PREDICTION OF FUTURE TREND OF THE LONG TERM STREAMFLOW PATTERN IN THE CONTEXT OF CLIMATE CHANGE

NURUL HAZIRAH BINTI MOHD SAAD

B. ENG(HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : NURUL HAZIRAH BINTI MOHD SAAD

Date of Birth : 23RD OF MAY 1994

Title : PREDICTION OF FUTURE TREND OF THE LONG TERM STREAMFLOW PATTERN IN THE CONTEXT OF CLIMATE CHANGE

Academic Session : 20162017

I declare that this thesis is classified as:

☐	CONFIDENTIAL	(Contains confidential information under the Official Secret Act 1997)*
☐	RESTRICTED	(Contains restricted information as specified by the organization where research was done)*
☑	OPEN ACCESS	I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

_______________________	_______________________
(Student's Signature)	(Supervisor's Signature)
940523-14-5162	Dr. Nurul Nadrah Aqilah bt Tukimat
New IC/Passport Number	Name of Supervisor
Date: 15TH OF JUNE 2017	Date: 15TH OF JUNE 2017

NOTE : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Civil Engineering

____

(Supervisor's Signature)

Full Name : DR. NURUL NADRAH AQILAH BINTI TUKIMAT

Position : SENIOR LECTURER

Date : 16^{th} JUNE 2017

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : NURUL HAZIRAH BINTI MOHD SAAD

ID Number : AA13225

Date : 16^{th} JUNE 2017

z

To my beloved parents and family,

Mohd Saad Bin Lateh
Fauziyah Binti Sahidon,
Muhammad Suzairi Bin Mohd Saad
Nurul Zawani Binti Mohd Saad
Sunil Shanaz Bin Redzuan Perpinder
Muhammad Haziq Bin Mohd Saad

And my pretty niece,
Maya Daania Binti Sunil Shanaz

PREDICTION OF FUTURE TREND OF THE LONG TERM STREAMFLOW PATTERN IN THE CONTEXT OF CLIMATE CHANGE

NURUL HAZIRAH BINTI MOHD SAAD

Thesis submitted in fulfillment of the requirements

for the award of the

Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2017

ACKNOWLEDGEMENTS

Bismillahirrahmanirrahim…
Alhamdulillah YA ALLAH,

Thanks to Allah SWT, the most gracious and most merciful, whom with Him willing giving me strength to complete this Final Year Project.

Special thanks to my beloved family, my parents, because of their courage and support during the period of completing the thesis. Support and motivates keep me motivated and alive to complete and produce a high quality of thesis

To my supervisor, Dr. Nurul Nadrah Binti Tukimat, special thanks for all the guidance, motivation and supports, thanks for the time spend with me, idea and courage. The supervision and support that she gave truly help the progression and smoothness of the project. With his presents, teaching and guidance, my final year project gone recognize by university.

In addition, I would like to thank all the lecturers whom have taught me in every semester. They have indeed helped me to reinforce my basic knowledge and theories in this field.

Finally, I would like to express my appreciation to all my course mates and my final year project teammates as they are always shared with me their knowledge in completing the study. Thanks for being with me through my ups and downs.

Thanks for the support, courage and assist me on writing and so on. Once again, thanks to all of you.

ABSTRACT

Climate change has to be one of the greatest environmental threats to the world and it has been measured that a greater negative impacts on human society and to the natural environment changes when it climates are drastically change. General Circulation Models (GCM) stated that the increment of concentration of greenhouse gases will have significant implications for climate at regional scales. In this simulation which so-called “downscaling” techniques are used to describe as a decision support tool for local climate change impacts. Statistical Downscaling Model (SDSM) is beneficial the rapid development of multiple, low cost, single-site scenarios of daily weather variables and future regional climate force. The application of SDSM is applied to simulate with respect to the generation of daily temperature and rainfall scenarios for Temerloh River, Pahang for 2040-2069. However, in this studies is supported on the capability of IHACRES model in area where hydrological data has a limitation factor. The IHACRES model is being applied in a regionalization approach to develop streamflow prediction. Using IHACRES rainfall-runoff model, it is a non-linear loss module which is to calculate the effective rainfall and routing a linear module converting effective rainfall into streamflow.

ABSTRAK

Perubahan iklim telah menjadi salah satu ancaman alam sekitar terbesar kepada dunia dan ia telah diukur bahawa kesan negatif yang lebih kepada masyarakat manusia dan alam sekitar semula jadi berubah apabila ia iklim secara drastik berubah. Model Edaran Umum (GCM) menyatakan bahawa kenaikan kepekatan gas rumah hijau akan mempunyai implikasi yang besar untuk iklim di skala serantau. Dalam simulasi ini yang dipanggil "penskalaan" teknik yang digunakan untuk menggambarkan sebagai alat sokongan keputusan untuk kesan perubahan iklim tempatan. Statistik penskalaan rendah Model (SDSM) memberi manfaat perkembangan pesat pelbagai, kos rendah, tapak tunggal senario pembolehubah cuaca harian dan daya iklim serantau masa depan. Permohonan SDSM digunakan untuk mensimulasikan berkenaan dengan penjanaan suhu dan hujan harian senario untuk Temerloh River, Pahang untuk 2040-2069. Walau bagaimanapun, dalam kajian ini disokong pada keupayaan model IHACRES di kawasan di mana data hidrologi mempunyai faktor had. Model IHACRES sedang digunakan dalam pendekatan serantau untuk membangunkan ramalan aliran sungai. Menggunakan IHACRES model hujan-air larian, ia adalah satu modul kehilangan bukan linear iaitu untuk mengira hujan yang berkesan dan laluan modul linear menukarkan hujan yang berkesan ke dalam aliran sungai.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

R	Coefficient of Correlation
t_k	Temperature reading (℃)
u_k	Quantity of Rainfall (mm)
x_k	Streamflow Estimated

LIST OF ABBREVIATIONS

SDSM	Statistical Downscaling Model
MMD	Malaysian Meteorological Department
DID	Department of Irrigation and Drainage Malaysia
GCM	Global Climate Model
AR5	Assessment Report 5
RCM	Regional Climate Model
MSW	Municipal Solid Waste
DD	Dynamical Downscaling
SD	Statistical Downscaling
NCEP	National Centres Environmental Prediction
RMSE	Root Mean Square Error
ARPE	Average Relative Parameter Error

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In the recent years, the world frequently exposed to the problems of natural disasters and natural changes that occur to the environment. A part of the natural occurrence phenomenon are the extreme weather and climate change which create serious matters and the greatest environmental threats to our society and the world. These phenomenon have been discovered that will indicate greater harmful effects to human and the natural circulation. The climate changes happened normally in the natural processes such as a change on radiation by sun, volcanoes or other internal variability in the changes of nature system but it could be disaster due to human activities. According to the Department of Ecology State of Washington, the increasing level of carbon dioxide and other heat trapping gases to the atmosphere have warmed the Earth that are causing to wide-ranging impacts, including rise of sea levels, melting snow and ice, more extreme heat events, fires and drought, more extreme storms, rainfall and floods. Most primarily happen when there is a presence of carbon dioxide, (CO_2) to the atmosphere and other greenhouse gases, methane produce by livestock and water (H_2O) from nitrogen-based fertilizers that contribute to the phenomenon.

Based on the 5th Assessment Report (AR5) by the International Panel on Climate Change (IPCC), the average global temperature shows that the reading it be 0.85℃ in a range of 0.65℃-1.06℃ had an increment over the period from 1800-2012 (IPCC, 2013) but during 100 years ago another increment of 0.74℃±0.18℃ during 1906-2005 (IPCC, 2007). The human society and the natural environment has been disrupted due to the changes of such that globe mean temperature (Ashiq *et.* al, 2010). In a last decade, there are many of studies has disclosed that different regions of the globe influenced the extreme change of temperature for example, summer heat wave over Russian and Europe in 2003 (Zong and Chen, 2000; Schar and Jendritzky, 2004; Cheng *et.* al, 2012; Frias *et.* al, 2012; Lau and Kim, 2012). In addition, the human mortality rates increased in the event due to the extreme changes in temperature (hot and cold) (Huynen *et.* al, 2001).

The impact of climate changes has been the main influences to the change of weather, temperature, rainfall and streamflow. In spite of the significance of rivers to humans, it has been vague whether volcanism causes discernible changes in streamflow, given huge impact of the nature characteristic. Regarding to the matters, an article from Nature Geoscience, stated that there is statistically significant reductions in flow decreases in flow following eruptions for the Amazon, Congo, Nile, Orange, Ob, Yenisey and Kolyma, amongst others supporting with the data from neighbouring rivers are combined based on the areas where climate models simulate either an increase or a decrease in precipitation following eruptions and a significant ($p < 0.1$) decrease in streamflow following eruptions is detected in northern South American, central African and high-latitude Asian rivers, and on average across wet tropical and subtropical regions (Carley E. Iles, 2015). This nature occurrence shows that future volcanic eruptions could substantially affect global water availability. Streams are critical for biological systems and individuals, including for local utilize, agribusiness, industry and power era. Streamflow coordinates surplus precipitation over a catchment, conquering testing issues related with rain gage information, especially inaccessible boundaries. Streamflow is controlled by precipitation less evaporation and transpiration, and changes away for example in snow, ice, groundwater or reservoirs.

Whereas, in Malaysia it frequently happened that high floods which occurred by the streamflow lead in budgetary harms and they are connected with human's life. Malaysia has been involved with a long time by flood disaster since 2020. Progressively, as we move towards the year 2020, the nation is relied upon to confront genuine difficulties identified with surge and dry spell administration. In addition, Malaysia has been associated with quite a while by surge fiasco since 1920. The nation has encountered real flood occasions in the times of 1926, 1963, 1965, 1967, 1969, 1971, 1973, 1979, 1983, 1988, 1993, 1998, 2005. In 1886, Kelantan was confronted with a serious floods with intense winds. Over a century, in 1967 tremendous floods occurred over Kelantan, Terengganu and Perak river basins. In 1971, a hilarious flood occured over many parts of the country, for example, Pahang. As of late, in December 2006 and January 2007 floods was primary worry of administrative issues for Johor. At last, floods happened in Kelantan in 2014 which made a disastrous wonder for who lives in urban region. However, inquire about on the reaction of streamflow to volcanism is constrained and has concentrated on individual ejections. A critical decline in worldwide streamflow was observed by the following after the 1991 Pinatubo emission, and direct abatements taking after the 1963 Agung and 1982 El Chichon ejections.

Therefore, various modelling and simulation has been made for predicting variability and changes in climate variables as well as parameter to forecast for long term framework of climate change. The most common approach in predicting the variability and changes in climate variables is Global Climate Model (GCM) with the existence of carbon dioxide (CO_2) in different excretion scenarios (Fowler *et.* al, 2007; Gu *et.* al, 2012). However, the GCMs require high resolution of regional scales to satisfy the represent of complex topographical features when there is hydrological and environmental impacts of climate changes need to be examined. To overcome the problem, a few statistical and dynamical downscaling has been established in order to make the GCM's output is useful at a local and regional level (Mahmood and Babel, 2013). Based on these downscaling models, the Statistical Downscaling Model (SDSM) has been exposed widely to the studies of the world climate change either in mean or extreme condition throughout the assessment (Wilby *et.* al, 2012; Mahmood and Babel, 2013). For conceptual models, it is complex description of the internal processes which that involved in determine the catchment response, can be more complex depending on the structure of the model. Whereas, physic-based models is a model which involve numerical solutions relate to relevant solutions of motion. Furthermore, the IHACRES model which is about six parameters, influence to regionalisation problems to make it easier than complex model so that it can be related to the features of landscape.

1.2 Statement of the Problem

The potential effects of climate change towards the hydrology and water resources provide a very large impact to our environment. The local and global climatic conditions has strongly been the greatest influencer in determining the characteristics of hydrology variables. It is very important to identify how great the changes of global climate may affect the characteristics of hydrology variables in a certain watershed which can cause flow of the stream to a different rivers, basins or seas. All the information is very important and valuable in order to measures hydrology variables for development and management in the future.

Malaysia is developing country and is located in a tropical rain forest region where it required an optimal management of water resources are at each major catchments area. It is generally had through experienced in two distinct seasons which is rainy season and dry season. Malaysia is estimated to receive more than 2500mm of rainfall annually. However, the total annual rainfall that has been received is not necessarily is the same in every month because it is depends on weather conditions which is influenced by the monsoon. Based on Ekkawatpanit *et.*al (2009) stated that extra planning should be taken in the strategy to maintain water resources in a sustainable and the range of extreme hydrology condition can be reduced. This is because, many South-East Asian countries has rapidly developed and urbanization which lead to the shortages in water supply. Therefore, the idea of attempt in streamflow modelling which is from precipitation to streamflow using algorithm of mathematics gives a better visualization in understanding the movement of water.

The parameters of streamflow has been simulated by streamflow modelling based on the streamflow data existing for last 30 years. In addition, the air temperature and rainfall events and climate is influenced to the impacts of hydrological cycle balance. In order to make a prediction towards the streamflow, the evaluating of impact of climate change is an important matter to be discussed in the hydrology research. For the Temerloh River in Pahang, it flooding frequently happened especially during northeast monsoon. The streamflow during dry season is low compared to wet season therefore, availability of data existing need to be accurate and precise in making long term prediction. From the previous studied around Peninsular Malaysia, four rivers including the Johor River located in southeast Peninsular Malaysia indicated significant increasing precipitation trends at the 95% significance level. Generally, catchments from tropical monsoon regions (i.e. Malaysia, Indonesia and Thailand) exhibited significant increasing precipitation trends due to climate change compared to humid and temperature zones. However, no regional trend analysis was performed due to lack of available data (Aizam Adnan, 2010).

The east coast Malaysia experienced humidity and heavy rains from November to February brought by northeast monsoon. Pahang River is the main channel to drain off water from the inundated area of Pahang Basin to the South China during wet season caused by northeast monsoon. Therefore, the aim of the study is to generate the long term streamflow trend.

1.3 Objective of the Study

The objective of the study is:

1. To generate the future trend of the rainfall and temperature using Statistical Downscalling (SDSM) model at Temerloh River in year (2040-2069).
2. To estimate the pattern changes of water streamflow using IHACRES model.

