ESTIMATING THE LONG TERM PATTERN OF WATER STREAMFLOW WITH CLIMATE CHANGE ADAPTATION

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ABSTRAK

Perubahan iklim dan kesannya kepada dunia telah menjadi salah satu isu yang penting kepada masyarakat. Ramalan hujan, suhu dan aliran sungai untuk masa depan telah digunakan dalam kandungan perubahan iklim global disebabkan keadaan semasa di mana perubahan iklim dunia yang berterusan. Ini berlaku kerana pelepasan karbon dioksida, CO2 yang berasal dari kilang, kenderaan dan faktor lain. Peningkatan karbon dioksida menyebabkan lapisan ozon berkurangan. Kajian ini memberi tumpuan dalam menganalisis ramalan hujan, suhu dan aliran sungai di negeri Pahang. Sementara itu, pola hujan dan suhu dapat dianggarkan menggunakan model penurunan statistik (SDSM) sementara untuk aliran aliran, kaedah yang digunakan adalah pengenalan unit hidrograf dan aliran komponen dari hujan, penyejatan dan aliran sungai (IHACRES). Model penurunan nilai statistik (SDSM) adalah salah satu daripada model SD yang mentafsirkan hubungan ramalan (iklim tempatan) - peramal (skala GCM) dengan menggunakan teknik regresi berganda dan membolehkan jenis data yang berbeza berubah menjadi pemboleh ubah ramalan piawai sebelum Dimeteraikan dan ditentukur untuk menghasilkan model regresi tak linear. Model penurunan nilai statistik boleh mengurangkan kesilapan standard estmate dan meningkatkan bilangan variasi yang dijelaskan menggunakan teknik pembetulan bias dan teknik inflasi varianc. Pengenalan unit hidrograf dan aliran komponen dari hujan, penyejatan dan aliran aliran (IHACRES) adalah model metrik konseptual-hibrid di mana ia dapat mengurangkan ketidakpastian parameter yang terlibat dan mewakili lebih banyak butiran proses dalaman.

ABSTRACT

The climate changes and its affects to the world have becoming one of the issues that is important to the society. The predictions of rainfall, temperature and streamflow for future have been used in content of global climate change due to current situation where the continuous changes of world climate. This happens because of emission of carbon dioxide, CO2 that came from factory, vehicles and other factors. The increased of carbon dioxide causing the depleting of ozone layers. The studies focus in analysing prediction of rainfall, temperature and streamflow of Pahang state. The rainfall and temperature pattern can be estimate using the statistical downscaling models (SDSM) meanwhile as for stream flow, the method used was identification of unit hydrographs and component flows from rainfall, evaporation and streamflow (IHACRES). The statistical downscaling models (SDSM) is one of the SD model that interpret the predictand (local climate) – predictor (GCMs-scale) relationship using multiple regression techniques and it is allows different types of data to be transformed into standard predictor variables before being downscaled and calibrated to produce nonlinear regression models. The statistical downscaling models can reduce the standard error of estmate and increased the number of explained variance using bias correction and varianc inflation techniques. The identification of unit hydrographs and component flows from rainfall, evaporation and streamflow (IHACRES) is a hybrid conceptual-metric models where it can reduce uncertainty of involved parameter and represent more details of the internal processes.

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LIST OF ABBREVIATIONS

SDSM	Statistical Downscaling Model
DD	Dynamical Downscaling
SD	Statistical Downscaling
GCM	Global Circulation Model
RCM	Regional Circulation Model
NCEP	National Centers for Environmental Prediction
MMD	Malaysia Meteorological Department
DID	Department of Irrigation and Drainage
MAE	Mean Absolute Error
DAT	predictand
OUT	output
PAR	parameter
MOS	model output statistic
mlsp	mean sea level pressure
p_f	surface airflow strength
p_u	surface zonal velocity
p_v	surface meridional velocity
p_z	surface vorticity
p_th	surface wind direction
p_zh	surface divergence
p5_f	500hpa airflow strength
p5_u	500hpa zonal velocity
p5_v	500hpa meridional velocity
p5_z	500hpa vorticity
p500	500hpa geopotential height
p5th	500hpa wind direction
p5zh	500hpa divergence
p8_f	850hpa airflow strength
p8_u	850hpa zonal velocity
p8_v	850hpa meridional velocity
p8_z	850hpa vorticity
p850	850hpa geopotential height
p8th	850hpa wind direction
p8zh	850hpa divergence

r500	relative humidity at 500hpa
r850	relative humidity at 850hpa
rhum	near surface relative humidity
shum	surface specific humidity
temp	mean temperature

CHAPTER 1

INTRODUCTION

1.1 Introduction and Background

Climate change is a change in global and regional climate pattern attributed largely to the increased level of greenhouse gases (Environmental Protection Agency, 2016). Since the last ice age, Earth's climate has been relatively stable at about 14^{o}C. However, through the recent year the average temperature has been increasing. Some of the main sources for climate change could have been higher temperatures, changing rainfall, changes in nature, sea level rises, retreating glaciers, sea ice and ice sheets. As an example, the sea ice has been declining since late 1970s. Even the calamities were affected by the natural of cyclical monsoons but could be extremely affected by the climate change impact. Climate change resulted to the properties destructed, food scarcity, social life and economy losses in million ringgits. Therefore, the estimation of streamflow is very important in preparing long term planning and management of water resources and development at the site study.

Based on the Malaysia Meteorological Department (MMD, 2016), the characteristic of climate in Malaysia are uniform temperature, high humidity and copious rainfall. Situated at the equatorial doldrums area, Malaysia is hardly to have a full day of completely clear sky even during the period of severe drought. Besides, it is also rare to have a few days with completely no sunshine except when it comes to northeast monsoon seasons. The local topographic features combine with the seasonal wind flow patterns determines the rainfall distribution patterns over the country. During the northeast monsoon season, the areas like east coast of Peninsular Malaysia, Western Sarawak and the northeast coast of Sabah would experience heavy rainfall seasons.

While for inland areas that sheltered by mountain ranges are relatively free from the heavy raining seasons.

Statistical downscaling model (SDSM) would be useful to predict the future changes of climate suit to the local scales. This is because downscaling take information at large scales to produce predictions at local scales. Besides, the statistical downscaling model is a decision support tool by using a robust statistical downscaling technique for assessing local climate change impacts.

Moreover, it is also being designed to help identify the large scale climate variables (the predictors), which explain most of the variability in the climate at a particular site and based on this information able to built the statistical models. Statistical models are built using the information of daily observed data which is a local climate data for a specific location that need to be predict and larger scale National Centers for Environmental Prediction (NCEP) data for the predictors, and these models are then used with general circulation models (GCM) for deriving predictors to obtain daily weather data at the site in question for a future time period. IHACRES was used to identify catchment-scale rainfall-runoff behaviour rather than the small-scale hydrological processes by which rainfall causes streamflow. The purpose of using IHACRES is to characterise the dynamic relationship between basin rainfall and streamflow.

1.2 Statement of the Problem

The trend of climates in Malaysia is based on the state location. The states which located at East-Coast areas such as Pahang, Kelantan, Terengganu and Mersing, Johor are facing the heaviest rainfall in November to January while June and July would be the driest months. The rest parts of Malaysia Peninsular which located at southwest coastal area, the rainfall pattern was classified into maximum and minimum rainfall. The maximum rain seasons occur in October until November while the second maximum will occur in April until May. The less rainy months are in January to February with secondary minimum in June to July.

In the recent years, Malaysia had been experienced with serious flood event during Northeast monsoon focused at east coast states (Gasim et al., 2014). Instead of rainy seasons, Malaysia also facing the drier season such as El Nino in year 2002, 2007, 2010, and 2014. Meanwhile, the strongest El-Nino was recorded in year 1982-1983 and 1997-1998 (MMD, 2009). When it is come to warming trend, Malaysia experience temperature changes range from +0.7°C to +2.6°C. Meanwhile, the precipitation changes range from -30% to +30% (Malaysian Meteorological Department, 2009). One of the causes of flood in Malaysia would be an improper drainage condition and developing of new buildings on water ways or flood prone areas (Gasim et al., 2014).

Pahang River is the main channel to drain off water from the inundated area of Pahang basin to the South China Sea especially during rainy season that caused by northeast monsoon season (Gasim et al., 2011). Historical flood in 2014 at Pahang River shows no signs of diminish while the normal water level was 60m while the danger level was at 68m (Star Media Group, 2014). Most flooding happens at the lower area of Pahang River basin was caused by overflowing of the Pahang River. Example of a lowland area that connected to Pahang River is Lubuk Paku (Gasim et al., 2011). It shows that Lubuk Paku have the highest level of water with 15.23m and the lowest was recorded as 12.70m, based on the calculated results of statistics rainfall and hydrological factors for period from 1980 to 2009 in terms of their means.

1.3 Objectives of Study

The objectives of this study are:

i. To predict the future changes of climate changes in term of temperature and rainfall.
ii. To estimate the long term pattern of water stream with concerned the climate change impact.

1.4 Scope of Study

The study is to estimate the long term pattern of water stream flow in the context of climate change impact. This study focused in the lowland area at Lubuk Paku, Pahang (3527092), due to the historical flood event. The rainfall data was provided from Malaysia Meteorological Department, MMD. The streamflow records was provided by Department of Irrigation and Drainage, DID which located at Lubuk Paku (3527410). Meanwhile, the temperature was provided by MMD which located at Temerloh (3242081).

The statistical modelling, SDSM were used to project the future climate trend with consider the greenhouse effect, while the method for rainfall-runoff modelling was IHACRES models. The rainfall trend in the future year at the site study was projected using the GCM model that is representing the physical atmospheric in the form of numerical number.

The future climate was predicted from year 2040 until 2069 and it was 30 years prediction of future changes, in term of temperature and rainfall with estimation for water streamflow for a long term pattern due to climate change. From calibrated and validated data that produced by statistical downscaling results, the validated data were used in general circulation models (GCM) for an estimated of future trend.

1.5 Significant of Study

The study is important to obtain estimated future trend of water streamflow from a long term prediction in Pahang state that has been affected by the climate change. The applied methods such as statistical downscaling models, general circulation models and IHACRES models were used to prove that it was an easiest and reliable method in order to predict the future. In fact, the accuracy and good performances produced by this method helps the people or any organisation to handle any kind of problems that could appear during the climate change. Especially when it comes to wet season that normally hit area located at East-Coast of Malaysia Peninsular such as Pahang, Kelantan, Terengganu and Mersing, Johor. Besides, rather than preventing it could be useful to make any improvement of environmental issue or construction technique at the area of water resources.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Climate, the condition of atmosphere in a particular location over a long period of time; which is the long-term summation of atmospheric elements and their variations that, over short time periods forming weather (Plelke et al., 2015). The elements of atmospheric are temperature, solar radiation, precipitation, humidity, atmospheric pressure and wind. From the climate classification, there are several individual climatic zones classified by type. The types consist of type A (Tropical humid), type B (Dry), type C (Humid subtropical, Mediterranean, marine west coast), type D (Humid continental), type D (Continental subarctic) and type E, H (Polar). In fact, there were many countries in climatic zones of type B (Dry). The countries that having the climatic zones of type B were United State of America, South America, Africa, Asia, Australia and New Zealand.

Moreover, climate change known to be large scale of the long-term shift planet's weather patterns or average temperatures. The seven possible main sources for climate change are higher temperatures, changing rainfall, changes in nature, sea level rises, retreating glaciers, sea ice and the ice sheets. Besides, the global warming means the increased heat trapped in earth's atmosphere causes by excess greenhouse gases such as Carbon Dioxide, CO_2.

