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Stream Flow Projection for Muar River in Malaysia using Précis – HEC-HMS Model

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In this study, the implementation of the Regional Climate Model into the hydrodynamic model has been applied for streamflow projection on a river located at the south of Peninsular Malaysia within the years 2070 till 2099. The data has been obtained from a Regional Climate Model (RCM), named Précis, on a daily basis. It begins by comparing historical rainfall data generated from Précis versus the actual gauged recorded rainfall data from Department of Irrigation and Drainage Malaysia (DID). The bias of the generated rainfall data has been reduced by statistical techniques. The same has been applied to the future generated rainfall data from 2070 to 2099. Using the generated precipitation data as input to the hydrological model, results in the daily output of river discharge identified as the main contributor of flood occurrences. Based on the results of the hydrological model utilised, e.g. HEC-HMS, comparison was made between the future and historical generated discharge data using Précis between the years 1960 till 1998. Dividing a year into three segments, e.g. January-April, May-August, September-December, the results show that there would be a significant drop of peak discharge in the third segment and an increase in discharge during the second segment. The first part remains almost with no changes. As an addition, the drop of the peak shows reduction in the probability of flood occurrences. It also indicates the reduction in water storage capacity which coherently affects the water supply scheme.

Key words: Regional Climate Model; Précis; streamflow projection; flood

INTRODUCTION

Knowledge to predict natural disasters such as floods, earthquakes, etc. have been human's desire. One of the most important elements to face disaster is being prepared of such occurrences. Nowadays, the current available tools such as computer technology have tremendously assisted us in the preparation of any forth coming disaster. Such initials are vital in order to allow sufficient warning system to be implemented.

Weather has always been a popular topic. Nevertheless, nowadays it has sparked more interest and debate as the public has become more concern about unforeseen changes in our climate. The increase in temperature is expected to continue, and by 2100 the average global temperature is likely to be 1.4–5.8 °C warmer (IPCC 2007).

One of the anticipated effects of climate change is the possible increase in both frequency and intensity of extreme weather events such as hurricanes, floods and droughts. The warming of the earth may fuel interactions between the ocean and atmosphere that will amplify the frequency and intensity of extreme weather events.

A prominent indication of a change in extremes is the observed evidence of increases in heavy precipitation events over the mid-latitudes in the last 50 years, even in places where mean precipitation amounts are not increasing. For very heavy precipitation events, increasing trends are reported as well, but results are only available for few areas (IPCC 2007).

Weather events can be classified as extreme through various factors such that the event has economically (insurance costs), socially (loss of life) and environmentally (destruction of habitat) impacts on the region. On the other hand, the deadliest extreme weather events often occur in developing countries where people live in vulnerable, marginalised areas.

Changes in climate around the world especially dramatic temperature increment within last decade has caused many problems for nations around the globe. Most of the time, these problems occur as deadly natural disasters. Malaysia is also a victim of this problem. The 2006-2007 heavy flooding in Johor are the outcome of significant changes in hydrological condition within southern region of Peninsular Malaysia. (Loy, K. *et al.* 2011).

The East coast of Malaysia experiences humidity and heavy rains from November to February, brought by the

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northeast monsoon. The west coast experiences its heavy rains during August. Conditions may vary according to the prevailing monsoon winds at the time. The flood was caused by above average rainfall, which was attributed to Typhoon Utter which had hit the Philippines and Vietnam a few days earlier. By the third week of January 2007, Johor, a state situated at the South of Peninsular Malaysia, was hit by a larger flood due to overflow of two main rivers in the region. Singapore and certain parts of Indonesia were flooded due to the same typhoon.

Throughout the week of December 18, 2006 a series of floods hit Johor, Melaka, Pahang and Negeri Sembilan. During this period, these states located in the south of Malaysia, along with Singapore experienced abnormal rainfall which resulted in massive floods. The rainfall recorded in the city of Johor Bahru on December 19 amounts to 289mm where the annual rainfall of the city alone is 2400mm. In Singapore, the 24-hour rainfall recorded on December 20 was 366 mm, the third highest recorded rainfall in 75 years.

The flooding began when torrential downpours since December 17 caused rivers and dams to overflow. Later that week, beginning December 22, North Sumatra and Aceh experienced abnormal rainfall which also caused flooding. There are fears flash floods could occur in Malaysia more frequently and severely. When a rare event occurs in a region it would be pertinent to investigate the origin parameters of the precipitation that shows different behaviour as compared to the norm. (Sow *et al*. 2011). The idea of utilising part of the results obtained from Regional Climate Model into a hydrological model to determine the changes in the behaviour of a specific hydrological element, e.g. river flow, has recently gained attention among researchers since the issue of global warming has directly effects our habitants.

This study is not only limited within countries in South East Asia, in fact different researchers such as M. Akhtar *et al.* (2009) within the Hindukush-Karakourum-Himalaya region, and also L. Phil Graham *et al.* (2007) within Europe, have utilised similar ideas to study the behaviour of hydrological elements such as river flow.

The methods used are rather similar but the sources of data, e.g. Global Climate Model (GCM) or Regional Climate Model (RCM) are different; depending on the availability of the source. Each researcher prefers either GCM (HadCm3A1B) or RCM (Précis) for the purpose of extraction on atmospheric parameters like precipitation.

