UNIVERSITI PUTRA MALAYSIA

CLIMATE CHANGE AND ITS IMPACT ON HYDROLOGICAL REGIME OF THE LANGAT RIVER BASIN, MALAYSIA

MAHDI AMIRABADIZADEH

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CLIMATE CHANGE AND ITS IMPACT ON HYDROLOGICAL REGIME OF THE LANGAT RIVER BASIN, MALAYSIA

By

MAHDI AMIRABADIZADEH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

July 2015

DEDICATION

This thesis is dedicated to my parents for their endless love

To my lovely wife and kindness daughter who have supported me in manywaysalong this journey

To my brothers and sisters who always support meduring the life

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

CLIMATE CHANGE AND ITS IMPACT ON HYDROLOGICAL REGIME OF THE LANGAT RIVER BASIN, MALAYSIA

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July 2015

Chairman : Assoc. Prof. Abdul Halim Bin Ghazali, PhD
Faculty : Engineering

The water resources in the Langat River Basin are the main sources of water supply for different usage in the Klang Valley area that includes the city of Kuala Lumpur. In this study the rainfall data and the maximum, minimum and mean temperatures data were investigated for the presence of annual and seasonal trends. The Mann-Kendall test and the Theil-Sen's Slope method were used to detect the existence and magnitude of changes in the significant trends. The analytical results indicated that there were significant increasing trends in the annual and seasonal precipitation as well as the maximum and minimum temperatures at the 95% confidence level.

This study also investigated the ability of the multiple linear (Statistical Downscaling Model) and nonlinear regression (Artificial Neural Network) methods with different complexity in downscaling and projection of climate variables in the Langat River Basin. These statistical downscaling models have been calibrated and validated using the NCEP/NCAR predictors in single station approach. The statistical validation of the generated precipitation, maximum and minimum temperatures on a daily scale, illustrated that the SDSM performs with better accuracy than the ANN model. The SDSM showed much ability to catch the wet spell and dry spell length than the ANN model. The calibrated models show more accuracy in simulating the temperature when compared with the capture of the variability of the precipitation. The better performing SDSM model was applied in projecting regional variables for two future periods (2030s and 2080s) by using predictors of the Coupled Global Climate Model version 3.1 under the A2 emissions scenario. The SDSM predicts an increase in mean monthly precipitationfor two future periods. This downscaling model predicts a similar pattern for maximum and minimum temperatures during future periods.

The GEV distribution was fitted to the observed and generated daily rainfall, maximum and minimum temperatures in two future periods (2030s and 2080s) as well as baseline period using the Maximum Likelihood Method (MLE) at different stations. The comparison between the return values for precipitation and maximum and minimum temperatures indicated that the precipitation increases more than the temperature at all stations under future scenarios.

Results of sensitivity analysis during the calibration process indicated that the mean monthly streamflow was sensitive to changes in seven parameters (v_ALPHA_BNK, v_CH_K2, r_SOL_K(…), r_CN2, v_EPCO, v_GW_REVAP, r_REVAPMN) out of 19 parameters. Four evaluation index values namely, NSE, PBIAS, RSR, and R^2 of 0.62, 5.7, 0.61, and 0.63, respectively indicated that the calibration was reasonable. These indexes during the validation period were 0.55, 3.5, 0.67, and 0.56 respectively. The SWAT modelwas applied to predict the values of the mean monthly discharges in the Hulu Langat basin for the three periods which are the baseline, 2030s, and 2080s and these values are 14.15, 24.20, and 29.42 m^3/s, respectively.The majorcontribution of this study was to identify the SDSM model as the more reliable downscaling model for the study area, which can be developed further by using of more General Circulation Model (GCM) outputs.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PERUBAHAN IKLIM DAN KESANNYA KE ATAS REJIM HIDROLOGI LEMBANGAN SUNGAI LANGAT, MALAYSIA

