Climate change impacts on river runoff in Klang watershed in WestMalaysia

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Abstract

The study assesses climate change impacts on Klang river runoff patterns by end of this century (2100). It was applied statistical downscaling model (SDSM) and the Rainfall-Runoff hydrological model HEC-HMS to the river basin inklang at Sulaiman Bridge discharge gauge. The study has run statistical downscaling for single site in the Klang watershed in Malaysia using SDSM to project the probable variability in precipitation characteristics at the station. The data generated by SDSM is used as input in hydrological model to estimate the future behavior and variation of runoff regime in the watershed. It has been attempted to set up a calibration and validation of the HEC-HMS hydrologic model with precipitation, stream flow data representing the current climate (1975-2001). Finally it was conducted to simulate the stream flow corresponding to the A2 and B2 scenarios IPCC based on the downscaled SDSM output. The results reveal that future precipitation and river runoff regime is expected to be changed. It can be concluded that a probability of flood happens to be higher due to increasing of rainfall intensity. Then, the days with heavy precipitation will be expected to be occurred more frequently during the year. The changes in runoff values considering the control period (1975-2001) will be expected according to the both scenarios. Overall, annual river runoff is predicted to decrease in the region. The mean annual runoff is predicted to decrease by 4 % for A2 scenario at 2020s and 2050s, and by 4.5 at 2080. And 2.1%, 2.7 % and 3.3 % for B2 scenario at the three time slices above respectively. It can be concluded that days with heavy precipitation will occur more frequently causing a higher frequency of high river flow events.

Keywords: Climate Change Downscaling, SDSM, Hydrological model, Rainfall-Runoff, HEC-HMS.

1 Introduction

Precipitationis considered as crucial parameter in climate change through the studies (Willems and Vrac 2011).Forecasting runoff trend might affect the development plan for an area due to changing in energy demand and water consumptionin different sectors. Runoff forecasting is one of the significant components in hydrological models which play an important role in water resources management.

The changes were predicted in river runoff patterns in the future according to the IPCC scenarios (e.g., Bolle et al., 2008; Jacob and Lorenz 2009; Teng et al., 2011; Vaze and Teng 2011;Zhang and Chiew 2009; Wang et al., 2011).

GCMs have become a main tool in addressing in climate change impact studies in environmental and water resources and are coupled atmospheric, oceanic, land surface and sea ice models (Trenberth 1992). The using of GCM’s results in hydrologic models is a reasonable approach to assess possible future hydrologic changes of basins (e.g., Fu and Charles 2011; Roy et al., 2001; Loukas et al., 2004; Whitfield et al., 2003). However, there been some limitations due to coarse spatial resolution of GCMs particularly estimating the hydrological parameters such as runoff in the watershed scale. Many studies conducted downscaling methods to make a link between GCMs output and hydrologic models at watershed scale (Fowler et al., 2007; Fowler et al., 2012; Dibike and

Coulibaly2007; Mejia 2012). In most of the studies, a historical climate data as a base period is entered into hydrological models to make a long time series of hydrological data, and then the hydrological model is calibrated against the base period data to verify the designed hydrological model in the scope of study. Finally, runoff value can be estimated by driving a future climate series projected according to the IPCC scenarios.

Downscaling techniqueshave emerged as useful tools to reduce the problemof discordant scales between coupled models. These techniques can be classified into two groups: statistical and dynamical downscaling.

The paperaims to assess climate change impacts on river runoff patternsin Klang watershed in the futuretime slice (2010-2040 (the 2020's), 2041-2070 (the 2050's) and 2071-2099 (the 2080's)using public domain hydrological model (HEC-HMS and HEC-GeoHMS) according to theIPCC emissions scenarios.

2 Materials and Methods

2.1 Study Area

This study was conducted in the Klang watershed**,** located in Kuala Lumpur, Selangor province in Malaysia as in Fig. 1. The arealies between 101°.30´ to 101°.55´ E Longitudes and 3° to 3°.30´ N latitude. Its total drainage area is 674 km², of which 50 % is occupied by the catchment of the urban area. Forests cover 37% of the territory. The climate of Klang river basin is warm and humid tropical with little variation in temperature or relative humidity throughout the year Mean annual. Precipitation over the catchment averages about 2350 mm. The most significant heavy precipitation had been observed during the months of October, November and December (Desa and Niemczynowicz1996).

