impacts of global climate change.

Flow regime

Three streamflow classes were assessed and studied on how they were influenced by the change in climate at the SKC station as presented in Table 1. The classes studied for streamflow are a high-flow disturbance, low-flow disturbance and variability in flow. There are three variables for the high-flow disturbance streamflow: a high-flow disturbance (Q1.67), a duration of the flood (FLDDUR), and a seven-day maximum-flow (7QMAX). The high-flow disturbance calculation was based on the most dominant channel forming flow (known as bankfull).

Low-flow disturbance streamflow indicators include a baseflow index (BFI) for a baseflow variable change measurement and a minimum 7-day (7QMIN) variable. Flow variability streamflow indicators include temporal shifts in peak flows (TSQPEAK) and coefficient of variation (DAYCV).

Table 1: Streamflow Regime Variables for Climate Changes Impacts Assessment

Variable Name	Symbol	Definition	Streamflow Classification
High-Flow disturbance	Q1.67	Flow of magnitude exceeding return interval of 1.67 years based on a log-normal distribution	High-Flow disturbance
Duration of flood	FLDDUR	The average number of days of flow equal to or exceeding Q1.67 per year	
7-day maximum flow	7QMAX	The average annual maxima of 7 day means of daily mean streamflow	
Base flow index	BFI	The ratio of the smallest annual daily flow to the mean daily flow multiplied by 100 over a water year	Low-flow disturbance
7-day minimum flow	7QMIN	The average annual minima of 7 day means of daily mean streamflow	
Coefficient of variation	DAYCV	The ratio of the standard deviation of daily flows to the average of daily flows multiplied by 100 during a water year	Flow variability
Temporal shifts in peak flows	TSQPEAK	Shifts of peak flows in timing and magnitude	

Results and Discussion

HEC-HMS model development

Land use map of the study area was processed within the ArcGIS 10.2.1 environment and reclassified into eleven classes as presented in Table 2. These classes are Aquaculture, Forest, Marshland, Oil palm, Paddy, Pasture, Rubber, Secondary forest, Swamp forest, Urban and Waterbody. The size of the land use classes of Bernam catchment ranges from 0.2% to about 41% with the largest area dominated by forest followed by Oil Palm. Moreover, the forest area contributed more to the impervious surfaces in the watershed followed by Oil Palm. This is expected, considering the nature of the land use within the watershed, majorly covered by forest and oil palm. Similarly, the soil was classified into two major hydrologic soil groups, namely groups B and C. About 84% and 16% groups B and C, respectively dominated the soil in the Bernam watershed. This means less runoff amount is averagely expected in the area.

Table 2: HEC-HMS land use Characteristics

Land use Name	Size (%)	Impervious Area (%)
Aquaculture	0.19	0.21
Forest	41.27	41.23
Marshland	0.74	0.77
Oil palm	34.52	34.44
Paddy	3.22	3.17
Pasture	0.17	0.17
Rubber	13.38	13.45
Secondary forest	1.49	1.49
Swamp forest	2.86	2.86
Urban	1.75	1.75
Waterbody	0.42	0.47

The Bernam watershed was delineated into sub-basins using the preprocessed DEM, land use and soil. The sizes of the sub-basins ranged between 160.49 km^2 to 370.32 km^2 interconnected with eight reaches, eight junctions and an outlet. This model was prepared and exported to the HEC-HMS interface. Land use and soil grids were processed to obtain the percentage of impervious area, maximum deficit, initial deficit and constant rate of each sub-basin as presented in Table 3.

Table 3: Characteristics of delineated sub-basins of Bernam river watershed.