Oleh

MAHDI AMIRABADIZADEH

Julai 2015

Pengerusi : Profesor Madya Abdul Halim Bin Ghazali, PhD
Fakulti : Kejuruteraan

Sumber air di Lembangan Sungai Langat adalah sumber utama bekalan air untuk pelbagai kegunaan di kawasan Lembah Klang dan ini termasuk bandar Kuala Lumpur. Dalam kajian ini, data taburan hujan dan data suhu maksimum, minimum dan min telah dikaji untuk mendapatkan kehadiran tren tahunan dan musim. Ujian Mann-Kendall kaedah Cerun Theil-Sen telah digunakan untuk mengesan kewujudan dan magnitud perubahan dalam tren yang signifikan. Keputusan-keputusan analitikal menunjukkan bahawa terdapat tren yang semakin meningkat secara signifikan dalam taburan hujan tahunan dan musim begitu juga dengan suhu-suhu maksimum dan minimum pada aras keyakinan 95%.

Kajian ini juga meneroka ke dalam kebolehan linear pelbagai (Model Penurun-skalaan Berstatistik) dan kaedah-kaedah regresi bukan-linear (Jaringan Neural Artifisial) dengan kompleksiti yang berbeza dalam penurun-skalaan dan projeksi pembolehubah iklim di Lembangan Sungai Langat. Model-model penurun-skalaan berstatistik ini telah dikalibrasikan dan disahkan menggunakan peramal-peramal NCEP/NCAR dalam pendekatan stesyen tunggal. Pengesahan berstatistik taburan hujan, serta suhu maksimum dan minimum pada skala harian, menunjukkan bahawa SDSM mempunyai ketepatan yang lebih baik dari model ANN. SDSM menunjukkan lebih kebolehan untuk merekodkan musim hujan dan musim kemarau dari model ANN. Model-model yang dikalibrasi menunjukkan lebih ketepatan dalam mensimulasi suhu jika dibandingkan dengan perekodan keboleh-varian hujan. Model SDSM yang lebih baik digunakan untuk memaparkan pembolehubah kewilayahan untuk dua jangkamasa hadapan (2030s dan 2080s) dengan menggunakan peramal-peramal Model Iklim Global Berpasangan versi 3.1 di bawah senario pengeluaran A2. SDSM meramal kenaikan dalam min taburan hujan bulanan untuk dua jangkamasa akan datang. Model penurun-skalaan ini meramalkan pola yang serupa untuk suhu-suhu maksimum dan minimum semasa jangkamasa di hadapan ini.

Pengagihan GEV disesuaikan dengan taburan hujan harian yang diperhatikan dan dijana, suhu-suhu maksimum dan minimumdalam dua jangkamasa akan datang (2030s dan 2080s) dan juga jangkamasa menggunakan Kaedah Kebarangkalian Maksimum (MLE) pada stesyen-stesyen yang berbeza. Perbandingan di antara nilai pulangan hujan

dan suhu-suhu maksimum dan minimum menunjukkan bahawa hujan meningkat lebih dari suhu di semua stesyen dalam senario-senario masa depan.

Keputusan-keputusan analisis sensitiviti semasa proses kalibrasi menunjukkan bahawa min aliran bulanan adalah sensitif kepada perubahan dalam tujuh parameter (v_ALPHA_BNK, v_CH_K2, r_SOL_K(…), r_CN2, v_EPCO, v_GW_REVAP, r_REVAPMN) daripada 19 parameter. Empat nilai indeks penilaian, iaitu NSE, PBIAS, RSR, dan R2 kepada 0.62, 5.7, 0.61, dan 0.63, menunjukkan bahawa kalibrasi adalah wajar. Indeks-indeks dalam waktu ini adalah 0.55, 3.5, 0.67, dan 0.56. Model SWAT model diaplikasi untuk meramal nilai-nilai min pengeluaran bulanan di lembangan Hulu Langat untuk tiga jangkamasa iaitu garis asas, 2030s, dan 2080s dan nilai-nilai ini adalah 14.15, 24.20, dan 29.42 m^3/s. Sumbangan utama kajian ini ialah untuk mengenalpasti model SDSM sebagai model penurun-skalaan yang lebih boleh dipercayai untuk kawasan kajian, dan yang boleh dibangunkan lagi dengan menggunakan lebih banyak output Model Edaran Umom (GCM).

