Malaysian Journal of Civil Engineering 25(1):33-44 (2013)

IMPACT OF CLIMATE CHANGE ON RAINFALL OVER KERIAN, MALAYSIA WITH LONG ASHTON RESEARCH STATION WEATHER GENERATOR (LARS-WG)

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Abstract: General circulation models (GCMs) have been widely used in the climate community, to generate the future climate variation based on the climate scenarios. However, the GCMs' variables need to be downscaled into a fine resolution before they can be applied for the climate impact assessment. Therefore, Long Ashton Research Station Weather Generator (LARS-WG), which utilized the Stochastic Weather Generators, is applied. The catchment at Kerian, located at the state of Perak, Malaysia had been chosen as the case study. Based on the LARS-WG simulation result, the rainfall trend is not much different from the present. From January until April and December, the daily rainfall is expected to decrease continuously for every interval future period. From May until November, the decrease of future daily rainfall is expected to happen. The annual rainfall pattern illustrates that the annual rainfall intensity is concentrated on the area at the upper stream of river (Selama and Batu Kurau) and it is expected to increase continuously for every interval future period.

Keywords: *Downscaling models, annual rainfall, climate model, every interval, global climate, climate change, rainfall corresponding*

1.0 Introduction

Climate change has become a great issue in the future in which an availability of water in years to come, can be doubt. The human activities, primarily the burning of fossil fuels and the changes in land cover and use, are believed to contribute to this problem. Therefore, there is a growing need for an integrated analysis that can quantify the impacts of climate change on the various aspects of water resources such as precipitation, hydrologic regimes, drought, and dam operations.

To estimate the future climate change, general circulation models (GCMs) are applied. GCMs are a computer based-model of the Earth system and are used mathematically to simulate the present and the project future climate, which is reinforced by greenhouse gases and aerosols. The GCMs output cannot directly be used for the hydrological assessment due to their coarse spatial resolution (Karamouz *et al*., 2009). Therefore, Long Ashton Research Station Weather Generator (LARS-WG), which utilized the Stochastic Weather Generators approach, is applied in order to convert the coarse spatial resolution of the GCMs output into a fine resolution.

The objective of this study is to downscale the current and the future daily rainfall corresponding to the GCMs-variables by applying the LARS-WG model.

2.0 Study Area and Data

The studied area (Figure 1) selected for this study is the Kerian catchment, which is located at the Northern Peninsular Malaysia, in the state of Perak. This catchment has two main rivers, which are as Kurau River and Kerian River. This area had been selected as the studied area because at the downstream of basin, a dam (named as Bukit Merah Dam) that acts as a main drainage for the paddy field and a sources of water suply is located. Hence, an assesment of the climate impact will give an insight upon which appropriate decisions about the water recourse's development can be made in the future.

The observed daily rainfall is used in this study. This data was obtained from the Department of Irrigation and Drainage Malaysia (DID). Arithmetic Mean Method is used to fill the missing daily rainfall. It can be defined as Eq. 1, where P_X is the missing rainfall value for station X; P_i is rainfall values at the adjacent stations for the current period; and n is the number of nearby stations:

$$P_x = \frac{1}{n}\sum_{i=1}^{n} P_i \tag{1}$$

The details of rainfall stations are illustrated in Table 1. 30 years of daily data series for daily rainfall (1961-1990) were used.

3.0 Materials and Methods

Long Ashton Research Station Weather Generator (LARS-WG) had been utilized by using a spell-length approach. The lengths of wet and dry spells are sampled from a semi-empirical distribution defined by a histogram of 10 intervals. Random deviates are sampled. It is done by randomly selecting one of the intervals, and then by selecting a value within that interval from the uniform distribution. The same form of semi-empirical distribution is used for wet-day precipitation amount and daily solar irradiance. Selection of the semi-empirical distribution of R_s is conditioned on precipitation (Mavromatis and Hansen, 2001 and Tukimat & Harun, 2011).

The recent LARS-WG model was applied in the paper, namely as LARS-WG 5.0. This model is a freeware and can be downloaded directly from *http://www.iacr.bbsrc.ac.uk/mas-models/larswg.html*. The input data of LARS-WG were sets of time series data of rainfall, maximum temperature, minimum temperature and solar radiation. However, the LARS-WG model works with the rainfall data alone and with rainfall plus any combination of the other input data. Therefore, only rainfall data was being run in this study. The sequence of study is exhibited in Figure 2 and each step are discussed below.