1.4 Scope of the Study

This study is focused on the long-term pattern of water streamflow in the context of climate change impact. In this project, the 30 years historical data of temperature, rainfall and streamflow were needed to generate the future changes in year of 2040 to 2069. These historical daily rainfall and streamflow data provided by the Malaysia Meteorological Department (MMD) meanwhile the historical mean temperature data provided by the Department of Irrigation and Drainage Malaysia (DID). In addition, the statistical downscaling model (SDSM) was used to predict the climate trend in the region with considered the GHGs contaminant. The study was focused at the Temerloh River in Pahang to analyse the climate change using the existing data variables.

1.5 The Importance of the Study

The importance of the study is to determine the long-term pattern streamflow in Temerloh River, Pahang which affected by the climate change. The performance of SDSM as a streamflow statistical model at Temerloh River can be measured by comparing the climate data based on MMD. Notwithstanding that, another figure in recreating and demonstrating of precipitation overflow is made by the IHACRES display in light of the late day by day precipitation information. The significance of this study is as effectively distinguish the information conveyance of precipitation and temperature in the zone under study and correspond between information for precipitation and temperature are broke down in the impact of environmental change in the zone. Thisly, in a roundabout way mindful of the foundation environment and hydrological attributes in the territory and ready to envision environmental change the circulation of the amount of rain will happen later on at region of study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The effect of stream increments because of urbanization would rely on upon the magnitude and type of climate changes. As a rule, streamflow is diminished by expanding air temperatures and expanded by rising amounts of precipitation. Based on the final report of the United States Environmental Protection Agency (EPA, 1995), an extraordinary environmental change, on a yearly premise, would be a 4℃ increment in air temperature and a 20 percent diminish in precipitation. EPA added that, for the 21 provincial watersheds concentrated, mean yearly streams would be diminished by around 40 to 50 percent if air temperature expanded by 4℃ and precipitation were lessened by 20 percent. It shows clearly that, a 103 percent expansion in stream because of urbanization would counterbalance the 40 to 50 percent diminish in stream because of environmental change to deliver a 53 to 63 percent net increment in stream. In addition, annually normal streamflow has expanded at many locales in the Northeast and Midwest, while different districts have seen couple of considerable changes. The potential ruling impact of urbanization adds to the unpredictability of evaluating future impacts of environmental change on streamflow. Consolidated changes in temperature and precipitation over a watershed will direct the impacts of environmental change on stream later on. The effect of urbanization on stream will rely on upon the adjustments in populace density.

The extreme changes of climate became one of the most major issues in society. Climate change can be defined as a change of long term weather patterns for several decades or longer and it is usually at least 30 years or more which happen towards our environment. Climate change happened normally in the Earth affected by the natural processes such as a change on a radiation by sun, volcanoes or other internal variability in the changes of nature system. But nowadays, the changes of climate become worse due to human activities such as land development. The climate expectation is not what it used to be it is because climate change for past is not usually can be reliable to the future. It might be change either it is very significant change or slightly differ compared to past data changes. According to the Department of Ecology State of Washington (DESW, 2007), the increasing level of carbon dioxide and other heat trapping gases to the atmosphere have warmed the Earth. The changing of climate trend are causing to rises of sea levels, melting snow and ice, frequent extreme event of heat, fire drought, storms, heavily rainfall and flood. Furthermore, the trend will continuing and some cases will causes significant risks to human health, forests, agriculture, freshwater supplies, coastlines and other natural resources that are vital to economy, environment and life quality.

Over the last 200 years, the human activities effects to the sustainable of environment quality. The biggest contribution is burning a fossil fuels such as charcoal, gases and oils which emits to the greenhouse effects. Most primarily happen when there is a presence of carbon dioxide (CO_2) to the atmosphere and other greenhouse gases, methane produce by livestock and water (H_2O) from nitrogen-based fertilizers that contribute to the phenomenon. Moreover, the population of human growth is increasing year by year which affected the rising of municipal solid waste (MSW) to the worldwide. Other alternatives of waste management to the landfilling should be taken in order to manage the MSW generation rate. Based on United Stated Environmental Protection Agency (USEPA, 2006) and European Environment Agency (EEA, 2013) stated that the MSW landfill in the US had decreased by 41.10^6 then slightly increased up to 28.10^6 during year 2001 to 2010. This report was supported by Themelis and Mussche (2014) and Ule'n (1997), which produce the same pattern and anticipated in the other fast growing World's countries. Furthermore, the composite of MSW gave out a critical problem when it expose to the surrounding area which compost to wind as well as rainfall that may cause filtering and overflow. The environmental impact which affected by runoff and filtering from the MSW compost is still be poorly distinguished. These circumstances may lead to the potential pollution to the environment with nutrients and heavy metals if it is not in a proper controlled.

Other impacts of climate changes is the temperature rises year by year. Since the last century, the Earth's average temperature increased to -17℃ and the average temperature are expected to rise as much as -11.40℃ over next century. Based on the climate pattern, the temperature is extremely increases parallel to the industrial revolution. Subsequently, developing studies were accounted for on environmental change and effect look into, including temperature increment, yearly precipitation change, and actuated overflow change over the Tibetan Level (Arora, 2002). In any case, learning on the change of atmosphere extremes over the area is still inadequate in this way. Referring to the Intergovernmental Panel on Climate Change (IPCC) report, the global surface temperature has rises up to 0.74℃ in the most recent century (1906-2005) and 0.13℃ for 10 years compared to the last 50 years the surface temperature is also estimating to increase in average 0.2℃ per decade for upcoming 20 years achieving 1.1-6.4℃ (IPCC, 2007).

United States of Environmental Protection Agency (USEPA) stated in the course of the most century, the annual temperature in the northwest has ascended by around -17.10℃. The temperature is anticipated to rise in range -16℃ to -12℃ at the end of the century. The biggest increment is expected happened during mid-year. The effects of rising temperatures, changes in precipitation and decreased soil dampness may affect forests which it ended up hotter and drier. An expansion in the number and size of rapidly spreading fires has been seen in the local in late decades. USEPA added that the temperature change is effect to the biological system and demonstrate the projections

2.2 Global Climate Model (GCM)

Climate model are refer to the mathematical formulation which presented the interaction and reaction between the environment, atmosphere, land, ocean, ice and the sun. It is impossible for human to make prediction without tools because it is very complex with only limited ablity of human nature. Therefore, models was introduced to predict and estimate the trend not an events. For example, model could tell you it will be cold during winter season but it could not tell you what is the specific temperature on a specific day and that is called weather forecasting. Usually, models will take about 30 years for future prediction on a climate trends which is weather and average over time to time.

Global climate model (GCM) which has been used to perform the climate change for developing the moderation and modification strategies in order to make prediction on climate in different scenarios of concentrations of aerosol and greenhouse gas or other forcings. Unfortunately, based on Houghton *et.* al (2001), McCarthy *et.* al (2001), McGuffie and Henderson-Sellers (1997), even the GCM simulate well in large scale climate but its application to regional studies are limited to its course resolutions and capability in sort out the local and regional scale dynamics.

Figure 2.1 shows that the GCMs delineate the atmosphere utilizing a three dimensional matrix over the globe, normally having a flat determination of in the vicinity of 250 and 600 km, 10 to 20 vertical layers in the environment and once in a while upwards of 30 layers in the seas. Their determination is along these lines very coarse with respect to the size of exposure units in most effect evaluation. In addition, numerous physical procedures, for example, those related to clouds, likewise happen at littler scales and can't be proper displayed. Rather, their known properties must be arrived at the midpoint of over the bigger scale in a strategy known as parameterization. This is one uncertainty in GCM-based simulations of future atmosphere. Others identify with the simulations of different criticism instruments in models concerning, for instance, water vapor and warming, clouds and radiation, sea dissemination and ice and snow albedo. Hence, GCMs may reproduce very extraordinary reactions to the same compelling, just due to the way certain procedures and criticisms are displayed.

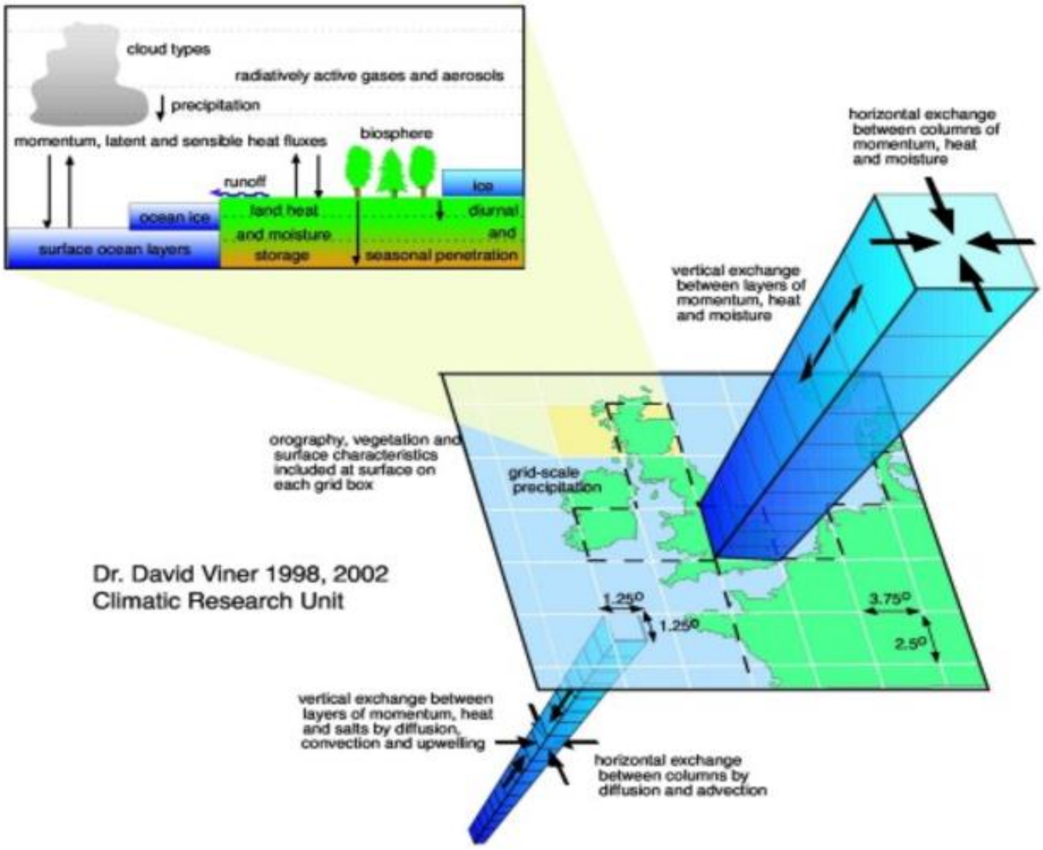


Figure 2.1: The view of the resolution of Global Climate Models depict the climate using a three dimensional grid over the globe.

After some time, high-resolution of the GCMs and advances in model detailing will decrease these obstructions, yet the heap of atmosphere effects questions makes it impossible that even these enhanced models will have the capacity to adequately address all scales and application of interest. In order to overcome the complexity of the GCM, a variety of downscaling techniques might be utilized to handle and refine GCM output with the point of delivering output more reasonable for effects thinks about. The refined output goals to address the confinements of coarse determination and additionally biases inclinations in the GCM output. However, the choices of potential predictors of the GCM is an important part in downscaling techniques. The predictor selection may vary in different area depending upon the characteristics of the output and the characteristics of the predictand.

2.3 Downscaling Model

Downscaling is a technique to take data in the large scales to make forecasts in the smaller scales. The two principle ways to deal with downscaling atmosphere there are dynamical and statistical. Dynamical downscaling (DD) requires running high-determination atmosphere models on a regional sub-space, utilizing observational information or lower-resolution atmosphere demonstrate yield as a limit condition. These models utilize physical standards to imitate nearby atmospheres, yet are computationally escalated. Statistical downscaling (SD) is a two-stage prepare comprising of i) the improvement of measurable connections between nearby atmosphere factors as an example is surface air temperature and precipitation with large scale predictors such as pressure fields; and ii) the use of such connections to the yield of global atmosphere show analyses to simulate local climate for the future.

DD show approach is a Regional Climate Model (RCM), which alludes to the physical limit conditions on a local scale GCM. This approach requires a complexity of design outline and high computational cost. SD model is a computationally basic and practical one that is done by deciding the empirical function that associates between atmospheric circulation variables and nearby local climate variables. In 1997, Wilby and Wigley split up downscaling into four classes: regression techniques, climate design based methodologies, stochastic climate generators, which are all factual downscaling strategies, and restricted range modelling. Among these methodologies regression techniques are favoured as a result of its simplicity of usage and low calculation prerequisites. Based on table 2.1, it shows that the comparison of the strength and the weaknesses between statistical downscaling and dynamical downscaling.

Table 2.1: Comparison of the main strengths and weaknesses of statistical downscaling and dynamical downscaling

	Statistical Downscaling	Dynamical Downscaling
Strength	• Climate bearing-scale's data from GCM-scale output • Allow assembles of climate scenarios permit risk • Flexible • Cheap, undemand computationally, transferable	• 10-50 km climate bearing-scale's data from GCM output • Resolve atmosphere process such precipitation topographic • Consistent with RCM • Feedback to physical consistent by external loadings
Weaknesses	• Depends on the realistic GCN boundary loading • Location & land size affects result • Predictor-predictand relationship common uniform • Need high quality data for calibration • Low-sensitivity climate variable problematic	• Depends on the realistic GCM boundary loading • Location & land size affects results • Gathered climate scenarios rarely produced • Require important computing resources • Unready transferred to new region

(Sources: R.L. Wilby, C.W. Dawson, E.M. Barrow 2000,2001, The strength and weakness of SD and DD)

2.3.1 Dynamical Downscaling (DD)

As DD require higher resolution RCM within a course in a resolution GCM (McGregor, 997; Giorgi and Means, 1999). By using horizontal grid spacing of 20 km to 50 km to simulate the physical dynamics of the atmosphere, it is to define the time vary with the atmospheric boundary conditions in a finite domain using Global Climate Model

(GCM). The situation simulate by The Regional Climate Models (RCM) also vulnerable to the choice of the state of the boundary (such as soil moisture) are used to established the experiments. The most barrier of RCMS is its computationally demanding as GCMS in a scope of limitation on putting the feasible domain size, amount of experiments and simulation's period. What is good about RCMs is it can fix the smaller-scale of atmospheric which is better than GCM. Other than that, RCMs can used to explore the relative significance of vary external loadings.