By increased a few degrees of earth's temperature can cause droughts and crop failures, melting ice caps that causing sea levels rises, as well as ecosystem imbalance. Typically, climate change is described in terms of average changes in precipitation and temperature, meanwhile the social and economic costs associated with climate change resulting from shifts in frequency and severity of extreme events (Huber and Gulledge, 2011). It is illustrated by a large number of costly weather disaster was in 2010, which stated 2005 as the warmest year globally since 1880. But, there is accidentally exceptionally damaging weather events happen in both years where hit in 2005 was Hurricane Katrina and the deadly Russian heat wave in 2010. The world's largest reinsurance company, Munich Re, has compiled global disaster for 1980-2010. In its analysis, after 2007 it is shows year 2010 was the second largest number of recorded natural disasters and the fifth greatest economic loses. In fact, there is about 874 weather and climate-related disasters resulted in 68,000 deaths and 99 billion dollar in damages worldwide in 2010.

For example, Greenland is losing more ice due to the rising temperature that melting the ice and sending it to the ocean. It is pushing the sea levels higher and altering the landscape at both poles (Kahn, 2016). The Greenland ice sheets containing enough water, that if melted would rise up the levels of sea till 23 feet. Rising temperature damaging the ice sheets and Greenland is responsible for about 30% observed foot of sea level rise since the start of 20^{th} century. The ice sheets are indicated melting faster at the areas where the ice sheets have a direct contact with the ocean. Moreover, it could be a phenomenon where there is heavy snow on the East Coast and Northwest Europe meanwhile the Great Lakes and Western Canada actually been less snow than usual because of El Niño events. It is shows that regardless of climate changing, snowy winter will still be present cause by the colliding two weather events such as El Niño and Atlantic Oscillation (McDermott, 2010)

Malaysia is one of the tropical countries, getting heavy rainfall all the year around causing flood which a very common disaster happens in Malaysia. As in Peninsular Malaysia, usually climate is affected by four seasons, two monsoons (the northeast and southwest monsoons) and two inter-monsoon seasons (Suhaila et al., 2010). Instead of rainy seasons, Malaysia also facing the drier years where took place severely in East Malaysia during the El Niño events. According to the Malaysian Meteorological Department (2009), the three driest years at Peninsular Malaysia was in 1963, 1997 and 2002 were recorded during the El Niño events. When it is come to warming trend, Malaysia experience temperature changes range from +0.7^oC to +2.6^oC. Meanwhile, precipitation changes range from -30% to +30% (Rahman, 2009).

Because of extremely rainfall consequence, it gives impact on Pahang River where the results of water level and higher river flow that finally contributing the serious flood events alongside the river basin (Gasim et al., 2012). As preview, the longest river at Peninsular Malaysia is Pahang River with a length of 459 km. The river's upstream located at Titiwangsa Main Range. Pahang River is a main drainage system that drains off water flowing from its upstream, Cameron Highland, into its downstream, Pekan, and it is particularly during wet season. Every year, the wet season begins from November till December and it could be extending to January. Extreme rainfall often resulting spilling over of the Pahang River leading to overflow conditions especially at lowland areas (Gasim et al., 2011).

Lubuk Paku is a lowland area that connected to Pahang River (Lun et al., 2011). The calculated results of statistics of rainfall and hydrological factors for period from 1980 to 2009 in terms of their means shows Lubuk Paku had the highest water level of 15.23 m and the lowest was recorded as 12.70 m. While the highest monthly total rainfall at Lubuk Paku was 324.57 mm and the lowest was 79.81 mm. The mean discharge of Pahang River to Lubuk Paku was 1184.46m^3/s. The direct relationship between water discharge and rainfall means the increasing of rainfall had caused higher discharge volume of river. With it, the direct effect of overflow in river given by rainfall could lead to flooding events.

2.2 Climate Modelling

According to the Climatica (2016), computer models could be used in many aspects of life, testing the structural integrity of buildings, directing airplanes and spacecraft, controlling traffic light, and can be in the form of video games. In Climate Science and the associated subjects of meteorology and oceanography that studies weather and oceans respectively, serve computer models to substitute reality for a range of scenarios. Goosse et al., (2010) in generals, climate model can be defined as mathematical representation of the climate system based on biological, physical, and chemical principles. Because of derivation equations from this law are so complex, it should be solved numerically. In fact, climate models provide solution that discrete in space and time, meaning the results obtained represents averages over regions which size of it depends on model resolution and for specific times. In addition, some input from observations is required for climate models.

According to Bader et al., (2008) climate models have been used in research on carbon dioxide and it is begin in the early 1970s. Followed with continuous improvement in both computer power and climate observations, modelling groups increased their models through steady but incremental improvement. Climate modelling is important to predict the future changes. It is not suitable to used observation based studies because there might be changes in natural events (Blackwell, 2011). Besides, it has been many climate models developed to perform climate projections, in example to simulate and understand climate changes in response to the emission of greenhouse gases and aerosols (Goosse et al., 2010).

Rubenstein (2010) states one of the most important characteristics of models is it can generally trade detail for scope. In order to paint smaller picture of something very large, there are certain amount of details need to sacrifice. The climate models aim is not only to represent the climate accurately but to foresee its changes. In other words, climate models serve two functions which are simulation and prediction. Unlike weather, it is only takes place in a matter of days while climate unfolds over decades. So it is crucial to used climate models because it is no simple task (Rubenstein, 2010).

2.2.1 Energy Balance Models (EBMs)

According to Université catholique de Louvain, UCL (2008) indicates energy balance models is used to estimating the climate system changes from an analysis of the Earth’s energy budget. Also, the energy balance models did not included any explicit spatial dimension and only provided globally averaged values as computed variables. The energy balance models only concern with two things which is radiation balance of between heat loss and incoming solar radiation and another one is latitudinal energy transfer. They are thus considered as zero-dimensional energy balance models, in case the latitudinal characteristics are ignored.

Based on the Shodor Education Foundation Incorporation (1998), in a simple energy balance model, the only variable is the temperature of the Earth. From the term “balance” it is shows that the system in equilibrium, means no energy is collected. In other words, the key idea of this model clearly expressed that the incoming radiation from the sun will be balanced by the outgoing radiation of the Earth (Pierrehumbert, n.d.). Mathematically, energy balance models can be described as energy absorbed is equal to energy emitted. In fact, most of energy balanced models not in global models, but zonal or latitudinal models. Thus, the temperature for each latitude band is calculated using an appropriate latitudinal value in a various climatic parameters.

2.2.2 Radiative-Convective Models (RCMs)

Radiative-convective models also known as one-dimensional in a category of vertical column energy balance model. Means that the single vertical column will be represent the entire atmosphere (Pierrehumbert, 2011). The column generally represent as global mean climate. Type of models vertically energy transport is radiative transport, turbulent transport due to convection and convection modelled as a one-dimensional mixing process. For radiative-convective models, it is only considered the altitude dimension (Ramanathan and Coakley, 1978). Futhermore, this model only determine the vertical distribution for one of the basic variables that associate with climate. Example of the basic variables that associate with climate is the globally and annually averaged surface and atmospheric temperatures.

In addition, radiative-convective models also can be either one-dimensional or two-dimensional models where the height will always be a dimension. Moreover, after considering the cloud amount, surface albedo and atmospheric turbidity, the radiative-convective models is able to calculate the heat absorption for various layers of atmospheric. The radiative-convective model also can simulate in details the transfer of energy through the depth of atmosphere, absorbed, emitted and scattered of radiative transformation that occur as energy and simulating the role of convection which transferring energy via vertical atmospheric motion in order to maintain stability. For two-dimensional radiative-convective models, it can simulate energy transfer for horizontally-averaged. Radiative-convective model is useful in studying forcing perturbations that have their own origin within the atmosphere, such as volcanic pollution’s effects.

2.2.3 Statistical-Downscaling Models (SDSM)

Downscaling in general is a name for procedure to take information at a large scale then make prediction at local scale (Hoar and Nychka, 2008). The downscaling climate information using two ways of approaches which is dynamical and statistical. As for dynamical downscaling, it needs a high-resolution running climate models on a regional sub-domain by using an observational data or lower-resolution climate model output as a boundary condition. Meanwhile, statistical downscaling actually is a two-steps process. The first step is a development of statistical relationship between local climate variables and a large scale predictor. Second, is to use the relationship as output of global climate model experiments to simulate characteristics of local climate in future. The statistical-dynamical model is a two-dimensional models form where usually one horizontal and one vertical dimension, although some models with two horizontal dimensions.

Furthermore, statistical-dynamical model is the combination between horizontal energy transfers of energy balance model with the radiative-convective models approach. Nevertheless, simulation of equator-to-pole energy transfer is more sophisticated based on empirical and theoretical relationships of the cellular flow between latitudes. The law of motion is used to simulate energy diffusion. Moreover, according to the United Nations Framework Convention, UNFC on Climate Change (2014), statistical downscaling model can be used if impact assessments require small-scale climate scenarios. It is also can provide a quality observational data and daily general circulation model outputs for the large-scale climate variables.

For study of Estimating the Long Term Pattern of Water Stream-flow with Climate Change Adaptation at Lubuk Paku, the method of statistical-downscaling Models have been chosen. This is because Franchito and Rao (2015) indicates compared to radiative-convective models and energy balance models, statistical-downscaling models is the inclusion of both latitudinal and vertical variation, allowing more treatment of feedback mechanisms that have to simplified in one-dimensional models. In comparison with radiative-convective models, statistical-downscaling model can estimate the latitudinal characteristic while treating the vertical structure of the atmosphere. Besides, it is hard to trace the cause-effect relationship in general circulation models compared to statistical-downscaling models because of simultaneous inclusion in several highly complex physical processes. And yet the statistical-downscaling model is more useful for a long-term climate variation studies than the general circulation models because statistical-downscaling models more computationally efficient (Franchito and Rao, 2015).

An example of studies was at Sarawak, Malaysia. The title of studies was Application of Statistical Downscaling Model for Long Term Prediction of Rainfall in Sarawak, Malaysia. Hussain et al., (2015) states the study was to evaluate performance of statistical-downscaling model developed by rainfall downscaling of annual and monthly sub models from general circulation model over two districts at Sarawak. The two districts were Belaga and Limbang. It is shown that the monthly sub models have better performance than the annual sub models, though both have poor correlation with the recorded rainfall for calibration and validation period. Moreover, statistical-downscaling model have predicted that the annual rainfall of Belaga and Limbang will be increased with 37.8% and 22.7% respectively by 2074. In brief, the statistical-downscaling model predicted the average rainfall very well during calibration and validation period but as for correlation between forecasted and observed the rainfall was not so good. Thus, there is a need to improve statistical-downscaling models to get a good correlation results between predict and predictors so that the model performance over the wet regions like Sarawak would be better.

2.2.4 General Circulation Models (GCM)

General circulation model also known as global climate model is used to simulate numerically the changes of climate as a result of slow changes at some boundary conditions or physical parameters (Geerts and Linacre, 1998). General circulation model also can predict climate for a long time period like years, and it is long enough to learn about climate in a statistical sense. According to the Intergovernmental Panel on Climate Change (2013), general circulation model can produce geographically and physically consistent estimation of regional climate change that required in impact analysis. In addition, general circulation model is available to study many kinds of climate attributes other than the surface temperature. For an example, general circulation model can used to study atmospheric temperature profile, atmospheric circulation, ocean circulation, rainfall, snow and ice distribution, wind pattern, and many other variables of global climate system.

The first general circulation model was developed in 1950's by Norman Philips. The general circulation model was a simple two layer consist of hemispheric and quasi-geostrophic computer model only. Next, the illustration of climate made by general circulation model was using a three dimensional grid over the globe. Based on Intergovernmental Panel on Climate Change (2013), typically general circulation model has a horizontal resolution between 250 and 600 km, 10 to 20 vertical layers in atmosphere and sometimes can be 30 layers in the oceans. The fundamental laws of physics that involve in three dimensional model formulation is conservative of energy, conservative of momentum, conservative of mass and the ideal gas law. Using a three dimensional model helps providing a reasonable accurate representation of planetary climate. But, general circulation model is unable to simulate regional meteorological phenomena and the spatial resolution also limited to vertical dimension.