Table 1: Rainfall stations for LARS-WG

IDs of Stations	Names of Stations	River Basins	Location	
			Latitude	Longitude
4906022	Stn. Petak Ujian Selinsing	Kurau River	04^0 57’ 10’’	100^0 37’ 50’’
4907019	Ldg.norseman	Kurau River	04^0 57’ 55’’	100^0 45’ 50’’
4908018	Pusat Kesihatan Kecil	Kurau River	04^0 58’ 45’’	100^0 48’ 15’’
5004027	Rumah Buroh Kuala Kurau	Kurau River	05^0 01’ 10’’	100^0 26’ 10’’
5005010	Ldg. Sg. Kerian	Kurau River	05^0 04’ 20’’	100^0 34’ 10’’
5006021	Kolam Air Bkt. Merah	Kurau River	5^0 01’ 06’’	100^0 39’ 11’’
5007020	Ldg. Pondoland	Kurau River	05^0 00’ 35’’	100^0 43’ 50’’
5104012	Stn. Petak Ujian Titi Serong	Kerian River	05^0 06’ 10’’	100^0 27’ 25’’
5106004	Ldg. Lumboh Kluang	Kerian River	05^0 09’ 45’’	100^0 39’ 10’’
5106008	Ldg. Hibernia	Kerian River	05^0 08’ 15’’	100^0 41’ 50’’
5107006	Ldg. Stoughton	Ijok River	05^0 06’ 25’’	100^0 46’ 20’’
5108005	Ibu Bekalan Ulu Ijok	Ijok River	05^0 07’ 20’’	100^0 48’ 20’’
5207002	Ldg. Seldings	Kerian River	5^0 15’ 05’’	100^0 43’ 40’’