On the second phase which is the application of the GCM/RCM output to the hydrological model. There are various hydrological models such as HEC-HMS, HBV and Hec-Ras modelling systems available for researchers to choose. The hydrological model would then be used to determine the behaviour of the river flow.

An ongoing research within Peninsular Malaysia performed by National Hydraulic Research Institute of Malaysia (NAHRIM) is assessing the impact of future climate change on the hydrologic regime and water resources of Peninsular Malaysia. A coupled hydrologic-atmospheric regional model of Peninsular Malaysia, named “RegHCM-PM”, was developed by coupling the MM5 Regional Atmospheric Model of United States, National Center for Atmospheric Research (NCAR), and the regional hydrologic model component of Integrated Regional Scale Hydrologic-Atmospheric Model (IRSHAM). The “RegHCM-PM” model was used to downscale the coarse-resolution (~410km) of climate change simulations of Canadian General Circulation Model (CGCM) to the region of Malaysia at a fine grid resolution (~9km). Downscaling is applied in order to assess the impact of future climate change on the hydrologic regime and water resources of Peninsular Malaysia. The downscaled hydro climatic data over Peninsular Malaysia for the future 2025-2034 and 2041-2050 periods were then compared against the corresponding historical hydro climatic data for the 1984-1993 period in order to evaluate the impact of climate change over the hydrology and water resources of Peninsular Malaysia. The parameters applied include air temperature, rainfall, evapotranspiration, soil water storage and river flow. (Shaaban *et al.* 2006)

In this study, the RCM utilised is Précis, with 25km × 25km resolutions and HEC-HMS as hydrological rainfall-runoff model chosen in order to prepare the hydrograph of Muar River in Johor.

MATERIAL AND METHODS

The observed dataset utilised in this study is the station data from Department of Irrigation and Drainage Malaysia (DID) on a daily basis. The simulated dataset used here is gridded data from Regional Climate Model (RCM) - Précis, using HadCM3A1B as the forcing data and boundary condition. The resolution of grid data utilised in this study is 25km by 25km. The study area is the Muar River watershed, situated within Muar and Segamat districts in the Johor State. It is located at the Southern Region of Peninsular Malaysia.

Since station rainfall gauge data is the best available source of the historical rainfall data, therefore the historical simulated data from Précis during 1960 till 1998 were validated with the actual historical data from DID. The annual cycles of the complete years with no missing rainfall data should be sorted out for all the 13 active stations in the Muar River watershed. The average of the cycles is calculated to represent the behaviour of the rainfall pattern within the region at the duration of 1960 till 1998.

Comparison between historical observed and historical simulated rainfall data has been made based on the average annual cycles of each. The Absolute error technique (M. A. Malek *et al.* 2009) is utilised to the average annual cycles in order to find the percentage of difference between the observation and simulation.

$$\text{Absolute Error} = \left[\frac{\sum_{1}^{365} \left(\frac{\text{Simulated data} - \text{Observed data}}{\text{Observed data}} \right)}{365} \times 100 \right] \quad (1)$$

To reduce the bias between two diagrams, i.e. observation's and simulation's average annual cycle, a statistical method is introduced. Bias Corrections were performed on the past simulated data. It was then applied directly to the future data, i.e. precipitation. To smooth the annual cycle diagrams, the moving average method is applied based on the least value of absolute error between observed and unmodified simulated rainfall data.

Figure 1 shows the observation rainfall (yellow) graph and simulated rainfall (red) graph has continues differences along the annual cycle. In general, the main peak of the annual cycle falls almost in the month of April and the dip of the cycles are in January to February. The simulated rainfall annual cycle is high in magnitude from April to December compared to the observe rainfall annual cycle. The fluctuations of the observed annual cycle graph are more severe than that of the simulated annual cycle graph. The graphs of both observed and simulated annual cycles vary in the same boundary from February to April.

Bias Correction

It is widely accepted (Feddersen *et al.* 2005) that outputs from GCMs and RCMs cannot be directly use to force hydrological models without removing the biases. There exist statistical downscaling methods to correct GCM predictions relative to observed climate. Quantile mapping has been used to correct bias of monthly precipitation (Wood *et al.* 2004). The corrected daily precipitation was constructed from GCM output by adjusting cumulative distribution function (CDF) separately for each of the 12 calendar months (Ines *et al.* 2006).