Sub-basin	Area (km^2)	Initial deficit (mm)	Maximum deficit (mm)	Constant rate (mm/hr)	Impervious surface (%)
1	325.38	50.457	50.457	50.457	2.5079
2	370.32	47.635	47.635	47.635	4.2771
3	160.49	50.546	50.546	50.546	5.1017
4	261.1	49.436	49.436	49.436	3.8311

HEC-HMS model evaluation

Monthly stream records of 30 years (1976-2006) were used for model evaluation. Out of the 30 years records, 18 years (1981-1998) was used for the calibration while 8 years (1999-2006) were used for the validation with 5 years warm-up period in each. In both calibration and validation periods, the monthly observed and simulated discharges from the model were compared. Four statistical criteria were employed to evaluate the hydrological goodness of fit; R^2, Nash-sutcliffe Efficiency (NSE), Percent Bias (PBIAS) and Root mean square error-standard deviation ratio (RSR). Results of R^2, NSE, PBIAS and RSR during the calibration period were 0.74, 0.71, 4.21 and 0.37, respectively and 0.71, 0.69, 5.32 and 0.31, respectively for the validation period. These results according to Moriasi et al (2007) indicated a satisfactory simulation, as the values are greater than 0.5. In addition, the R^2, NSE, PBIAS obtained in this study are higher than the values obtained by Dlamini (2017) when the SWAT model was used in the same watershed. This shows that the DCL method coupled with GIS extension is a good option for continuous simulation in HEC-HMS.

The simulated and observed streamflows matched well during the calibration period as shown in Figure 3. However, there was consistent under-prediction of the peak flows with much higher values for most of the years during the calibration period. Moreover, flows with very less value were over-predicted for most of the months. In general, most of the excess and deficit simulations might be due to uncertainties in the observed discharge data used, which was generated using rating curves that are subject to errors. In addition, it was noticed from the historical data that a large variation of discharge values exists in some of the years at the gauging station of Bernam. Also, Dlamini (2017) noticed a similar challenge and concluded that the problem was attributed to the poor quality of the data in the watershed. The simulated and observed flows matched very well during the validation period. However, there was under-prediction of the peak flows with much higher values for some months during the validation period, for example in November 2002 and 2003, and September in 2006. Moreover, flows with very less value were over-predicted for some months, for example in March 1999, August 2001, February 2002 and 2005, and July and September 2005.

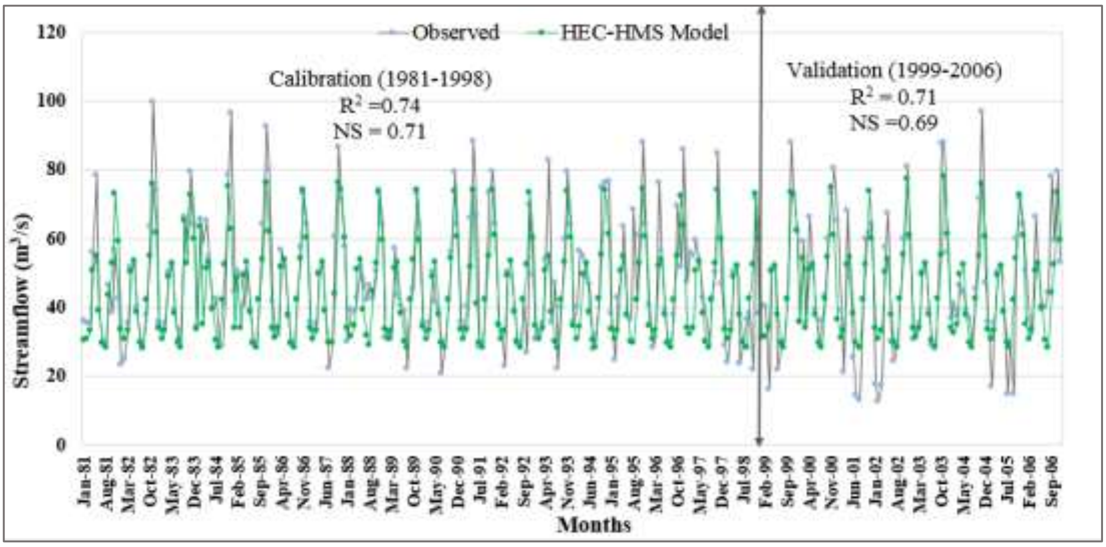
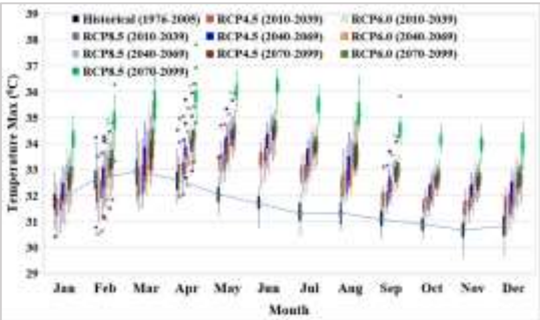