2.3 Providing Regional Climates for Impact Studies (PRECIS)

PRECIS is essentially a regional climate modelling system, developed by Hadley Centre at the UK Met Office. Furthermore, PRECIS was used to assist the development of climate change scenarios for application in any region of the globe. In other words, a regional climate model, RCM within the PRECIS is a model of atmosphere and land surface of limited area with a high resolution and locatable for any part of the world (Mawe, 2012). Just like the other models, PRECIS's boundary conditions are simulated by general circulation models, GCM. Function of PRECIS is also to generate finer-resolution which is physically consistent regional climate projections, if the outputs of general circulation models are not sufficient in providing regional details.

In comparison with statistical-downscaling models, there are tools accompanied with online handbook and technical manual that need to be installed from PRECIS website in order to use the software. Besides, according to protocol, the tools only can get after attending the PRECIS workshop. In fact, the software only runs on a Linux based PC though it has been developed with a user-friendly interface. According to the United Nations Framework Convention on Climate Change (2014), compared with statistical-downscaling models, it is only requires little training to use the software and the statistical-downscaling models software only need PC Windows to perform the analysis.

2.4 Rainfall-Runoff Modelling

The rainfall-runoff modelling is useful to get means of extrapolating from available measurements for both space and time, particularly to unmeasured catchments and to assess the impact of future hydrological change. The rainfall-runoff modelling can be carried out within the analytical framework from observation of inputs and outputs of catchment area (Beven, 2012). As in early 19th century, the origin of rainfall-runoff modelling arising in response of three type engineering problems which is urban sewer design, reservoir spillway design, and land reclamation drainage systems design (Chong, 2002). Among the three problems, major parameter of interest was to know the design discharge. By using the rational formula to determine peak discharge, the catchment characteristics and rainfall intensity are uniformly distributed in space and time, but this formula only limited to small urban catchment.

As for present day, to take proper account of the nonlinearities of runoff production process are still difficult, especially in situations where data are limited (Beven, 2012). It might be easy to obtain effective parameter values by calibration or back-calculation where observations are available. But to predict the effective parameter values for more extreme storm or ungauged catchment are still remain difficult. Moreover, the problem comes when separating out the effects of runoff generation and routing the model parameterisations. However, to make predictions is not impossible even though using only simple models. This is because, the Rational Model have been evolved into the Graphical Estimation technique since the pre-computer era in attempt to summarise a wide range of analysis into a set of graph that could be used to predict peak discharge under different antecedent conditions and rainfall.

2.4.1. Empirical Models

Empirical models also known as metric model or black box model or input output model, but does not aid in physical understanding. The models are observation oriented models because it is only take information from existing data while not considering the processes and features of hydrological system, hence these models also called as data driven models (Devi et al., 2015). Moreover, the models also contain parameters that have little direct physical significance that can be estimated by using a simultaneously measurement of input and output (Chong, 2002). These models only valid within the boundaries, for an example the stochastic time series models. Regression and correlation models are used in statistically based method where the function is to find functional relationship between input and outputs. In addition, a black box method means that it is a method that providing little explanation of its output and has no ability to extrapolate or extending to the new versions of problems. But it is best used as a compromise in condition that theoretical modelling framework is unavailable. Besides, the main reasons for the successfully performance of black box models due to their mathematical structure underlying the physical system but the prediction is entirely based on mathematics (Jajarmizadeh et al., 2016).

2.4.2 Conceptual Models

Conceptual models also know as parametric models or a grey box models (Chong, 2002). Jajarmizadeh et al., (2016) states the conceptual model is an intermediate between deterministic and the black box models. This model describes all the components in hydrological processes. Basically, conceptual model consider physical laws in a highly simplified form. Moreover, the conceptual model can be less or more complex between the used of simple mass balance equations for components representing storage in the catchment to coupled nonlinear partial differential equations (Beven, 2012). In other words, this method used the semi empirical equations and the model parameters are assessed not only from field data but also through calibration (Devi et al., 2015). Large numbers of hydrological and meteorological records are required for calibration. Nevertheless, if the equation cannot be solved analytically then an additional stage of approximation is necessary to applied by using numerical analysis to define a procedural model in the form of code that will run on the computer. As reminder, the potential to add significant error relative to the true solution of the original equations might occur after the transformation of conceptual models to the code of the procedural model. Thus, can affecting the behaviour of a model in the calibration process.

2.4.3 Theoretical Models

Chong (2002) indicates the theoretical models can be called as white box models or physically based models. Theoretical models also known as mechanistic models which include the principles of physical processes (Devi et al., 2015). This model is mathematically idealized representation of the real phenomenon. Besides, the model has a logical structure similar to the real world system and it is helpful under changed circumstances. Furthermore, it uses state variables that are measurable and functions in both time and space. For calibration, there is no need for extensive hydrological and meteorological data but the parameter's evaluations are required in describing the physical characteristics of catchment (Abbott et al., 1986 as cited in Devi et al., 2015). The physically based model can overcome defects of other two models due to the use of parameters having physical interpretation. Besides, it can apply for a wide range of situations and providing lots of information even outside the boundary.

2.4.4 The IHACRES Model

IHACRES stands for the identification of unit hydrographs and component flows from rainfall, evaporation and stream flow data model. It is used to avoid problem of hydrograph separation in classical unit hydrograph models by relating between total discharge and total rainfall (Beven, 2012). Furthermore, Jakeman and Croke (n.d.) states the IHACRES model is a hybrid metric-conceptual model which means the simplicity of metric models have been use to reduce uncertainty of parameters in hydrological models while attempting to represent more details of the internal processes than the typical metric models. According to eWater, Innovation Centre (n.d.) IHACRES is a catchment-scale rainfall-stream flow modelling methodology in purpose of characterise the dynamic relationship between rainfall and stream flow, using data of rainfall and temperature, and to predict stream flow. Similarly to Abushandi et al.,

(2013) IHACRES requires only three data sets which are temperature, rainfall and stream flow per time unit.

In comparison with HEC-HMS that stands for hydrologic engineering center-hydrologic modelling system, it is designed to describe the physical properties of river basins, the meteorology that occurs on river basin and result of runoff and stream flow that are produce (Maidment, 2013). In simple, HEC-HMS is use for simulation of both continuous and single event runoff of a basin. Between the HEC-HMS and IHACRES, application of IHACRES is just using Java-based version model which more simpler compared to HEC-HMS model that need to apply using the HEC-GeoHMS extension in ArcView 3.3.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The phases of work of study are determined. The rainfall and temperature data from MMD were used to develop the future rainfall pattern in the site study. The methodology was constructed to achieve the objectives of study. In this study, methods used were statistical downscaling models (SDSM) and identification of unit hydrographs and component flows from rainfall, evaporation and streamflow (IHACRES). Statistical downscaling models (SDSM) is one of the statistical downscaling models that interpret the predictand (local climate) – predictor (GCMs-scale) relationship using the multiple regression techniques (Tukimat and Harun, 2013). It is allows different types of data to be transformed into standard predictor variables before being downscaled and calibrated to produce nonlinear regression models (Tukimat and Harun, 2013). This method also helps in reducing the standard error of estimate and increase the number of explained variance using the bias correction and variance inflation techniques (Wilby et al., 2002; Paulin et al., 2005). Meanwhile, the IHACRES is a hybrid conceptual-metric models that were used to reduced uncertainty of involved parameter and represent more detailed of the internal processes (Croke et al., 2005).

Figure 3.1 presents a flow of methodological project which involved with 2 methods in achieving the objectives of study.

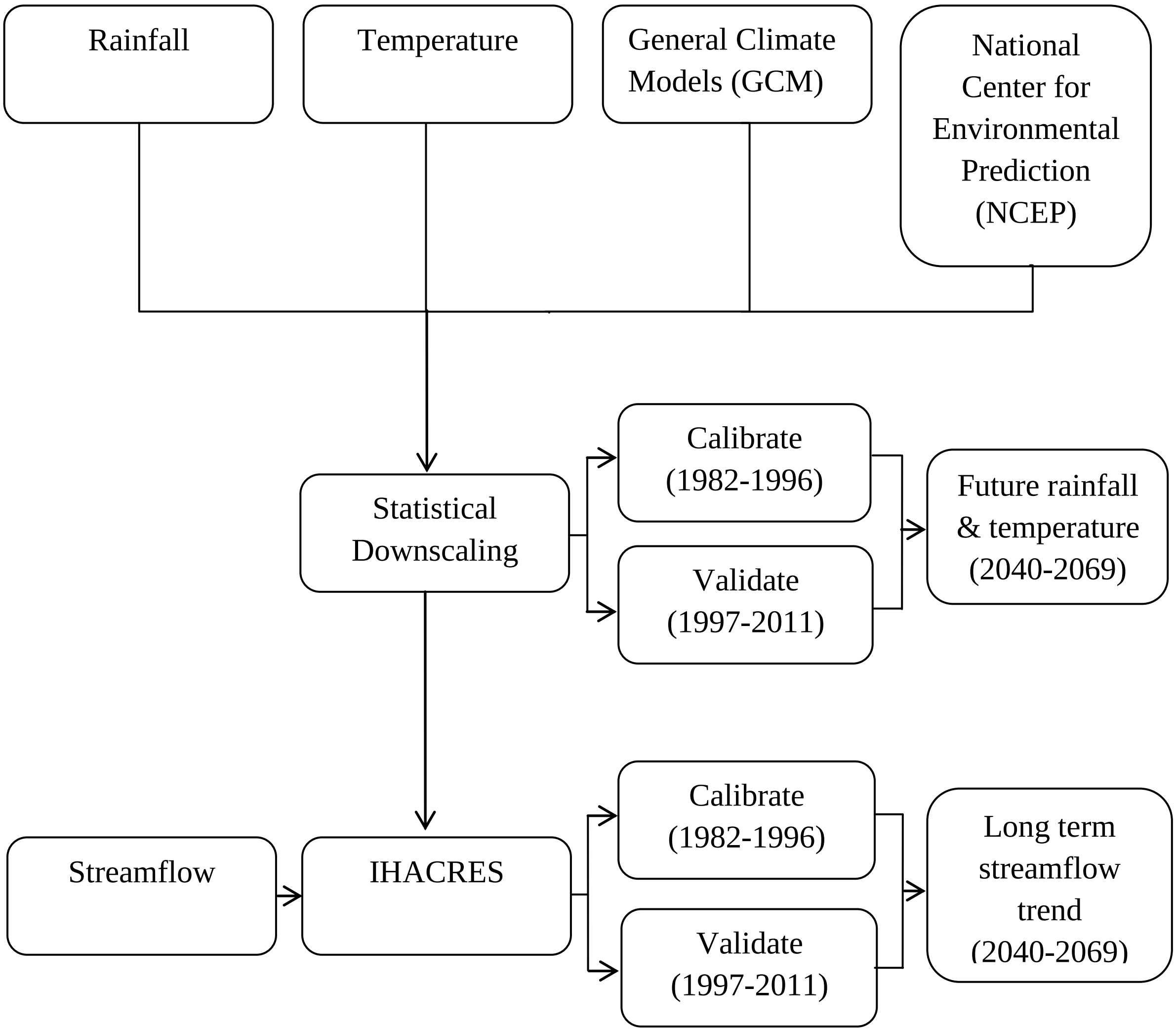

Figure 3.1: Flow chart of research methodology

The study used climate model, statistical downscaling model (SDSM) meanwhile as for rainfall-runoff models was the IHACRES. The models used specifically for estimated the long term pattern of water streamflow with climate change adaptation. The data used in this study were rainfall, temperature and streamflow that get from trusted agencies. The agencies that was responsible in providing rainfall and temperature data was the Malaysia Meteorological Department, MMD. Meanwhile for streamflow data, it got from the Department of Irrigation and Drainage, DID. The data was original and accordance to the study as it was came from the responsible agency that review, store information and data about this distribution.

