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ORIGINAL ARTICLE

Assessment of hydrologic impacts of climate change on the runoff trend in Klang Watershed, Malaysia

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Abstract The research involves connecting hydrology modelling to climate change downscaled output by GIS system to enhance the understanding of the impact of climate change scenarios on the river flow. The study provides the useful hydrology data for the future development in Klang watershed. The Hadley Centre Third Generation—GCM model has been employed for emission scenarios A2 and B2 for the period 2001–2100. The output from statistical downscaling model is used as input into HEC-HMS hydrological modelling to project the discharge of Klang River. Then, the hydrological model output is used to determine the future streamflow in the watershed. To evaluate the future climate change, the long time period of projection to 2100 is divided into three parts (2020s, 2050s and 2080s). The mean annual discharge is predicted to be decreasing by 9.4, 4.9 %, and an increase of 3.4 % for the A2 and a decrease of about 17.3, 14.3 and 6.2 % for the B2 scenario, respectively, in the 2020s, 2050s, and 2080s.

Keywords Climate change downscaling · Hydrologic model · Runoff · SDSM · HEC-HMS

Introduction

The changes in climate potentially affect the regional hydrological processes and long-term water availability (Fu et al. 2007) changing in overall flow magnitude, variability and timing of the main flow event (Wurbs et al. 2005) and the occurrences of floods (Bronstert et al. 2007). The use of Global Climate Change (GCM) models as an input to the hydrological models can be seen in many studies to estimate the hydrological behaviour at the fine scale based on climate change scenarios (e.g. Khazaei et al. 2012; Randin et al. 2009; Day 2013). They have attempted to employ statistical downscaling of different GCMs to determine hydrological responses to climate change.

Statistical DownScale Modelling (SDSM) generates the unique meteorological characteristics at a single station scale which is a valuable ability in hydrology studies. It is one of the most efficient tools in downscaling of large-scale daily GCMs climate variables into local scale, particularly in heterogeneous regions (Wilby et al. 2004). There are many studies that use statistical climate change methods in climate change impact assessments (Wilby and Dawson 2007; Meenu et al. 2012; Fiseha et al. 2012; Yang et al. 2012).

Malaysian Meteorological Department (2009) has studied the global analysis of the impacts of climate change in Malaysia using nine different GCMs to investigate an ensemble projection for the climate data (temperature and rainfall) to the 2100 year. The results of all nine models showed an increase in temperature with the ensemble mean of 2.6 °C for the peninsular. However, there was no clear trend of precipitation due to the high variability in the precipitation which indicates an increase of 6–10 % over the west coast and a decrease of 4–6 % over central Pahang and coastal Kelantan compared to 1990–1999. Kavvas et al. (2006) have investigated the impact of climate change on the hydrologic regime for Peninsular Malaysia. They developed the hydrologic–atmospheric model, RegHCM-PM, which is an integration model of MM5 atmospheric model of US National Center for Atmospheric Research and Integrated Regional Scale Hydrologic–Atmospheric

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hydrology model (IRSHAM). The large-scale CGCM1 (410 km) model was downscaled to a fine grid resolution (9 km) to assess the climate change impacts on the hydrological regime in Peninsular Malaysia. The projection was run for the middle future of the 2050s to assess the monthly river flows at some streamflow gauges. They found that there was a higher discharge peak through the flood season and a lower streamflow in the dry season in Klang watershed in the 2050s comparing to the observed data.

Since precipitation is the main component in runoff modelling which specifies the discharge behaviour along with the river, this study has accomplished the modelling of surface runoff of Klang watershed. The aim of the study is to assess the impact of climate change on future runoff and peak flow over Klang watershed. The result of the hydrological model is generation of the runoff hydrograph by a spatially distributed rainfall over the watershed in the future (2100 year).

Study area

Klang watershed is located at the west coast of Peninsular Malaysia. The watershed consists of Kuala Lumpur in the state of Selangor in Malaysia, a country in south-east Asia, between 101°0.30′ to 101°0.55′E longitudes and 3° to 3°0.30′N latitude. Figure 1 shows the geographical location of the study area chosen. The region experiences heavy precipitation particularly during the Northeast and Southwest monsoon which is from November to March and Southwest monsoon which is from late May to September (Sayang et al. 2010). Obviously, the climate of the study area is warm with a high percentage of humidity throughout the year. The mean precipitation over the watershed is about 2,350 mm. The most significant heavy precipitation had been observed during the months of October, November and December (Desa and Niemczynowicz 1996).

Predictands data include rainfall, temperature and evaporation stations in Klang watershed. Ten rain gauge stations have been selected to make a spatial downscaling and also one temperature and evaporation station has been downscaled in Klang area. Daily time series data are used for all the variables to run the statistical downscaling in SDSM. The Subang temperature station as the nearest temperature station to Klang watershed was used to downscale maximum and minimum daily temperatures by SDSM. Daily temperature of years (1975–2001) and daily Batu Dam evaporation station (1985–2001) are used for modelling. The selected stations for downscaling are listed in Table 1. Daily river discharge data of 33 years (1975–2007) of the Sulaiman flow station were used.

Observed large-scale NCEP reanalysis data are prepared by the Canadian Institute for climate studies under the Canadian Climate Impact Scenarios (CCIS) project. NCEP data are composed of 26 daily atmospheric variables which are extracted from the grid box covering the predictands. The data can be obtained from http://www.cics.uvic.ca/scenarios/index.cgi.