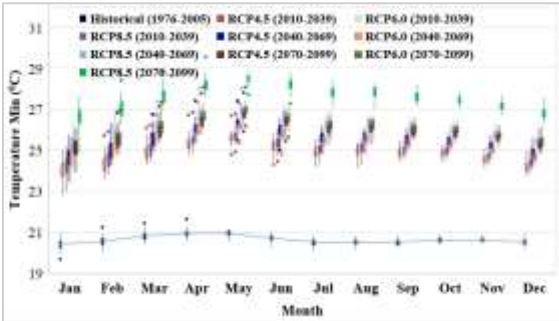
Figure 3: Simulated and observed monthly discharges for Bernam River Basin

Impacts of climate change on climate variables

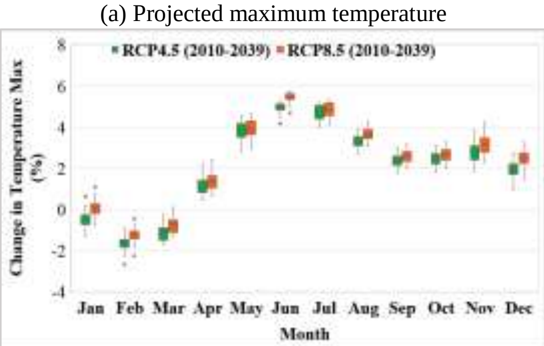
The validated HEC-HMS Model was used to assess the future changes in streamflow of the Bernam river basin. Climate change impacts were assessed by combining all simulations of similar carbon emission scenarios for the three future periods irrespective of the GCM. Temperature (maximum and minimum) and rainfall are among the key climatic variables that bring about the change in the climate of an area. It has the greatest effect on the estimation of evapotranspiration (Goodarzi and Eslamian, 2018). The future temperature was predicted to increase with a higher increase in RCP8.5 as shown in Figures 4. The mean maximum temperature was predicted to increase under RCP 4.5 and 8.5, by an average of 1.2 ºC and 2.01 ºC, respectively compared to the baseline period. Similarly, the minimum temperature was predicted to increase by 4.77 ºC and 5.59 ºC for the same future period. As expected, the largest change in both the maximum and minimum temperatures was projected under the higher RCP8.5 scenario for all future periods.



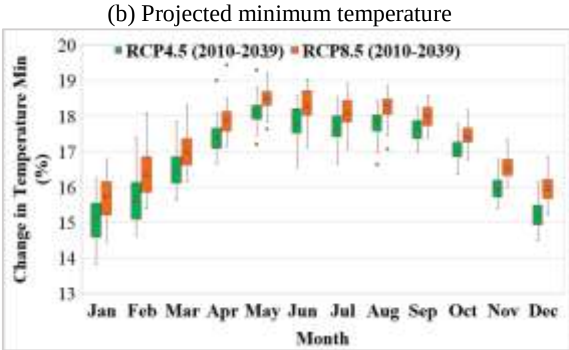
(a) Projected maximum temperature



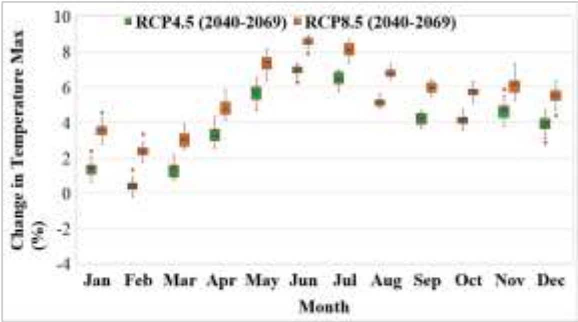
(b) Projected minimum temperature



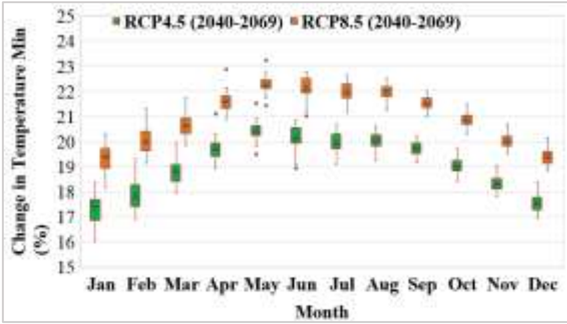
(c) % Changes of max Temperature (2020s)