Downscaling procedures can be moderately uncomplicated. For instance, contrasts between a future period and the present are computed for each GCM framework cell, the irregularities are interjected to a high determination network and the distinctions are included to observe climatology a similar high resolution grid (Tabor and Williams, 2010). An extra calculation is generally utilized for precipitation to scale demonstrated modelled so the progressions are basically changed over to percent change that is reliable with observed values. Dynamical downscaling or regional climate modelling (RCM) additionally depends on output from GCM simulations. Output from GCM reproductions is utilized to infer time-fluctuating (for instance, 6-hour) lateral (vertical profiles of temperature, humidity, wind) and surface (weight and ocean surface temperature) limit conditions for a three-dimensional model area that is chosen to catch the imperative and mesoscale environmental course features that decide the climatology of a region of interest. The 6-hour limit conditions are absorbed along the four edges and surface (sea) of the model area and the RCM at that point simulate environmental flow and surface interactions inside.

In addition, the atmosphere variability of the driving GCM decides the change of the atmosphere produced by the RCM. Even though local climates models can enhance the points of interest of GCM reproductions through dynamical downscaling over complex landscape, they cannot for instance, enhance significant improvements to features of the large scale delivered by a GCM. It means, for instance, if the jet stream is erroneously set in a GCM, it is also will be inaccurately set in the RCM. Regional climate simulations reflect not just model-to-model contrasts among the driving GCMs but additionally added interior biases with parameterization of physical procedures. It is known, for instance, that the decision of the numerical plan that is utilized as a part of

RegCM3 to reproduce convective precipitation impacts another fields for example air temperature.

2.3.2 Statistical Downscaling (SD)

The Statistical Downscaling Model (SDSM) was developed by Willy *et.* al (2002). SDSM is a combination of the Stochastic Weather Generator (SWG) with Multiple Linear Regression (MLR). The function of MLR is to generate either statistical or empirical relationship between predictors and predictands of NCEP in the screening process of predictors as well as SDSM results to some regression parameters in calibration process. Those parameters together with NCEP and GCM predictors is to generate a maximum of 100 daily time series so that it is fit closely with the observed data validation. Furthermore, there is two types of models which each conditional and unconditional sub model used as an independent variable while the conditional sub model used as a dependent variable (Willy *et.* al, 2002; Ashiq *et.* al, 2010). Statistical downscaling is a like to the "Perfect Program" and "Model Output Statistics" (MOS) which exposure used for numerical weather prediction in a short-range (Klein and Glahn, 1974). Moreover, most of methodologies of statistical downscaling have various advantages than studies of dynamical downscaling. Statistical downscaling are currently provide more options in a situation of low-cost and require fast valuation of impacts on high climate change localized.

In addition to that, SDSM is the first instrument of its type that present for broader climate change which impacts to community. Most statistical downscaling models are constricted on its usage only to specialist researchers on established their research. The operation and structure of downscaling techniques can be relate to preliminary screening of possible downscale predictor variables, gathering information and calibration of SDSM, composition of present climate data using predictor variables and analyse observed data and climate change scenarios. Before proceeding these five scope of operations, the assumptions and outlined of SDSM prerequisites are required. Downscaling are initiate when the simulations of GCM or RCM of require variables are irrelevant at the temporal scales it's either because the point scales are not in range of climate model's plan or model deficiencies.

Based on the article Royal Meteorological Society (RMets), two models were produced with National Centres for Environmental Prediction (NCEP) reanalysis and HadCM3 outputs, for statistically downscaling these outputs to monthly precipitation at a site in north-western Victoria, Australia seen that the downscaling model created with NCEP performs much superior to anything the model created with HadCM3 outputs (D. A. Sachindra, F.Huang, A. Barton, 2014). Besides, it was discovered that there is bias in HadCM3 output which should be remedied compared to the downscaling model created with NCEP outputs was utilized to downscale HadCM3 twentieth century atmosphere explore outputs to monthly precipitation over the period 1950–1999. It shows that, the performance of SDSM produced a better simulation of climate change using NCEP compared to the outputs of HadCM3 scenarios.

2.4 National Centers for Environmental Prediction (NCEP) Variables

The United States National Centres for Environmental Prediction (NCEP) conveys national and worldwide climate weather, water, atmosphere and space climate direction, forecasts, notices and analyses to its Partners and External User Communities. These items and administrations depend on an administration science inheritance and react to client needs to ensure life and property, upgrade that country's economy and bolster the country's developing requirement for environmental data. The observed large-scale predictors have been gotten from the NCEP reanalysis dataset (Kalnay et al., 1996). There are no general rules for the determination of predictors in various parts of the world, and in this way, therefore, reaching pursuit of predictors is vital. Twenty-six NCEP factors that are generally anticipated by different atmosphere models, for the determination of indicators. The depiction of 26 NCEP factors is given in Table 2.2.

The climatic framework is impacted by the consolidated activity of numerous air factors in a wide tempo-spatial space. Any single course predictor or small tempo-spatial space are probably not going to be adequate for atmosphere projection, as they neglect to capture key precipitation mechanism in view of thermodynamics and vapour content. Based on the recommendations of Wilby and Wigley, the regional sypnotic circulation pattern that added to the irregular precipitation design in Malaysia were considered in the choice of the spatial space of every indicator, represented as 42 matrix focuses encompassing the study area.

Table 2.2: Description of 26 NCEP variables used for predictor variables

No.	variables	Description	No.	variables	Description
1	mslp	Mean sea level pressure	14	p5zh	500 hPa divergence
2	p_f	Surface airflow strength	15	p8_f	8500 hPa airflow strength
3	p_u	Surface zonal velocity	16	p8_u	850 hPa zonal velocity
4	p_v	Surface meridional velocity	17	p8_v	850 hPa meridional velocity
5	p_z	Surface vorticity	18	p8_z	850 hPa vorticity
6	p_th	Surface wind direction	19	p800	850 hPa geopotential height
7	p_zh	Surface divergence	20	p8th	500 hPa wind direction
8	p5_f	500 hPa airflow strength	21	p8zh	850 hPa divergence
9	p5_u	500 hPa zonal velocity	22	rhum	Near surface relative humidity
10	p5_v	500 hPa meridional velocity	23	r500	Relative humidity at 500 hPa
11	p5_z	500 hPa vorticity	24	r850	Relative humidity at 850 hPa
12	p500	500 hPa geopotential height	25	shum	Near surface specific humidity
13	p5th	500 hPa wind direction	26	temp	Mean temperature

2.5 Emission Scenarios Affected the Climate Change

The planet's climate has always been changing over topographical time. The global of the average temperature today is around 15C, however geographical proof recommends it has been significantly higher and lower previously. In addition, the present time of warming is happening more rapidly than numerous past events. Researchers are concerned that the regular change, or inconstancy, is being overwhelmed by a quick human-incited warming that has genuine implications for the steadiness of the planet's climate. The essential cause of the change of climate is the consuming of fossil fuels, for example, oil and coal, which emits greenhouse gases into the atmosphere—basically carbon dioxide, CO_2.

Our comprehension of climate change is to a great results from the Intergovernmental Panel on Climate Change (IPCC), the world's most definitive voice on the topic. Produced by the United Nations, the IPCC evaluates the scientific and socio-economic data applicable to the change of climate. In addition, The IPCC looks at the potential effects of environmental change, and alternatives for backing it off or adjusting to it. Regarding on the IPCC, they has established a few appraisal reports throughout the years. More than 2,500 scientific master reviewers, 800 contributing authors and 450 lead authors from more than 130 nations added to the last one, the Fourth Assessment Report (AR4). The Fifth Assessment Report's Working Group I (AR5) report is relied upon to be released in 2013.

In order to overcome the problem of climate change which is it potential to become more seriousness is extremely high, the IPCC has established a several emission scenarios. The primary reasons for socio-economic scenarios in the assessment of climate impacts, adjustment and helplessness are to portray the statistic, socio-economic and technological driving forces of fundamental anthropogenic greenhouse substance outflows which cause environmental change; and to portray the affectability, adaptive capacity and powerlessness of social and economic frameworks in connection to climate change (Carter et al., 2001). In spite of the fact that greater emphasis in these rules is put on the second goal, the Data Distribution Centre (DDC) socio-economic pages give data supporting both, perceiving that the scenarios supporting effect and adjustment studies should be consistent with those expected for emissions and thus for atmosphere and for other environmental scenarios.

Based on the Intergovernmental Panel on Climate Change (IPCC, 2013), five criteria that ought to be met by atmosphere scenarios in the event that they are to be helpful for effect scientists and approach producers are proposed is for Criterion 1, consistency with worldwide projections. It is to be predictable with a wide range of a global warming projections in view of concentration greenhouse gasses. This range is differently referred to as 1.4°C to 5.8°C by 2100, or 1.5°C to 4.5°C for a concentration of carbon dioxide, CO_2. The Criterion 2, it should be physical believability. This criterion is to be physically conceivable; that it is ought not to damage the fundamental laws of physics. Subsequently, changes in one district ought to be physically constant with those in another area and all inclusive. In addition, the combination of changes in various factors (which are frequently related with each other) ought to be physically predictable. Another Criterion 3 is applicability in effect evaluations. This scenario is to depict changes in an adequate number of factors on a spatial and temporal scale that takes into account affect evaluation. For instance, affect models may require input information on factors, for example, precipitation, sunlight based radiation, temperature, humidity and windspeed at spatial scales going from worldwide to site and at temporal scales going from annual intends to daily or hourly esteems. For the Criterion 4, it is a representative and is to be illustrative of the potential scope of future provincial environmental change. Just thusly can a practical scope of conceivable effects be evaluated. Finally, for the Criterion 5 it is accessibility where it is to be clear to get, interpret and apply for effect assessment. Many effect assessment projects with different scenarios advancement segment which particularly intends to address this last point. The DDC and this direction report are likewise intended to enable meet this to require.

2.5.1 Representative Concentration Pathways (RCPs)

Representative Concentration Pathways (RCP) is a types of scenarios processes for 5th IPCC Assessment Report (AR5). Four RCPs were chosen and characterized by their aggregate radiative forcing which is a cumulative measure of human emission of Greenhouse Gas Emission (GHGs) from all sources communicated in Watts per square meter pathway and level by the year of 2100. The RCPs were selected to a wide range of climate results, in light of a literature review, and are neither forecasts nor arrangement suggestions. However, RCPs had it uses and points of confinement of the RCPs. While each single RCP depends on an internally consistent set of socioeconomic presumptions, the four RCPs together can't be dealt with as a set with reliable interior socioeconomic rationale. For instance, RCP8.5 can't be utilized as a no-atmosphere approach financial reference situation for alternate RCPs in light of the fact that RCP8.5's socio-economic, technology, and biophysical assumptions contrast from those of other alternate RCPs.

Each RCP could results of various of economic, technology, statistic, policy, and institutional fates. For instance, the second-to-most minimal RCP could be considered as a moderation mitigation scenario. In any case, it is likewise consistent with a baseline scenario that accept a global development that focuses on technological enhancements and a move to service industries yet does not mean to lessen the ozone greenhouse gases emission as an objective in itself.

The four RCPs utilized a typical historical emissions information to instate the assessment models. The four RCPs were recreated in Integrated Assessment Models to 2100. The climate modelling group requested for extra scenario instruction out to 2300 for long term climate reaction research. Table 2.3 shows give connects to original informational indexes as posted by these researchers.

Table 2.3: Representative Concentration Pathways (RCPs) description and citations

	Description	IA Model	Publication – IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m² in 2100	MASSAGE	Riahi *et.* al (2007) Rao & Riahi (2006)
RCP6	Stabilization without overshoot pathway to 6 W/m² at stabilization after 2100	AIM	Fujino *et.* al (2006) Hijoka *et.* al (2008)
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m² at stabilization after 2100	GCAM (MiniCAM)	Smith and Wingley (2006) Clarke *et.* al (2007) Wise *et.* al (2009)
RCP2.6	Peak radiative forcing at ~ 3 W/m² before 2100 and decline	IMAGE	Van Vuuren *et.* al (2006; 2007)

2.6 Rainfall-Runoff Modelling

Burns and James (1972) developed a streamflow accounting model of the basin to address many of the same issues described in this report. The model was simplistic by comparison with current standards, however, and its ability to address complex hydrologic problems was limited. For example, the model calculated streamflow in subbasins with the streamflow per unit drainage area that was measured at the gaging stations, and thus, the model did not account for differences in the land use or physical properties of the subbasins. Further, the model simulated streamflow with a monthly time step that is inadequate for evaluating the magnitude and frequency of low flows.

A runoff model is a scientific model depicting the rainfall–runoff relations of a precipitation catchment area, drainage or watershed. All the more definitely, it creates a surface overflow hydrograph in response to rainfall event, represented by and contribution as a hyetograph. At the end of the day, the model ascertains the change of precipitation into overflow.

A common runoff model is the linear reservoir, yet it has restricted contributions. The runoff model with a non-linear reservoir is all the more generally relevant, yet at the same time it holds just for catchments whose surface range is constrained by the condition that the precipitation can be viewed as more or less consistently dispersed over the zone. The greatest size of the watershed at that point relies on upon the characteristics of rainfall of the district. At the point when the review zone is too large, it can be partitioned into sub-catchments and the different runoff hydrographs might be combined using flood routing techniques. Rainfall-runoff models should be calibrated before they can be utilized. Table 2.4 shows model type of rainfall-runoff modelling with assessment of strength and weaknesses of different runoff model structures.