Climate change downscale modelling

SDSM as a statistical tool was adopted due to several advantages such as low cost and user friendly over dynamical models. It was developed by Wilby and Dawson (2007) at Kings College London. In this study, SDSM version 4.2 was used to construct climate change scenarios for Klang watershed in Malaysia. It uses the grid resolution GCM output from the HadCM3 experiments. Generally, statistical downscaling implements a quantitative relationship between large-scale atmospheric variable (predictors) and local surface variable (predictands). Equation 1 is the most general form of a downscaling model as defined by Wilby et al. (1999).

$$R_t = F(X_T) \qquad F(X_T) \text{ for } T \leq t. \tag{1}$$

where, $R_t$is the local scale predictand at single or multiple sites at time t, $X_T$is the predictor data of large-scale atmospheric variables and F is the technique used to quantify the relationship between two disparate spatial scales.

It combines a stochastic weather generator and transfer function method to relate large-scale GCM output (the predictors) to local variables such as precipitation (the predictands) (Wilby and Dawson 2007; Wilby et al. 1999).

The precipitation, maximum and minimum temperatures and evaporation as predictand data are downscaled for the study area. According to Wilby et al. (2001), SDSM needs to set up for the various predictands to get a reliable result. It transforms a fourth root model function to normalise the distribution and makes it less skewed to low precipitation values. The fourth root transformation is used as distribution of data is skewed in a conditional process (Khan et al. 2005). The threshold value of precipitation is set to 0.3 mm per day which specifies to trace the rainy days in calibration and validation in SDSM. Bias correction is set to value of 1 for all the predictands. It means the process will run without any bias correction. The bias correction is able to moderate for any tendency to over or underestimate the mean of conditional processes by the downscaling model.

SDSM presents two kinds of model calibration based on the nature of climate data which are categorised into conditional and unconditional processes. A conditional process is defined for the precipitation and evaporation data as dependent on the regional scale predictors. There is an

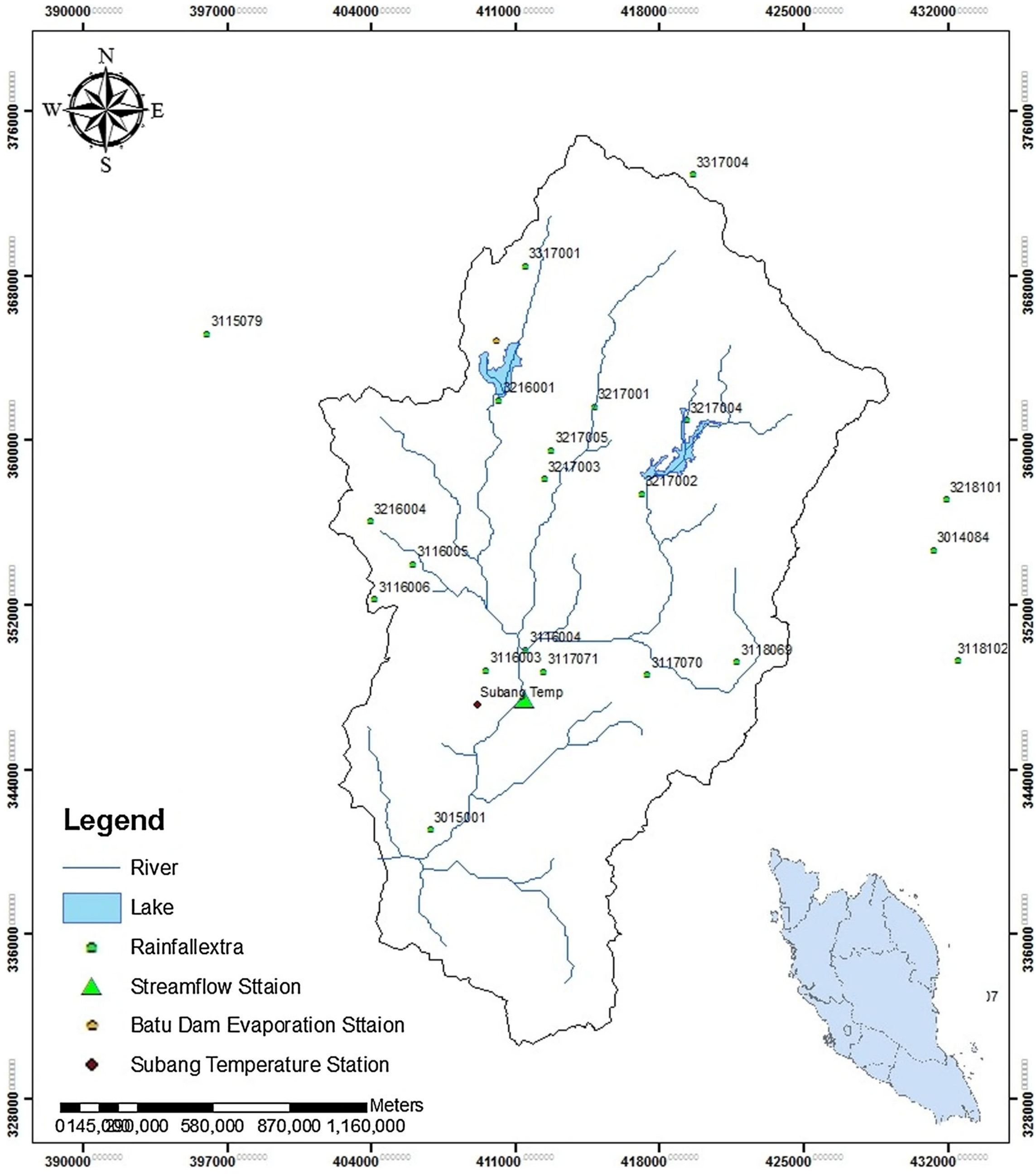

Fig. 1 Location of the raingauges and stream gauging stations in Klang watershed

indirect link assumed between the data and predictors, whereas an unconditional process can be established for the temperature data as a direct link to the predictors assumed. Therefore, in conditional process, some local parameters of precipitation would estimate such as wet/dry-day occurrences.