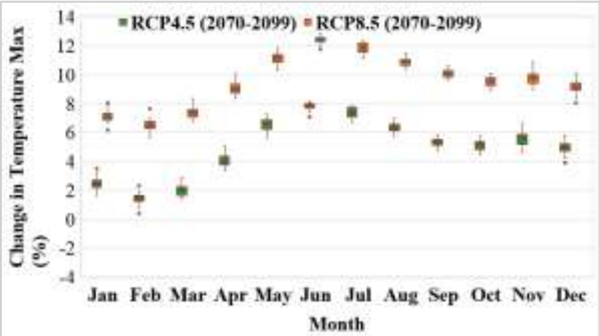
(d) % Changes of min Temperature (2020s)



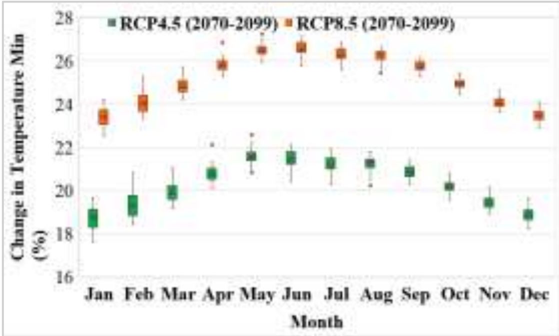
(e) % Changes of max Temperature (2050s)



(f) % Changes of min Temperature (2050s)



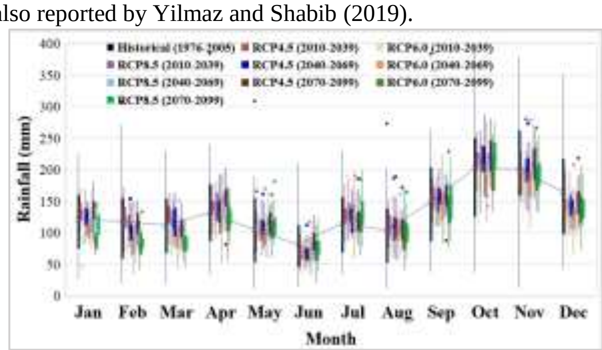
(g) % Changes of max Temperature (2080s)



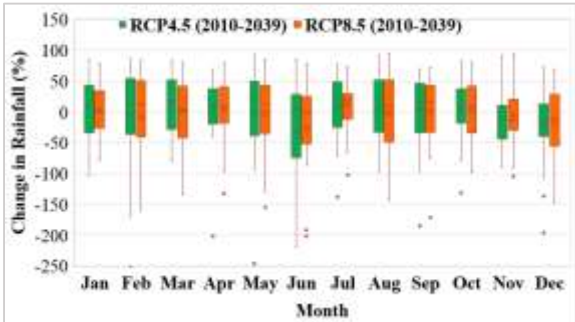
(h) % Changes of min Temperature(2080s)

Figure 4: Projected ensemble mean monthly maximum and minimum temperatures and future changes under RCPs for 2010–2039, 2040-2069 and 2070–2099 to 1976–2005

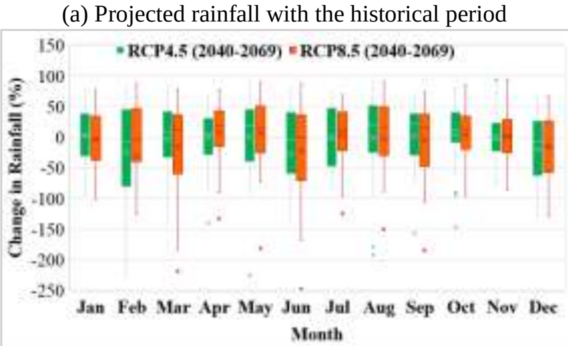
In the other hand, rainfall was slightly increase in the main season (July to December) and decrease in the off-season (January to June) during the future period as shown in Figure 5. The main-season average changes are projected to be 1.0 and 2.4% under RCPs 4.5 and 8.5 scenarios, respectively with a range of 0.2% for 4.5 in the 2050s to 2.7% for the RCP8.5 in the 2080s. Whereas, the average changes for the off-season are -2.4 % and -3.7 % under RCPS 4.5 and 8.5 scenarios, respectively with a range of -0.4 % (RCP4.5) in the 2020s to -7.1 % in the 2080s under the most severe scenario (RCP8.5). A similar increase in temperature was observed by Guo et al (2018). A significant rise in temperature and slight variation in rainfall was also reported by Yilmaz and Shabib (2019).