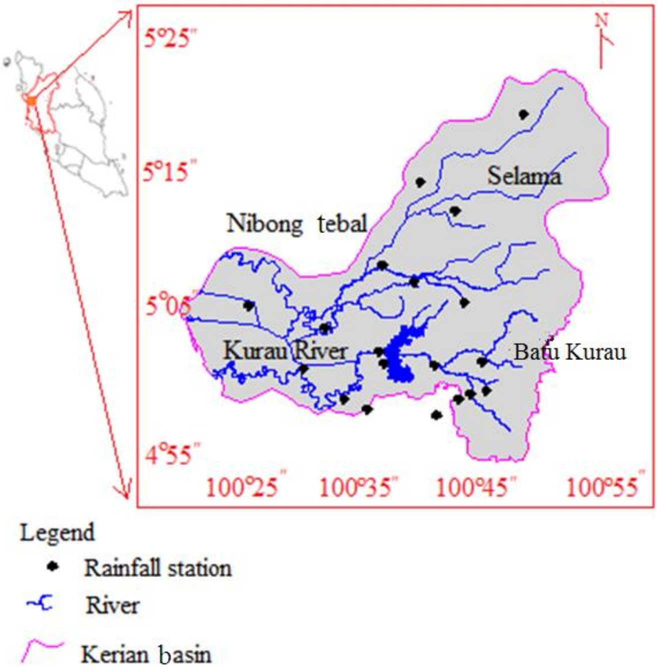


Figure 1: Location of case study

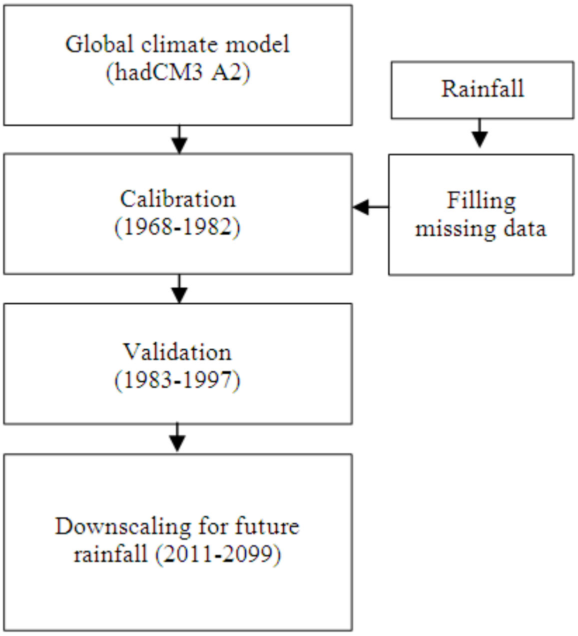


Figure 2: The sequence of the study

3.1 General Circulation Models

HadCM3 with A2 scenario has been used as a general circulation models (GCMs). This model is a coupled atmosphere-ocean GCMs which has been developed at the Hadley Centre of the United Kingdom's National Meteorological Service. The GCMs contain a complex model of land surface processes, includes 23 land cover classifications, four layers of soil where temperature, freezing and melting are tracked, and a detailed evapotranspiration function that depends on temperature, vapour pressure, vegetation type and ambient carbon dioxide concentrations (Mohammed, 2009). HadCM3 was chosen because this model is widely used in many climate-change impact studies. Furthermore, it has the ability to simulate for a period of thousand years and it shows a little drift in its surface climate (McCarthy *et al*., 2001). The A2 scenario is considered as among the worst case scenarios, projecting high emissions for the future and the case study identified in this scenario.

3.2 Calibration and Validation

Calibration was carried out using the "Site Analysis" function on the main menu of the LARS-WG model, which aimed to determine the statistical characteristics of the observed weather data. 30 years (1961-1990) of daily rainfall data was used and divided into two period times, which are 1961-1985 for calibration period and 1986-1990 for validation period. Once the model had been well calibrated, then it needed to be validated by using independent daily rainfall data, which was not being used during calibration. It is a process to determine how well the model performs.

Performance during the calibration and the validation was checked by using the statistical parameters which are mean daily rainfall, variance, average dry-spell length and average wet-spell length for all months of the year. The performances was also checked by using coefficient of correlation (R), which is defined as;

$$R = \frac{\sum\left(\mathrm{obs} - \overline{\mathrm{obs}}\right)(\mathrm{pred} - \overline{\mathrm{pred}})}{\sqrt{\sum(\mathrm{obs} - \overline{\mathrm{obs}})^2 \sum(\mathrm{pred} - \overline{\mathrm{pred}})^2}} \tag{2}$$

where, obs = observed stream flow value; pred = predicted stream flow value; $\overline{\mathrm{obs}}$ = mean streamflow observed value; and $\overline{\mathrm{pred}}$ = mean streamflow predicted. R measures how well the predicted values from a forecast model fit with the real-life data, with a perfect fit gives a coefficient of 1.0.

3.3 Downscaling for Future Rainfall

The production of regression weighted during the calibration process was applied into downscaling for future rainfall. The assumption of the relationship between daily rainfall and the GCMs variables under the observed conditions is remain valid for the future climate conditions. The synthetic daily time series of rainfall corresponding to the HadCM3 A2 is produced for 2011 until 2099. The outcome will be averaged and divided into three (3) periods of time, which are 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099).

4.0 Results

4.1 Calibration and Validation of LARS-WG Model

Figure 3 shows the calibration results of the LARS-WG model downscaled at the station gauge 5007020. There was under estimate for the mean daily rainfall and the rainfall variance, from January until Jun. However, from September until November, the model can simulated well for the daily rainfall and the rainfall variance. Moreover, the figure gives satisfied results in term of the average dry-spell and wet-spell.