A multiple linear regression equation is constructed via an optimisation algorithm (dual simplex/ordinary least squares) between predictands and the predictors that are determined through screening variables step. Screening variables in SDSM show a linear regression between gridded predictors and predictands which is the most significant phase to the statistical downscaling method to choose appropriate downscaling predictor variables which largely affects the generated scenarios. It made a correlation of each predictand data to the 26 reanalysis NCEP predictor variables listed in SDSM as provided by reanalyses data set (Kalnay et al. 1996). SDSM generates a correlation matrix and explained variance reveals the correlations between the predictand and predictors. The predictors which have a high correlation with the predictans ($p < 5\ \%$) are chosen for the future processes.

Table 1 The climatological stations used for the downscaling in Klang watershed

ID	Station name	Station no.	Longitude (°)	Latitude (°)	Period (year)
1	Taman maluri	3116005	101.65	3.20	1977–2001
2	Edinburgh	3116006	101.63	3.18	1977–2001
3	Pusat penyelidekan	3117070	101.75	3.15	1972–2001
4	Pemasokan ampang	3118069	101.79	3.16	1972–2001
5	Kg. Sg. Tua	3216001	101.69	3.27	1973–2001
6	Ibu bekalan km	3217001	101.73	3.27	1975–2001
7	Empangan genting klang	3217002	101.75	3.23	1975–2001
8	Ibu bekalan km	3217003	101.71	3.24	1975–2001
9	Kg.kuala sleh	3217004	101.77	3.26	1975–2001
10	Genting sempah	3317004	101.77	3.37	1975–2001
11	Subang (Temperature)	486470	101.55	3.11	1975–2001
12	Batu Dam (Evaporation)	–	101.68	3.27	1985–2001

The scenario generator in SDSM produces ensembles of synthetic daily weather series for the current and future climate using NCEP reanalysis and GCM. The simulation of HadCM3-GCM model using A2 and B2 scenarios is run in SDSM to project the trend of future climate change variables at watershed scale. To evaluate the future climate change, the long time period of projection to 2100 is divided into three parts (2020s, 2050s and 2080s) to compare the observed precipitation, temperature and evaporation.

Calibration and validation of the climate change downscaled outputs

The historical data of predictands are split into two parts, the first part is used for calibration and the second part of the data is used for validation as an independent dataset. Best performed calibration results are obtained with correlation and standard errors for every month. A validation test is conducted after obtaining the agreeable result of the calibration test. A validation test is run to identify the accuracy of the model which is likely to downscale for the future projections. During validation, mean and variance of downscaled daily predictands are adjusted by bias correction and variance inflation factor to force the model to replicate the observed data. Bias correction compensates any tendency to over or under estimates the mean of downscaled variables.

Hydrological modelling

The rainfall–runoff approach was used to simulate the impact of climate change on runoff value. HEC-HMS is the software to simulate the rainfall–runoff processes of watershed system which can be obtained from the Hydrologic Engineering Centre's home page at: http://www.wrc-hec.usace.army.mil/. The main reason for using rainfall–runoff HEC-HMS is to account for the influences of the watershed representing the boundary condition over the watershed to simulate runoff.

GIS system facilitates driving hydrologic parameters required for the watershed and hydrologic modelling to simulate surface runoff. Hec-Geo-HMS extension is able to derive and transfer the hydrological parameters into HEC-HMS to implement further analysis of the hydrology modelling of Klang watershed.

Two steps have been conducted to simulate the hydrologic modelling using HEC-HMS in Klang watershed. Initially, the watershed was divided into homogeneous sub-watersheds using Hec-Geo-HMS to get the sub-watershed geometric data. Then, the hydrological modelling was developed in HEC-HMS for the watershed using all the parameters obtained from the previous step.

USACE-HEC (2000) hydrologic model was used to predict runoff in the watershed. The rainfall–runoff model takes into account the influences of physical parameters of the watershed such as climatic, topography, landuse and soil data representing the boundary condition over the watershed to simulate runoff. It provides the Curve Number (CN) value for the different landuse considering the four soil groups. To construct the CN value of Klang watershed, two landuse and soil layer in GIS were overlaid. The standard shape was employed in HEC-HMS to define the shape of the unit hydrograph. In this method, the standard lag is defined as the length of time between the centroid of precipitation mass and the peak flow of the resulting hydrograph. Watershed lag is considered as 0.6 times the time of concentration of the flow.

To define the meteorological model in HEC-HMS for Klang watershed, the Gauge Weight method was used to allocate the climatic parameters for each sub-watershed

(Meenu et al. 2012). The daily time series of the 23 raingauges was entered into the meteorological model to develop hydrograph at the sub-watersheds. The meteorological model used Monthly average Evapotranspiration (ET) method for the rainfall–runoff simulation. The daily evaporation from Batu dam station for the period (1985–2001) was used. The empirical Hargreaves method (Salazar et al. 1984) was used to calculate the ET. It is based on the air temperature and requires the maximum and minimum air temperatures to calculate ET. This method was used as its simplicity and modest data requirement which made it attractive for the hydrology modelling. The Hargreaves and Samani (1985) developed Eq. 2 as below:

$$E_t = 0.0023 R_{\mathrm{a}} (T_{\mathrm{mean}} + 17.8)(\sqrt{T_{\max} - T_{\min}}), \tag{2}$$

where T_{mean}: daily mean air temperature (°C), it is equivalent to $T_{\max} + T_{\min}/2$, $T_{\max}$: daily maximum air temperature (°C), $T_{\min}$: daily minimum air temperature (°C), R_{a}: extraterrestrial radiation in equivalent evaporation in mm/day. The mean air temperature in the Hargreaves equation is calculated as an average of $T_{\max}$ and $T_{\min}$.