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I certify that a Thesis Examination Committee has met on 29 July 2015 to conduct the final examination of Mahdi Amirabadizadeh on his thesis entitled "Climate Change and its Impact on Hydrological Regime of The Langat River Basin, Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Helmi Zulhaidi bin Mohd Shafri, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Badronnisa binti Yusuf, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Thamer Ahmad Mohammad Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Kwok-Wing Chau, PhD
Professor
Hong Kong Polytechnic University
Hong Kong
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 22 September 2015

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Abdul Halim Bin Ghazali, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairperson)

Aimrun Wayayok, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Yuk Feng Huang, PhD
Assistant Professor
Faculty of Engineering and Science
Universiti Tunku Abdul Rahman
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Name and Matric No: Mahdi Amirabadizadeh (GS31482)

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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Signature: ______________________________
Name of Chairman of Supervisory Committee: Abdul Halim Bin Ghazali, PhD

Signature: ______________________________
Name of Member of Supervisory Committee: Aimrun Wayayok, PhD

Signature: ______________________________
Name of Member of Supervisory Committee: Yuk Feng Huang, PhD

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LIST OF ABBREVIATIONS

95PPU	95 Percent of Prediction Uncertainty
AAFC-WG	Agriculture and Agri-Food Canada-Weather Generator
ACF	Autocorrelation Function
AGCM	Atmospheric General Circulation Model
ANN	Artificial Neural Network
AOGCM	Coupled Atmosphere-Ocean General Circulation Models
ArcSWAT	The ArcGIS Integrated SWAT Hydrological Model
CCA	Canonical Correlation Analysis
CCCMA	Canadian Center for Climate Modeling and Analysis
CG	Conjugate Gradient
CGCM3.1	The third Generation Coupled Global Climate Model
CN	Curve Number
CSIRO	Commonwealth Scientific and Industrial Research Organization
DEM	Digital Elevation Model
DID	Department of Irrigation and Drainage
EOF	Empirical Orthogonal Function
GA	Genetic Algorithm
GCM	Global Climate Model or General Circulation Model
GEV	Generalized Extreme Value
GIS	Geographic Information System
HadCM3	Hadley Centre Coupled Model, version 3
HBV	Hydrologiska Byråns Vattenbalansavdelning
HRU	Hydrological Response Units
HT	Hyperbolic Tangent
IPCC	Intergovernmental Panel on Climate Change
LARS-WG	Long Ashton Research Station – Weather Generator
LM	Levenberg-Marquardt
LSE	Least Square Error
MAE	Mean Absolute Error
MC	Markov Chain
MLP	Multilayer Perceptron
MLR	Multi Linear Regression

MMD	Malaysian Meteorological Department
MSLP	Mean Sea Level Pressure
NAHRIM	National Hydraulics Research Institute Malaysia
NCAR	National Center For Atmospheric Research
NCEP	National Centre for Environmental Prediction
NRCS	US Natural Resource Conservation Service
NSE	Nash-Sutcliffe Efficiency
OGCM	Ocean General Circulation Models
P500	500 hPa Geopotential Height
P850	850 hPa Geopotential Height
PBIAS	Percent Bias
P-factor	Percent of observations that are within the given uncertainty bounds
PRCP	Accumulated Precipitation
PW	Prewhitening
Q_1	First Quartile
Q_2	Second Quartile
Q_3	Third Quartile
Q_4	Fourth Quartile
R^2	Coefficient of Determination
RCM	Regional Climate Model
RegCM	Regional Climate Model
R-factor	Thickness of the uncertainty band divided by standard deviation
RMSE	Root Mean Square Error
RSR	RMSE- observation Standard deviation Ratio
S500	500 hPa Specific Humidity
S850	850hPa Specific Humidity
SCS	Soil Conservation Service
SD	Standard Deviation
SDSM	Statistical Downscaling Model
SE	Standard Error
SHUM	Near Surface Specific Humidity
Sig	Sigmoid
SRES	Special Report on Emission Scenarios

SRTM	Shuttle Radar Topography Mission
SVM	Support Vector Machine
SWAT	The Soil and Water Assessment Tools
SWAT-CUP	SWAT Calibration and Uncertainty Procedures
TEMP	Mean Temperature at 2m
TF	Transfer Function
TFPW	Trend-Free Pre-Whitening
T_{Max}	Maximum Temperature
T_{Min}	Minimum Temperature
TT	Travel Time
USDA	United State Department of Agriculture