The study needs to be accurately and smoothly process, as to achieve it some other data and information needed in this study. The important data needed would be mean, minimum and maximum temperature data. After gain the data, checked if the data can be filtered and analysed so that any defect is inevitable. The analysed data would be used as input in the models to see if the data can process the weather data or not. The input entered in models must be correct and result obtained in range. This is because, to avoid any incorrect results and minimise the disability.

After that, it was the beginning of analysis which the climate modelling used to project the current and future climate trend at the site study. The type of climate modelling that used was statistical downscaling model (SDSM). The statistical downscaling model (SDSM) version 4.2.9 used to downscaled the raw atmospheric resolutions turn to smaller climatic information scale that focus on the local station by using regression analysis. After that, the projection of local climate trend would be used to simulated and generated the monthly inflow time series via rainfall-runoff model, IHACRES model. The emphasis in IHACRES model was on modelling identifiable catchment-scale rainfall-runoff behaviour rather than the small-scale hydrological processes as an example the rainfall causes streamflow.

3.2 Analysis of Missing Data

Some of the precipitation stations may have short breaks in the record because of absence of the observer or the failures of the instrumental. It is necessary in estimated the missing record. The station whose data were missing was called as interpolation station while gauging stations was a station whose data were used to calculate the missing station data were called as index stations. It was important to consider the percentage of missing data in order to maintain the quality of the input data into the models. The percentage value of missing data should be less than 10%.

There were several methods for estimation of missing data such as arithmetic mean method, normal ratio method, distance power method, mass curve method, thiessen method and isohyetal method. As for this study, the method used to calculate the missing data was arithmetic mean method as it is the most suitable method to use when normal annual precipitation is within 10% of the gauge for which data are being reconstructed. According to the arithmetic mean method the missing precipitation ‘Px’ is given as in Eq. (3.1)

$$P_x = \frac{1}{n} \sum_{i=1}^{i=n} P_i \qquad (3.1)$$

where ‘n’ is the number of nearby stations, ‘Pi’ is precipitation at the station and ‘Px’ is missing precipitation.

3.3 Statistical Downscaling Model (SDSM) Methodology

The rainfall and temperature data that given was sorted from the file of text document into the predictand file (DAT file). From the SDSM 4.2.9 software started by checking the predictor from NCEP at quality control tab one by one to make sure there were no missing value. After that, used the screen variable tab to analyse the sorting data and produced a table consist of correlation value for each predictor. The best predictors among the 26 predictors were chosen based on the correlation value, which means the most suitable predictors have the higher correlation value and relate to the rainfall or temperature. Based on Figure 3.5 it shows an example of the table that produce after analyse in the screen variables tab.

Analysis Period: 1/1/1982 - 31/12/2011
Significance level: 0.05

Total missing values: 0

Predictand: mean.temp 1984-2013.dat

Predictors:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ncep_p__f.dat	0.171	0.203	0.086	0.011		0.023	0.013		0.027		0.104	0.113
ncep_p__u.dat	0.136	0.131	0.026			0.022	0.007		0.023	0.006	0.075	0.117

Figure 3.2: Example of analyse table

When the predictors set have been chosen, the model was proceed to the calibration and validation processes. In the calibrate model tab, the data period would be set as 15 early years from the 30 years of study. The predictand file (DAT file) selected was a file that contained the sorting data and as for the predictor variables, only the chosen predictor would be selected to calibrate the data. The calibrated data then will be saved into parameter file (PAR file). Next, in the weather generator tab the process was to synthesize the PAR file to ensemble size of 100. This means that it will produce an output file (OUT file) that containing 100 times of synthesis data according to the date of period. Move on to the summary statistics tab, it was where the previous output file produced in weather generator tab would be analysed into another output file that helps producing the graph of modelled and observed data of calibrated and validated. This graph can be produced in compare results tab.

The statistical downscaling model (SDSM) version 4.2.9 was used in this study to downscale the general climate model (GCM) output to a regional scale as well as to project the rainfall and temperature data from a year of 1982-2011 and 1984-2013. General climate model (GCM) produce global climate forecasts using different emission scenarios. However, GCM outputs cannot be used directly for impact assessments and frequency analysis, thus the statistical downscaling model (SDSM) is applied (Lansigan et al., n.d). The statistical downscaling is an analogous to the “model output statistics” (MOS) and a “perfect program” approaches used for short-range numerical weather prediction (Wilby and Dawson, 2007). It is believes to will continue play a significant role in the assessment of potential climate change impacts arising from future increases in greenhouse-gas concentrations. Besides, SDSM was the first tool of its type freely offered to the broader climate change impacts community. Other software, although more accessible, produces relatively coarse regional scenarios of climate change (both spatially and temporally). The SDSM will generate of ensembles of future weather data using the GCM-derived predictor variables. The key functions of SDSM will be illustrated using observed and climate model data for a hypothetical station, comparing downscaled daily precipitation and temperature series for year of 1982-2011 and 1984-2013.

The SDSM software reduces the task of statistically downscaling daily weather series into seven discrete steps:

1) Quality control and data transformation
2) Screening of predictor variables
3) Model calibration
4) Weather generation (using observed predictors)
5) Statistical analyses
6) Graphing model output
7) Scenario generation (using climate model predictors)

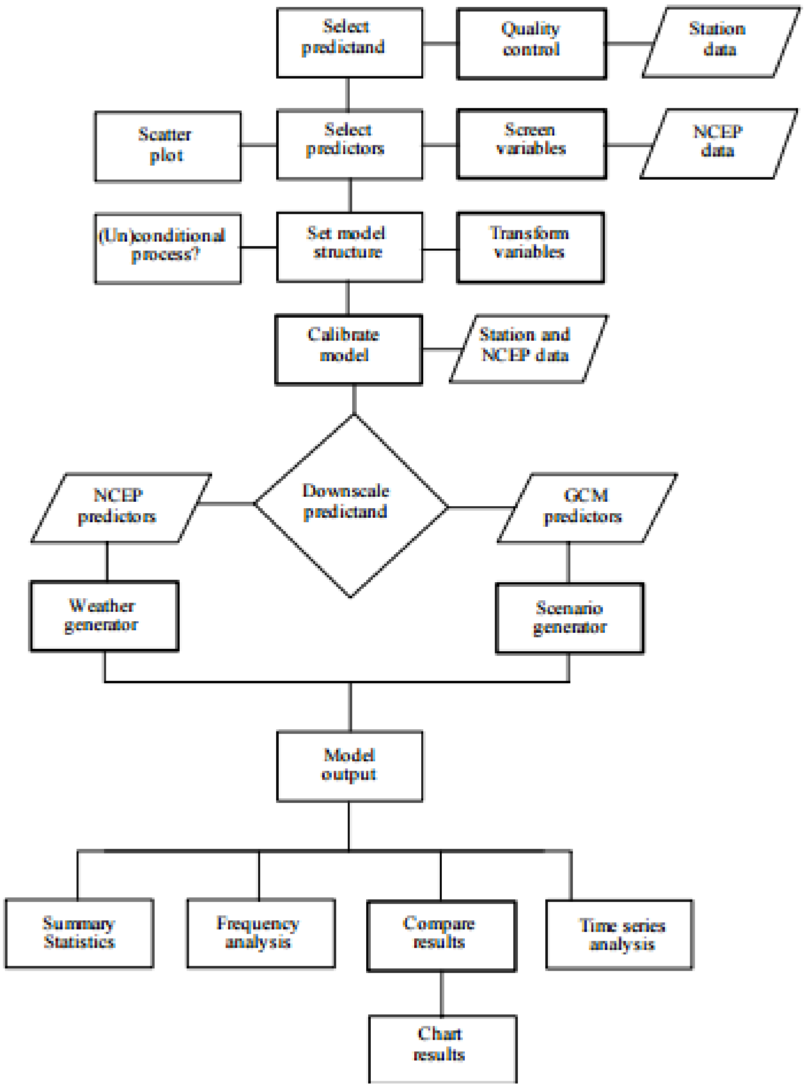

Figure 3.3: SDSM version 4.2.9 climate scenario generation

The downscaling technique, SDSM is best described as a hybrid of the stochastic weather generator and transfer function methods.

3.3.1 Predictors Selection

Identifying empirical relationships between gridded predictors and single site predictands is central to all statistical downscaling methods.

The selection of an appropriate downscaling predictor variable is important for this study. This is because the choice of predictors largely determines the character of the downscaled climate scenario. Through screen variables operation in SDSM 4.2.9, the predictor variables were selected. The decision process is also complicated by the fact that the explanatory power of individual predictor variables varies both spatially and temporally. Screen variable facilitated the examination of seasonal variations in predictor skill.

Table 3.1: List of predictors in the SDSM analysis

No.	Predictor Variables	Predictor Description
1	mlsp	mean sea level pressure
2	p_f	surface airflow strength
3	p_u	surface zonal velocity
4	p_v	surface meridional velocity
5	p_z	surface vorticity
6	p_th	surface wind direction
7	p_zh	surface divergence
8	p5_f	500hpa airflow strength
9	p5_u	500hpa zonal velocity
10	p5_v	500hpa meridional velocity
11	p5_z	500hpa vorticity
12	p500	500hpa geopotential height
13	p5th	500hpa wind direction
14	p5zh	500hpa divergence
15	p8_f	850hpa airflow strength
16	p8_u	850hpa zonal velocity
17	p8_v	850hpa meridional velocity
18	p8_z	850hpa vorticity
19	p850	850hpa geopotential height
20	p8th	850hpa wind direction
21	p8zh	850hpa divergence
22	r500	relative humidity at 500hpa
23	r850	relative humidity at 850hpa
24	rhum	near surface relative humidity
25	shum	surface specific humidity
26	temp	mean temperature

3.4 IHACRES Model Methodology

The data requirement for input data were observed rainfall, temperature and observed streamflow. The unit used for rainfall was millimetres, temperature wass celsius, and for the streamflow was cubic metres per second (cumecs). First step, load the data by selecting the import tab that give access to of observed rainfall, temperature (mean, minimum and maximum), and observed streamflow. Before loading it, make sure that the data was in DAT file. Finished loading the data, check whether they synchronised and the data were corrected at summary tab. Step 2, defined the calibration period. In the calibration tab, the observed rainfall, temperature and observed streamflow can be viewed as a graph. Step 3, calibrated the linear module. This step helps to identify the delay between time series by run a cross correlation between rainfall and streamflow. For any IHACRES calculated delay, it can be override to zero as there is not very much different of one day delay to zero delay. Step 4, calibrated the non-linear module. By pressed the grid search in the non linear module area, the tools can performed a search through parameter space to find a good parameter set. The classic module has 5 parameters and there are:

- drying rate at reference temperature (tw)
- temperature dependence of drying rate (f)
- reference temperature (tref)
- moisture threshold for producing flow (l)
- power on soil moisture (p)

The final step was simulation. By clicking on the simulation tab, a hydrograph of the model output and flow observations was displayed.

3.5 Description of Site Study

The study located at Pahang state. It is known as the largest state in Peninsular Malaysia with the land area 35,965 km^2. The land area is covered with dense tropical rainforest, making it a repository for Malaysia’s natural treasures. Peninsular Malaysia’s largest state is bordered on the north by the states of Kelantan and

Terengganu, on the south by Negeri Sembilan and Johor, on the west by Perak and Selangor meanwhile on the east side bordered with the South China Sea. Tropical monsoon at Pahang state brings with the series of uniform temperature between 21°C to 32°C throughout the year. Usually during months of January to April, it will be dry and warm while the months of May until December would be the wettest. The average rainfall of Pahang each year will be falls between 2,032 mm to 2,540 mm with a high humidity between 82-86%.