Model calibration and validation of hydrological modelling

The characteristics of the hydrological watershed used are assumed to be constant throughout the simulation period. The daily rainfall data for the 23 raingauges over a long period were used for calibration and validation of HEC-HMS simulation for Klang watershed. 16 years (from 1975–1990) and the 11 years lengths from 1991–2001 were selected for calibration and validation, respectively. Figures 2 and 3 show the calibration and validation test in HEC-HMS.

Assessment of impact of climate change on the runoff

The present and future streamflow was compared to reveal the possible changes of runoff behaviour for the future based on the climate change scenarios. HEC-HMS hydrological model in Klang watershed was found skilful through the long time series streamflow record. It handles geospatial data and distributed grid-based precipitation data for the multi raingauge stations. Using appropriate hydrological model to predict the future streamflow depends on its ability to model the current scenarios (Dibike and Coulibaly 2007).

The assessment of climate change impacts on the river discharge at Sulaiman streamflow station has been performed to estimate mean monthly river hydrograph for three time slices period (2020s, 2050s and 2080s). The downscaled baseline and future precipitation, temperature and evaporation obtained from SDSM are entered into HEC-HMS model to simulate the baseline and future streamflows. The validated HEC-HMS model is used to simulate the runoff at Sulaiman streamflow station located at the outlet of the watershed. However, neither change in soil nor in land-use cover is considered to project future streamflow which makes it assure that the streamflow projections for future are solely dependent on the climate change scenarios.

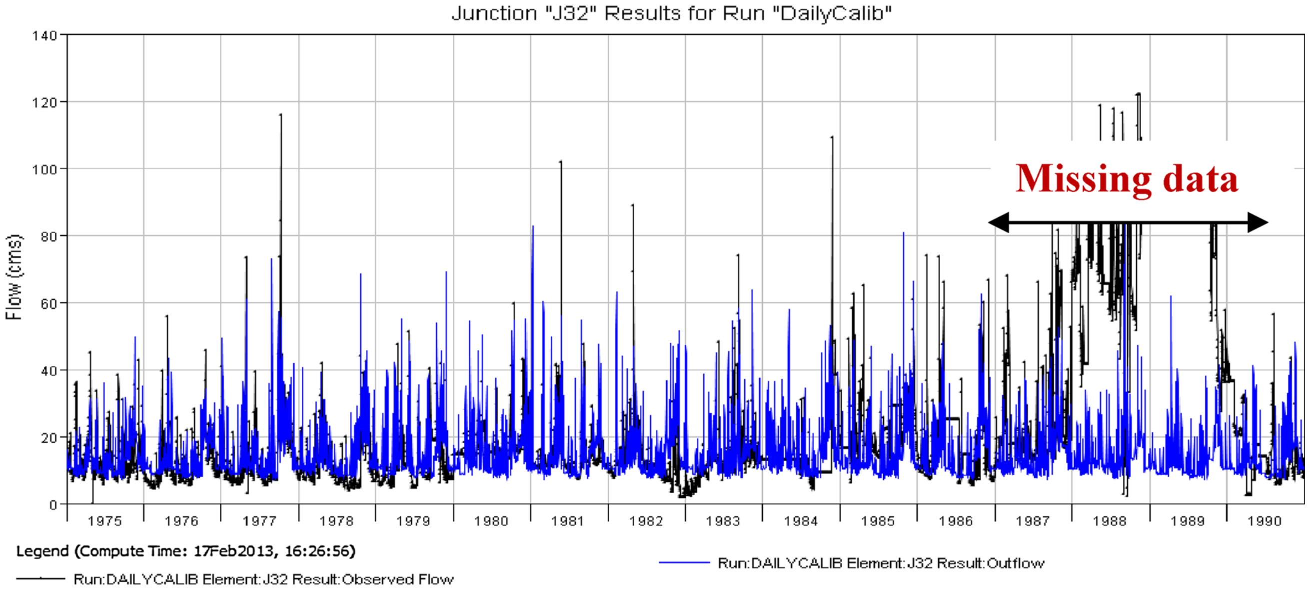

Fig. 2 Calibrated result of observed and simulated daily discharge at the Sulaiman streamflow during the calibration period (1975–1990)