Table 2.4: Assessment of strengths and weaknesses of Different Rainfall-runoff Model Structures

Criteria	Model Type			
	Empirical	**Large Scale Energy-Water Balance**	**Conceptual**	**Landscape Daily**
Run time step	Daily (if flow from another gauge), annual	Mean annual runoff	daily	daily
Number of parameters	1 to 5	2 to 4	4 to 20	10 to 100
Risk of over-fitting	Low	Very low	moderate	high
Need for high resolution	none	Low to moderate	low	high
Ability to implement run for calibration	Not required– obtained by least square fitting	Not required	Very good	good
Level of expertise within Australian water industry	strong	moderate	strong	weak
Previous calibrated model available	Moderate to low	moderate	Very high	low

2.6.1 Empirical methods

Empirical methods to rainfall-runoff modelling typically involve the fitting and application of simple equation(s) that relate drivers of runoff response to flow at the catchment outlet. Empirical equations are most often derived using regression relationship. Regression relationships are black-box models, although some degree of process reasoning can come in. Due to the availability of catchment attributes in geographic information systems, correlations between model parameters and catchment attributes are widely used in regionalization (e.g. Sefton & Howarth, 1998, Seibert, 1999;

Kokkonen et al., 2003; Merz & Blöschl, 2004). In multiple regressions, one may encounter the problem of multicollinearity, when at least one of the attributes is highly correlated with another attribute or with some linear combination of them. If multicollinearity is present, the regression coefficient can be highly unstable and unreliable (Hirsch et al., 1992). One therefore limits the number of catchment attributes used in the regression, sometimes combining a number of attributes into an index, which is assumed to be representative of one aspect of the rainfall–runoff relationship (such as the base flow index, IH, 1999).

In the streamflow analysis, common predictor variables may include rainfall for the catchment, flow observed at another gauge in the vicinity, evapotranspiration, groundwater levels, vegetation cover and the impervious area within the catchment. Where rainfall is used as a predictor variable, regression relationships derived almost always include a non-linear relationship between rainfall and runoff.

All catchments incorporate storage elements, including interception by vegetation, storage within the soil column, groundwater storage and storage within stream channels. Catchment storage typically results in runoff from the catchment being within stream channels. Catchment storage typically results in runoff from the catchment being an integrated function of the climatic conditions for the catchment over some period prior to the period for which runoff is to be calculated by the model. Therefore, the empirical models that produce acceptably accurate simulations of runoff are either applied at sufficiently long time steps that changes in internal water storage within the catchment can be ignored as an example annual time step or applied to represent an integration of the climatic conditions that occurred over some time period prior. As a practical example, for most catchments a regression model that only includes daily rainfall on the current day is likely to produce a very poor estimation of daily runoff but a model for predicting daily runoff that used individual values of daily rainfall for several days prior may produce acceptable runoff estimates.

Empirical regression relationship are often developed using spreadsheets. They can also be fitted using more sophisticated statistical analysis packages, which may more facilitate the investigation of predictor variables. For general information on the development of regression relationships, the modeller is referred to NIST/SEMATECH e-Handbook of Statistical Method (Nist and Sematech, 2010).

Empirical regression equations are the best suited to situations where there are two flow gauges on the stream with partially overlapping periods of record, which are therefore subject to similar climatic drivers, and the regression equation is used to extend the simulated flow to the combined period of record from both sites. They can also produce adequate simulations for neighbouring gauged catchments with overlapping periods of record in situations where the two catchments are subject to similar rainfall time series and are relatively similar hydrologically.

2.6.2 Large Scale Energy-water Balance Equations

The large scale energy-water balance methods are based on the hypothesis of available energy and water governing large scale water balance. These are usually developed using large scale observed data sets as an example the Budyko curve (Budyko, 1958) was developed using mainly European data and numerous other forms have been proposed to improve estimates in local regions and to account for different land cover types (Aurora, 2002). One of the popular forms of the Budyko method is the rational function equation (Zhang *et.* al, 2004) where a single parameter, α, in the equation can be calibrated against local data to tune the method for the local conditions. The inputs to these equations are rainfall and potential evapotranspiration (PET) and the output is runoff at mean annual time step.

2.6.3 Conceptual Rainfall-Runoff Models

Conceptual rainfall-runoff models represent the conversion of rainfall to runoff, evapotranspiration, movement of water to and from groundwater systems and change in the volume of water within the catchment using a series of mathematical relationships. Conceptual rainfall runoff models almost always represent storage of water within the catchment using several conceptual stores that can notionally represent water held within the soil moisture, vegetation, and groundwater or within stream channels within the catchment. Fluxes of water between these stores ad in and out of the model are controlled by mathematical equations.

Most applications of conceptual rainfall runoff models treat the model in a spatially lumped manner, assuming that the time series of climatic conditions and the model parameter values are consistent across the catchment. There have been implementations in more recent times of conceptual rainfall runoff models in semi-spatially distributed and spatially distributed frameworks. In distributed application, the catchment is defined by grid cells or subcatchments within the catchment that are assigned the same rainfall runoff parameter values but different time series of climatic inputs so that different grid cells or subcatchments within the catchment produce different contributions to the overall runoff. This is effectively a series of lumped rainfall runoff models, with lumped sets of model parameters that are applied with spatially distributed rainfall.

Conceptual rainfall-runoff models have been widely used in Australia for water resources planning and operational management because they are relatively easily calibrated and they provide good estimates of flows in gauged and ungauged catchments, provided good climate data is available. In Australia there are six widely used conceptual rainfall-runoff models that is AWBM (Boughton, 2004), IHACRES (Croke *et.* al, 2006), Sacramento (Burnash *et.* al, 1973), SIMHYD (Chiew *et.* al, 2002), SMARG (Vaze *et.* al, 2006) and GR4J (Perrin *et.* al, 2003). The input data into the models are daily rainfall and PET, and the models simulate daily runoff. The models are typical of lumped conceptual rainfall-runoff models, with interconnected storages and algorithms that mimic the hydrological processes used to describe movement of water into and out of storages. They vary in terms of the complexity of the catchment processes that they try to simulate and in terms of the number of calibration parameters which vary from four to eighteen.

2.6.3.1 IHACRES Model

The mathematical representation are often used is a rainfall-runoff model because some available data for every catchments is only limited to daily temperature and rainfall as well as some cases is stream discharge. Based on Wheater *et.*al (1993), rainfall-runoff models came into several classification which is metric models, conceptual models and physic-based models. Metric models is the simplest model using observed data which is rainfall and streamflow data to describe the response of catchment area. For conceptual models, it is complex description of the internal processes which that involved in determine the catchment response, can be more complex depending on the structure of the model. Whereas, physic-based models is a model which involve numerical solutions relate to relevant solutions of motion. Furthermore, the IHACRES model is efficient parametric rainfall-runoff model which has been applied to a number of large catchment area and covered a diverse range of climatologies. In a model structure, the IHACRES model is a hybrid conceptual-metric model which used the simplest metric to minimize the risky parameter innate in hydrological models and to show the internal processes more detail simultaneously. Recently, the IHACRES_v2.0 has been released including modified loss module and a cross-correlation analysis tools, new fit of indicators and visualisation tools. In IHACRES, the non-linear loss module converts to rainfall into effective rainfall which is it eventually reach at the stream prediction point. For this non-linear module, it is been used within IHACRES which increase its flexibility to obtain the impact of climate and the change of land use. For the linear module, the effective rainfall is transferred to stream discharge. It is routes the effective rainfall to stream by any arrangement of stores in parallel or series order. The configuration of stores is defined based on the time series of rainfall and discharge but it is either one, represent ephemeral streams, or two that allow baseflow, slowflow or quickly to be represent as in parallel order.

In regionalisation, the IHACRES presented in several versions (Post and Jakeman, 1996; Sefton and Howarth, 1998; Kokkonen *et.* al, 2003) which is the main purpose is to estimate the parameters of models from an independent means for example, the features of landscape rather than directly from time series of rainfall-discharge. The efficiency of parametric of IHACRES which is about the parameters, influence to regionalisation problems to make it easier than complex model so that it can be related to the features of landscape. In addition to that, IHACRES model is one of the models that has been used by the Top-Down Working Group, as a part of the prediction in ungauged basins endeavour of the International Association of Hydrological Sciences (Littlewood *et.* al, 2003). Based on the resources, they have used IHACRES to model pluvial of watershed in mountainous region (David Hutchinson, Paul H. Whitfield and Paola Allamano). The calibration was successful at 23 out of 31 of watershed has been selected for analysis. The result of the calibrations had an average coefficient of determination of 0.60 in a range from 0.45 to 0.80. The lack of success in another 8 watershed may be due to failure of the representativeness of climate input. The main criteria to select the hydrometric stations is too much been disregard in mountain regions. There is a several alternative parameter which perform as almost the same and the parameter set are optimally-chosen eventhough IHACRES model is illiberal in structure. Moreover, in order to expose the extent which the variability controls and trend of the observed relationship between alternatives parameter sets and the physical catchments description (PCD), it useful to be plotted both variables, alternatives parameter sets against the PCDs.

The model IHACRES are able to define the identification of unit hydrographs and component flows from rainfall, evapotranspiration and streamflow data is a simple model designed to avoid the problems described before. its subsequent development and application has demonstrated the following. Its subsequent development and application has demonstrated that it is simple, parametrically efficient and statistically rigorous as well as the results are data-based, and require no subjectively estimated parameter values. The model provides a unique identification of system response even with only a few years of input data (Jakeman *et* al, 1990). In addition, the model can be run on any size of catchment and the time steps are recommended is in Hourly for catchments up to 1 km^2 while a daily time step is appropriate for larger catchments (Jakeman and Hornberger, 1993). The model efficiently describes the dynamic response characteristics of catchments (Jakeman et al., 1992; Sefton and Howarth, 1998). Statistical relationships may be developed relating these dynamic response characteristics to physical catchment descriptors (Post and Jakeman, 1996; Sefton and Howarth, 1998; Sefton et al., 1995). Such relationships provide a basis for regionalising results of sample catchments. It can also be used to assess changes in streamflow following a change of land-use in a catchment (Post et al., 1996).

2.6.4 Landscape Daily Hydrological Models

Landscape Daily Hydrological models are based on the concept of landscape processes and they model the typical landscape processes using simplified physical equations such as VIC Model (Liang *et.* al, 1994), 2CSALT (Stenson *et*. al, 2011) and AWRA-L (Van Dijk, 2010). A catchment is usually conceptualised as a combination of landscapes which are delineated using some combination of outputs from digital elevation model analysis, underlying geology, soil types and land use. Hydrological models has been applied across many landscape types and broad spatial scales. At the broader spatial scales, it is often calibrated in forested headwaters. BROOK90 is a one-dimensional process-based hydrological model that operates on daily time step and was originally developed for forested catchments in the north-eastern USA (Federer *et* al, 2003). The model includes components for interception by a single layer canopy, snow accumulation and melt, direct evaporation from soil and snow and transpiration from single-layer canopy and multi-layered soil. In addition, The distributed Hydrology Soil Vegetation Model (DHSVM) is a watershed-scale hydrological model that operates at sub-daily to annual steps (Wigmosta *et* al, 1994, 2002). In DHSVM, it is composed of seven modules representing evapotranspiration, snow-pack accumulation and melting, canopy snow interception and release, unsaturated subsurface flow, saturated subsurface flow, surface overland flow and channel flow. DHSVM is frequently applied to evaluate forest management hydrological affects across variety of physiographical settings (Storck *et* al, 1998; Bowling and Lettenmaier, 2001).

Another hydrological model is The Variable Infiltration Capacity (VIC) model. VIC is a macro-scale hydrological model that operates at daily to monthly time steps where it compliments global-scale general circulation models (GCMs) used for climate simulations and weather prediction (Liang *et* al, 1994, 1996). In VIC, it has includes simulated forest evapotranspiration, canopy storage, surface and surface runoff, aerodynamic flux and snow accumulation and melt.

Thus, often these models have been designed to reproduce other variables in addition to streamflow as an example distributed evapotranspiration, soil moisture, recharge and salinity. As a result, it have a greater complexity to methods that target streamflow alone.

2.7 CONVENTIONAL STREAMFLOW MODEL

The riskiness of hydrological impacts due to streamflow such as floods, tsunamis and high tide might be reduced if we have an effective streamflow prediction system. However, the dynamic of streamflow are highly non-linear model therefore, types of conventional linear streamflow model such as ARIMAX, ARMA or ARX are failed to make prediction. Many of neural networks with algorithms method and various structures are made to forecasting and modelling for non-linear streamflow. Based on a few researchers, they stated that parallel recursive prediction error algorithm gave the good result in presenting the modelling better than recursive prediction error by using Mutilayered Perceptron (MLP) network (Mashor, 1991; Karunithi *et.* al, 1994; Hsu *et.* al, 1998; Phien and Ming-An, 1996; Harun *et.* al, 1996; Achela *et.* al, 1998; Zealand *et.* al, 1998; Jaya, 2000; Mashor and Abdullah, 1990, 2000). However, using back propagation of MLP network still can be success based on the different data streamflow (Karunithi *et.* al, 1994; Harun *et.* al, 1996; Phien and Ming-An, 1996). In other contrast, a several types of streamflow modelling has been made at Pari River that is neural RBF using orthogonal least square algorithm and Hybrid Multilayered Perceptron (HMLP) and it shows the performance of HMLP network using recursive prediction error has a better generalisation properties and higher rate of learning compared to the performance of MLP using back propagation (Jayawardena, 2000; Mashor and Abdullah, 2000).

Conventional streamflow model studies are based on off-line technique of streamflow. The performance of streamflow will forecast by off-line models and will be generated with time as the dynamic of streamflow will change with time. However, this difficulties can be control by on-line modelling because the on-line technique does not need collected data streamflow in order to fit the modelling. On-line forecasting system will own the flow sensor and measured it directly and the parameter will be estimated and the streamflow will be forecast simultaneously. The main studies is to show the capability of neural network of on-line (non-linear) streamflow which is Multilayered Perceptron Network (MLP), Hybrid Multilayered Perception Network (HMLP) and Radial Basic Function Network (RBF). HMLP and RBF has shown faster performance than MLP (Mashor, 2009). HMLP has been chosen for on-line non-linear modelling for streamflow in Pari River because HMLP more simple and has better general performance (Mashor, 2009). Based on 150 data samples, the forecasting performance up to 3-hours lead time and after 300 data sample has been trained, it shows up to 24-hours lead time of modelling. In addition to that, a good match of peak flows, rising limbs ad recession limbs of actual flow as well as low flows shows is quite well. Neural network is to control the inconsistencies of conventional linear time models as well as convenient system could be built in order to forecast and simulate the streamflow efficiently.