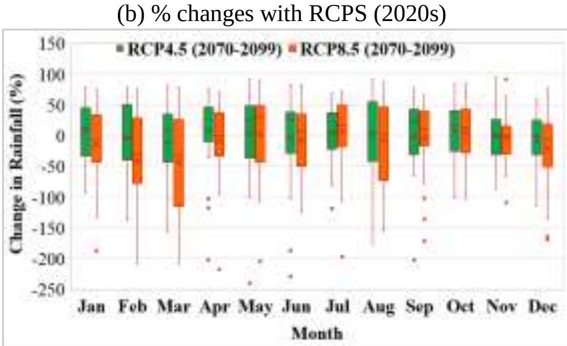
(a) Projected rainfall with the historical period



(b) % changes with RCPS (2020s)



(c) % changes with RCPS (2050s)

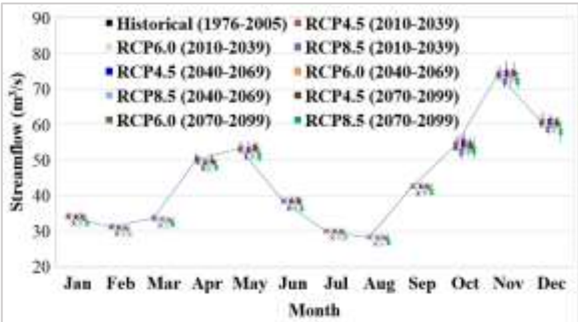


(d) % changes with RCPS (2080s)

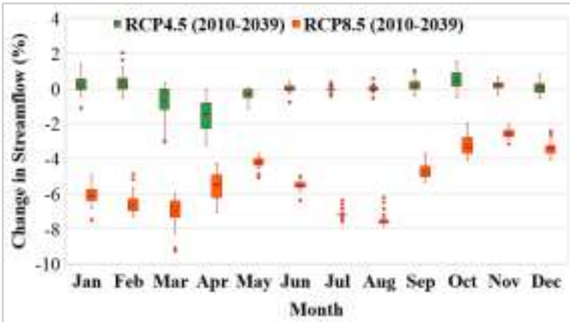
Figure 5: Projected ensemble mean monthly rainfalls and future changes under RCPs for 2010–2039, 2040-2069 and 2070–2099 relative to 1976–2005.

Impacts of climate change on future changes of streamflow

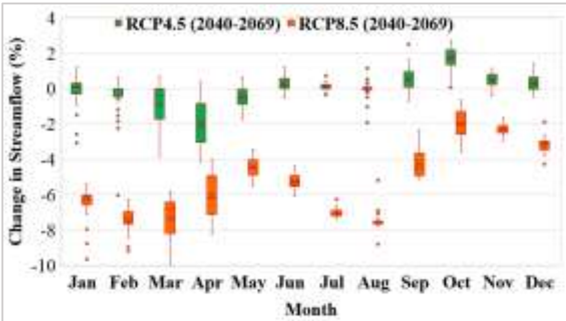
The changes in major rice farming (off and main) seasons results were assessed. The assessed changes are the differences relative to the baseline period (1976-2005) for the three 30-year defined future period (2020s, 2050s and 2080s). However, neither change in soil nor a land-use cover is considered to project future streamflow. This is to ensure that the streamflow projections for the future are solely dependent on the climate change scenarios. Moreover, the relative effect of climate change on streamflows is more significant compared to that of land-use change (Yan et al., 2016). Future streamflow decreases in all future periods during main and off-seasons as shown in Figure 6. However, the changes in future streamflow at the Bernam river basin are more pronounced during the off-season period with a significant decrease of 9.14% under the worst-case scenario (RCP8.5) during 2050s. This is expected because the warmer temperature during the off-season usually increases the rate of evapotranspiration more compared to wet season period, which consequently affects the future streamflow. A similar decrease in annual streamflow was observed by Chien et al (2013). Also, Arnell and Reynard (1996) reported a decrease in annual streamflow in the wettest scenarios and a declined in the driest scenarios. The highest changes in streamflow during the main season was -8.97% under the worst-case scenario (RCP8.5) in 2020s period. A significant downward trend in annual streamflow was also reported by Ma et al (2008).