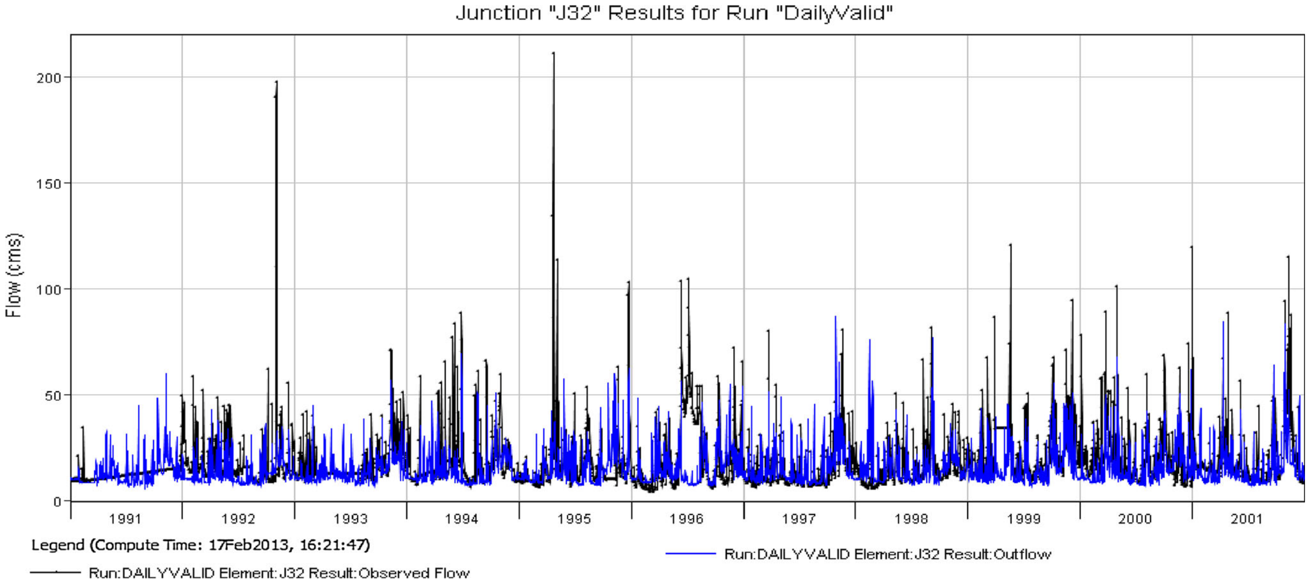

Fig. 3 Validated result of observed and simulated daily discharge at the Sulaiman streamflow during the calibration period (1990–2001)

Table 2 Large-scale predictor variables selected for predicting daily precipitation, maximum and minimum temperatures and evaporation

Predictors	Predictands					
	ncepmslpas	ncepp850as	ncepp500as	nceprhumas	ncepshumas	nceptempas
3116005	*	*				*
3116006	*	*		*		*
3117070	*	*	*	*	*	*
3118069	*	*	*	*	*	*
3217001	*	*	*	*	*	*
3216001	*	*	*	*	*	*
3217002	*		*	*	*	
3217003	*	*	*	*		
3217004		*		*	*	*
3317004	*		*	*	*	*
T_{max}					*	*
T_{min}			*		*	*
Evaporation					*	*

Results and discussion

Selected predictors

The selected large-scale predictors for all the local predictands are listed in Table 2. For precipitation, mean sea level pressure, 850 hPa Geopotential height, 500 hPa Geopotential height, near surface relative humidity, Surface specific humidity and Mean temperature at 2 m were chosen as predictors to provide a good correlation to the observed data. For the temperature, Surface specific humidity, Mean temperature at 2 m and 500 hPa Geopotential height are selected. For the evaporation, the surface specific humidity and mean temperature at 2 m were chosen as represented the best correlation of the daily evaporation to the large-scale predictors NCEP reanalysis data. Table 3 gives the accuracy of the calibrated data.

To evaluate the validation output of precipitation parameters (as conditional variable), Dry spell and Wet spell length of observed and validated were compared in Table 4. The results indicate that the model run is satisfactorily validated and it can be seen that there is a remarkable skill of simulation data compared to the observed.

Table 3 R-Square of the calibration modelled for the downscaled rainfall, temperature and evaporation stations

Predictand variables	Mean	Maximum	Variance
3116006	0.966	0.689	0.802
3117070	0.884	0.121	0.907
3118069	0.968	0.236	0.992
3216001	0.990	0.120	0.993
3217001	0.998	0.114	0.918
3217002	0.996	0.780	0.914
3217003	0.960	0.232	0.814
3217004	0.920	0.632	0.853
3317004	0.990	0.990	0.892
$T_{\max}$	0.990	0.560	0.950
$T_{\min}$	0.990	0.585	0.990
Evaporation	0.990	0.885	0.990

Table 4 Correlation of the validation modelled for the downscaled rainfall, temperature and evaporation stations

Predictand	Mean	Maximum	Variance	Dry spell	Wet spell
3116005	0.47	0.27	0.62	0.65	0.41
3116006	0.49	0.22	0.35	0.67	0.72
3117070	0.87	0.54	0.72	0.78	0.69
3118069	0.50	0.30	0.62	0.53	0.44
3216001	0.68	0.16	0.05	0.64	0.48
3217001	0.51	0.32	0.40	0.82	0.54
3217002	0.20	0.11	0.40	0.75	0.56
3217003	0.80	0.45	0.82	–	0.19
3217004	0.72	0.35	0.43	0.51	0.67
3317004	0.33	0.14	0.10	0.46	0.75
$T_{\max}$	0.88	0.54	0.98	–	–
$T_{\min}$	0.98	0.43	1.00	–	–
Evaporation	0.99	0.93	0.73	–	–

Change in amounts of rainfall variable

SDSM generated different scenarios for the individual precipitation raingauge station by projecting the possible climate in the future in three time slices (2020s, 2050s and 2080s). The rainfall variables are Mean, Max, Wet Dry, Dry Spell and Wet Spell. After all the precipitation data have been downscaled by SDSM, the spatial analysis was conducted to achieve the average precipitation for the entire Klang watershed. The interpolation produced the monthly plot by assuming the current and future downscaled data. To interpolate and plot the maps, the spatial mean value is used. GIS is able to estimate a mean value of each map as an average of all the point data values distributed over the whole watershed. Tables 5 and 6 show the monthly average of Mean, Max, Wet Dry, Dry Spell and Wet Spell for the current and the 2020s, 2050s and 2080s for as an average value of precipitation variables for whole the watershed.