2.2Data Used

Five kinds of data were used in the study which consists of Digital Elevation Model (DEM), precipitation, observed large scale NCEP reanalysis data and Hadley Centre Third Generation (HadCM3) dataset as predictors and streamflow. The rainfall station namely Kg. Sg. Tua (K.S.T) is considered as predictand covering the 1975-2001 period time series is used for the downscaling experiments. It is located in Kuala Lumpur state at 03° 16´ 12″ N latitude and 101° 40´ 48″ E longitude with the minimum of missing data. The observed stream flow data series for the hydrometric station was extracted from the DID database provided by MOSTI (Ministry of Science, Technology and Innovation). Observed large-scale NCEP (national centre for environmental prediction) reanalysis data are obtained from its website: http://www.cdc.noaa.gov/

HadCM3-GCM developed at the Hadley Centre in the United Kingdom (Gordon et al., 2000; Pope 2000; Collins et al., 2001) is simulated based on Special Report on emission Scenarios A2 and B2. Scenario A2 is a high emissions scenario in comparison with B2 and was chosen for this study to illustrate the worst-case situation.

3 Methodology

At first, the study has run statistical downscaling for single site in the Klang watershed in Malaysia using SDSM to project the probable variability in precipitation characteristics at the station. The data generated by SDSM is used as input in hydrological model to estimate the future behavior and variation of runoff regime in the watershed. Secondly, it has been attempted to set up a calibration and validation of the HEC-HMS hydrologic model with precipitation, stream flow data representing the current climate (1975-2001). The third phase is to simulate the stream flow corresponding to the A2 and B2 scenarios IPCC based on the downscaled SDSM output. Fig.1 shows the work flow of Runoff modeling and linking to Climate Change downscaling.

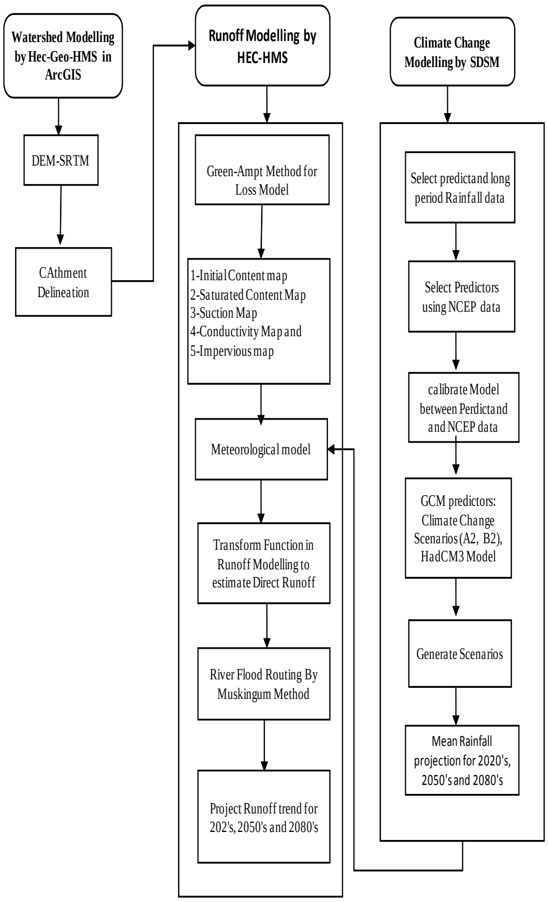

Fig.1. Work flow of Runoff modeling and linking to Climate Change downscaling

3.1Statistical downscaling model

It is used statistical method when the downscaling requires at point-scale. It will provide a reliable correlation of observational data (predictand) and large scale daily GCMs climate variables (predictors) using multiple linear regression techniques. The statistical regression is run between predictors and predictand to make spatial scale reduction of the climate data by applying the monthly explained variance and partial correlation coefficient throughout predictand. SDSM performance is estimated by validation of calibration result using some parameters such as wet/dry day for precipitation data in addition to mean and variance values used in calibration uncertainty. The detailed description of the mathematical and approach of SDSM was explained by Wilby et al., (1997 and 1999) and Wilby and Dawson (2007). The calibration is conducted between selected large-scale NCEP predictor variables and the rainfall station (K.S.T) to quantify the accuracy of data modeled. During calibration, mean and variance of downscaled daily precipitation are adjusted by bias correction and variance inflation factor to force the model to replicate the observed data (Khan et al., 2006).

Both the rainfall data and selected large-scale NCEP predictors for the period 1975-2001 are split into 16 years (1975-1990) which is assumes in model calibration while the remained 11 years (1991-2001) are employed for model validation to check of the statistical downscaled model output from calibration. The validation uses parameters of mean and variance values and also wet and dry spell length because of setting up the conditional model in SDSM for daily precipitation data which depends on an intermediate variable such as the probability of wet/day occurrence.