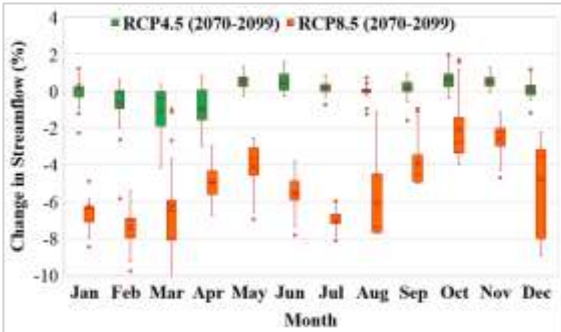
(a) Projected streamflow with historical period



(b) % changes with RCPS (2020s)



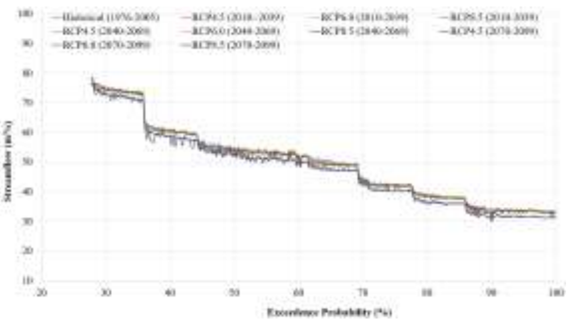
(c) % changes with RCPS (2050s)



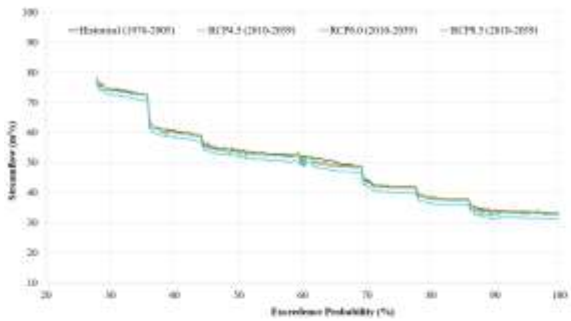
(d) % changes with RCPS (2080s)

Figure 6: Projected ensemble mean monthly streamflow and future changes under RCPs for 2010–2039, 2040-2069 and 2070–2099 relative to 1976–2005.

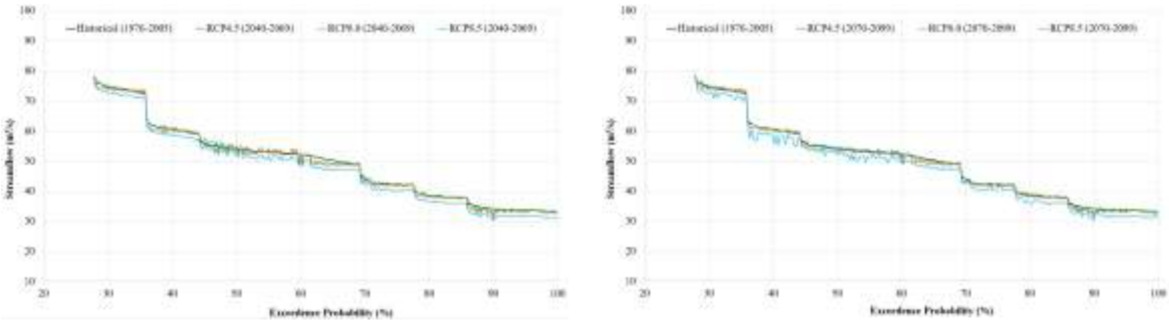
Figure 7 presents the cumulative frequency distribution for the ensemble mean monthly projected streamflow of the basin. The projected outputs show that streamflow is more likely to decrease for all RCPs in the future periods. In general, there are no many differences found among RCPs. But there is an important decreasing streamflows in every future periods. Therefore, based on projected streamflow, it confirms that climate change will have impacts on the hydrologic response of the basin. With increasing reliability, the streamflow could decrease due to climate change in the future periods and the balance of the water resource structure may change.