Changes in temperature

Output generated by the Had-CM3 GCM model has projected an increase in both maximum and minimum temperatures for Klang watershed. The maximum and minimum temperatures increased towards the end of the century by 2.7 and 0.8 °C, respectively, compared to the current observed temperature at Subang temperature station. Tables 7 and 8 reveal the continually increasing temperature of Subang station at Klang watershed. The maximum daily temperature under A2 scenario increased the most in May by 1.6, 2.2 and 2.7 °C for the 2020s, 2050s and 2080s, respectively, which is a considerable increase in daily temperature through the year. The trend under B2 scenario is similar in May which is 1.4, 1.5 and 2.4 °C. The minimum daily temperature decreased (October, November and December) and increased from January to May, August and September, with no significant variation through June and July under A2 and B2 scenarios.

Change in evaporation and evapotranspiration (et)

An examination of Table 9 shows that in general, there is a little to no change in the Evaporation value over Klang watershed using Batu Dam evaporation station.

The future ET was calculated for the three time horizons (2020s, 2050s and 2080s) based on the climate change scenarios using Hargreaves equation. The $T_{\max}$, $T_{\min}$ and evaporation data are used to calculate ET. The projected mean ET value increases by 4.3 % in the 2020s and 2050s, 3.8 % in the 2080s, under A2 scenario. The trend for B2 scenario is likely to be a decrease by 1.5 % for the 2020s and an increase by 2.2 and 2.7 % for the 2050s and 2080s, respectively.

The results reveal that there is no significant change of future ET to the observed for Klang watershed. The most ET value is expected in July for the future demonstrates dependency on the amount of evaporation and temperature in Hargreaves ET equation. There is an increase in mean monthly ET throughout the year except March, April and a slight decrease in January affected by a decrease in evaporation in these months for the future period under A2 and B2 scenarios. The future ET is shown in Table 10.

Calibration and validation of rainfall–runoff Hec-HMS model

The hydrology parameters needed in the rainfall–runoff modelling were generated using Hec-Geo-HMS. These

Table 5 Changes in precipitation variables in Klang watershed relative to the observed data under A2 scenario

Precipitation variable	2020s	2050s	2080s	Observed	Change in 2020s	Change in 2050s	Change in 2080s
Mean precipitation (mm)	202.81	218.94	247.5	220.27	−17.46	−1.33	27.23
Wet spell (day)	2.40	2.55	2.91	5.33	−2.93	−2.78	−2.42
Wet day (%)	0.55	0.55	0.56	0.58	−0.03	−0.03	−0.02
Max precipitation (mm)	291.04	323.34	394.3	228.4	62.64	94.94	165.9
Dry spell (day)	1.96	2.21	2.87	2.61	−0.65	−0.4	0.26

Table 6 Changes in precipitation variables in Klang watershed relative to the observed data under B2 scenario

Precipitation variable	2020s	2050s	2080s	Observed	Change in 2020s	Change in 2050s	Change in 2080s
Mean precipitation (mm)	194.91	205.69	226.02	220.27	−25.36	−14.58	5.75
Wet spell (day)	2.35	2.52	2.77	5.33	−2.98	−2.81	−2.56
Wet day (%)	0.56	0.56	0.56	0.58	−0.02	−0.02	−0.02
Max precipitation (mm)	278.17	312.04	362.27	228.4	49.77	83.64	133.87
Dry spell (day)	1.93	2.11	2.65	2.61	−0.68	−0.5	0.04

Table 7 Projected changes in maximum daily Maximum temperature at Subang station in Klang watershed (in °C)

Month	A2			B2		
	2020s	2050s	2080s	2020s	2050s	2080s
Jan	1.30	1.60	2.10	1.07	1.17	1.87
Feb	1.46	1.43	1.51	1.36	1.25	1.46
Mar	1.03	1.04	0.97	1.01	1.03	0.51
Apr	1.33	1.44	1.69	0.84	1.14	1.58
May	1.58	2.18	2.68	1.37	1.47	2.37
Jun	1.39	1.44	1.47	0.82	0.82	0.86
Jul	0.89	0.97	1.00	0.16	0.96	0.80
Aug	0.98	1.02	0.99	0.85	0.75	0.85
Sep	0.97	1.01	1.10	0.62	0.42	0.62
Oct	1.05	1.16	1.37	1.01	1.00	1.10
Nov	1.21	1.44	1.77	1.19	1.17	1.55
Dec	1.03	1.24	1.48	0.86	0.46	1.06
Annual	1.19	1.33	1.51	0.93	0.97	1.22

Table 8 Projected changes in minimum daily temperature at Subang station in Klang watershed (in °C)

Month	A2			B2		
	2020s	2050s	2080s	2020s	2050s	2080s
Jan	0.08	0.13	0.18	0.09	0.10	0.12
Feb	0.09	0.17	0.29	0.10	0.16	0.21
Mar	0.04	0.04	0.06	0.08	0.10	0.07
Apr	0.29	0.42	0.78	0.26	0.40	0.62
May	0.12	0.26	0.46	0.12	0.22	0.39
Jun	−0.01	−0.01	0.00	0.01	0.00	−0.01
Jul	0.01	0.01	0.00	0.01	0.02	0.00
Aug	0.07	0.16	0.29	0.08	0.13	0.22
Sep	0.08	0.18	0.33	0.10	0.16	0.25
Oct	−0.04	−0.09	−0.16	−0.05	−0.06	−0.09
Nov	−0.15	−0.28	−0.47	−0.14	−0.24	−0.35
Dec	−0.01	−0.05	−0.07	−0.04	−0.04	−0.07
Annual	0.05	0.08	0.14	0.05	0.08	0.11

hydrological parameters were generated automatically by GIS system using Hec-Geo-HMS for each sub-watershed of Klang. Thus, runoff processes are simulated on each sub-watershed system from the upstream to the watershed outlet throughout the streamflow network. Nine series of topo maps at 1:25,000 scale were used to make the elevation map of Klang watershed.