Figure 3.4: Map of Pahang state

The site study focus at Lubuk Paku, Maran. This catchment area for this site study is 239.0862 km^2. It is where the rainfall and streamflow data collected. As for the temperature data, the collected data comes from Pahang's district, Temerloh. From Figure 3.3 and 3.4 it shows the specific location of site study.

Table 3.2: Site locations and site stations of the study

Data	Site location	Site station
Rainfall	Lubuk Paku	3527092
Streamflow	Lubuk Paku	3527410
Temperature	Temerloh	3242081

Figure 3.5: Map mapping of Lubuk Paku

Table 3.3: Meteorological data of Lubuk Paku (1980-2009)

Data information	unit
Highest water level	15.23m
Lower water level	12.70m
Highest monthly total	324.57mm

rainfall	
Lowest monthly total rainfall	79.81mm
Mean discharge	1184.46m^3/s
Wind speed	33.5m/s

Figure 3.6: Map mapping of Temerloh

Pahang's district Temerloh chosen to be site station for temperature as it is the closest one with Lubuk Paku site study compare with other station for collection of temperature data.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Climate Trend at Site Study

Changing of precipitation pattern and increased evapotranspiration due to rising temperature will increase the frequency and severity of droughts and floods at specific region (Shaaban et al., 2011). During 23 December 2014, according to the Department of Irrigation and Drainage stated flood event causing the 4 main river at Pahang passed the danger level and it is located at Sungai Tembeling with 75.35m (danger level: 68m), Sungai Yap with 54.93m (danger level: 52m), Sungai Kuantan at Pasir Kemudi with 8.79m (danger level: 8.2m) and Sungai Kuantan Bypass with 5.27m (danger level: 3.5m). From this, it shows that the pattern of climate may consider as a core factor to the hydrological systems effect. The prediction of climate trend at site study for the historical year of rainfall (1982-2011), temperature (1984-2013), and streamflow (1999-2009) with the future year (2040-2069) were produced by the simulated of mathematical relationship between the local climate pattern and information of the atmospheric circulation at specific sub-grid. The prediction involving daily and monthly rainfall data at site station 3527092 and streamflow data at site station 3527410 which both located at Lubuk Paku. Meanwhile as for the temperature, site station is 3242081 and located at Temerloh. The climate prediction was conducted by using multi-regression techniques in the version of SDSM 4.2.9.

In the SDSM 4.2.9 version, it was started with key function of quality control. From here, the SDSM checked the data if it enable the identification of gross data errors, specification of missing data codes and outliers prior to model calibration. Follow with screening process, the operation is to assist the user in the selection of appropriate downscaling predictor variables. The local rainfall and temperature stations would be the predictand. The screening process involved with 31 of NCEP predictors and 2 of local predictands. Based on the results, 3 predictors were selected to simulate with local climate characteristics. Afterward, each of the local predictand calibrated with rainfall from year (1982-1996) and temperature from year (1984-1998). Besides, continued with validated for rainfall (1997-2011) and temperature (1999-2013). These predictand were calibrated and validated to the predictors set from NCEP data to evaluate the performances of the simulated results compared with observed data. The GCM-derived predictors were then used to generate the daily weather series based on re-analysis predictor variables for the future year.

4.1.1 Temperature Simulation Result

The simulation of temperature data (predictand) was referred to Temerloh (3242081). Using the SDSM model, the predictors set was selected during screening process. From Table 4.1, it shows the selected 3 predictors for the analysis.

Table 4.1: List of selected temperature predictors

No.	**Predictor Variables**	**Predictor Description**
1	p__f	Geostrophic airflow velocity near the surface
2	p8__f	Geostrophic airflow velocity at 850hPa
3	shum	Near surface specific humidity

Figure 4.1 to 4.3 present the simulated result produces by calibrated (1984-1998) and Figure 4.4 until 4.6 shows result of validated (1999-2013) process using

predictors set from NCEP for three conditions; maximum, mean, and minimum of temperature. For the calibrated line graphs, it revealed that the selected predictors set were generated well close to the observed data. This proved that they have a good correlation to the predictand data. Meanwhile, validated results line graphs shows selected predictors set that generated slightly close to the observed data. The graph with highest error can be seen at the validation result of minimum temperature; Figure 4.6 with the highest % of mean absolute error (MAE) is 1.42% and correlation value 0.95. However, the model still successfully produced similar trend with the observed temperature.

Based on Figure 4.7 to 4.9, the maximum, mean, and minimum of temperature at Temerloh were projected for the year 2040-2069. The results present in the average temperature for year period 2040-2069. From the maximum temperature, the results indicated that the study area's average temperature will be constantly celsius in range of 30°C to 35°C for the whole months. Meanwhile, as for mean and minimum temperature there were vary results for each month but well close to the historical data. From mean graphs, it shows that the highest temperature was 27.5°C during May and the minimum would be 25.4°C during December. For minimum temperature, the highest would be during May with 23.5°C and the lowest was during January with 22.3°C.

The results shows that in the future, the warmest season is still on the month of May and the rainy season are between December until February of the next year. The results also indicated that there was still increment for maximum, mean, and minimum temperature for future. Even though the estimated reading was not extremely high, but the precautions are still necessary. In the upcoming year, people especially farmers should be aware of the rising of temperature reading may cause soil moisture losses and increasing of evapotranspiration process. The irrigated demand also expected to be increase consistently due to climate change.

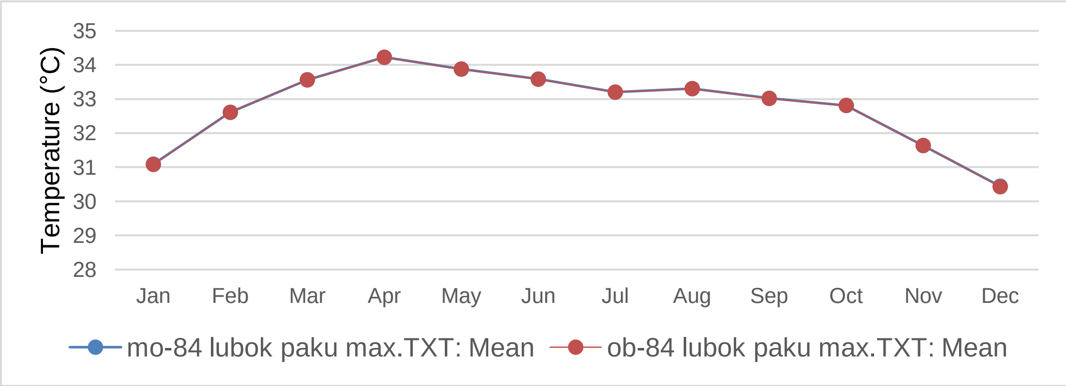

Figure 4.1: Calibrated result 1984-1998 for the maximum temperature using the SDSM model

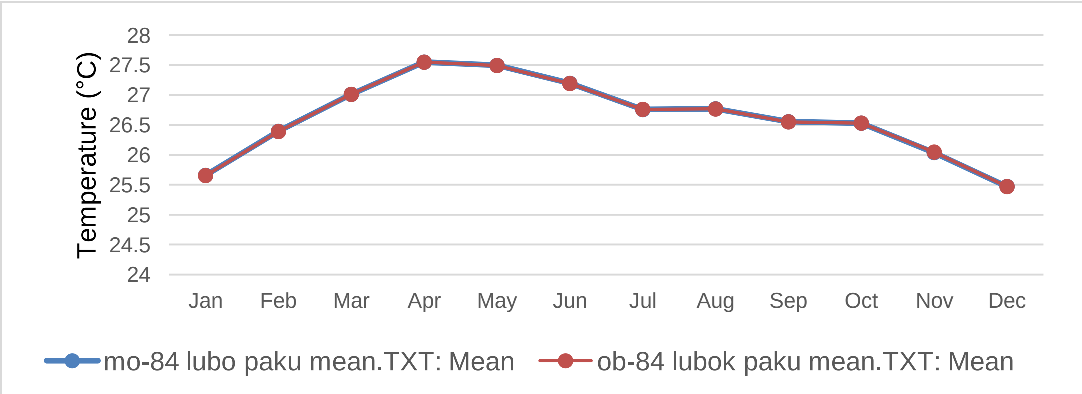

Figure 4.2: Calibrated result 1984-1998 for the mean temperature using the SDSM model

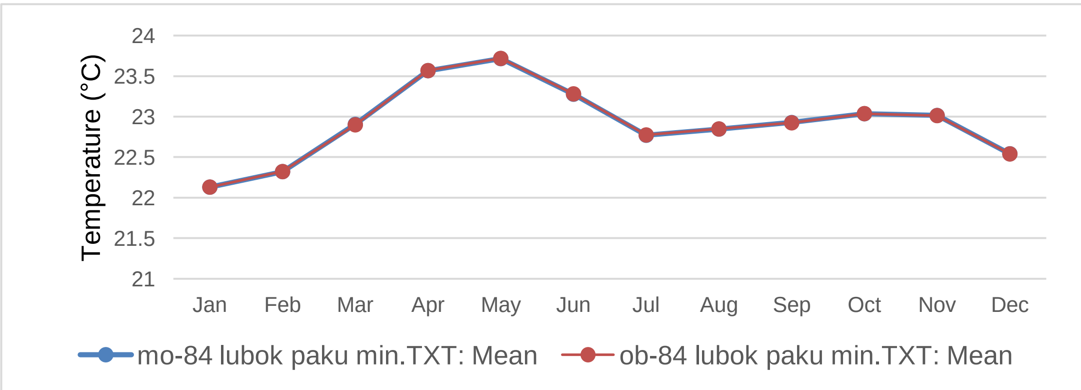

Figure 4.3: Calibrated result 1984-1998 for the minimum temperature using the SDSM model

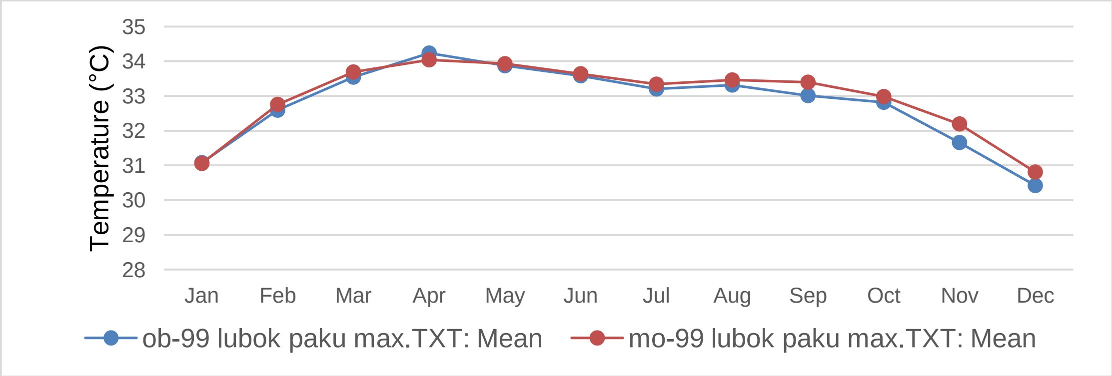

Figure 4.4: Validated result 1999-2013 for the maximum temperature using the SDSM model