(a) Multi-scenarios for historical and simulated



(b) Multi-scenarios for historical and 2010-2039



(c) Multi-scenarios for historical and 2040-2069 (d) Multi-scenarios for historical and 2070-2099

Figure 7: Cumulative frequency distribution curves of the projected ensemble mean monthly streamflow at SKC.

Flow regime

The assessment of climate-induced shifts in high flow disturbances indicated that all parameters that assess high flow disturbances (Q1.67, FLD-DUR and 7QMAX) showed a decrease in the future irrespective of the emission scenario. The Q1.67 for the SKC in the baseline period showed a decrease of about 5 to 6% during the future period under the RCPs scenarios. Flood duration (FLD-DUR) decreased from 6 days during the baseline period to a mean of less than one day in all the future periods under the three emission scenarios. Although the pattern of change in 7QMAX with years is not clear, however, for the three emission scenarios, results indicate that the average of the seven maximum runoffs in the future will shift by 6% on average. Results for all variables that quantify high flow disturbances indicate non-significant changes in the flow regime. This implies that the Bernam River is likely to be safer against flooding towards the late century. Though the changes in streamflow are not much, the basin might suffer water pressure, particularly during the dry season period.

Furthermore, climate-induced shifts in low-flow disturbances were also assessed. The findings showed that the indicators quantifying low-flow disturbances (BFI and 7QMIN) revealed minor changes in future for both emission scenarios. Historical and future streamflow data indicate that the median of BFI and 7QMIN at the study area is 64% and 28 m^3/s, respectively. This implies that the flow in the Bernam River Basin is stable and not susceptible to drying.

The DAYCV defines total flow variability without taking into account the temporal sequence flow variation. Baseline and future data indicate that the DAYCV median at the study catchment is about 32%, suggesting a small streamflow change. The future peak flows were not temporally shifted from the baseline period for all the future period irrespective of the RCP scenario. Conversely, the magnitude of the future monthly peak flows has decreased from baseline peak flow by 0.24 to 4.94%, through the three future periods under the RCP scenarios. These results inferred that the Bernam basin may not face an increase in the frequency of floods but the magnitude of future peak flows might slightly decrease.

CONCLUSION

HEC-HMS model was evaluated for the assessment of climate change impacts in the Bernam watershed, Malaysia using the deficit and constant loss (DCL) method. Results from the model evaluation indicate reasonable spatial and temporal predictions of streamflow using the DCL method. This shows that the DCL method with GIS extension is a good option for continuous simulation in HEC-HMS. The reasons for lower results of the objective functions in the validation could be due to the data uncertainty of soil, rainfall and streamflow. Climate change impacts were assessed by combining all simulations of similar carbon emission scenarios for the three future periods irrespective of the GCM using the validated HEC-HMS model. Compared with baseline streamflow records, predicted future streamflow would tend to decrease in all future periods during main and off-seasons. However, the changes in future streamflow at the River Basin would be more pronounced during the dry season period with a significant decrease under the worst-case scenario (RCP8.5). It can be inferred from the results that the Bernam River Basin may likely experience tremendous pressure in the late century due to low streamflow, particularly during the off-season months. Therefore, integrated water resources management strategies are necessary to ensure adequate irrigation activates for rice production in the Basin. The future peak flows were not temporally shifted from the baseline period for all the future periods irrespective of the RCP scenario. However, the magnitude of the future peak flows may likely decrease towards the late century. The estimated future streamflow in this study are based on predicted changes in precipitation and temperature. However, other factors like human activities, particularly related to land transformations may also have significant impacts on the hydrologic cycle in the area. Hydrological models themselves can reduce the uncertainty in simulation. However, better sub-grid scale parameterization with appropriate hydrological models is recommended.

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