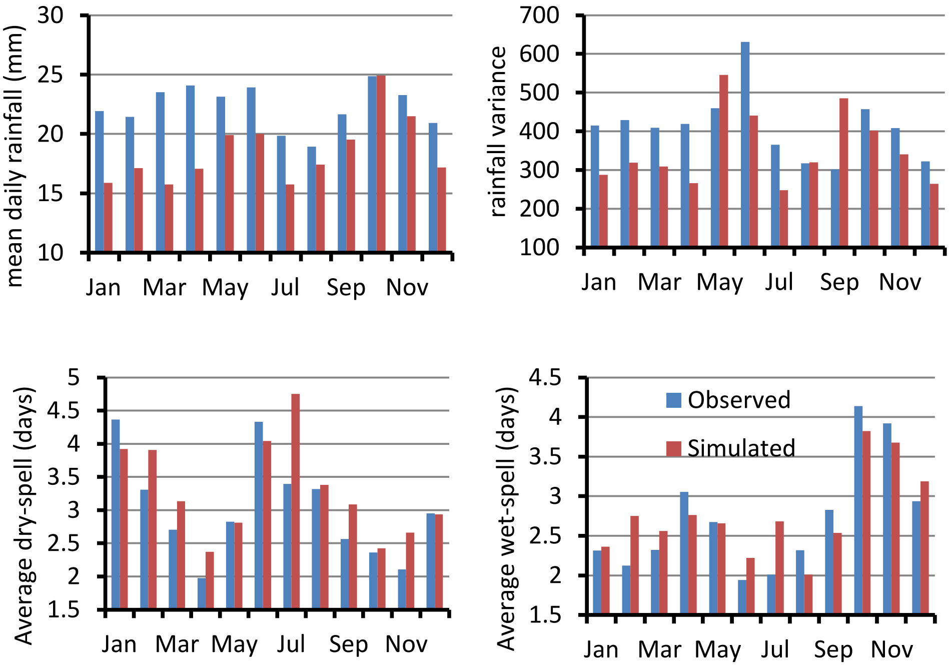


Figure 3: Calibration result of LARS-WG model downscaled (1961-1975) for daily precipitation at station 5007020

Meanwhile, the validation results for the station gauge 5007020 are illustrated in Figure 4. The graph of the mean daily rainfall, rainfall variance and the dry-spell give a good agreement between the observed and the simulated data. However, the graph of wet-spell shows an under-estimated for the several months such October and November. It is difficult to improve this result since the improvement of the wet-spell's result will automatically affect~~s~~ other variables of rainfall, which originally well calibrated.

The performances of calibration and validation results in-term of daily and monthly rainfall are exhibited in Table 2. The model is unable to simulate well for daily rainfall series as shown in that table, in which it produces R<0.1. However, the model gives a better simulation result for monthly rainfall series, in which it produces R>0.1.

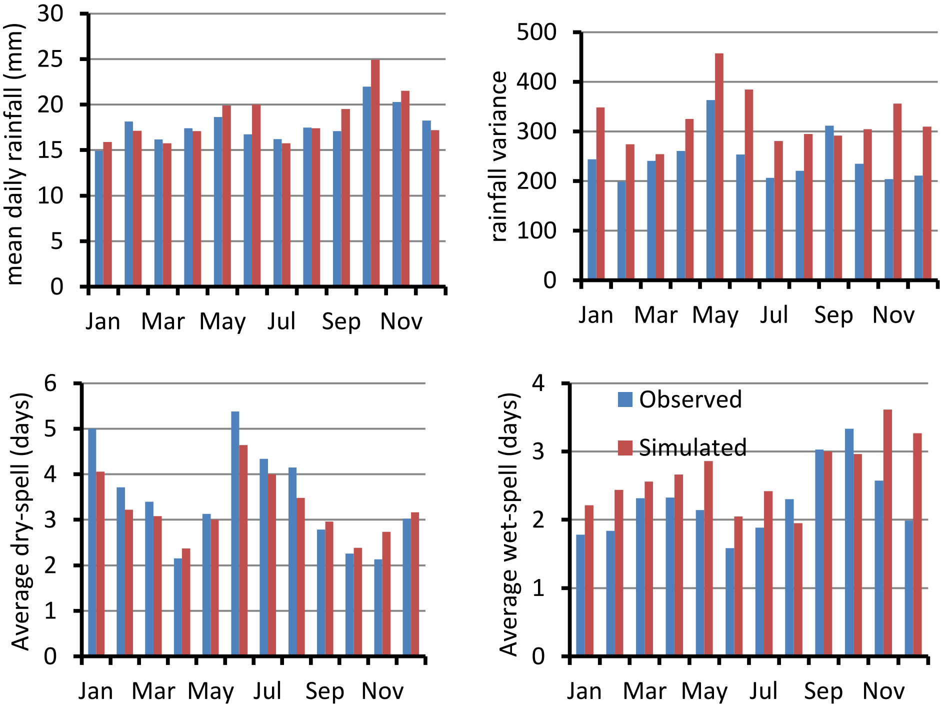


Figure 4: Validation result of LARS-WG model downscaled (1976-1990) of daily precipitation at station 5007020

Table 2: Performance (R) of the LARS-WG model during calibration and validation

Station No.	Daily		Monthly	
	cal	val	cal	val
5108005	0.0152	0.0211	0.3427	0.2613
4905023	0.0046	0.0313	0.3075	0.2840
4906022	0.0135	0.0034	0.2001	0.3294
5004027	0.0273	0.0174	0.2336	0.3235
5005010	0.0001	0.0448	0.2356	0.2636
5006021	0.0423	0.0342	0.4873	0.2931
5007020	0.0441	0.0239	0.4279	0.2366
5104012	0.0143	0.0146	0.3414	0.1159
5106004	0.0294	0.0345	0.3144	0.3172
4907019	0.0143	0.0098	0.2666	0.2744
4908018	0.0255	0.0513	0.2444	0.3276
5107006	0.0441	0.0267	0.3543	0.2662
5108005	0.0153	0.0211	0.3427	0.2552