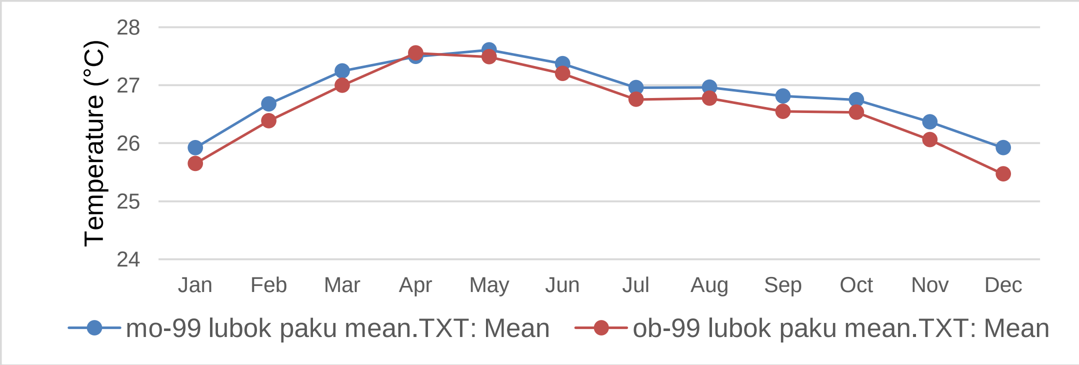

Figure 4.5: Validated result 1999-2013 for the mean temperature using the SDSM model

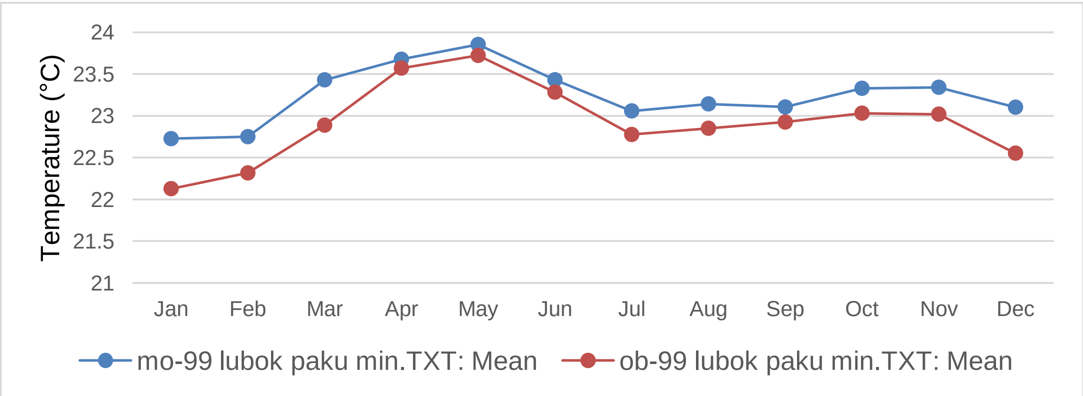

Figure 4.6: Validated result 1999-2013 for the minimum temperature using the SDSM model

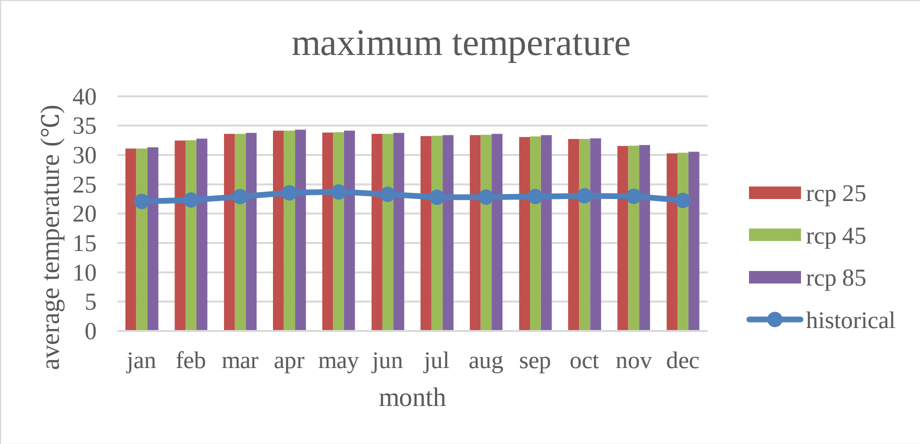

Figure 4.7: Projected maximum temperature for year 2040-2069

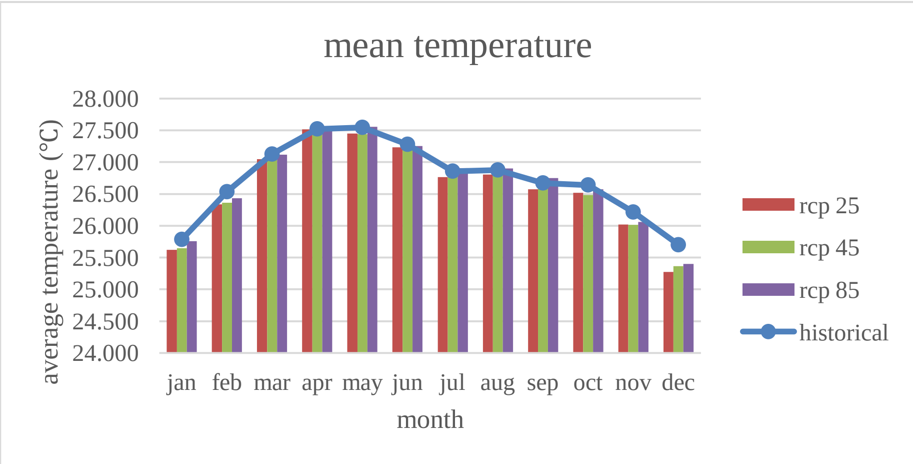

Figure 4.8: Projected mean temperature for year 2040-2069

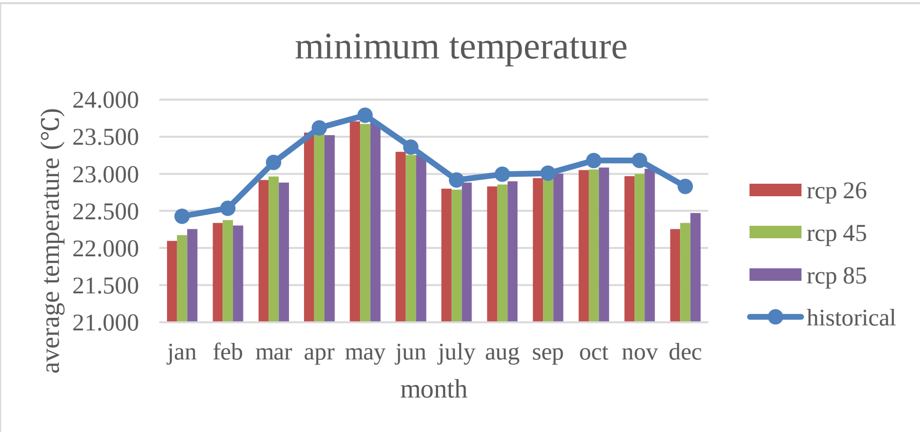

Figure 4.9: Projected minimum temperature for year 2040-2069

4.1.2 Rainfall Simulation Result

4.1.2.1 Predictors Selection through Screening Process

The validity and reliability of the simulation results in the SDSM model was referred to the workability of the predictor variables selection to the all local climate surrounding areas at Lubuk Paku. In the screening process, the relationship of 30 years length record for 31 predictor variables and 1 site station of local predictand was presented in the form of correlation table.

From Figure 4.10, it shows the correlation value for each relationship. The highest correlation value recorded at predictor r850 with 0.141 on January, while the predictor with the lowest value is p8zh, 0.005 on October.

8 out of 31 predictors (lftw, pr_wtr, p__u, p5_u, p8_f, p8_u) produced better correlation with predictand involves as proved they have potential to simulate well to the local climate. However, not all predictors that produce better correlation can be use in the GCM model. Therefore, only this 3 predictors were selected to use in developing the statistical relationship between local and regional scale of climate association which were p__f, Geostrophic airflow velocity near the surface, p8_f, geostrophic airflow velocity at 850 hPa, and shum, near surface specific humidity. For detailed, the performances of predictors set were calibrated and validated for every single rainfall station by using SDSM analysis.

RESULTS: EXPLAINED VARIANCE

Analysis Period: 1/1/1982 - 31/12/2011
Significance level: 0.05

Total missing values: 0

Predictand: rainfall 1982-2011.dat

Predictors:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ncep_dswr.dat	0.121	0.098	0.180	0.024	0.007	0.009						0.056
ncep_lftx.dat	0.122	0.045	0.039	0.006								0.056
ncep_mslp.dat	0.026	0.021	0.020			0.013						
ncep_pottmp.dat	0.032	0.008		0.011	0.015		0.011	0.020	0.012	0.006	0.008	0.022
ncep_pr_wtr.dat	0.178	0.149	0.202	0.047	0.022	0.048	0.015	0.034	0.014			0.051
ncep_prec.dat	0.060	0.046	0.115		0.006	0.014					0.012	0.042
ncepp__u.dat			0.007		0.023	0.007	0.010	0.014	0.007	0.012	0.018	
ncepp__v.dat	0.050	0.073	0.078							0.006		
ncepp__z.dat	0.072	0.018	0.025		0.007				0.011	0.010		0.033
ncepp_th.dat	0.031	0.034	0.031	0.007	0.012							
ncepp_zh.dat	0.026	0.046	0.041							0.007		
ncepp5_f.dat	0.009		0.009							0.006		0.013
ncepp5_u.dat	0.006	0.006	0.008		0.010	0.019	0.015	0.036		0.013	0.006	0.009
ncepp5_v.dat		0.007	0.008				0.009					0.008
ncepp5_z.dat			0.006							0.007		
ncepp500.dat		0.022	0.047	0.007								
ncepp5th.dat						0.007		0.029				0.007
ncepp5zh.dat		0.007	0.010				0.006					0.008
ncepp__f.dat	0.012	0.008					0.010	0.016		0.017		
ncepp8_f.dat	0.009	0.025						0.019	0.007	0.028		
ncepp8_u.dat	0.013	0.039			0.013		0.011	0.023	0.007	0.016	0.019	0.018
ncepp8_v.dat												
ncepp8_z.dat	0.020					0.007						
ncepp850.dat	0.014	0.019	0.029		0.006	0.015						
ncepp8th.dat							0.015	0.006			0.011	0.017
ncepp8zh.dat										0.005		
ncepr500.dat	0.074	0.062	0.100	0.029		0.007		0.007		0.006		
ncepr850.dat	0.141	0.094	0.173	0.036	0.021	0.039	0.016	0.022	0.018	0.007	0.007	0.017
nceprhum.dat	0.107	0.042	0.087	0.015	0.017	0.016	0.009	0.013	0.007		0.010	0.027
ncepshum.dat	0.115	0.031	0.015				0.006	0.009				0.065
nceptemp.dat	0.027		0.018	0.013	0.015			0.011	0.012	0.008	0.008	0.019

Figure 4.10: Correlation values of rainfall station

4.1.2.2 The Calibrated and Validated Performance

By using the selected predictors set, the rainfall station was calibrated (1982-1996) and validated (1997-2011) with the NCEP data. Figure 4.11 shows the calibrated results between modelled and observed data for rainfall station 3527092 meanwhile Figure 4.12 indicate the validated results of rainfall station respectively. From the calibrated results, the line graphs revealed the selected predictors set were well close generated to the observed data except on December, there was a bit gap between modelled and observed data. The % MAE for the calibrated results was 9.51% with correlation value 0.99. Based on the findings, the simulated results considered as acceptable due to % MAE less than 20% and correlation value close to 1. Moreover, for validated result shows that line graph was slightly close to the observed data and there was also a bit gap on October with % MAE, 15.37% and correlation was 0.98. From this simulated results, it is also acceptable because % MAE less than 20% and correlation value close to 1.