3.2The hydrological model

Downscaled precipitation data by SDSM are used as inputs for the Rainfall-Runoff hydrologic model (HEC-HMS). The HEC-HMS was developed by U.S. Army Corps of Engineers (USACE-HEC, 2009), is a numerical model which provides a variety of methods to simulate watershed hydrological parameters such as runoff, infiltration losses and river routing to predict runoff and flow (Ford et al., 2008). It is a semi-distributed model that requires physical data to anticipate hydrologic simulations and requires detailed data and more complex parameterization compare to the lumped conceptual model which requires minimal input data. The main reason using of HEC-HMS is due to a loose coupling with GIS software (GeoHMS extension) and also is well known Rain-Runoff simulation model.

Green-Ampt infiltration method in HEC-HMS provides a conceptual model for calculation of precipitation loss in permissible surfaces in a specific time period in a watershed (Chu 1978). Parameters of Green-Ampt loss method are depend on the soil characterization such as initial water, saturated water content, hydraulic conductivity and wetting from suction. Snyder unit hydrograph transform method which is compatible to the Green-Ampt loss method in HEC-HMS was employed to calculate surface runoff. Muskingum river routing technique (Tan et al., 2005) is used based on the continuity equation (Al-humoud and

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Esen2006). To model detention with the program, the storage-outflow relationship for the existing reservoirs (batu dam and Klang gate dam) was set.

4 Results

The results of the correlation analysis reveal the correlation between NCEP-reanalysis variables predictors in the scope of study along with predictand. The four variable predictors namely relative humidity at 500 hPa, relative humidity at 850 hPa, near surface relative humidity and surface specific humidity are used as input data for the statistical model due to high correlation.

4.1 Calibration and validation of the statistical downscaling model

Variance and standard deviation of data modelled were obtained to measure the performance of calibration models. To compare the observed rainfall to the selected large scale NCEP data for the time periods of 1975-1990, R-Square and standard deviation were calculated which is shown in table 1. Figs. (2 and 3) show that the observed and simulated precipitation is close to together and there in no significant varies of mean and variance of observed and simulated precipitation.

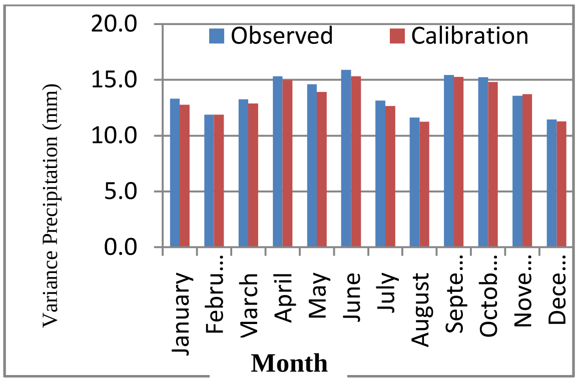

Fig. (2)

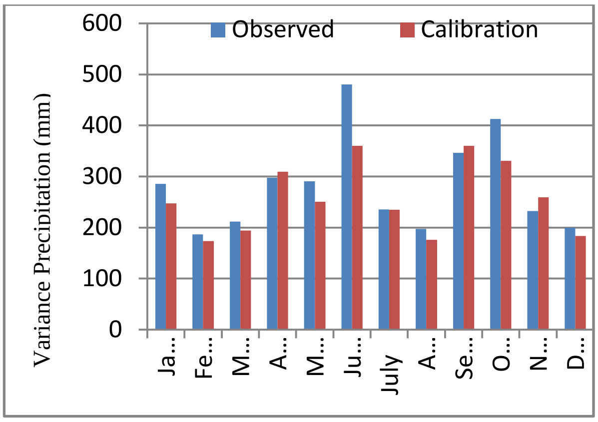

Fig. (3)

Month

Statistical properties such as Mean, Maximum, Variance, Dry-spell and Wet-spell of modelled and observed data for the years of 1991-2001 was run as an independent set of data to check the performance of data calibrated. The simulation of wet/dry spell lengths are run in validation test in climate change studies due to conditional process of precipitation data. Validation test is conducted after getting the agreeable results of calibration test which has been compared with observed data at the same period year. The validation results reveal that the model run is satisfactory validated and it can be seen that there is a remarkable skill of simulation data in compare with observed.