LIST OF NOTATIONS

P500	500 hpa geopotential height
S500	500hpa Specific Humidity
P850	850 hpa geopotential height
S850	850hpa Specific Humidity
R	A data analysis software
PRCP	Accumulated precipitation
E_A	Amount of evapotranspiration
R_{day}	Amount of precipitation
Q_{gw}	Amount of return flow
W_{seep}	Amount of water entering the vadose zone
$q_{in,aver}$	Average inflow between sections 1 and 2
Q_{mean}^{obs}	Average of observed discharge
v__ALPHA_BNK.rte	Baseflow alpha factor for bank storage
S_a	Basin potential retention capacity
ΔV_{stored}	Change in the volume of storage
t_{conc}	Concentration time
r_{1C}	Critical autocorrelation
E	Depth rate of evaporation
Y_t	De-trended series
r_a	Diffusion resistance of the air layer
v__CH_K2.rte	Effective hydraulic conductivity
e_i	Error value
SW_t	Final soil water content
Q_1	First quartile
a_{tc}	Fraction of daily rainfall
F_x	GEV distribution function
R(i)	Gross rainfall depth in day (i)
v__GW_REVAP.gw	Groundwater "revap" coefficient
$q_{in,1}$	Inflow rate at the beginning of the time step
$q_{in,2}$	Inflow rate at the end of the time
I_a	Initial abstraction

r__CN2.mgt	Initial SCS runoff curve number
SW_0	Initial soil water content
β_0	Intercept variable
T	Is the time
J	Jacobian of m output errors
X	Large scale climate variable
Λ	Latent heat flux density
λ	Learning rate
δ_i	Local error-gradient in neuron (i)
μ	Location parameter of extreme value
$\overline{y_{obs}}$	Mean observed values
$\bar{V}_j$	Mean of predictor
E(s)	Mean of S values
MSLP	Mean sea level pressure
$\overline{y_{sim}}$	Mean simulated value
TEMP	Mean Temperature At 2m
μ	Momentum factor
SHUM	Near surface specific humidity
H_{net}	Net Radiation
w_{ij}	Network weight
y_i	New outcome of the model
K	Number of independent variables
N	Number of recorded
t_i	Number of ties in group i
Xi	Observation value in i^{th} rank
xj	Observation value in j^{th} rank
Q_i^{obs}	Observed discharge on the i^{th} day
y_{obs}	Observed value
$q_{out,1}$	Outflow rate at the beginning of the time step
$q_{out,2}$	Outflow rate at the end of the time step
Q_{peak}	Peak runoff rate
r_c	Plant canopy resistance
v__EPCO.bsn	Plant uptake compensation factor

S_a	Potential retention capacity of the basin
v_{ij}	Predictor
x_{ij}	Predictor variable on the day i
y_{i-1}	Previous output of the model
Y_t'	Prewhitened series
γ	Psychrometric constant
I	Rainfall intensity
C	Runoff coefficient
e_z^o	Saturation of vapor pressure of air at height z
α	Scale parameter of extreme value
k	Shape parameter of extreme value
S	Sign parameter
Q_i^{sim}	Simulated discharge in i^{th} day
y_{sim}	Simulated value
β_k	Slope coefficient for explanatory variable k
β	Slope of trend
r__SOL_K(..).sol	Soil saturated hydraulic conductivity
G	Specific heat at the constant pressure
Z	Standard deviation
σ_j	Standard deviation of predictor
SC	Storage coefficient
$V_{stored,1}$	Storage volume at the beginning of the time step
$V_{stored,2}$	Storage volume at the end of the time step
A	Area
Q_{surf}	Surface runoff
Q_{surf}	Surface runoff
Q_3	Third quartile
r__REVAPMN.gw	Threshold depth of water in shallow aquifer
X_T	Threshold of climatic variable
t_{ch}	Time of concentration for channel flow
t_{ov}	Time of concentration for overland flow
P_i	Total precipitation
TT	Travel time

V	Variance of S values
V_{in}	Volume of inflow
V_{out}	Volume of outflow
e_z	Water vapor pressure of air
w_i	Wet-day occurrence