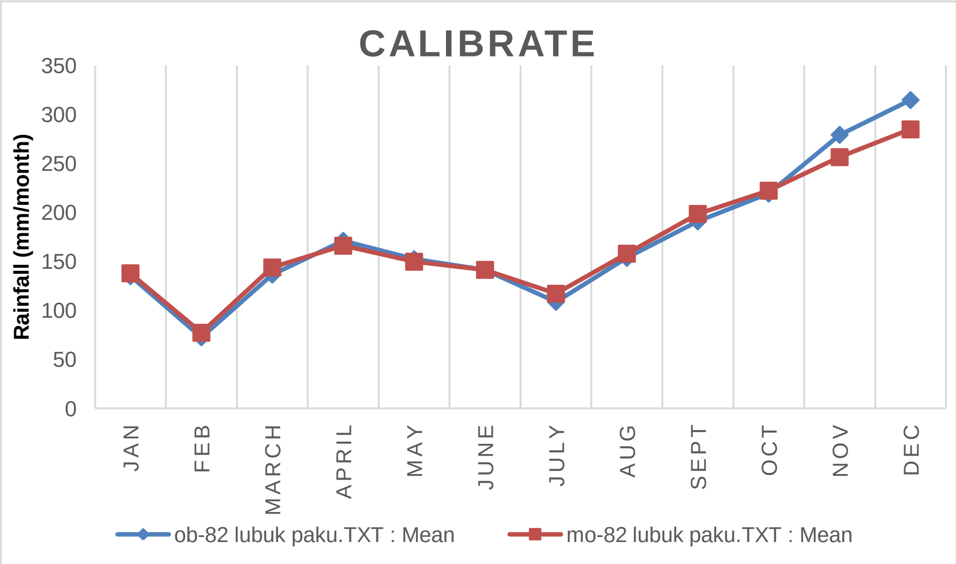

Figure 4.11: Calibrated result 1982-1996 for rainfall station using SDSM model

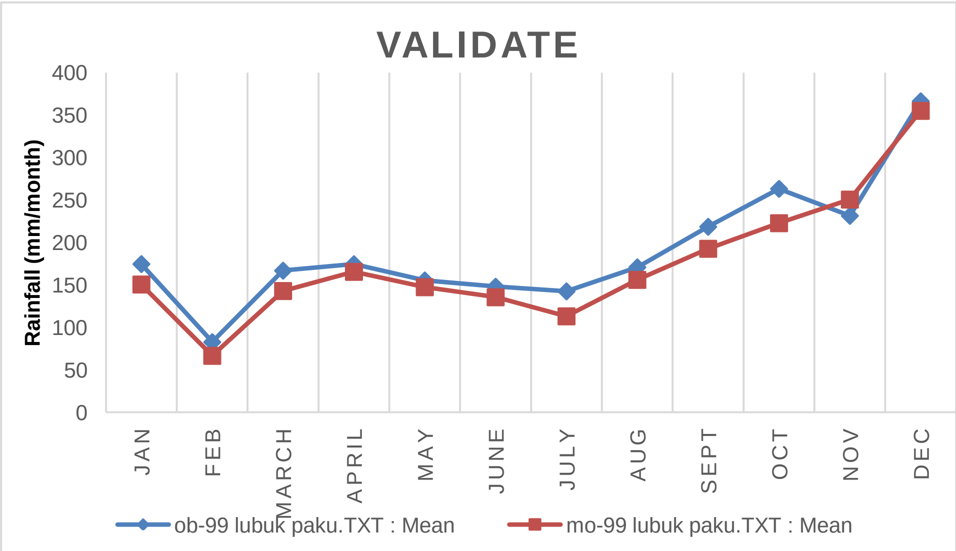

Figure 4.12: Validated result 1997-2011 for the rainfall station using the SDSM model

In general, the simulation using 3 predictors selected set based on screening process were almost well generated to the observed data. Even though there were some error during simulated, but the range was low and reasonable for the rainfall station. The accuracy of the simulated data was also proved that the selection predictor for the location plays a vital role in the calibration process. Therefore, these predictors set will be used to develop climate trend for the future year.

4.1.2.3 Rainfall Trend in Year 2040-2069

The rainfall trend in the future year at the site study was projected using the GCM model that is representing the physical atmospheric in the form of numerical number. The future trending was generated at the rainfall station using the same types of predictors set (p__f, p8_f, and shum). The future year that will be projected is 2040-2069.

During year 2040-2069, the heavy rainfall was estimated struck in the month of November and December with highest value reaching 290mm/month. According to the results, there was an increment between modelled and observed data of rainfall on November which producing a huge gap. It is calculated that the % rises for modelled of rcp 26 is 11.29%, rcp 45 with 10.09% and rcp 85 with 11.30% compare to the historical rainfall. The minimum intensity is expected during January to March which known as dry season with less than 150mm/month.

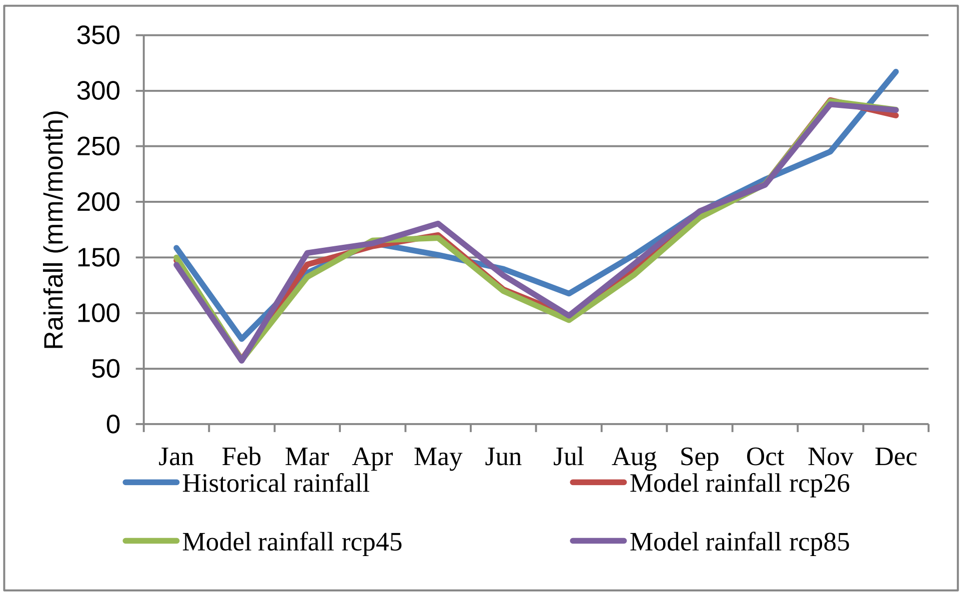

Figure 4.13: Projected rainfall trend for year 2040-2069

4.2 Hydrological Model

4.2.1 Rainfall-Runoff Prediction Model

The time series of monthly runoff that expected to be part of site station was predicted for the period year 1999-2009. The type of rainfall-runoff modelling that has been chosen was IHACRES model because this method considers the effect of rainfall and temperature at the study area in simulating the runoff value. Through the analysis, the best %ARPE and R-squared values were 0.001% and 0.371 respectively with drying rate at reference temperature (τ_w) 4.0°C and temperature dependence of drying rate (*f*), 0.0°C.

4.2.1.1 Streamflow Simulation Using IHACRES Model

From Figure 4.14, it shows the observed and modeled streamflow for the calibrated and validated period 1999-2009. The performance of model was satisfactory and the result shows the simulated analysis produced almost similar to the observed data. The arithmetic relative parameter error, %ARPE estimated to be 27.62% meanwhile the explained variance, R-value would be 0.79 which satisfy for this study. It is expected that the simulation would be better by producing a less amount of error for each month. In fact, the error should not exceed more than 50%. Therefore, the modeled of monthly runoff generation time series produced by this analysis can be consider as reliable for the future trend generation.

Table 4.2 present the parameter values that have been used to model the streamflow generation.

Table 4.2: Calibrated model parameters value for IHACRES model

Parameter	Values
Mass balance term (c)	$157*10^{12} m^3$/day
Drying rate at reference temperature (τ_w)	4.0°C
Temperature dependence of drying rate (*f*)	0.0°C
Reference temperature (tref)	20.0°C
Moisture threshold for producing flow (l)	0.0
Power on soil moisture (p)	1.0

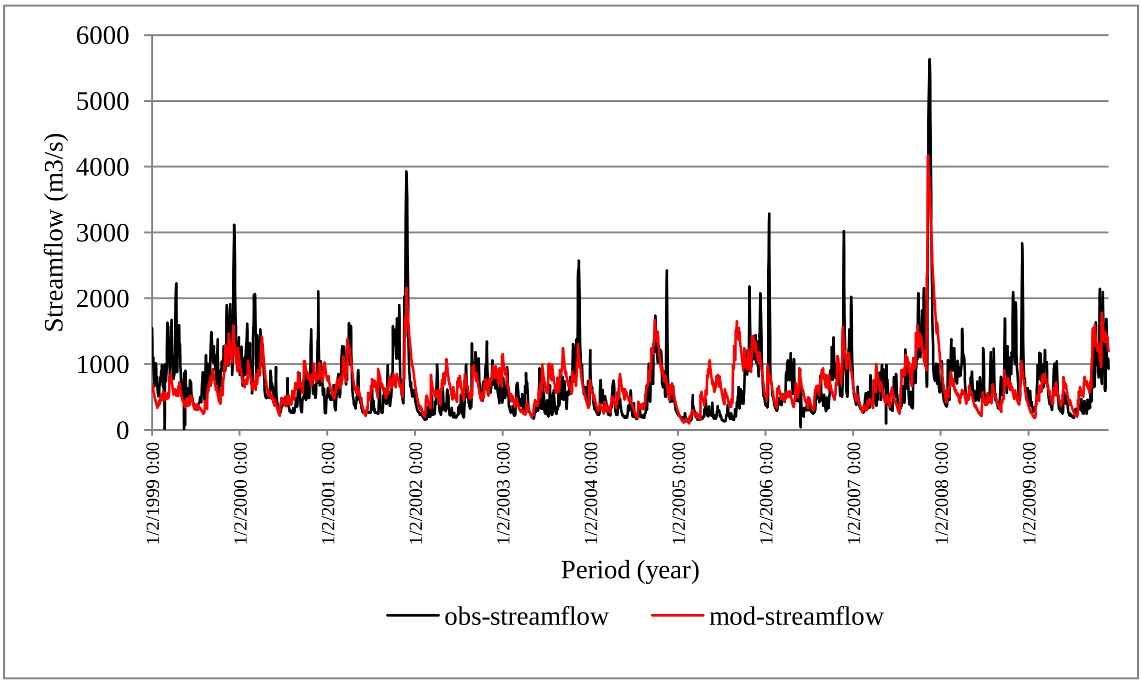

Figure 4.14: The calibrated 1999-2004 and validated 2005-2009 for streamflow

4.2.1.2 Streamflow Trend in the Year 2040-2069

The streamflow time series was simulated for the future year 2040-2069 through the model. The parameters that have been used for this projection was similar to the simulated process to make sure the validity and reliability of the data. Figure 4.15 present the projected streamflow trend for year 2040-2069 at Lubuk Paku (3527410). The streamflow was estimated to become higher year by year. It was consistent to the rainfall pattern at this area which may rise yearly due to climate change. The highest volume predicted by this model was during November with volume of streamflow, 292 m^3/s. Meanwhile the lowest would be in February with streamflow volume, 58 m^3/s. This streamflow pattern was equivalent to the predicted intensity of rainfall trend for future.