The calibration of the rainfall–runoff model in HEC-HMS for Klang watershed is performed by comparing the modelled daily streamflows with the observed flow at Sulaiman streamflow station. Table 11 gives the statistics of the daily observed and modelled streamflow at Sulaiman streamflow station for the calibration and validation periods. The maximum and mean values of daily flows are underestimated during calibration and validation periods in the table.

The statistics of lengthy daily data flow modelling which are illustrated in Figs. 2 and 3 indicate that flows are well simulated. However, most of daily high flows simulated in calibration and validation periods are underpredicted. The discrepancy of daily flow modelling at Sulaiman streamflow station has already been commented by Kavvas et al. (2006).

The results give the performance assessment for the daily discharges in the calibration and validation periods. The calibration and validation results represented a

Table 9 Projected changes in mean daily evaporation at Batu dam station in Klang watershed (%)

Month	A2			B2		
	2020s	2050s	2080s	2020s	2050s	2080s
Jan	−2.16	−5.16	−9.64	−1.64	−4.86	−7.15
Feb	0.07	0.24	0.61	0.15	0.35	0.46
Mar	−1.20	−3.10	−7.30	−2.14	−3.83	−6.17
Apr	−2.67	−5.32	−9.37	−2.87	−4.85	−7.50
May	−1.41	−3.15	−6.13	−1.39	−3.14	−4.94
Jun	−0.53	−1.18	−1.38	−0.41	−0.71	−1.59
Jul	0.97	2.01	3.84	0.84	1.88	2.85
Aug	−0.32	−0.28	−0.52	−0.15	−0.10	−0.31
Sep	−0.39	−0.76	−1.55	−0.13	−0.40	−0.88
Oct	−1.05	−2.43	−4.25	−1.34	−2.06	−3.42
Nov	0.68	1.23	2.09	1.16	1.73	2.06
Dec	0.37	1.34	1.80	0.79	1.31	1.87
Annual	−0.64	−1.38	−2.65	−0.59	−1.22	−2.06

Table 10 Projected changes in the monthly Evapotranspiration values for future under A2 and B2 scenarios

Month	A2			B2		
	2020s (mm)	2050s (mm)	2080s (mm)	2020s (mm)	2050s (mm)	2080s (mm)
Jan	45.45	44.76	43.80	44.89	43.66	44.35
Feb	42.25	42.14	42.32	42.03	41.76	42.23
Mar	50.20	49.28	46.91	49.93	49.07	46.44
Apr	52.80	51.44	49.27	51.21	50.81	50.30
May	67.15	67.85	67.09	66.39	65.33	66.99
Jun	69.03	68.76	68.74	66.70	66.51	66.13
Jul	81.14	82.35	84.00	77.48	82.30	82.35
Aug	75.09	75.06	74.39	74.41	73.83	73.90
Sep	62.74	62.43	61.90	61.40	60.31	60.57
Oct	52.52	52.21	52.00	52.33	51.95	51.58
Nov	48.47	49.60	51.27	48.58	48.98	50.37
Dec	45.79	46.91	47.81	45.43	44.54	46.55

Table 11 Statistics of the observed and simulated daily flows at the Sulaiman station during calibration and validation

	Calibration (1975–1990)		Validation (1991–2001)	
	Simulated (m^3/s)	Observed (m^3/s)	Simulated (m^3/s)	Observed (m^3/s)
Max	93.80	121.60	87.10	211.00
Mean	15.49	19.15	16.25	18.79
SD	8.76	16.80	9.50	13.96

good fit between the observed and simulated daily discharges. Thus, it can be concluded that HEC-HMS model responds well in simulation of hydrological processes in Klang watershed using meteorological observation data.

Assessment of climate change impact on the river discharge

Discharges are produced by providing observed and downscaled precipitation for A2 and B2 scenarios of HadCM3 model. Likewise, downscaled temperature data for ET calculation using Hargreaves method are also entered into the HEC-HMS for discharge simulation.

The assessment of climate change impacts on the river discharge at Sulaiman streamflow station has been performed to estimate mean monthly river hydrograph for three time slices period (2020s, 2050s and 2080s). The downscaled baseline and future precipitation, temperature and evaporation obtained from SDSM are entered into the HEC-HMS model to simulate the baseline and future streamflows. The validated HEC-HMS model is used to simulate the runoff at Sulaiman streamflow station as the outlet in Klang watershed. The assessment is conducted for the current as well as future periods (current, 2020s, 2050s and 2080s) corresponding to the A2 and B2 scenarios developed by the HadCM3. However, neither change in soil nor land-use cover is considered to project future streamflow which makes it assure that the streamflow projections for future are solely dependent on the climate change scenarios.