CHAPTER 1

INTRODUCTION

1.1 General Background

Global warming is one of the most talked about subjects in the 21st century, which affects our sphere of life. Its main problem is that global warming is not only a concern for the scientificcommunity, but it also affects the economy, geopolitics, health, local politics, and even our lifestyle. Since 1800s, there has been a significant increase in the amounts of fossil fuel usedto produce power for factories and global civilization. As such, it is expected that the global warming would affectsworld'saverage temperature, and its precipitation, ice and snow cover and sea level directly. Subsequently It will affect the water resources, economy, health, agriculture, forest and etc.(Solmon et al., 2007).

Therefore, it is important to address the many impacts of global warming on the environment of a region. The two known effects of global warmingon a regional scale are the increasingfrequency and severity of floods. The Global Climate Model (GCM) and statistical downscaling model are widely used in the researches to evaluate these effects (Duan & Mei, 2013; Hellstrom et al., 2001; Seidou et al., 2011). For simulating the hydrological response of a region against the changing climate, the Soil and Water Assessment Tool (SWAT) which is a long-term, continuous and spatially distributed model, is one of the most appropriate models.

1.1.1 Climate Change

Climate change refers to the statistically significant variations of the mean state of the climate or of its variability for decades or longer period. The atmospheric circulation and its interaction with the large-scale ocean currents and land with its features such as Albedo, vegetation, and soil moisture specify the climate(Houghton et al., 2001).

In other words, there is a climate system such that interactions between its components determine the climate. The climate system consists ofthese components: atmosphere, hydrosphere, cryosphere, land surface and biosphere(Figure 1.1). Changing each part of this system will create a change in the whole climate system and also in their interactions. As water is involved in all components of the climate system, therefore any change in the climate system will affect water through a number of mechanisms.

The oceans have an important role in the climate system with their huge capacity to store the heat and also their large thermal inertia. Half of solar radiation to the earth is on the ocean and it absorbs and stores that energy before escaping to the earth and reinforces the greenhouse warming process. As such, the oceans produce a balance against rapid climate fluctuations (Solmon et al., 2007). So, the oceans reduce the effects of rapid climate change during the time. (Houghton et al., 1990).

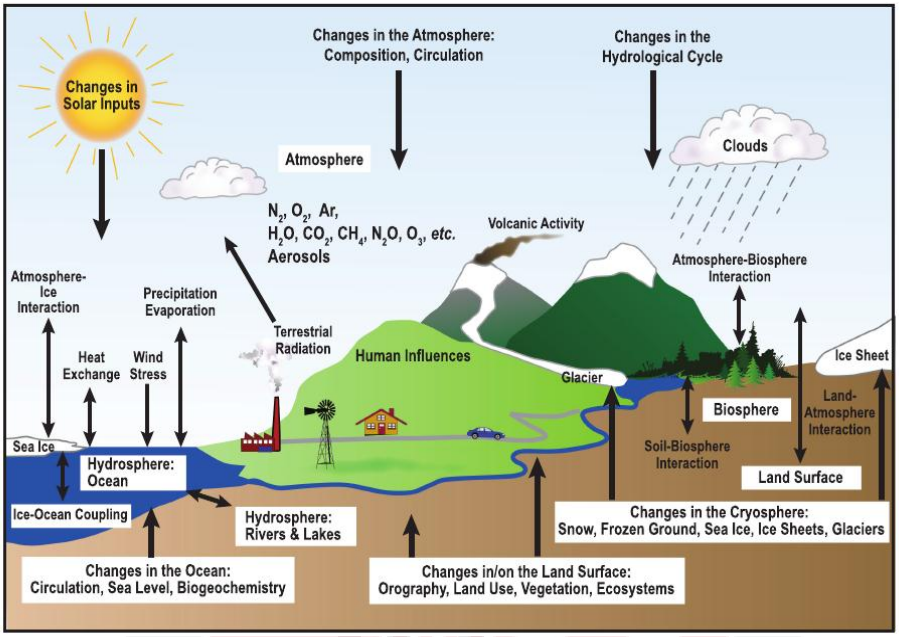

Figure 1.1.Schematic view of climate system components and their interactions(Solmon et al., 2007)

Scientists make qualified projection about the state of the climate in the future using some data analysis and special tools like climate and statistical models. The report from the IntergovernmentalPanel on Climate Change (IPCC) states that there is a 0.6°C increase in global temperatures and an increase of 20 cm in the level of sea water surface during the 20th century. The IPCC survey also predictsa rise of between 1.4°C to 5.8°C for mean global temperature and a rise of 20cm to 88 cm in sea surface level by the year 2100(Solmon et al., 2007).