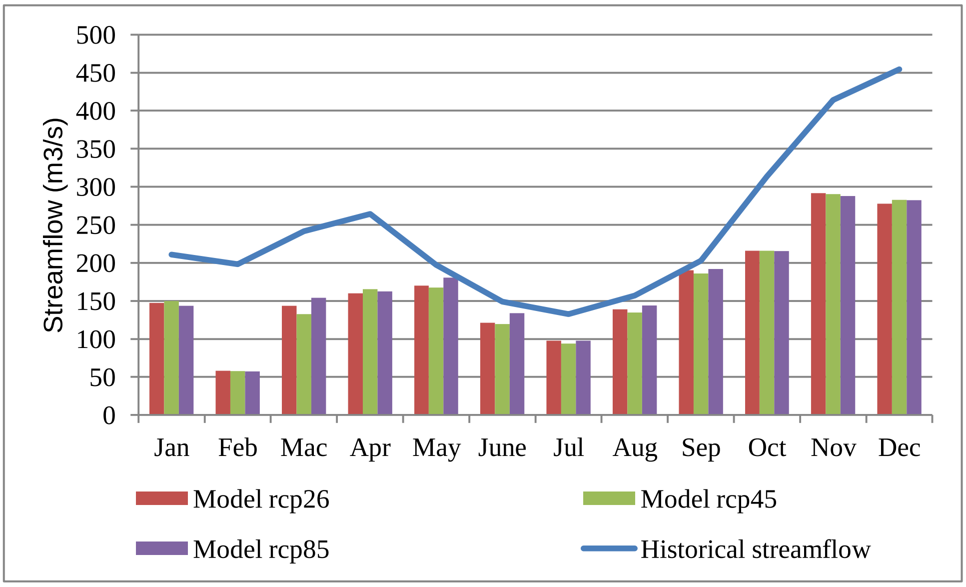

Figure 4.15: Projected streamflow trend for year 2040-2069

CHAPTER 5

CONCLUSION

5.1 Conclusion

Nowadays, it is important to take climate change matters seriously. This is because, due to modern era technology it causing a lot of carbon dioxide production to the surface and consume much of the land that used to have trees surrounding it. The intensive to solve the problems are still lacking in their operation planning and management of water resources. The global climate change reading seems to have non-stop of increasing without given any warning signal to the living. Even the calamity also might happen without noticing at anywhere and anytime. Besides, the problems arise can make the operation planning become harder to handle and work properly even though it have to sustain with the current climate situations.

Pahang was known to be the longest river at Peninsular Malaysia. The water that flows through it is important for the living. Especially to the area that connect with Pahang River. One of the places that connect with Pahang River is Lubuk Paku, means the area also depends on Pahang River to provide sufficient amount of water demand especially during the drying season. Previous study also indicated that Lubuk Paku once facing the bad calamity, which is flood and El-Nino. The calamity causes the food scarcity, cancelation products and losses to the people and government due to many damages that happens during flood season. Thus, the adaptation for irrigation system have to be improve to enhance the capability and reliability of the water streamflow fit to the future conditions.

Due to this concern, the study proposed an improvement method for the long term water streamflow operation system and management with climate change adaptation. For the best results, there are several approaches that can take place which are; 1) apply the downscaling model by using calibration and validation analysis in effort to obtain a better association among predictand-predictor relationship; 2) simulate and project the current year and future climate trend which consist of rainfall, temperature and streamflow. In this study, the development method started with analysis of climate model which is by using SDSM model approaches and continued with rainfall-runoff modelling, IHACRES model. These models were used to generate the rainfall, temperature and streamflow projection for comparison of current and future trend.

5.2 Recommendation

There are several recommendation provided in enhancing the water streamflow operation management;

The global climate change is an important factor to consider whenever preparing the water streamflow operation management. The uncertainty of climate will changes the hydrology circulation systems directly and the irrigation system indirectly.

The prediction of rainfall trend is very sensitive to the atmospheric circulation changes. Because of that, it would be better to not only focusing on one site station but adding more selected stations especially at the place where facing a lot of damage after the calamity happen. This is to understand the climatic trend generally and obtain the average intensity for the study area.

To make sure the efficiency and accuracy results for SDSM model analysis, during screening process it is important to choose the correct predictors variable for analysis. It is more applicable when involving many climatic stations (temperature or rainfall) in the analysis structure to screen the correlation relationship between predictors and predictand entirely.

As for rainfall-runoff model, it would be best to consider using IHACRES model to generate streamflow series. The model is defined by seven parameters, which together predict the daily hydrologic response of a catchment. IHACRES have a potential to generate useful information on prediction of streamflow using observed data for arid and semi arid catchment. Generally, IHACRES model are essential in water resource management of areas where limitation in availability data is observed since the model is perform enough to produce vital source of information.

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APPENDIX A

Calibrate maximum temperature		
Month	ob-84 lubok paku max.TXT: Mean	mo-84 lubok paku max.TXT: Mean
Jan	31.0809	31.0894
Feb	32.6083	32.609
March	33.5589	33.5625
April	34.2202	34.2229
May	33.8774	33.8761
June	33.5793	33.5831
July	33.2024	33.1985
Aug	33.3011	33.3053
Sept	33.016	33.0194
Oct	32.8118	32.809
Nov	31.6369	31.6338
Dec	30.4267	30.4431

Validate maximum temperature		
Month	ob-99 lubok paku max.TXT: Mean	mo-99 lubok paku max.TXT: Mean
Jan	31.0789	31.0572
Feb	32.5908	32.7558
March	33.5422	33.6892
April	34.2331	34.04
May	33.8703	33.927
June	33.582	33.6381
July	33.2006	33.3374
Aug	33.3142	33.4597
Sept	33.0104	33.3943
Oct	32.8168	32.9814
Nov	31.6589	32.1938
Dec	30.4211	30.8094

APPENDIX B

Calibrate mean temperature		
Month	ob-84 lubok paku mean.TXT: Mean	mo-84 lubo paku mean.TXT: Mean
Jan	25.6533	25.6575
Feb	26.3889	26.3935
March	27.0108	27.0105
April	27.5487	27.5488
May	27.4925	27.4943
June	27.1916	27.1952
July	26.7598	26.7553
Aug	26.766	26.7693
Sept	26.5509	26.5533
Oct	26.5303	26.5287
Nov	26.046	26.0374
Dec	25.469	25.471

Validate mean temperature		
Month	ob-99 lubok paku mean.TXT: Mean	mo-99 lubok paku mean.TXT: Mean
Jan	25.648	31.0894
Feb	26.3847	32.609
March	26.9961	33.5625
April	27.5538	34.2229
May	27.4886	33.8761
June	27.2004	33.5831
July	26.7551	33.1985
Aug	26.7735	33.3053
Sept	26.5467	33.0194
Oct	26.532	32.809
Nov	26.0596	31.6338
Dec	25.4696	30.4431

APPENDIX C

Calibrate minimum temperature		
Month	ob-84 lubok paku min.TXT: Mean	mo-84 lubok paku min.TXT: Mean
Jan	22.1305	22.13
Feb	22.3222	22.3215
March	22.8989	22.9054
April	23.5684	23.5677
May	23.7189	23.7165
June	23.2813	23.2771
July	22.774	22.7703
Aug	22.8484	22.847
Sept	22.9242	22.9275
Oct	23.0374	23.0361
Nov	23.0133	23.0144
Dec	22.5401	22.5416

Validate minimum temperature		
Month	ob-99 lubok paku min.TXT: Mean	mo-99 lubok paku min.TXT: Mean
Jan	22.1271	22.7258
Feb	22.3158	22.7497
March	22.8873	23.4298
April	23.57	23.676
May	23.7222	23.8532
June	23.2829	23.4307
July	22.7755	23.0576
Aug	22.8501	23.142
Sept	22.9244	23.105
Oct	23.0308	23.3283
Nov	23.0191	23.3408
Dec	22.5524	23.1025

APPENDIX D

Projection maximum temperature				
Month	Historical	rcp 25	rcp 45	rcp 85
Jan	22.09536432	31.075913	31.07678255	31.31216873
Feb	22.33844948	32.481843	32.50642729	32.78456174
March	22.9167363	33.6052013	33.5978504	33.75910079
April	23.55297671	34.1386286	34.1415576	34.33131538
May	23.70785538	33.8387645	33.90499693	34.14623657
June	23.29773555	33.614717	33.61827742	33.77084689
July	22.79908997	33.2431325	33.2560783	33.41280924
Aug	22.83192579	33.3811811	33.42748855	33.58166731
Sept	22.94050676	33.0375278	33.16434333	33.37042574
Oct	23.05118957	32.720618	32.72579739	32.84481628
Nov	22.96618162	31.5450891	31.59440596	31.69240537
Dec	22.25620244	30.3023619	30.40735183	30.54004607

Projection mean temperature				
Month	Historical	rcp 25	rcp 45	rcp 85
Jan	25.784	25.622	25.648	25.758
Feb	26.534	26.338	26.363	26.431
March	27.126	27.046	27.061	27.116
April	27.522	27.513	27.516	27.555
May	27.546	27.451	27.438	27.555
June	27.280	27.232	27.209	27.252
July	26.857	26.767	26.803	26.906
Aug	26.876	26.804	26.840	26.903
Sept	26.672	26.576	26.607	26.747
Oct	26.641	26.520	26.482	26.575
Nov	26.215	26.021	26.016	26.061
Dec	25.700	25.272	25.364	25.401

APPENDIX E

Projection maximum temperature				
Month	Historical	rcp 26	rcp 45	rcp 85
Jan	22.429	22.095	22.173	22.258
Feb	22.536	22.338	22.377	22.302
March	23.153	22.917	22.962	22.883
April	23.619	23.553	23.548	23.521
May	23.789	23.708	23.673	23.697
June	23.360	23.298	23.252	23.254
July	22.917	22.799	22.787	22.881
Aug	22.995	22.832	22.856	22.901
Sept	23.009	22.941	22.930	23.004
Oct	23.179	23.051	23.060	23.083
Nov	23.180	22.966	22.998	23.066
Dec	22.831	22.256	22.340	22.472

APPENDIX F

Calibrate rainfall station		
Month	ob-82 lubok paku.TXT: Mean	mo-82 lubok paku.TXT: Mean
Jan	10.976	10.6849
Feb	9.52054	8.92902
March	14.209	13.5192
April	13.9585	13.6069
May	11.9491	11.5915
June	15.0629	14.6771
July	11.8968	11.4653
Aug	12.5773	12.3329
Sept	14.6552	14.2094
Oct	13.7609	13.0855
Nov	16.5408	16.4342
Dec	17.0409	16.3901

Validate rainfall station		
Month	ob-99 lubok paku.TXT: Mean	mo-99 lubok paku.TXT: Mean
Jan	11.0507	10.9902
Feb	9.67303	10.1507
March	14.32	11.2499
April	12.8254	11.8446
May	12.8322	11.4994
June	13.299	12.5116
July	11.0385	12.3166
Aug	12.3732	12.8215
Sept	15.2847	14.4659
Oct	14.1624	15.4157
Nov	18.3381	11.3738
Dec	17.5765	18.7524

APPENDIX G

Projection maximum temperature				
Month	Historical	rcp 26	rcp 45	rcp 85
Jan	5.11588586	4.753076	4.859831529	4.639283626
Feb	2.739058988	1.879596	2.079568565	2.063620665
March	4.393715806	4.631765	4.367303954	4.960082113
April	5.434658611	5.158873	5.508296603	5.412888874
May	4.913843925	5.488188	5.39298124	5.827330044
June	4.658901	3.914567	3.967862046	4.453273069
July	3.794275484	3.146407	3.051686168	3.161576396
Aug	4.909984785	4.483521	4.331971808	4.633221368
Sept	6.372482667	6.135872	6.204106534	6.409514632
Oct	7.102091559	6.961336	6.95142168	6.953437942
Nov	8.173770833	9.403308	9.714586356	9.578897092
Dec	10.22869602	8.961604	9.151002586	9.134602592