4.2 Calibration and validation of the Rainfall-Runoff model

It has been attempted to assess HEC-HMS model for quality and accuracy of predictive. The Rainfall-Runoff model was calibrated and validated for klang watershed. The calibration period of the hydrological model for the Klang watershed is from 1975 to 1990 as the same period for calibration run period in SDSM simulation. Selection of 16 years period (1975-1990) in the HEC-HMS calibration procedure amplifies the performance of the hydrological modelling particularly in high and low water years. Validation test in hydrology model is important after finalizing calibration data to test the simulation capacity. It is run using independent data by period time (1991-2000).

4.3Changes in precipitation data based on A2 and B2 scenarios

Results of changes in precipitation data as differences between the scenarios and control periods are presented in Figs. (5 and 6). From

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the figures is determined that mean annual precipitation amount are projected to increase in the future for A2 compare B2 scenario.The precipitation experiences a mean annul increase amount by 0.19 %, 5.5 % and 13% for A2 scenario at 2020s, 2050s and 2080 respectively. And 0.4%, 3.5% and 9.6% for B2 scenario at the three time slices above respectively.

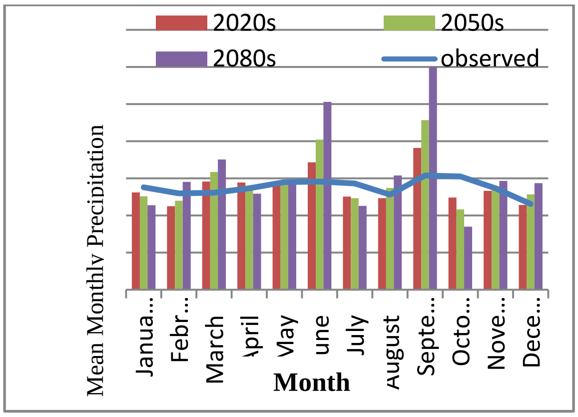

Fig. 5. Average daily mean in the observed and simulated precipitation forcing A2 emission scenario

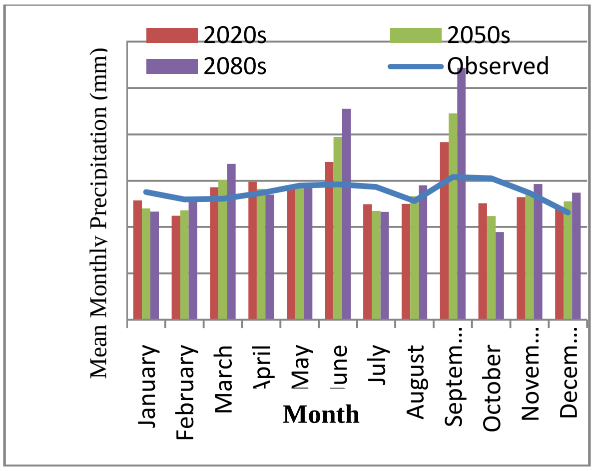

Fig. 6. Average daily mean in the observed and simulated precipitation forcing B2 emission scenario

4.4Changes in runoff patterns

Simulation of runoff is run based on changing in the precipitation corresponding to future climate change in the Klang watershed. Mean precipitation which been generated by SDSM is used as the input into Rainfall-Runoff model in HEC-HMS to simulate the runoff for the future (2100). The climate change impacts on river runoff patterns is carried out in Klang watershed in the future time slice 2010-2040 (the 2020's), 2041-2070 (the 2050's) and 2071-2099 (the 2080's). The simulation of runoff consists of changing in the average monthly mean runoff in Klang river at Sulaiman Bridge discharge gauge. Simulation results of the hydrological model showed that the river runoff patterns will change according to both A2 and B2 scenarios. Major changes are predicted according to the A2 scenario due to it is high value in mean precipitation generated by SDSM than B2.