Trend analysis done over a time period from 1900 to 2005 describes a significant increase in the amount of precipitation in many parts of the world. In this time period, the precipitation in eastern parts of North and South America, northern Europe and northern and central Asia has increased while in other parts of the world drought is dominant. IPCC's long-term observation of precipitation from 1950 to 2005 indicated a significant increase in the numbers of heavy precipitation in many land regions even in those regions that the total amount of precipitation has reduced(Solmon et al., 2007b). The study also states that more intense and longer droughts have happened since 1970, particularly in tropical and subtropical regions. Increasing temperature and decreasing land precipitation have contributed to these droughts.

Water resource projects needs to be evaluated with regard to possible changes in climate during the service period of the project. The most important water resource projects are dam construction, water supply infrastructure, wastewater treatment and reuse, desalination, pollutant emission, irrigation systems, hydropower generation and watershed management (Bryson et al., 2008).

1.2 Statement ofthe Problem

The frequency of occurrence and severity of some events like floods, drought and other hydrological events have significant effects on economic and social activity.According to IPCC (2007),experienced increasing temperature will continue with higher rate until the end of this century. Since one third of the population of Malaysia depends on the agriculture sector for their livelihood, so climate change in this country definitely has an influence on agriculture productions.More frequent occurrence of flood and drought are the two consequences of the changing in climate, which then cause significant socioeconomic impacts to the nation. Thus, climate change may affect the water resources of a region by variation in the input parameters to hydrologic cycle.

The water resources in the Langat River Basin provides two third of water demand in the state of Selangor (Juahir et al., 2010).As the surface water is the main source for providing water in the Langat River Basin, estimation of streamflow in the future is an essential work for water management and conservation. On the other hands, managing a water projects during the service periodwill be more applicable with information about the components of hydrological cycle, especially streamflow, under the effect of climate change.Using of continues, and physically based hydrological model which is calibrated on observed data is the most common procedure to deal with this issue (Singh et al., 2011). Hence, the main problems which exist regarding climate change is obtaining the change in the regime of this watershed in two future periods which arethe 2030s (2020-2049) and 2080s (2070-2099). Furthermore, simulating the behavior of hydrological cycle's components needs to downscale the meteorological parameters which include precipitation as well as maximum and minimum temperatures in the future period using the predictors of a GCM model.

As the spatial scales of GCMs and hydrological model are inconsistent, the output of GCMs cannot be uses directly as input to hydrological model. The statistical downscaling models are known approach to bridge the difference between large scale and regional scale models. It is a well-accepted fact that there are uncertainty in the outputs of downscaling models and hydrological modeling(Chen et al., 2012). Thus, comparison of downscaling model (SDSM and ANN models) and applying the more accurate model could decrease the rate of errors in simulating the hydrological response of Hulu Langat basin against the climate change in two future periods.

On the other hands, design amounts for different return value for most of water projects are vital. The frequency analysis of downscaled meteorological parameters in the future (like the precipitation and maximum and minimum temperatures) under the A2 emission scenario provides the extreme condition that expected to happen for the water project. As the A2 emission scenario describes the worst condition of climate change effect, therefore the estimated values of precipitation, temperature, and monthly streamflow will be the extreme condition for the forecasted climate in the Langat River Basin. The current study tries to provide a more clear view on the components of hydrologic cycle in the future due to climate change in the Langat River Basin.