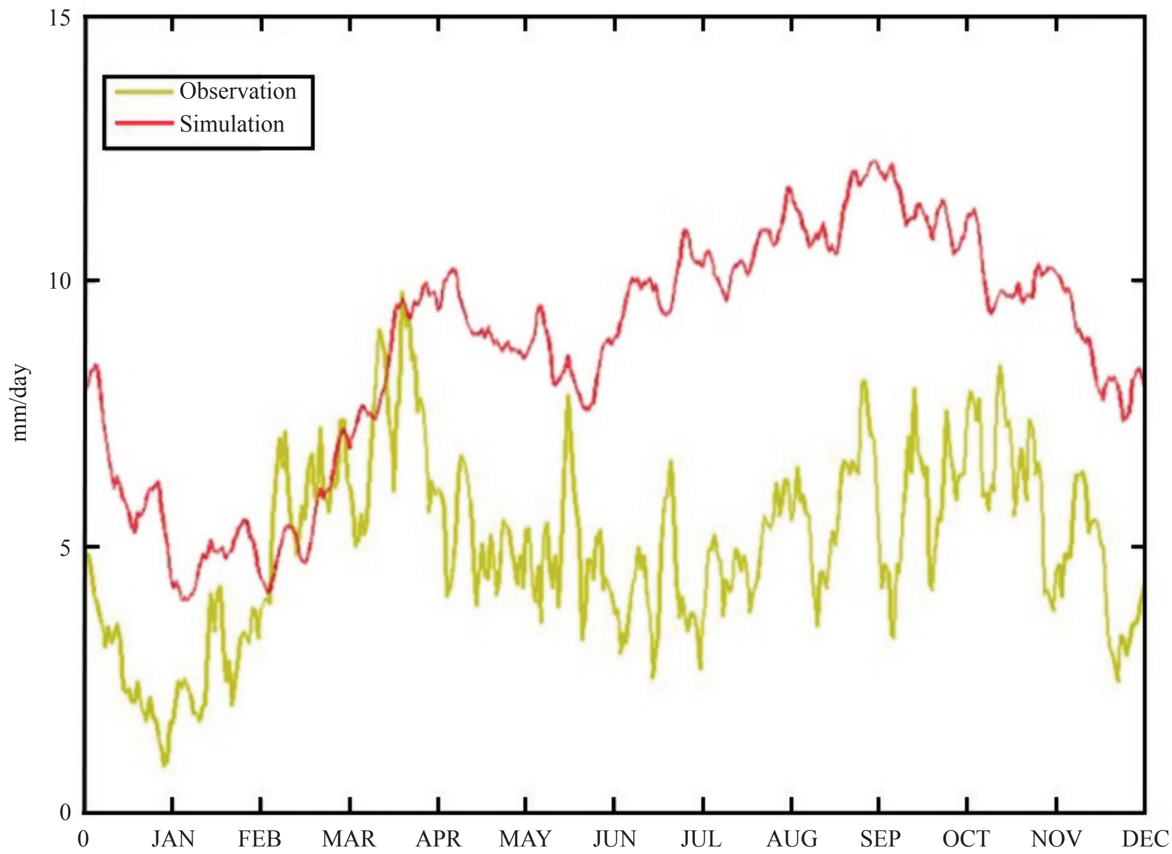

Figure 1. Observation rainfall versus unmodified simulated rainfall

A statistical method was chosen to reduce the bias occurred in the simulated precipitation data with respect to the observation data as in Figure 2. A correction function was then developed for this purpose. (J. Sennikovs *et al*. 2009)

The gamma distribution, being zero bounded provides a reasonably good fit to rainfall data. This has been widely used by many researchers (Mooley 1973; Hutchinson 1990; Ropelewski *et al.* 1985). In probability theory and statistics, it is a two-parameter family of continuous probability distributions.

Let x denotes the considered variable, F(x) denotes the CDF of x. The particular simulated daily value of RCM model (x_{sim}) to modified (bias-corrected) value of (x_{mod}) at particular observation station is:

$$xmod = F^{-1}_{\text{obs}}\,(F_{sim}\,(x_{sim})) \tag{2}$$

Cumulative Distribution Function (CDF)

The cumulative distribution function is the regularised gamma function:

$$F\ (x;\ k;\ \theta) = \int_0^x f(u;\ k;\ \theta)du = \frac{\gamma(k,\ \frac{x}{\theta})}{\Gamma(k)} \tag{3}$$

Where $\boldsymbol{\theta}$ is the scale parameter, k is the shape parameter and is the gamma function. The cumulative distribution function would be utilised to find the probability of rainfall on daily basis. In the other words, it provides the probability values for 365 days a year.

The bias correction is performed in a way to have equal probabilities of particular daily parameter for both observed