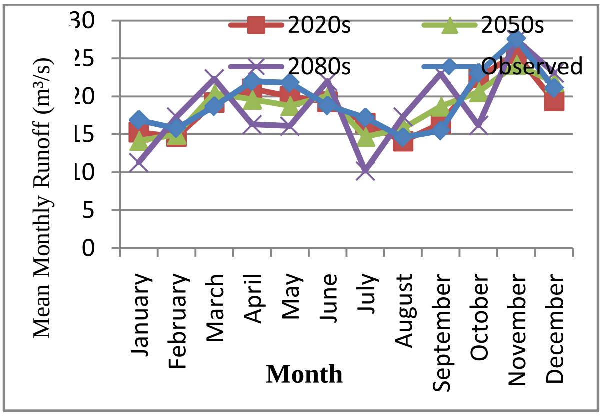

Fig. (7)

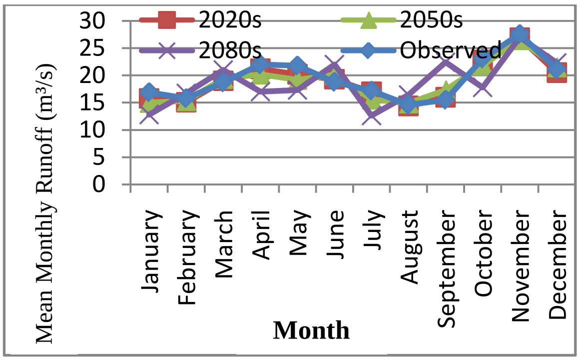

Fig. (8)

In the period from 1975 to 2001, Klang river is characterized by a typical hydrograph of river which consists two main discharge peaks (first during April and second in November) due to high precipitation, and low river discharge in Febuary and August. It is determined that mean annual runoff amount are projected to decrease in the future for A2 compare B2 scenarios. These future changes in the river runoff are compared which are specified as the difference between the scenarios and current periods (1975-2001) runoff. The mean annual runoff is predicted to decrease by 4 % for A2 scenario at 2020s and 2050s, and by 4.5 at 2080. And 2.1%, 2.7 % and 3.3 % for B2 scenario at the three time slices above respectively.

5 Conclusions

The assessment of climate change impacts on river runoff prediction in Klang watershed was studied base on future climate change scenarios A2 and B2 from statistical downscaling driven by GCM-HadCM3. The Rainfall-Runoff model HEC-HMS was used to simulate hydrological processes in the Klang river basin. The results reveal that future precipitation and river runoff regime is expected to be changed. The highest of incremental precipitation likely to be happened on September corresponding A2 scenario. It can be concluded that a probability of flood happens to be higher due to increasing of rainfall intensity. Then, the days with heavy precipitation will be expected to be occurred more frequently during the year. The changes in runoff values considering the control period (1975-2001) will be expected according to the both scenarios. Overall annual river runoff is predicted to decrease in the region. It can be concluded that days with heavy precipitation will occur more frequently causing a higher frequency of high river flow events.

There is a need for further work to reduce and evaluate the uncertainty associated with predictions of future climate conditions and land use, and to test the Rainfall-Runoff HEC-HMS model for a particular basin in another part of the Klang watershed.

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7 References

1 Al-humoud, j. M., and Esen, I. I., 2006. Approximate Methods for the Estimation of Muskingum Flood Routing Parameters. Water Resources Management 20, 979-990.

2 Apsite1, E., Bakute1, A., Elferts, D., Kurpniece1, L., Pallo1, L., 2011. Climate change impacts on river runoff in Latvia. Climate research 48, 57-71.

3 Bolle, H.J., Menenti, M., Rasool, I., 2008. Assessment of climate change for the Baltic Sea basin. Regional Climate Studies. Springer-Verlag, Berlin/Heidelberg.

4 Chu, S. T., 1978. Infiltration during unsteady rain. Water Resources Research 14(3), 461-466.

5 Collins, M., Tett, S.F., Cooper, C., 2001.The internal climate variability of HadCM3, a version of the Hadley Centre coupled model without flux adjustments.Climate Dynamics 17, 61-81.

6 Desa, M.N., and Niemczynowicz, J., 1996. Spatial variability of rainfall in Kuala Lumpur, Malaysia: Long and short term characteristics. Hydrological Sciences 41, 345-362.

7 Dibike, Y.B., Coulibaly, P., 2007.Validation of hydrologic models for climate scenario simulation: The case of Saguenay watershed in Quebec.Hydrological Processes 21(23), 3123-3135.

8 Fowler, H. J., Blenkinsop, S., Tebaldi. C., 2007. Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling. International Journal of Climatology 27, 1547-1578.

9 Ford, D., Pingel, N., Devries, J. J., 2008. Hydrologic Modeling System HEC-HMS ,Applications Guid. Davis, CA: U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC.

10 Fu, G.B., Charles, S. P., 2011. Statistical downscaling of daily rainfall for southeastern Australia. In: Hydroclimatology: Variability and change (Proceedings of symposium JH02 held during IUGG2011 in Melbourne, Australia, July 2011), IAHS Publ. 344, 69-74.