A Multilayered Perceptron Network (MLP) is a system of simple direct neurons called perceptrons. The concept of the idea of a solitary perceptron was presented by Rosenblatt in 1958. The perceptron determine a single output from multiple real-valued inputs by framing a linear according to its information weights and after that potentially putting the output through some nonlinear activation function.

This kind of system is prepared with the backpropagation learning algorithm. MLPs are broadly utilized for pattern arrangement, recognition, prediction and estimation. Multilayer Perceptron can take care of issues which are not directly seperable.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The main aim of this study is to generate the future trend of long-term streamflow pattern with concerned to the climate change impact. SDSM model was used to predict the long term climate change patternand then the IHACRES model were applied to generate the streamflow pattern. IHACRES model has been used to achieve more accurate and less bias comparing between the modelled streamflow with the observed streamflow.

The schematic flow of the methodology has been illustrated in Figure 3.1. In the beginning of the analysis, SDSM was used to perform the local pattern of climatic variability for future trend which is consists of rainfall intensity, temperature, dry and wet spell length. The software performs additional tasks for predictor variable in pre-screening, the calibration of the model, basic diagnostic testing, statistical of analysis and graphing for climate data. In SDSM, NCEP predictor variables is used for this site which is available in the period of 1948 to 2015. Statistical Downscaling is help to downscale the actual or large atmospheric resolutions which is produced by GCM predictor variables into small scale resolutions and it focused on the local climate station.

In another stage, IHACRES model is a catchment-scale rainfall-streamflow modelling was applied to characterise the relationship between streamflow and rainfall using the historical rainfall data and historical temperature data to predict future streamflow. In addition to that, IHACRES model can be amplify over in a range of spatial and temporal scale. The purpose of IHACRES model in this simulation is to identify the impacts of climate changes and what is the effects of land use can change the hydrological cycle in our daily life.

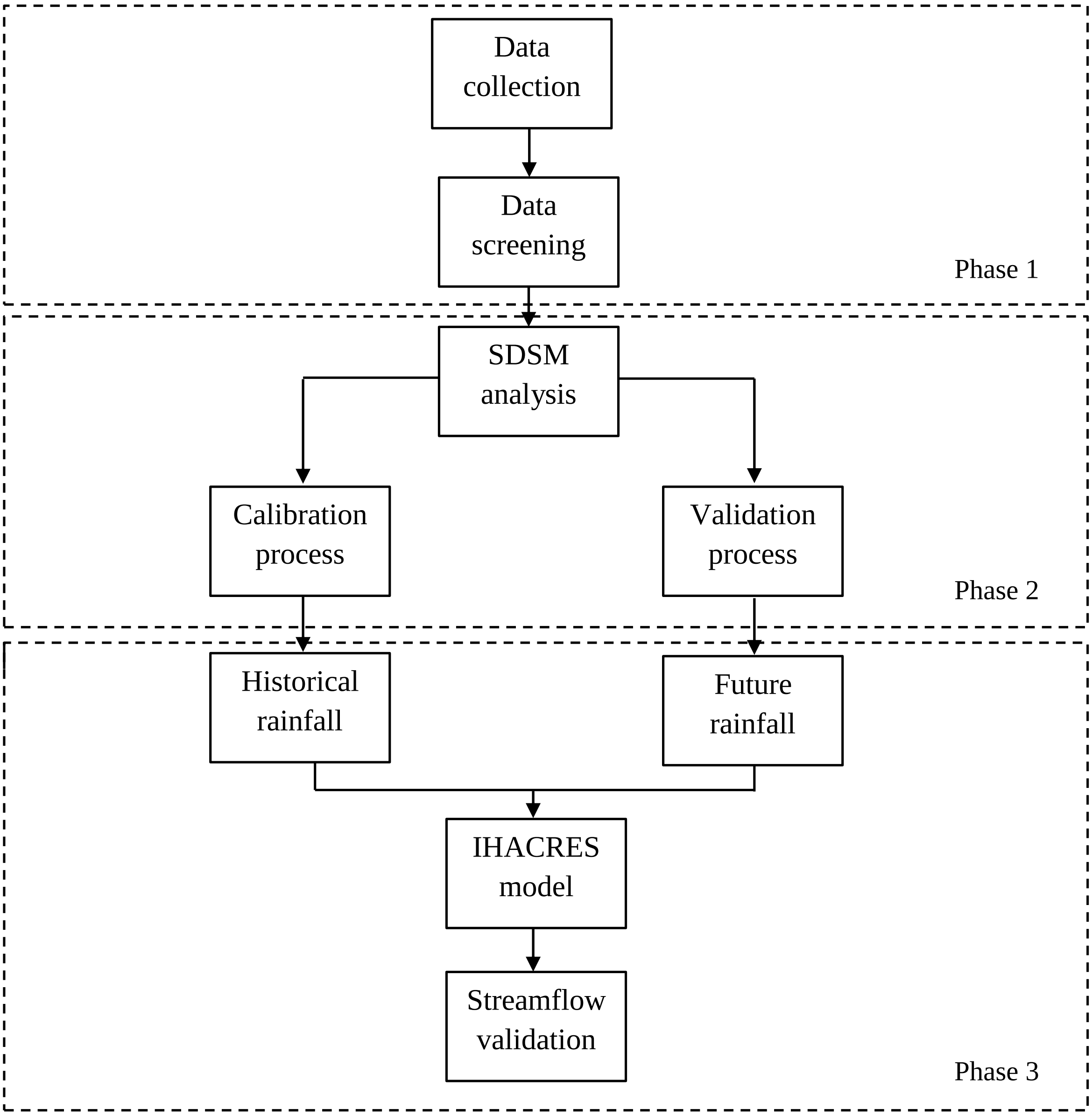


Figure 3.1: The schematic diagram of methodology of the study

3.2 Statistical Downscaling Model (SDSM)

Statistical Downscaling Model 4.2 (SDSM) is a support tool for the assessment of regional climate change impacts. SDSM 4.2 is supported by the Environment Agency of England and Wales as part of the Thames Estuary 2100 project. Statistical downscaling methodologies have a few viable points of benefits over dynamical downscaling approaches. In this study, it can be figured and occur with statistical downscaling methodology which permit the setting up of climate change scenarios at daily time-scales apply by resolution of GCM output. In addition, by taking a concise outline of downscaling method, the structure and the operation of SDSM can be describe regarding by a several chore: 1) quality control and data transformation; 2) screening data for potential downscaling predictor variables; 3) model calibration; 4) weather generator for present climate information using observed predictor variable; 5) statistical analysis for the change of climate with observed data; 6) generate graphing for model output; 7) generation of ensembles for future climate using GCM-derived predictor variables. The key elements of SDSM will be outlined using observed and climate model information for a theoretical station (Temerloh), looking at downscaled daily precipitation in the year of 1975 to 2004 and temperature arrangement in the year of 1984 to 2013 with future climate pattern in the year of 2040 to 2069.

Inside the scientific classification of downscaling procedures, SDSM is ideal depicted as a crossover of the stochastic climate generator and exchange work techniques. This is on account of large-scale dissemination designs and environmental dampness factors are utilized to condition local-scale climate generator parameters as an examples precipitation event and power. Furthermore, stochastic methods are utilized to falsely blow up the fluctuation of the downscaled daily time series arrangement to better accord with precipitations. To date, downscaling calculation of SDSM has been connected to a host of meteorological, hydrological and ecological appraisals as well as scope of geological settings including Africa, Europe, North America and Asia. The accompanying areas diagram the product's seven center operations, along with the UKSDSM information document and prescribed record conventions.

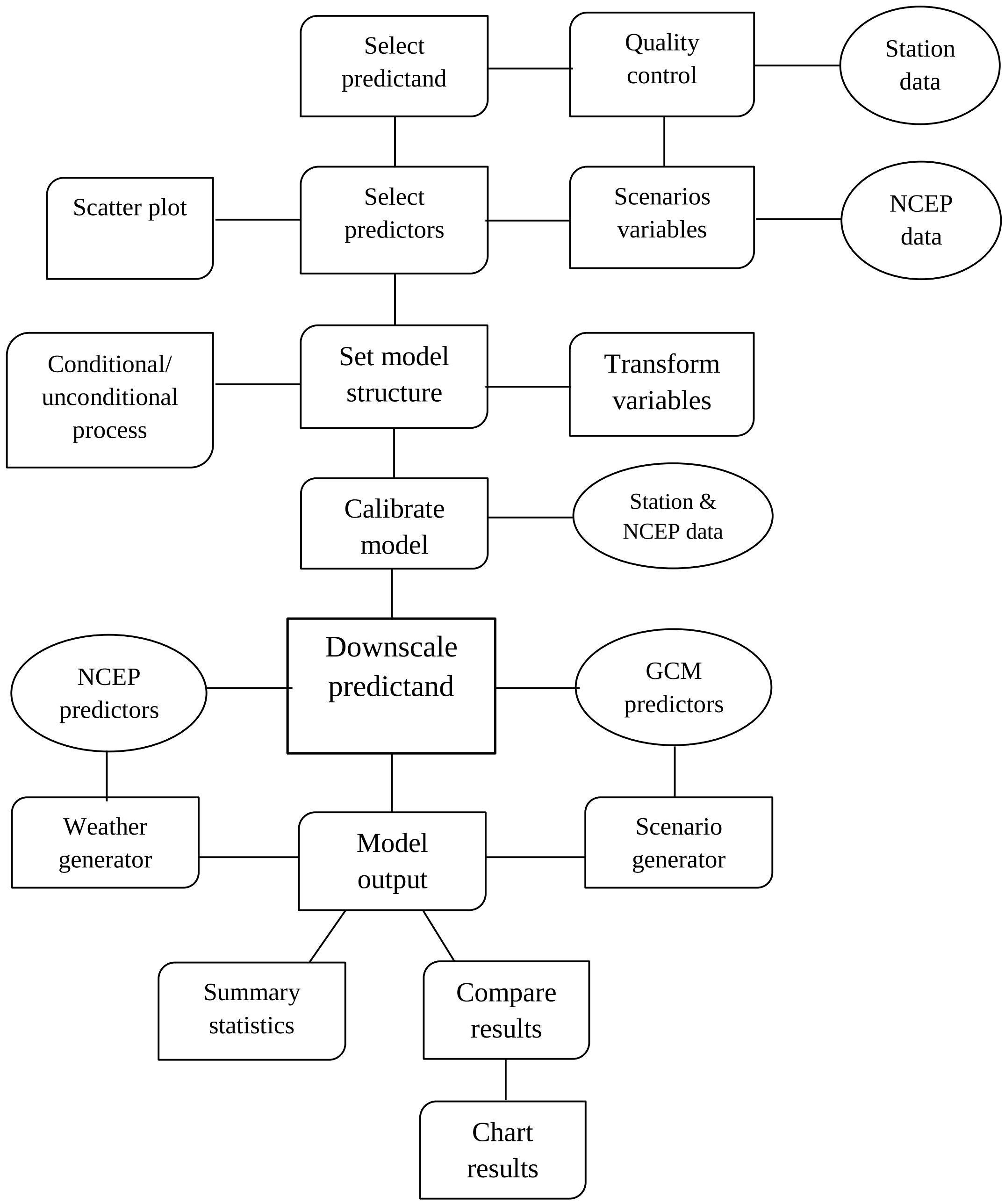


Figure 3.2: SDSM model climate scenario generation methodology

3.2.1 Quality control and data transformation

Couple of meteorological stations have complete and in addition totally correct educational records. Managing of missing and imperfect data is essential for most reasonable conditions. Some of the time it may in like manner be imperative to change data before model arrangement. SDSM enables both quality control and data change.

3.2.2 Screening of Downscaling predictor variables

Recognizing observational connections between gridded indicators, as an example, mean ocean level weight and single site predictands, (for example, station precipitation) is key to all measurable downscaling techniques. The principle reason for the Screen Variables operation is to help the client in the choice of fitting downscaling indicator factors. This is a standout amongst the most testing stages in the advancement of any factual downscaling model since the selection of indicators to a great extent decides the character of the downscaled atmosphere situation. The choice procedure is likewise convoluted by the way that the informative energy of individual indicator factors shifts both spatially and transiently. Screen Factors encourages the examination of regular varieties in indicator aptitude.

3.2.3 Calibration and Validation Processes

The Calibrate Model operation takes a User–specified predictand alongside an arrangement of indicator factors, and figures the parameters of different relapse conditions by means of a streamlining calculation (either double simplex of conventional minimum squares). The User indicates the model structure: regardless of whether month to month, regular or yearly sub–models are required; regardless of whether the procedure is unequivocal or contingent. In unequivocal models an immediate connection is accepted between the indicators and predictand (e.g., neighborhood wind rates might be an element of territorial wind stream files). In contingent models, there is a middle of the road procedure between provincial compelling and neighborhood climate (e.g., neighborhood precipitation sums rely on upon the event of wet–days, which thusly.

Based on the available observed data, two daily datasets on the year of 1984-1998 were selected for the calibration and year of 1999-2013 for validation of the temperature for maximum, mean and minimum. For the rainfall observed data, two daily datasets on the year of 1975-1989 were selected for the calibration and year of 1990-2004. In the study, SDSM using a monthly sub-model, was developed with the NCEP predictors that were selected during the screening process at each process at site in Temerloh. Explained Correlation of Coefficient (r) and Mean Square Error (MSE) were used as performance indicators during the calibration of SDSM. With the calibrated model, for maximum, mean and minimum temperature were simulated for 1984-1998 and rainfall for 1975-1089 feeding the NCEP predictors. The mean values of these ensembles were used in this study. The model was validated with observed temperature data for 1999-2013 and observed rainfall data for 1990-2004 using daily and monthly. In the present study, two performance indicators which is Correlation of Coefficient (r) and Mean Square Error (MSE) were used for validation. R and MSE describe the accuracy of the model. For this study, these indicators were calculated for the Temerloh station and then the mean values of each indicator were obtained. In addition, the daily of maximum values of indicators calculated from simulated daily time series (NCEP) were plotted against the observed datasets.