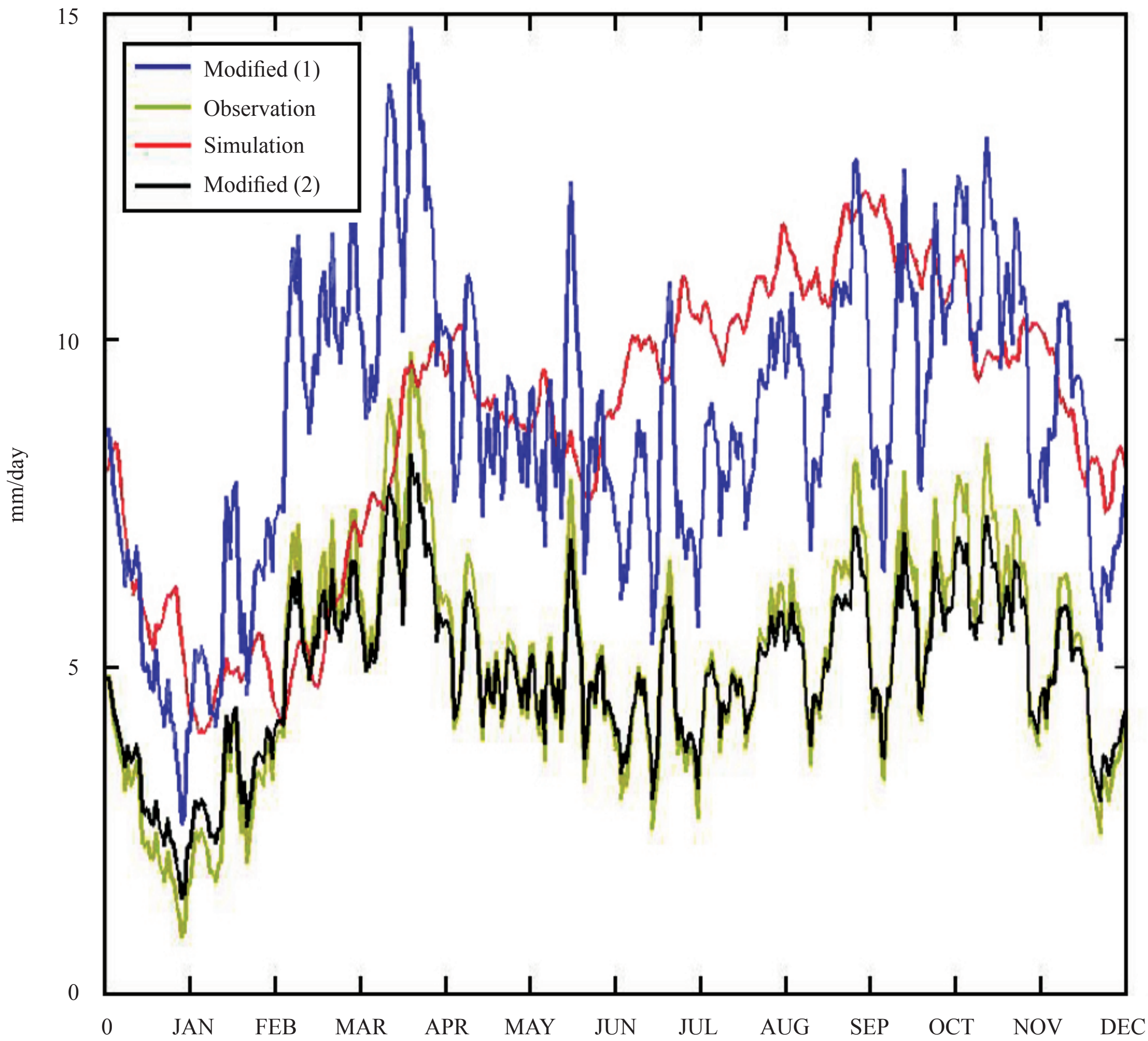

Figure 2. 31-days moving average of Bias correction's steps for one station

and corrected RCM data (J. Sennikovs *et al.* 2009). Obtaining the CDF values of daily simulated Précis data, using simulated data parameters, will invert them from the observed data. This will provide significant reduction in the bias of simulated rainfall data from Précis versus DID recorded rainfall data.

Division is made between observed and simulated data within a complete annual cycle. The average value among them is taken. This would result in finding the best Modification Factor to implement on the past simulated data from 1960 to 1999 for each station. Applying the modification factor to the corrected simulated data will result in a very small bias.

$$\text{Modification Factor} = \frac{\sum_{1}^{365}\left(\frac{-\text{ Observed data}}{\text{Corrected simulate data}}\right)}{365} \quad (4)$$

In this study, similar correction procedures were applied to the future rainfall data simulated from the model, where shape and value corrections were employed in the first and second step respectively.

Hydrological Model

In order to use HEC-HMS as the hydrological model, additional information regarding the basin conditions is required. Digital Elevation Map (DEM) of the study area (Figure 3 and 4) was used to obtain additional information on the watershed of Muar River. The DEM used in this study was obtained from the Shuttle Radar Topographic Mission, (SRTM) with resolution of 90m × 90m.

The HEC-GeoHMS was used to process the details of river watershed. The details required are the area and centroids' coordinates located beside the slope of the river in each sub basin. The shape file of the river basin was obtained from HEC-GeoHMS. These properties were then applied to the hydrological model in order to obtain the river flow.

Simulation of the hydrological model was then performed for the desired duration from January 1960 to December 1998, and January 2070 to December 2098. The results obtained were sorted into annual cycles in order to analyse the behaviour of future peaks as compared to the past hygrograph's peaks.

RESULTS AND DISCUSSION

The average daily discharge of Muar River at the four points within the catchment (upstream, mid catchment, downstream and the outlet to the sea) is illustrated in the Figures 5 to 8 respectively. All the data is within a year of 365 days and the unit for the river discharge is m^3/s.