4.2 Downscaling for Future Rainfall

Figure 5 shows a general trend of mean daily rainfall corresponding to a climate change scenario downscaled with LARS-WG at station gauge 5007020. It shows a decreasing trend from January until April, followed by an increase from May until December. In the December, a decrease in mean daily rainfall is exhibited.

The spatial distribution of annual rainfall in the present period is illustrated in Figure 6a and corresponding to LARS-WG is illustrated in Figure 6b, 6c and 6d for 2020s, 2050s and 2080s respectively. From all graphs, there is a remarkable spatial difference of changes in the intensity of annual rainfall. In the 2020s (Figure 6b), the analysis found that there is an increase in intensity of annual mean rainfall for all distributions of the catchment area compared to the the present period (Figure 6a) However, there is a decrease in intensity as illustrated in the 2050s (Figure 6c). The decrease is obviously happened especially at the area of paddy field at the left side (Piandang and Kuala Kurau) of catchment area, in which it gives a decrease in intensity of annual rainfall. Conversely, in the 2080s (Figure 6d), the intensity of the annual rainfall is increased with the same condition as shown in the 2020s. From the observation, the area of Bukit Merah Dam, which is located at the middle of catchment, will face an increase in an intensity of the annual mean rainfall. However at area of agriculture, which is located at the left side of the basin (Tanjung Piandang and Kuala Kurau), will face a decrease for the received rainfall.

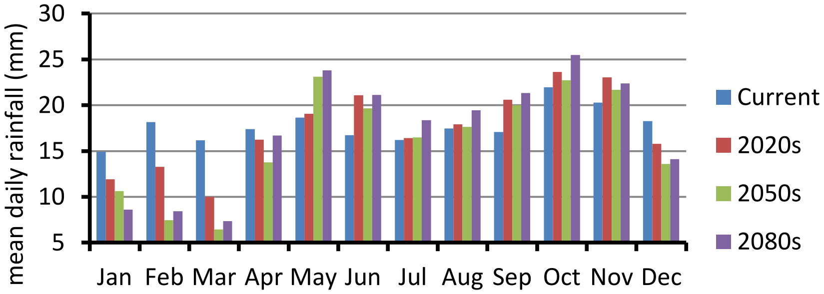
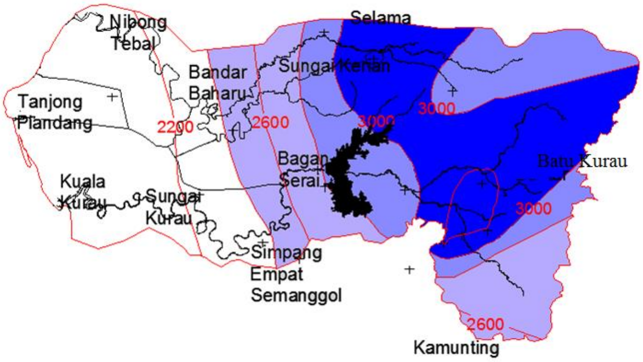
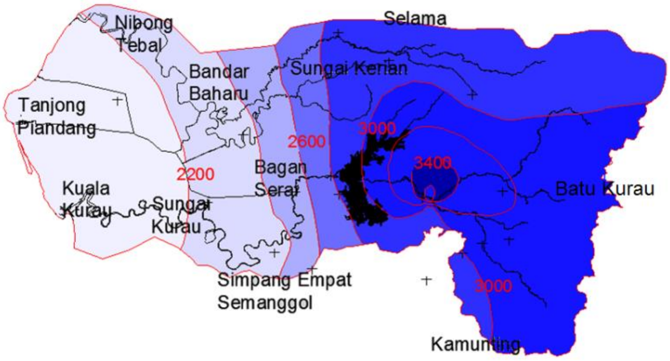