A simulation of mean daily and monthly rainfall, Tmax, Tmean and Tmin, during the calibration and validation of the SDSM time series were checked by using the coefficient of correlation (R) and root mean square error (RMSE), and it is defined as:

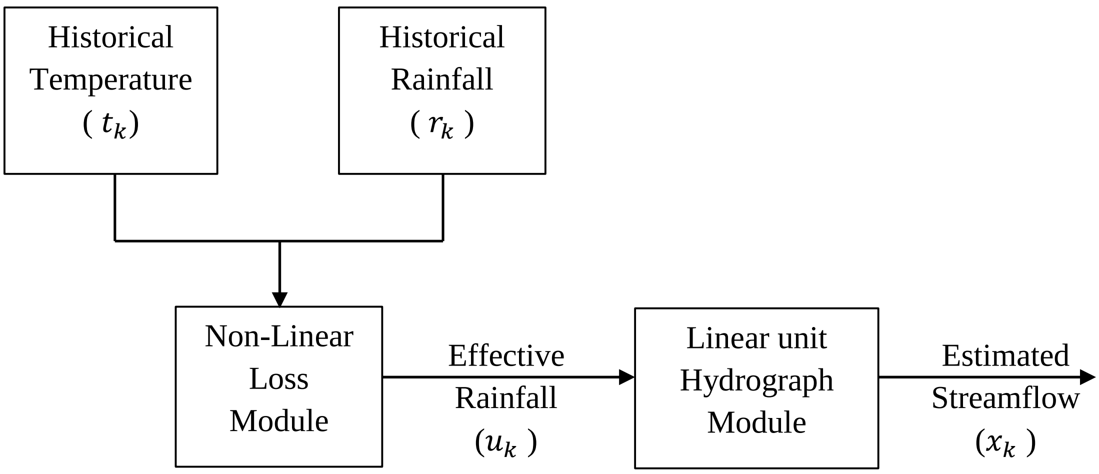
$$R = \frac{\sum\left(obs - \overrightarrow{obs}\right)\left(pred - \overrightarrow{pred}\right)}{\sum\sqrt{\sum\left(Q_o - \overrightarrow{Q_M}\right)^2 \sum\left(pred - \overrightarrow{pred}\right)^2}} \qquad 3.1$$

$$\text{RMSE} = \sqrt{\frac{\left(obs - \overrightarrow{pred}\right)^2}{n}} \qquad 3.2$$

In which, obs = observed data value; $pred$ = predicted data value; $\overrightarrow{obs}$ = mean observed data value and $\overrightarrow{pred}$ = predicted mean data. The closer R value to 1 and RMSE value to 0, the predictions are better.

3.4 Hybrid Conceptual Matrix Model-IHACRES Model

IHACRES is a catchment-scale precipitation streamflow displaying technique. Its motivation is to help the hydrologist or water assets designer to portray the dynamic relationship between bowl precipitation and streamflow. The purpose of the application is to recognizable proof of unit hydrographs and continous time arrangement streamflow demonstrating. In addition, IHACRES model are able to make a predictiction on ecological change specifically in a hydrological administration studies. In a projection using IHACRES rainfall runoff model, the main three components structure of IHACRES which is 1) Data and its preparation; 2) calibration; and 3) simulation of the prediction streamflow pattern. Figure 3.3 are shown the basic concept of the streamflow approach methodology.



(Source: Croke *et* al., 2005)

Figure 3.3: Basic concept of IHACRES rainfall-runoff model methodology

The streamflow (x_k) volume estimates in unit cumecs from the following equations:

$$x_k = ax_{(k-1)} + bu_k \qquad 3.3$$

$$u_k = r_k s_k \qquad 3.4$$

$$s_k = Cr_k + (1 - \frac{1}{\tau_w(t_k)})s_{(k-1)}$$ 3.5

$$\tau_w(t_k) = \tau_w e^{0.062 f(R - t_k)}$$ 3.6

where r_k refers to the observed rainfall (mm), *a* and *b* are the parameters of unit effective rainfall in a linear unit hydrograph module with $b>0$ *and* $-1<a<0$.

$$b_0 = b_0^{(q)} + b_0^{(s)}$$ 3.7

$$b_1 = b_0^{(q)} a_1^{(s)} + b_0^{(s)} a_1^{(q)}$$ 3.8

$$a_1 = a_1^{(q)} + a_1^{(s)}$$ 3.9

$$a_2 = a_1^{(q)} \times a_1^{(s)}$$ 3.10

3.4.1 Data Requirements

In the projection of IHACRES model, it is indicates the current state of the three time series that are imported which is observed rainfall, temperature and observed streamflow. The status column indicates the state of each time series so it must be in "synchronised" status which is means that the data has been imported and synchronised. The observed data for streamflow supposedly in a unit of cumecs for the time step of the time series. Moreover, in. The data contained within a raw data file must be in ASCII text format with with partitioned time series in sections isolated by commas (void area is disregarded). At the point when a raw data record is opened the top piece of the document shows up in the table in the Import File Data region of the Import Data Tool board. On the off chance that the Open is sucessful, the substance of the information document are shown. The Time Parameters range of the Import Data Tool board is utilized to determine the time parameters of the time series that has been imported.

The Start Time parameters allude to the time comparing to the first time step of a period arrangement that is being imported. The start time is determined by modifying the Year, Month, Day, Hour and Minute at the run boxes so as the right begin time is appeared. The Time Step parameter alludes to the time between each time step of a period arrangement that is being imported. The time step is indicated by choosing the units utilizing the rundown box (Minutes, Hours or Days) and determining a sum utilizing the content field.

Based on the data required in the import procedure it is includes four main stages that must be satisfy. Firstly, select a cell on the Import File Data table that is inside the segment relating to the time series that will be imported. Clicking a table cell will choose the table section. A table cell that is chosen has a yellow fringe. Secondly, select the kind of the time series that is being imported by tapping on the proper tab as an example for the Obs. Rain it must be historical rainfall data whereas Temperature or Obs. Stream should be the historical streamflow. Thirdly, select the unit of the time series being imported utilizing the Unit list box. The substance of the Unit list box are reliant on the sort of the at present chose time series. Lastly, press the Import key. In the event that the select unit requires a catchment region esteem then a request can be made to determine the catchment region esteem (in sq km) utilizing a dialog box after the Import key. It is conceivable to import data for various data sorts from various raw data records. At the point when all time series have been initialised they will be synchronized.

3.4.2 Calibration and Validation for IHACRES Model

The very important phase in calibration is establishing the calibration period which is for this projection the selected period is from year of 2000 to 2004. Another phase that required in calibration is defining the linear module and non-linear module.

Every calibration period tab has a Pre Grid Search tab which contains a section for each of the current non direct module parameters. The Classic Plus model has five parameters which is Mass Balance (c), Drying rate at reference temperature (τ_w), Temperature dependence of drying rate (f), Reference temperature (t_{ref}) and Moisture threshold for producing flow (l).

Using IHACRES model, the calibration and validation processes for the streamflow are analysed for the period 2000 to 2004. The best calibration was based on the higher value of Coefficient of Determination (R^2) with the lower percentage of Average Relative Parameter Error (% ARPE) based on the following equations:

$$R^2 = 1 - \frac{\sum (Q_o - Q_M)^2}{\sum (Q_o - \overrightarrow{Q_M})^2} \quad 3.11$$

$$\% ARPE = \frac{1}{n} \sum \frac{(Q_o - Q_M)^2}{Q_o} \times 100 \quad 3.12$$

Where Q_o is refer to the observed streamflow, while Q_M is refer to the modelled streamflow whereas $\vec{Q}$ is the mean of observed streamflow and *n* is the total number of streamflow.

3.4.3 Simulation for IHACRES Model

The Simulation takes into consideration examination of the information made subsequently of running the IHACRES model utilizing the current determined calibrations. A calibration is a linear module calibration consolidated with a non-linear module calibration. Every calibration period has its own particular tab which gives get to the following after points of interest for every adjustment period that is Calibration, Simulation Summary, Statistic Summary, Charts and Hydrograph. IHACRES was integrated to simulate and generate the runoff behaviour under projected climatic changes. Various versions of the IHACRES model have also been used to address regionalisation issues (Post and Jakeman, 1996; Sefton and Howarth, 1998, Kokkonen et al, 2001). These issues require methods for estimating the parameters of models directly from rainfall-discharge time series.

In addition to the current simple refined instrumental variable (SRIV) method of parameter estimation (eg Jakeman et al., 1990), a method based on estimating hydrographs directly from streamflow data without the need for rainfall data has been developed (Croke, 2004). This enables higher resolution streamflow data to be used, reducing the loss of information which occurs when data is binned to a daily timestep. In order to use this model independent parameter estimation software, the IHACRES model needs to be able to be run from the command line.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the result of the study are presented and analysed in two main scopes as follows:

a) The selection of predictors for the local weather in the Statistical Downscaling Model (SDSM)

b) Projection of future climate variation of hydrological features which consist of precipitation and temperature.

c) The generation of streamflow using IHACRES model.

The prediction of climate future trend at the site study in Temerloh for the historical years in 1975 to 2004 and future years of 2040 to 2069 were produced by performing calibration and validation simulation to obtain the relationship between local climate pattern and information of the atmospheric features at specific sub-grid using SDSM. The SDSM model was generated the precipitation and daily temperature for a single hydrological station at Temerloh (3424081). Multiple regression technique was used in SDSM model to select he predictor-predictand relationship.

4.2 Temperature Simulation

The simulation of temperature data were referred to the hydrological station at Sg. Pahang, Temerloh. It is assumed that the recorded temperature at the station could represent the district of Temerloh. The observed temperature data were simulated for the year 1984-2013. The climate simulation in the SDSM model started with the screening variables to evaluate the performance of the correlation among predictors-predictands.

4.2.1 Predictor Selections for Temperature Projection

The climate simulation in the SDSM model began with the process of screening variables to measure the performance in focused on correlation among predictors-predictand relationships. In the SDSM model, the screening section involves 26 NCEP predictors and a local predictand which is analysed directly applied in the SDSM model. The purpose of the correlation is to screen the predictor-predictand relationship in a single-shot analysis.

The simulation of historical temperature data refers to the meteorological station at Temerloh. Based on the temperature trend in Malaysia, the monthly temperature range is small and it has small variation at different areas. In addition, the historical temperature data was well correlated to the atmospheric characteristics and the selection of predictor can be easily done. Based on 26 predictors of NCEP, the best 5 predictors has been selected for projecting the temperature trend at the site study. Table 4.1 shows, the selected of 5 predictors which most affected to the pattern of projection for temperature trend at Temerloh**.**

Table 4.1: The selected predictor variable in SDSM model of historical temperature

No	Predictor variable	Predictor Description	Correlation Values
1	p500	500 hpa geopotential height	0.055
2	p_v	Surface meridional velocity	0.135
3	r500	Relative humidity at 500 hpa	0.091
4	temp	Near surface air temperature	0.196
5	r850	Relative humidity at 850 hpa height	0.154

4.2.2 Calibrated and Validated Results for Temperature Simulation

In the calibration and validation process, each local predictand was used in calibrated for the first 15 years and validated for the remaining 15 years with the selected NCEP predictors to analyse the performance of the simulated result compared to the historical data. Lastly, the GCM-derived predictors were used to generate the daily weather series using as the same for the NCEP predictor variable for the future year.

Figures 4.1 to 4.3 shows the simulated results produced calibration in the year of 1984 to 1998 and validation in the year of 1999 to 2013 processes using predictors set from NCEP for three conditions which is maximum, mean and minimum temperature. The performance of calibration and validation results that were presented in Table 4.2 consists of correlation coefficient (r) and mean absolute error (MAE). Based on the results, the MAE values were very small in the whole analysis, ranging from 0.0 to 0.6℃. Higher correlation values were estimated in the calibrated and validated results for maximum, mean and minimum temperature simulation closer to 1.0. The value shows the calibrated and validated values were in a good agreement with historical records.

The graphs disclose that the selected predictors were well correlated to the local predictand producing very close simulated results to historical temperature. However, the result suggest that the projection analysis results are reliable and acceptable at this phase.