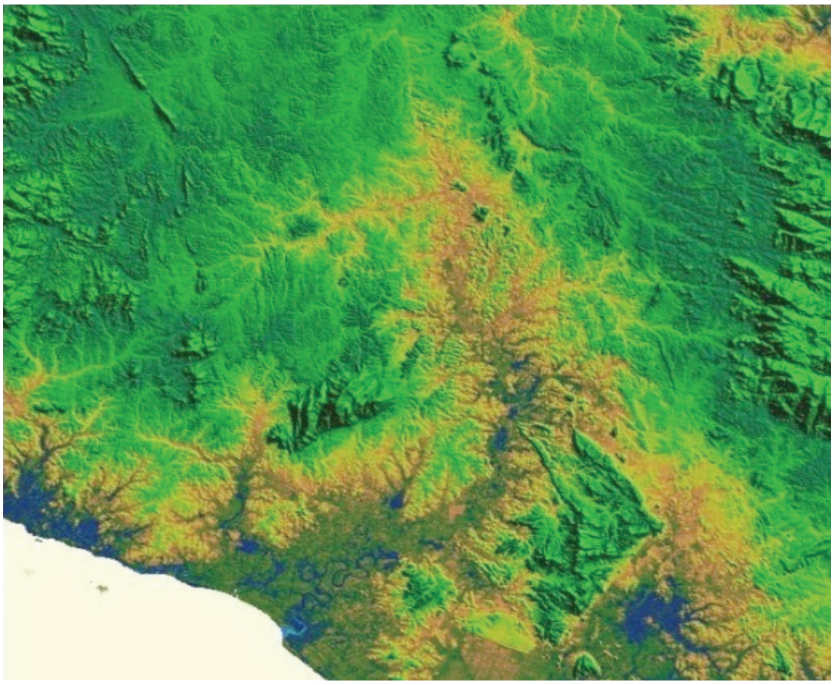

Figure 3. Raw DEM of the river watershed

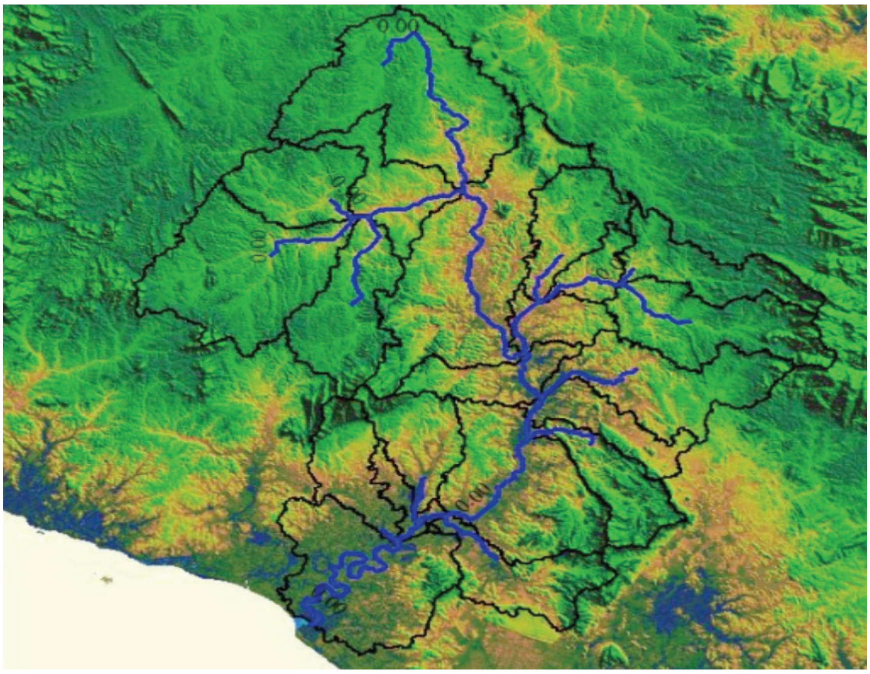

Figure 4. DEM of river watershed with sub basins

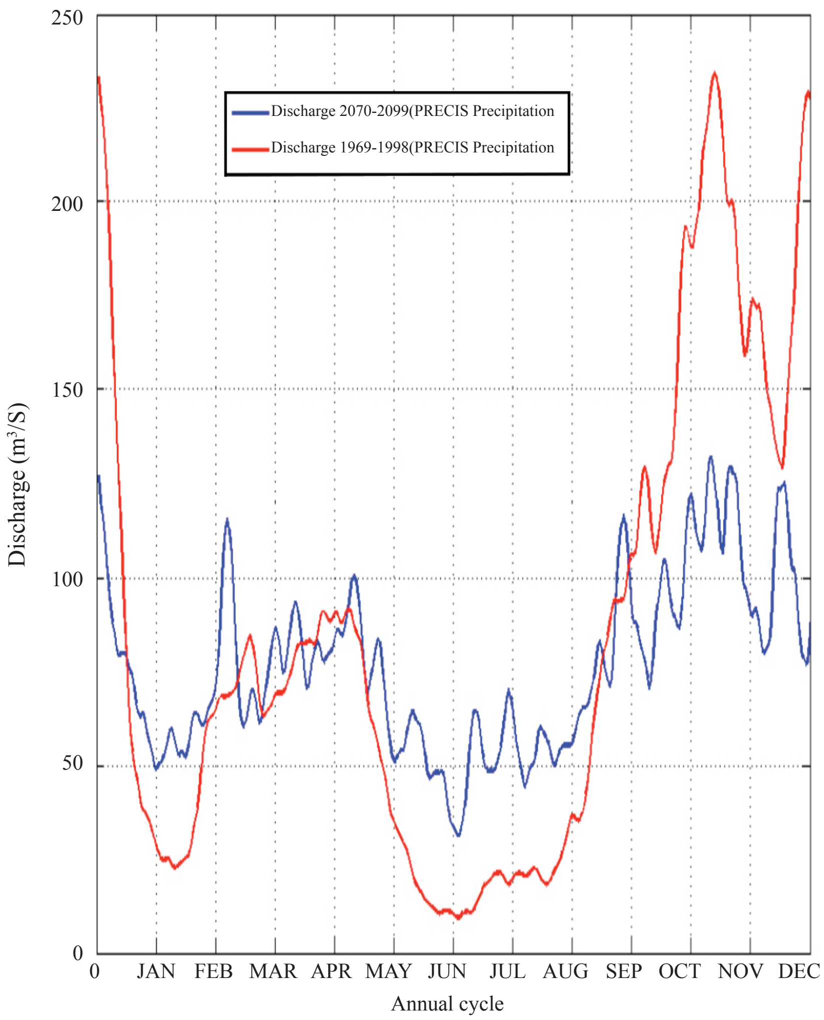

Figure 5. Daily average discharge at the upstream

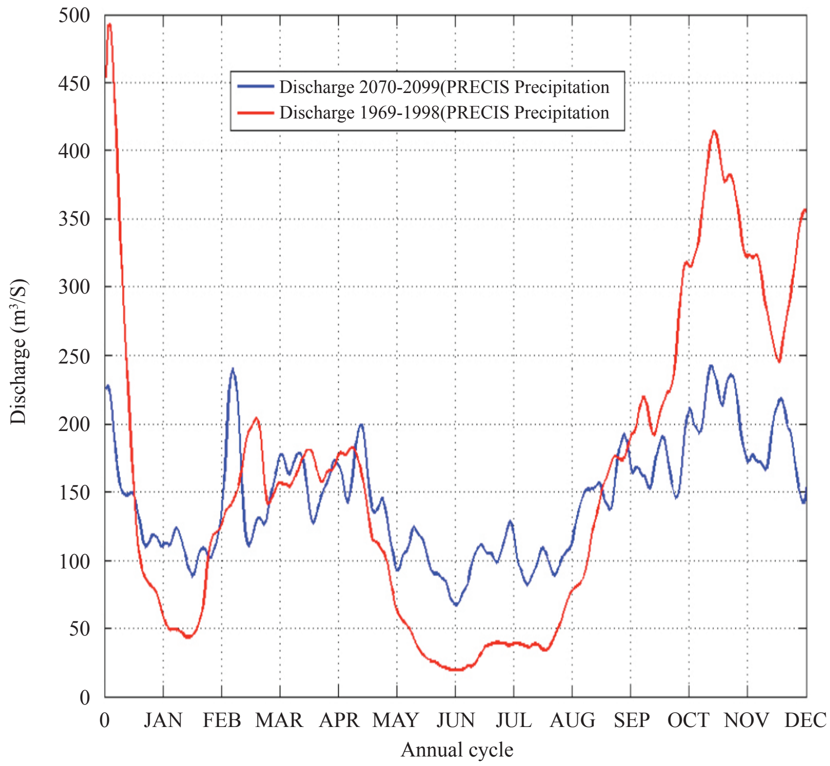

Figure 6. Daily average discharge at mid catchment

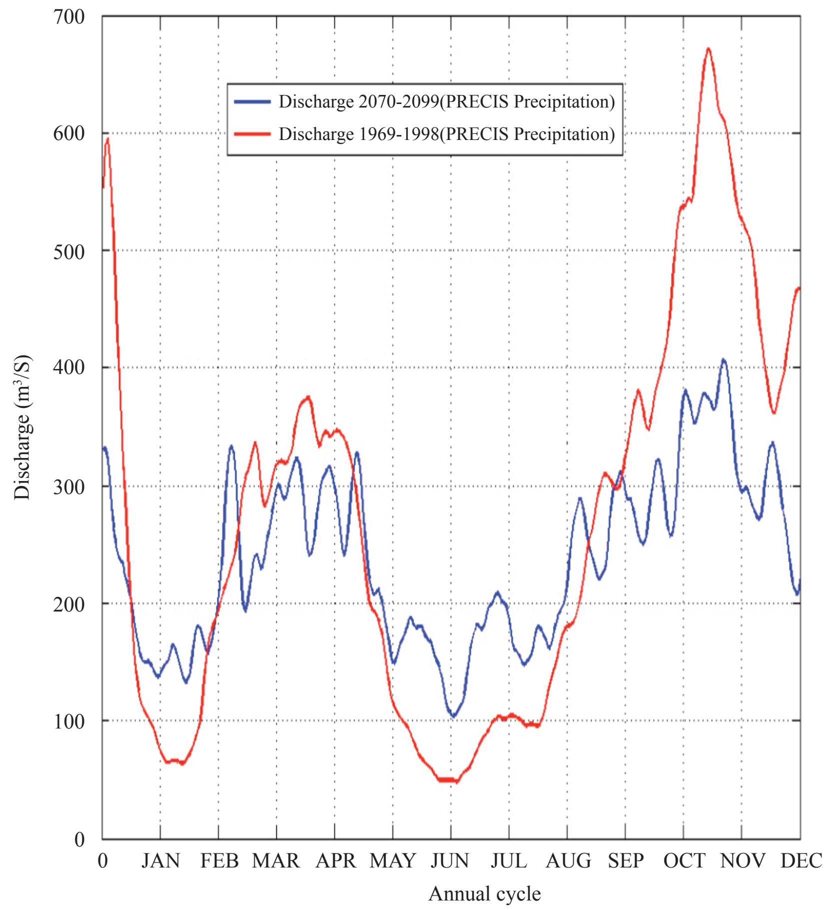

Figure 7. Daily average discharge at the downstream

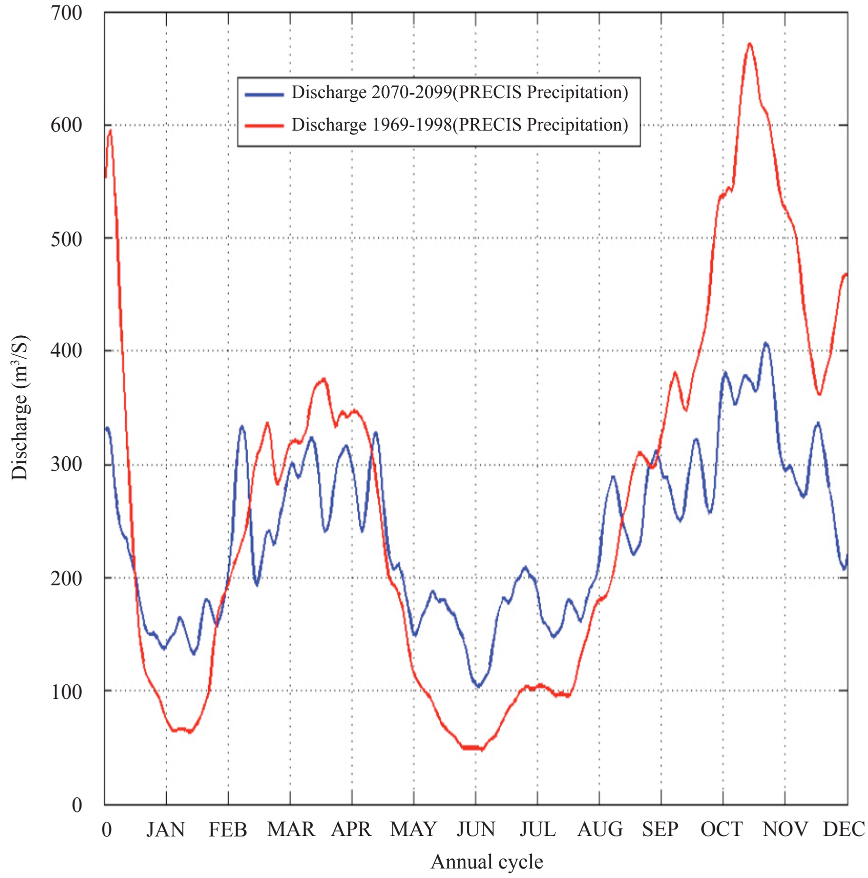

Figure 8. Daily average discharge at the outlet to sea

The maximum and minimum discharges from Figure 5 to 8 are summarised in Table 1. The values in Table 1 are the averages for each of the 4 months.

Conducting the hydrological model with precipitation data obtained from Regional Climate Model (Précis) and other boundary conditions will produce river run-off hydrographs within the same duration of the precipitation data prepared. The model was generated three times at three different sets of precipitation data. (DID data, past simulated data from Précis and future simulated data from Précis)