1.3 Objectives

The main objective of this research is to study the climate change and its impacts on the hydrological regime of the Langat River Basin in two future periods by applying appropriate downscaling and hydrologic models. To achieve the main objective of this study, the followingspecific objectives have been established:

i. To determine thetrends in rainfallas well asthe maximum and minimum temperaturesatthe Langat River Basin.
ii. To downscalethe daily rainfall, and also the maximum and minimum temperaturesusing two statistical downscaling models and determine the best model for the study area.
iii. To create scenarios by projection of climate data for 2020-2049 and 2070-2099 using the Coupled Global Climate model 3rd generation (CGCM3.1) predictors under the most severe emission (A2).
iv. To fita Generalized Extreme Value (GEV) distribution to the annual maximum precipitationas well asthe maximum and minimum temperaturesduringthe control and projectedperiods with return periods of 5, 10, 20, 50, and 100years.
v. To simulatethe water balance and streamflow in the Hulu Langat basin due to climate change for the projected time periods using the SWAT model.

1.4 Scope of Work and Limitation of the Study

The primary effort of this thesis is to analyze the long time changing in the climate of the Langat River Basin by detecting trends in precipitation and maximum and minimum temperatures. In this way, the Mann-Kendall and Theil-Sen's Slope methods were applied to determine the significance of the occurrence and rate of change in the climatic variables. The other effort is to do a comparison of Statistical Downscaling Model (SDSM) and Artificial Neural Network (ANN) in downscaling the daily rainfall,maximum and minimum temperatures and chooses the more appropriatemodel for hydrological impact studies due to climate change in two future periods. The efforts also include an analysis of hydrological response of the Hulu Langatbasin using the SWAT model against the climate change by importing the downscaled rainfall and maximumand minimum temperatures into the SWAT model.

The scope of this study is limited to long period data so as to reach better accuracy in estimated values. In the current study, the available recorded data covered a period of 27 to 41 years that was obtained from Department of Irrigation and Drainage (DID) and Malaysian Meteorology department (MMD). The other limitation is lack of long time data for the Semenyih reservoirregarding storage and release relation. This limitation changed the area of study for the SWAT model simulation to the Hulu Langat basin that excludes the Semenyih reservoir.

1.5 Significance of the Study

The climate change in Malaysia will affect several significant sectors, mainly water resources, agriculture, forest, energy and public health. It directly affects water resources and agriculture as the pattern of precipitation and temperature change. As one third of people in Malaysia are working in the agriculture sector, thus any change in agricultural resources creates profound risks in the life of people in this sector.

Reservoirs and rivers are very important forirrigation, hydropower, water supply, and health. Amounts of water which is stored in the Langat reservoir to provide enough water for all consumptions, water level in reservoir for hydropower, reducing damage during and after flooding period, designing new reservoirs, design and improve sewer systems and many other water projects require the knowledge of the impacts of climate change in these areas.Simulating the behavior of streamflow as the main source of water in the Langat River Basin due to climate change is an essential work in managing the water projects. Therefore, studying the potential impacts of climate change on meteorological parameters as well as water resources helps to provide a better policy decision for water projects in the Langat River Basin.

In planning and management of the water resources in the Langat River Basin to supply all the consumptionneeds ofthree large cities like Kuala Lumpur, Kajang, and Bangi; it requires clear view about the reliability of these water resources due to climate change. So, the master plan for the development of water resources in the study areaneeds to have a figure about regional climate for a long time in the future. As a matter of fact, pattern of precipitation, temperature,and evapotranspirationare so significant inthe management of crisis in the water district in the Langat River Basin.

1.6 Organization of the Thesis

Following the chapteron introduction, there are four chapters not including the appendices. Chapter Twocovers the literature review, which includes several background concepts in climate change, trend analysis,statistical downscaling, and the SWAT model. In Chapter Three, a description of the study area, trend analysis of threeclimatic variables (precipitation, maximum and minimum temperatures), and two statistical downscaling models are presented. Generalized extreme value distribution and the hydrological SWAT model are also discussed in this chapter. In Chapter Four, quality testing of data and detection of trend in climatic parametersat tenstations are presented.The performance of two downscaling models in regenerating local time series is analyzed. Theapplication of the SWAT model to simulate the monthly streamflow in the outlet of the Hulu Langatbasin is also presented in this chapter.This thesis ends with a conclusion that synthesizes the results and summarizes the main findings of the study in Chapter Five.

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