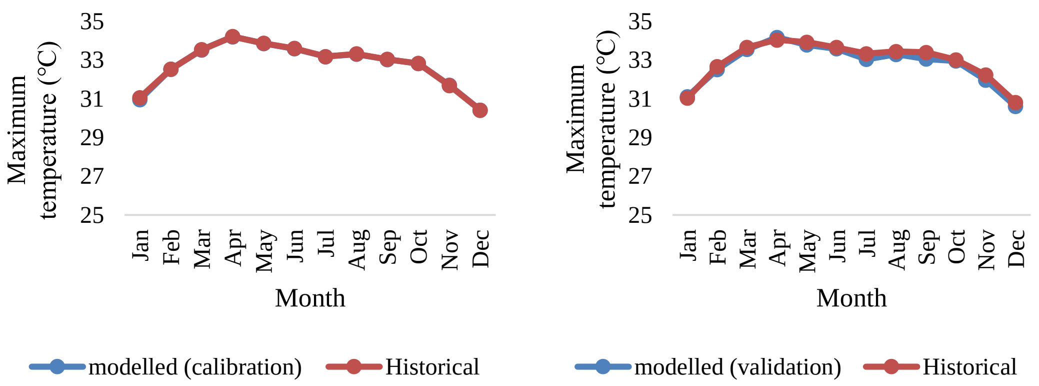


Figure 4.1: Results of calibration (1984-1998) and validation (1999-2013) maximum temperature at Temerloh station using SDSM model

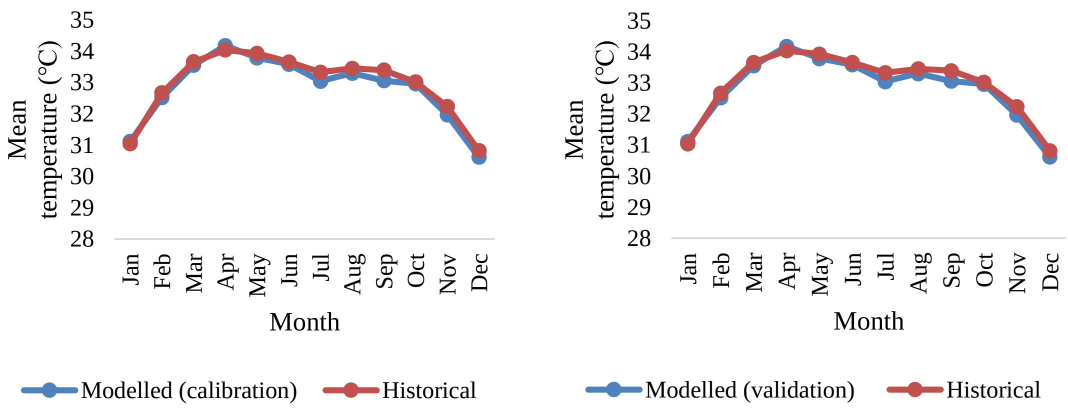


Figure 4.2: Results of calibration (1984-1998) and validation (1999-2013) mean temperature at Temerloh station using SDSM model

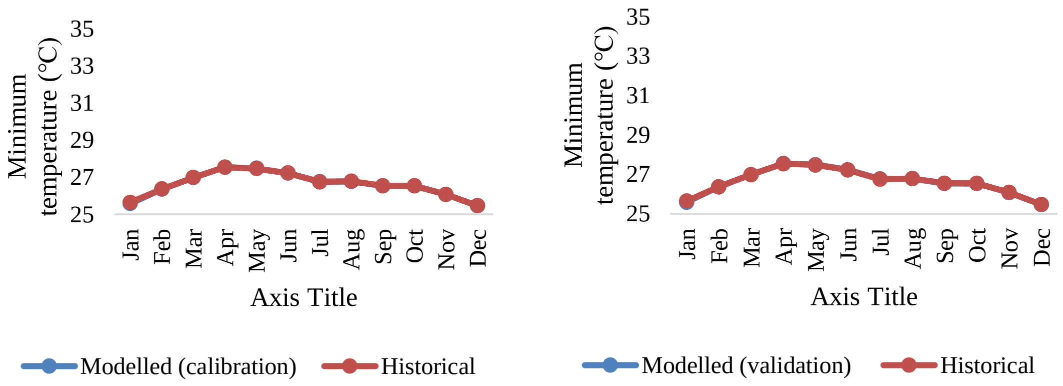


Figure 4.3: Results of calibration (1984-1998) and validation (1999-2013) minimum temperature at Temerloh station using SDSM model

Table 4.2: Performance of calibration and validation results of temperature using SDSM model

	Maximum		Mean		Minimum	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
r	1.0	0.992	1.0	1.0	0.992	0.992
MAE	0.48	0.504	0.037	0.037	0.504	0.054

4.2.3 Projection of Temperature Pattern in year 2040-2069

Figure 4.4 to 4.6 designate the projection of temperature in a phase of maximum, mean and minimum during year of 2040 to 2069. The results were presented in the average of monthly temperature for the interval of 2040-2069. Results show that the average temperature will continue to increase for another 30 years. Based on the monthly average temperature, it shows that the highest temperature will rise on April which during the month it is hot and sunny season in the east coast states in Malaysia. Based on the Malaysian Meteorological Department, Malaysia report (MMD, 2016), it stated that the temperature in the year of 2000 is 26.92°C but it continued to increased in the year of 2010 which is at 27.21°C. the increment will continue to rise about 1°C to 3°C for another decades. The increment of temperature may be affected the interchange of east coast monsoon.

Based on the projection for another 30 years, a safety precaution is highly recommended which it might be achieve at extreme temperature. Global climate is anticipated to keep on changing over this century and beyond. The extreme environmental change for a couple of past decades essentially depends on the measure of heat-trapping gases emmitted and how sensitive the Earth's atmosphere to those emission. Based on the The Star newpaper (The Star, 2016) the Minister of Science, Technology and Innovation, Datuk Seri Madius Tengau says that the temperature in Pahang exceeding 37°C at Batu Embun in the April. The El-Nino event in 1998 has contributed towards higher significant trend with sharp increased in annual mean temperature indicated. Therefore, the reduced demand of an open activities such as open burning and deforestation should be taken which is expected to inconsistent and possibly increased by changes of climate variable for future year.

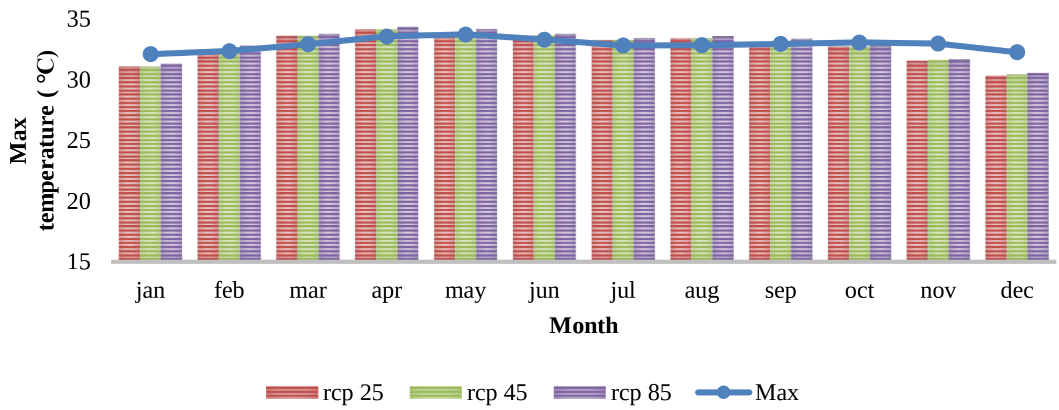


Figure 4.4: Projection of maximum temperature pattern with the GCM projection by RCP26, RCP45 and RCP 85 scenarios during 2040 to 2069

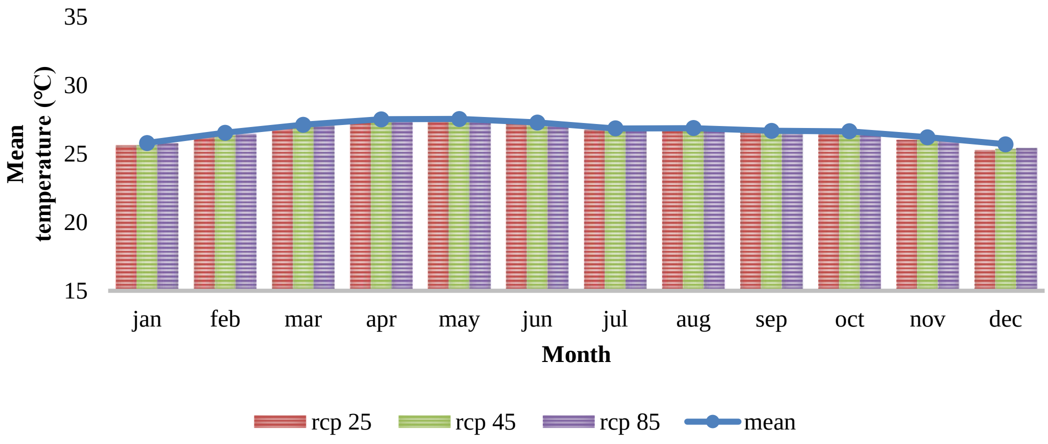


Figure 4.5: Projection of mean temperature pattern with the GCM projection by RCP26, RCP45 and RCP 85 scenarios during 2040 to 2069

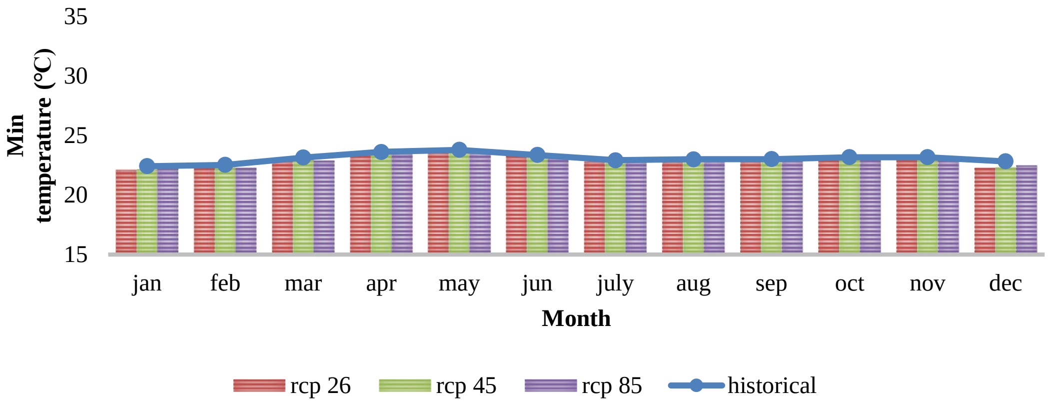


Figure 4.6: Projection of minimum temperature pattern with the GCM projection by RCP26, RCP45 and RCP 85 scenarios during 2040 to 2069

4.3 Rainfall Simulation

The simulation of temperature data were referred to the hydrological station at Sg. Pahang, Temerloh. It is assumed that the recorded temperature at the station could represent the district of Temerloh. The observed temperature data were simulated for the year 1975-2004. The climate simulation in the SDSM model started with the screening variables to evaluate the performance of the correlation among predictors-predictands.

4.3.1 Predictor Selection for Rainfall Simulation

The rainfall simulation was directed as the same station for the temperature simulation temperature at Temerloh. Furthermore, the analysis were started with the data screening to select the predictors affected the volume of rainfall. Then, the calibration and validation stages were conducted between the selected predictor with the rainfall station (local predictand) to investigate the performance of the model. The GCMs predictor were used to project and generate the local climate trend for the future year with consideration the future potential phase of greenhouse gases.

The reliability of the simulation results in the SDSM model refer to the workability of the selected atmospheric variables with local climates in Temerloh station. Using directly analysis in SDSM model the relationship among 26 of NCEP predictors with the station of local predictand at Temerloh were discovered and presented in a single correlation matrix form by monthly. The selected predictors is chosen based on the correlation value in SDSM model. The most highest and consistent average range of correlation value for monthly is the most affected to the change of climate which is influenced to the amount of annual precipitation. No correlation were predicted among predictor-predictand in Temerloh station. Predictors which are not selected shows that these relationships are unnecessarily to associate them together in projection for the future climate trend because it is estimated to produce the least value of correlation and do not really contributed to the projection in rainfall stations therefore, the parameters were eliminated from the selection list.

Five out 26 predictors has been chosen which it is yield a better correlation with all the predictands. In other words, this five predictands suggest that they have a potential accurately simulate the local climate change. Based on the predictors selected, a rainfall station were expected to accurately simulate the rainfall during calibration and validation processes. Table 4.3 shows the selected of 5 predictors which most affected to the pattern of projection for rainfall trend at Temerloh.

Table 4.3: The selected predictor variable in SDSM model of historical rainfall with the predictor description

No	Predictor variable	Predictor Description	Correlation Values
1	p_f	Geostrophic airflow velocity near the surface	0.006
2	p_u	Zonal velocity component near the surface	0.024
3	p_v	Meridional velocity component near the surface	0.016
4	shum	Near surface specific humidity	0.044
5	r850	Relative humidity at 850 hpa height	0.022

Those five parameters were used in the calibration and validation of the rainfall station using weather generator in the SDSM model. Figure 4.7 shows the results of calibration and validation for the rainfall station at Temerloh.

4.3.2 Calibrated and Validated Results for Rainfall Simulation

The simulation of rainfall data were referred to the hydrological station at Sg. Pahang, Temerloh. It is assumed that the recorded temperature at the station could represent the district of Temerloh. The observed temperature data were simulated for the year 1975-2004. The climate simulation in the SDSM model started with the screening variables to evaluate the performance of the correlation among predictors-predictands.

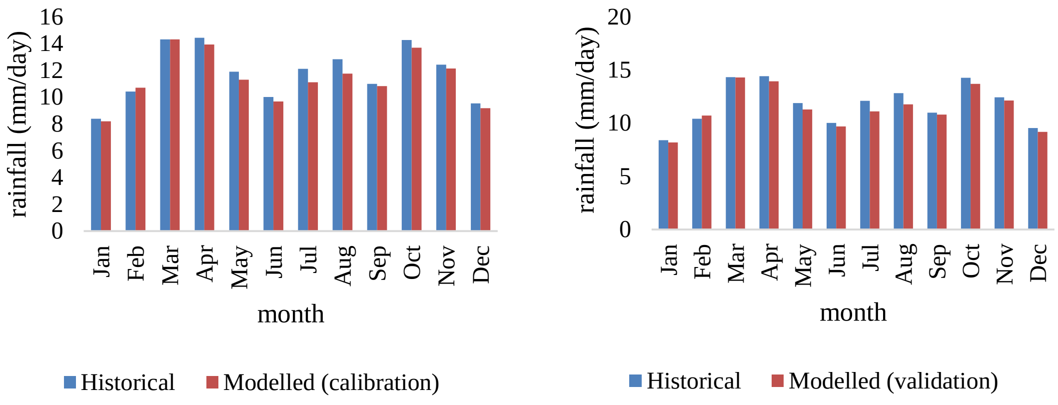


Figure 4.7: Results of calibration (1975-1989) and validation (1990-2004) of historical rainfall at Temerloh station using SDSM model

The simulated rainfall at Temerloh station is in close agreement with the historical rainfall. It yields minimal error in March which is less than 1.0mm/day. The simulated rainfall reflects the reliability of the model. In addition, the simulated rainfall is in good agreement with the modelled rainfall. However, the difference between between historical and modelled values is obvious during May, July and August which it range is between 0.0 to 2.0 mm/day. It is suspected that the error might influence the projection of future rainfall for Temerloh station. It is expected that the projected rainfall at Temerloh station would be underestimated. This is because, there is uncertainty rainfall of the historical data which is based on the Department of Irrigation and Drainage Malaysia (DID) at Temerloh station it recorded that there is zero amount of effective rainfall during the month. To overcome this problem, the nearest station has been chosen to in to get a reliable data using an arithmetic method. However, the results would not significantly affect the analysis at Temerloh station.