The number of observation data for precipitation is found to be less as compared to the generated precipitation data. The

Table 1. Summary of the average values of discharges at four points shown in Figures 5 to 8 along the Muar River

	Description	Jan-Feb-Mar-Apr (m^3/s)	May-Jun-July-Aug (m^3/s)	Sep-Oct-Nov-Dec (m^3/s)
Down stream	Average of discharge with Précis historical data	247.4	130.40	427.2
	Average of discharge with Précis future data	229.3	186.3	298.4
Mid catchment	Average of discharge with Précis historical data	152.7	62.2	164.8
	Average of discharge with Précis future data	143.5	112.04	145.4
Upstream	Average of discharge with Précis historical data	72.9	32.07	91.8
	Average of discharge with Précis future data	74.4	59.4	77.9
Outlet	Average of discharge with Précis historical data	247.7	130.7	280.3
	Average of discharge with Précis future data	236.4	192.1	249.3

generated precipitation data are the results of interpolation between four points of a grid box with resolution of 25 km × 25 km.

The only possible situation for the generated precipitation data to be equal zero is that all four points (respective points of the grid box to the specific stations) are equal to zero which rarely happens since an area of (25 km × 25 km =) 625 km^2 in this region has less probability of not having any rainfall. The 25 km × 25 km grid box is the result of a bigger downscaled grid box (150 km × 150 km – HadCM3).

Figure 9 shows the comparison between three Average Annual Cycles from recorded rainfall versus past simulated rainfall by Précis and future simulated rainfall data by Précis. All data is within a year of 365 days and the unit for the river discharge is m^3/s. The highest and lowest discharges obtained are summarised in Table 2. In general, the position of the hydrographs' peaks and dips are similar. Despite of their magnitudes, the discharge trends remain in the future.

The discharge pattern for the future tends to have more fluctuation in the annual cycle which is the direct result of the fluctuated precipitation that has been applied in the HEC-HMS. In fact, if these fluctuations of discharge have large magnitudes within a very short period such as one or two days, it may result in flash floods within the study area. This matter will be further aggravated, since the Muar River is located near the intersection to the sea.