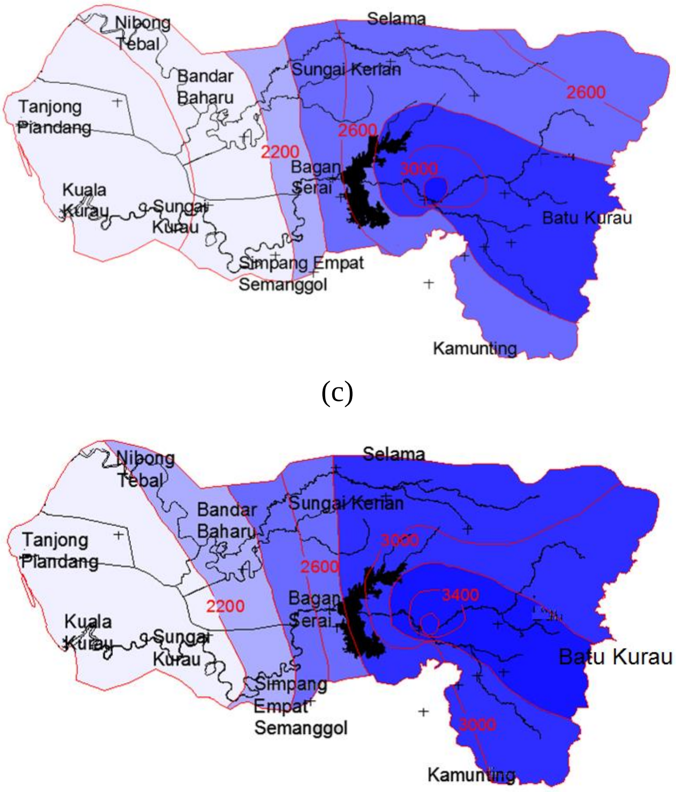
Figure 5: General trend of mean daily precipitation corresponding to a climate change scenario



(a)



(b)



(c)

(d)

Figure 6: Spatial distribution for the annual mean rainfall (in mm) on a) present; b) 2020; c) 2050s; and d) 2080

5.0 Discussion

In the LARS-WG model, the general circulation models (GCMs) variables are not directly applied, but the model is applying the proportionally local station climate variables, which are adjusted, to present the climate change (Sajjad Khan *et al*., 2006). Therefore, the model is simple and easy to handle than other downscaling models (such as SDSM-Statistical Downscaling Model and ASD-Automatic Statistical Downscaling Model) which involved a direct selection of the GCMs-variables. In addition, the recent LARS-WG model, which is LARS-WG 5.0 can be utilized within the climate scenarios based on the general circulation models (GCMs) data sets. These climate scenarios are produced by the leading modeling groups worldwide who performed a set of coordinated climate experiments in which numerous GCMs have been run for a common set of experiments and various emission scenarios. Therefore, the model allows the exploring of the uncertainty in the climate predictions resulting from structural differences in the global climate model design, as well as the uncertainty in variations of initial conditions or model parameters.

During the calibration and the validation process, the results show a small value of R for the prediction of daily rainfall. This situation indicates that the model is poor in predicting the daily rainfall. However, the results are still a satisfactory because predicting on the daily rainfall is the most difficult process in the climate analysis. In addition, the daily rainfall is a conditional process and involves many relationships with other parameters, which make the daily rainfall is difficult to simulate. Previous climate studies such as Karamouz *et al*. (2009); Dibike and Coulibaly (2005); and Chu *et al*. (2009) which downscaling the rainfall also give a poor prediction on the daily rainfall.

After the calibration has been finalized, then the model is generated for the future daily rainfall. The results simulated that the future daily rainfall will decrease from December until April, compared to the present daily rainfall. For the rest of the months, the increase of future daily rainfall is illustrated. In term of the annual rainfall, the study finds that the area at the upper stream of river (Selama and Batu Kurau) will face an increase of annual rainfall corresponding to the climate scenario. However, the area of agriculture and the downstream of river (Nibong Tebal and Kuala Kurau) will face an decrease of annual rainfall.

6.0 Conclusions

HadCM3 A2 has been found suitable to be used for the climate impact on the Kerian agricultural watershed. This climate model had been downscaled using the LARS-WG model. The study founds that the model has given satisfied results during the calibration and validation process. The future rainfall variation corresponding to HadCM3 has been generated from the LARS-WG model. These changes will have significant impacts on the studied region and the sustainable adaptation strategies to rescue the future of the water supply.

Acknowledgments

This study has been financially supported by Ministry of Higher Education Malaysia, under EScience Fund vote 79385 and UTM.

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