Klang River at Sulaiman discharge station is identified during the base period 1975–2001 by a typical hydrograph with two main discharge peaks in April and November with high precipitation during these months, whereas February and August are attributed with the least amount of discharge of Sulaiman discharge station. It is clear from the figures that the hydrographs of predicted daily discharge for the two periods (2020s and 2050s) and discharges are decreasing while for the period 2080s, it is increasing corresponding to both A2 and B2 scenarios. The average annual mean discharge is predicted to be decreasing by 9.4, 4.9 %, and an increase of 3.4 % for the A2 and a decrease about 17.3, 14.3 and 6.2 % for the B2 scenario, respectively. The maximum absolute increase in the mean peak runoff was projected in May and October for the 2080s under A2 scenario, with a difference of 7.6 m^3/s (29.7 m^3/s as compared to 21.9 m^3/s in May) and 7.6 m^3/s (28.9 m^3/s as compared to 21.3 m^3/s in October). Absolute increase of mean precipitation in May, September and November is 145.8, 206.7 and 46.8 mm in the 2080s under A2 scenario. The changes in mean precipitation in these months (32 % in May, 88 % in September, 17 % in November) result in the increase of mean runoff by 34, 52 and 4 %, respectively. The highest increase in evapotranspiration and rather increase in maximum temperature in November,

Table 12 Projected percent change in monthly streamflows at Sulaiman discharge station under A2 and B2 scenarios

Month	A2 (m^3/s)			B2 (m^3/s)		
	2020s	2050s	2080s	2020s	2050s	2080s
Jan	−41.57	−48.32	−52.21	−42.36	−50.12	−54.44
Feb	−19.05	−17.86	−16.67	−22.02	−20.24	−15.48
Mar	−19.60	−18.09	−17.09	−24.12	−22.61	−14.57
Apr	−17.89	−15.6	−11.47	−23.85	−22.02	−15.60
May	−0.90	11.31	34.39	−11.31	−1.36	18.55
Jun	2.26	9.60	28.25	−7.34	−1.13	15.25
Jul	−21.74	−21.74	−20.29	−27.54	−27.54	−26.09
Aug	−18.26	−16.44	−13.70	−26.03	−24.20	−21.46
Sep	26.35	34.13	52.69	12.57	18.56	34.73
Oct	8.45	19.25	35.68	−4.23	4.23	18.31
Nov	−7.72	−2.44	4.07	−18.29	−14.23	−8.54
Dec	−2.82	0.47	7.04	−13.62	−11.27	−5.16
Annual	−9.37	−4.92	3.44	−17.34	−14.33	−6.21

cause the changes of mean runoff by 4 % in this month. Mean precipitation is expected to a rather increase in July by 5 % but an increase in evapotranspiration in this month causes a reduction in mean runoff. A reduction of precipitation by 24.6 and 5.7 % in January and March in the 2080s under A2 scenario, results in a reduction of runoff by 52 and 17 %, respectively. However, there is a reduction of precipitation in June by 31 %; the runoff is affected by the high volume of precipitation in May (455.9 mm). It can produce a large amount of baseflow or delayed runoff in the watershed. The baseflow or delayed runoff affects the part of runoff that occurs after the end of the flood which produces the continuous high flow rates in the runoff. The simulation of discharge consists of changing in the monthly mean discharge at Sulaiman discharge station in Klang watershed. Table 12 shows the projected percent change in the mean monthly discharge for three time slices of future corresponding to the A2 and B2 scenarios with respect to the baseline discharge (1975–1991) at Sulaiman station.

Conclusion

SDSM produces ensembles of synthetic daily weather series for the current and future climate using NCEP reanalysis and GCM model. The simulation of HadCM3-GCM model using A2 and B2 scenarios was run in SDSM to project the trend of future climate change variables at watershed scale. To evaluate the future climate, the long time period of projection to 2100 is divided into three parts (2020s, 2050s and 2080s) to compare the observed precipitation, temperature and evaporation. The calibration and testing of the downscaling procedure reveal that statistical downscaling model can be used as reliable downscaling tool in Klang watershed. It has been ascertained that SDSM resolves the local climate change scenarios of the precipitation, temperature and evaporation in Klang watershed by generating accurate results and in good agreement with observed.

The maximum and minimum temperatures are likely to be increasing towards the end of the century by more than approximately 2.7 and 0.8 °C, respectively, compared to the observed temperature (1975–2001) at Subang temperature station. The watershed seems to experience increased rainfall towards the end of the century. However, the analysis indicates that there will likely be a negative trend of mean precipitation in the 2020s and with no difference in the 2050s. The precipitation experiences a mean annual decrease amount by 7, 0.6 % for A2 scenario in the 2020s and 2050s, respectively, and an increase by 12.4 % in the 2080s. According to the RCM result investigated by Meteorological Dep. Malaysia (2009), the change in rainfall shows no clear trend by all of the nine models due to the high variability in the precipitation-modulating factor.

A decreasing of average wet spell length for the future, approximately 50 %, is projected as an increasing of average dry spell length to 10 % as compared to the current condition by the 2080s. There will be a decrease in consecutive days without rainfall approximately 10 and 15.5 % for A2 scenario in the 2020s and 2050s, respectively. The analysis indicates that there will be an increase in mean monthly precipitation but with a decrease in the number of consecutive wet days which can be concluded as a possibility of more precipitation amount in fewer days.

Sulaiman streamflow station in Klang River is identified by a typical hydrograph, which includes two main discharge peaks which are in April and November for the period 1975–2001; whereas February and September are attributed as the least amount of discharge of Sulaiman streamflow station. It reveals that the wet season is from April to June and October to December, while the dry season is from January to March and July to September. It is obvious from the results that the predicted annual mean discharge for future periods is decreasing, except the period 2080s, it is increasing according to A2 scenario. The projected mean discharge indicated a decline from January to April and also from July to August in all the three time slice periods for A2 and B2 scenarios. There is an increasing trend in the discharge of June, September and October in all the three future periods under A2 scenario. However, peak flow of mean runoff in May and June did not change much for the 2020s and 2050s. Obviously, the magnitude of increasing is higher in A2 than in B2 scenario.

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