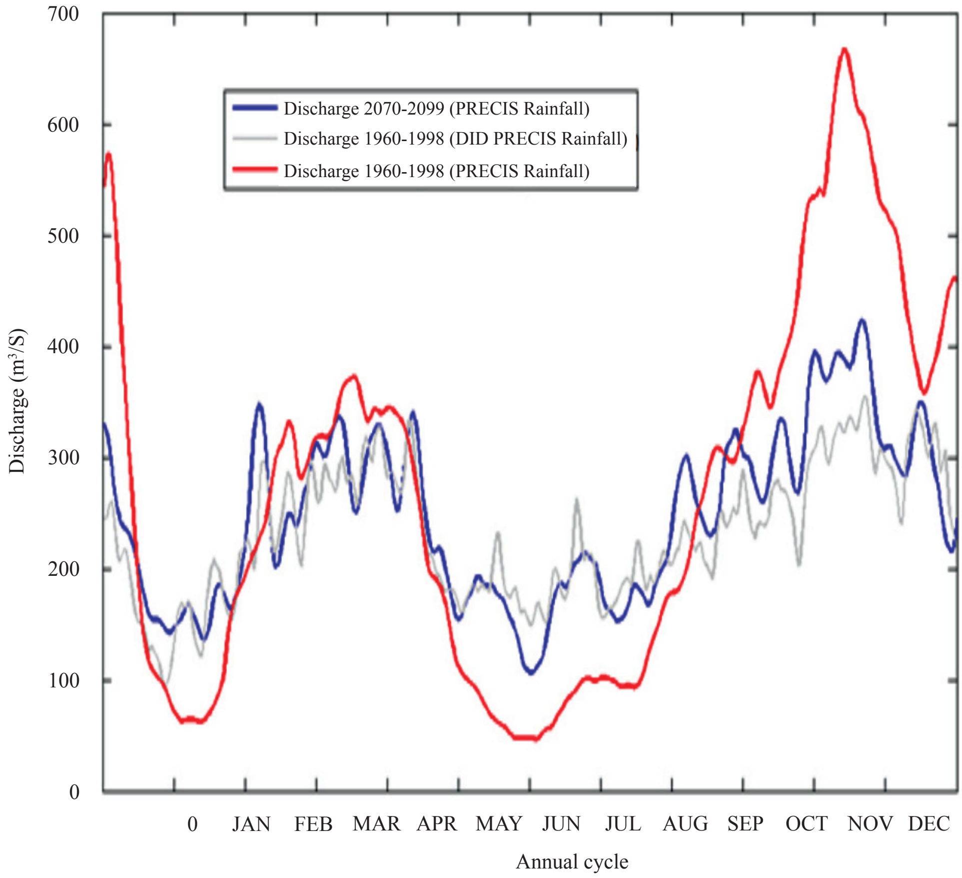

Figure 9. Comparison between three averages annual cycles

Table 2. Average of the values categorised into three segments of the year

Description	Beginning (m^3/s)	Middle (m^3/s)	End (m^3/s)
Average Future Data	236.13	190.63	310.92
Average Past Data	243.97	125.88	424.58
Average Department of Irrigation and Drainage Malaysia Data	218.72	199.42	273.81
Total Average	232.94	171.98	336.44

By dividing the whole year into 3 equivalent segments (3 × 120 days ~ 365 days [1-120, 121-240, 241-365 days]), the diagram can be interpreted in three stages, which are beginning, middle and end part of the year. As plotted in Figure 9, the average intensity of the discharge can be described in three levels as medium for the beginning, low for the middle and high for the end of the year. The values are summarised in Table 2.

It is found that the risks of floods occurrences within the end part of the year (September to December) are much greater as compared to the beginning and middle of the year. The predicted highest discharge value can be obtained from the end part of the year. The results also show that the middle segment of the year has the least discharge compared to the other two segments which led us to trigger the alarm of experiencing drought in the region of the Muar district.

Concentrating on the future discharge and comparing it to the discharge from generated Précis, precipitation data of 1960-1999 leads to the following discussions:

Results obtained from Précis – HEC-HMS model show that, the discharge values obtain for the future is projected to be reduced, where the average magnitude of the peak hydrograph at the end segment has reduced significantly from 425 m^3/s to 311 m^3/s. Such drops can be explained due to the reduction of precipitation in the future during September to December, as simulated by the Précis model.

Drop of the peak in the end segment of the annual cycle can be interpreted as reduced discharge values during the last four months of the year. Considering the middle segment of the graph (May to August), the average value of future discharge generated by Précis as compared to the past has increased of about 65 m^3/s, from 126 m^3/s to 191 m^3/s. Increment of the discharge value within this segment indicated that drought is not likely to occur. On the other hand, the beginning segment of the future graphs has the least variation as compared to the past, at 236 m^3/s for the future, whereas 244 m^3/s for the past.

CONCLUSION AND RECOMMENDATION

This study is being undertaken at a time when the issue of climate change is highly controversial. Applying modern computer science in various fields allows us to explore into possible predictions. In other words, the interplay between applications and the more humanistic aspirations continues to inspire challenging questions.

In this study Muar River is chosen to be analysed since it is the main river in Johor where the floods of 2006 December and 2007 January occurred. Due to the importance of the Muar River, it is recommended that Department of Irrigation and Drainage Malaysia install more flow meters in order to record accurately the stream flow within this catchment. It is also recommended that similar studies should be performed on other rivers where full recorded stream flow data is available.

Simulation of the river flow with HEC-HMS using the Précis model to generate future precipitation data shows the future trend of discharges at the Muar River. The magnitudes are expected to change in the future as there is expectation of reduction in the northeast monsoon and increment in the southwest monsoon at the study area. Reduction of discharge in northeast monsoon can be interpreted as reduction in probabilities of flood occurrences. The increase of discharge in southwest monsoon will be a reduction in drought occurrences.

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