The performance of the predictors selection to inter-react with the local climate was evaluated using the statistical parameters that measure the monthly discrepancies between historical and modelled data at Temerloh rainfall station. The statistical parameters are mean absolute error (MAE). Table 4.4 summarizes the MAE results for monthly mean rainfall of modelled and historical values. The highest error is estimated in a month of which is the value is. The errors in other remaining months are slightly low which is in a range of 0.0 to 0.5 mm/day.

Table 4.4: Performance of calibration and validation results of rainfall using SDSM model

	Validation	Calibration
r	0.981	0.981
MAE	3.772	3.772

4.3.3 The Projection of Rainfall in year 2040-2069

The analysis of climate change at Temerloh rainfall station is necessary in preparing for the reservoir management. The projection of rainfall in this area is used to estimate the rainfall volume that will be stored in the reservoir. Furthermore, the rainfall depth is also used in the rainfall-runoff model to generate the streamflow that will enter the reservoir storage.

Figure 4.8 show the projection of rainfall for Temerloh station for the year of 2040 to 2069 with the constant predictors used for GCM data type RCP26, RCP45 and RCP85 scenarios. The graph reveal that the selected predictors were well correlated to the local predictand, producing slightly closed simulated results to historical rainfall. However, the simulated rainfall of RCP26 scenario produce is lower than the historical rainfall for the overall range of months. Based on the graph, it shows the greatest percent of reduce is in a month of January. For the RCP 26, 45 and 85 it reduce at 26, 28 and 25 percent respectively. Whereas, the greatest increment from the historical data is in the month of October. The highest increment for the October is RCP 85 which is at 9.90 percent. However, the error is in an acceptable range of 1.0 to 3.0 mm/day for every range of months. Therefore, these results suggest that the projection analysis results is reliable and acceptable at this stage.

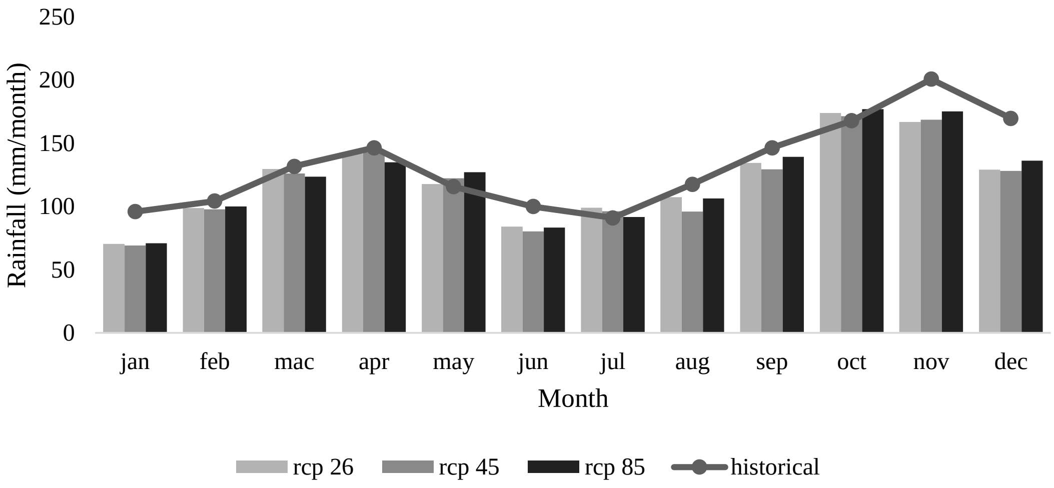


Figure 4.8: Result of simulated rainfall at Temerloh station with the GCM projection by RCP26, RCP45 and RCP 85 scenarios during 2040 to 2069

4.4 Inflow Prediction

The inflow prediction were made for year 2040 until 2069 using IHACRES model. In general, the applicaton of rainfall-runoff model outputs of simulated value should be closer to observed data.

4.4.1 Parameter Selection for Streamflow Simulation

In preparing water balance for Temerloh station, predictions was made for the year of 2000 to 2004 for the time series of monthly runoff that will be used to simulate the reservoir storage. The streamflow is treated equally to the reservoir inflow. The IHACRES model were used for making the analysis of streamflow as it affected by the rainfall and streamflow pattern at the Temerloh station. Table 4.5 shows the parameters values which has been used in this study.

Based on the calibrated value of parameter in IHACRES model, it shows that the percentage of ARPE is quite high which is at 7.74%. however, the values of correlation r of parameters is low which is at 0.66. It is shows that the is still in a good range of correlation parameters.

Table 4.5: Calibration model parameters value for IHACRES model

Parameters	Values
Mass Balance (c)	0.01
Drying rate at reference temperature (τ_w)	4
Temperture dependence of drying rate (f)	0
Reference temperature (t_{ref})	20
Moisture threshold for producing flow (l)	0
Correlation Coefficient (r)	0.66
Average Relative Parameter Error (% ARPE)	7.74

4.4.2 Inflow Simulation using IHACRES Rainfall-Runoff Model

Figure 4.9 shows the association between historical and modelled streamflow for the calibration and validation in the year of 2000 to 2004 results. Generally, the accuracy model prediction is an average except from the August of 2000 to the September 2004 that was drastically decreases than historical record. The good performance of IHACRES model for runoff modelling is proved by the closed agreement between the results of historical and simulated runoff.

Figure 4.10 shows the performance among simulated monthly inflow time series and the historical record in the year of 2000 to 2004 were compared. The purpose of the figure is to evaluate the performance of IHACRES model in the streamflow generation. The mean comparison based on Figure 4.10 shows the fluctuation with the observed data. The underestimated simulation shows in the February to April and the overestimated simulation stated in June to September and continue to underestimated in October to December. Based on the analyses the generated streamflow series using IHACRES model is unsatisfied as reliable for the future streamflow generation.

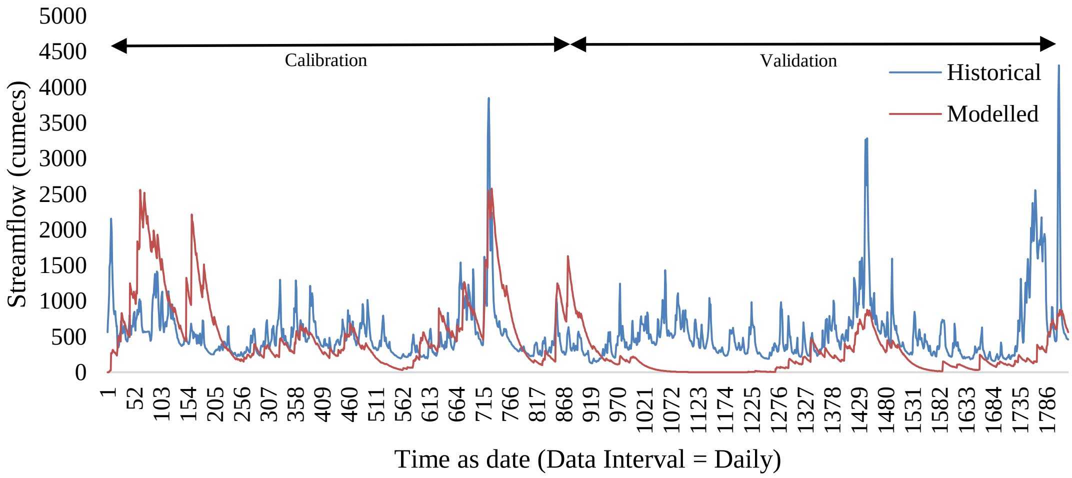


Figure 4.9: Result of calibration (2000-2002) and validation (2002-2004) for streamflow simulation using IHACRES model

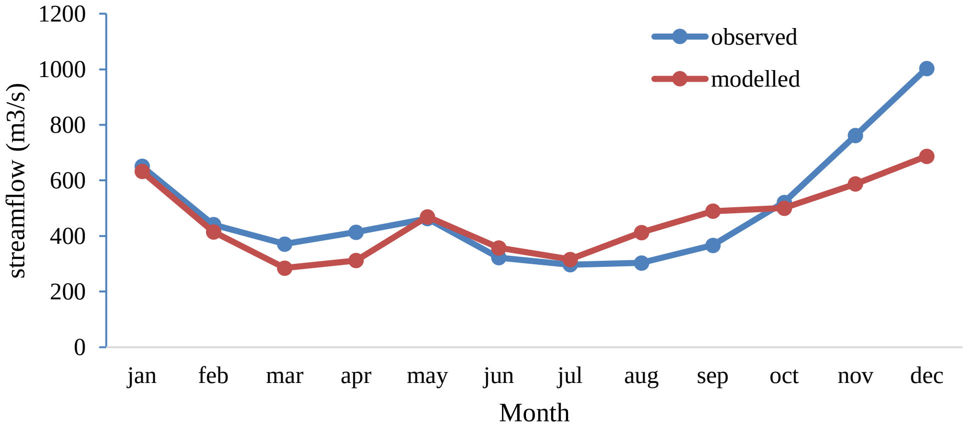


Figure 4.10: Comparison between mean observed and modelled result during 2000 to 2004

Based on the Figure 4.10, the overall trend of streamflow of the simulation is fluctuated during year 2000 to 2004. The highest percentage of error is during December. The flow of stream for modelled is reduced at 31% compared to observed streamflow. However, modelled streamflow were increased during September which is at 25%. This is shows that, analysis of the statistics for individual years shows that the model performed slightly poor.

4.4.3 Future Inflow Pattern

The inflow time series was generated for the future year of 2040 to 2069 with the historical streamflow. The generated inflow time series is depends on the rainfall depth and the local temperature at Temerloh station area in the future using SDSM projection. The inflow is probably estimated to become higher at end of the century because the consistency of the increment of rainfall at this area was estimated due to the climate change impact. In addition, the monthly streamflow volume is un-synchronize affected by the local monsoon disturbance.

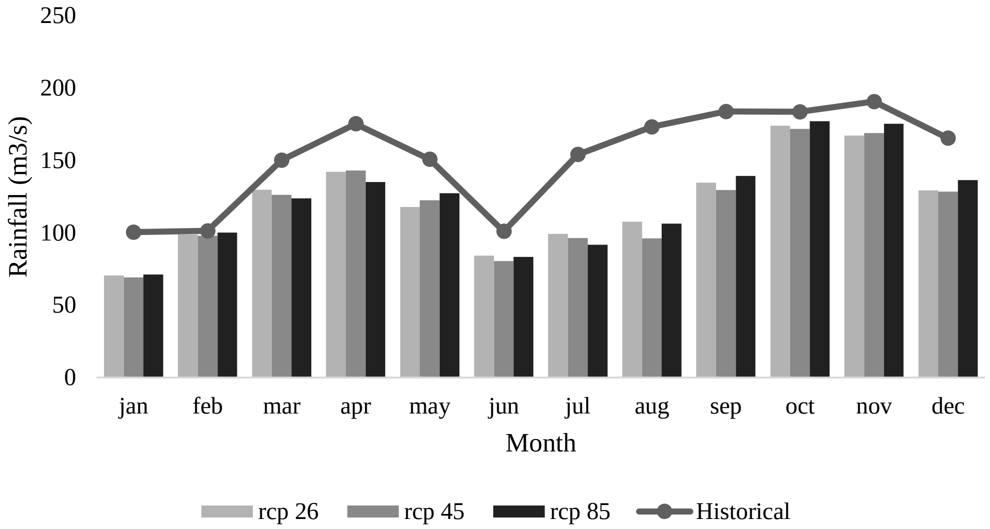


Figure 4.11: The comparison between monthly generated inflow with the historical inflow at Temerloh station

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The study is to show the performance of the software which contributes to the advancement tools in the operations for a long term and maintainable in order to manage the flow of hydrological cycle at the site study. Therefore, a useful and accurate software is needed to perform a good projection of climate change so a step on safety precaution can be taken seriously. The Statistical Downscaling Model (SDSM) has contributed to the good projection of average rainfall and temperature of the site study. With supported of the results from SDSM, another software of rainfall-runoff model has been introduced to give a stronger and precise results which is IHACRES model. This chapter were discussed on the main conclusions for the study. Based on the discussion from the previous chapter, a several specific conclusions as listed in the following section.

5.2 Conclusions

a) Statistical Downscaling model has been established a good selection predictors in data screening processes. Selection predictors is important in order to obtain a good results of calibration and validation. On the other aspect, each of the predictors has a different characteristics which is contributed to the change of climate impact.

b) In SDSM this shows that, the model performed slightly better in the simulation period than in the calibration period.

c) The inflow of projection by IHACRES model is found to be reliable and the model is simulated almost similarly to the historical.

d) The catchment has a dry tropical climate, with rainfall dominated by high intensity events. This is the result of the lack of any baseflow component in this catchment

e) The streamflow projection shows the increment for each year and it is consistent to the pattern of rainfall and mean temperature from SDSM projection.

f) The highest range of flow is in the month of November as expected based on the historical flow for the site study at Temerloh.

g) In addition, the functionality of the software has been increased through the inclusion of additional non-linear modules and alternative calibration techniques, as well as improved visualisation of data and modelled results. The model can be applied to arid and semi-arid catchments, though the length of the calibration period should be increased to accommodate the lower frequency of streamflow events.

5.3 Recommendations

Several guidance and recommendations were needed in improving the prediction of trend for the long term of climate change purpose;

a) The methodology of this study are recommended to be analyse at several district or other near stations of hydrological in Pahang state in achieve a full view of the projection in a larger area.

b) The raw material and data should be taken in details for the process of sorting and analysis the data in order to produce for a precise and accurate projection of the weather climate change.

REFERENCES

Pervez, M. S., & Henebry, G. M. (2014). Projections of the Ganges–Brahmaputra precipitation—Downscaled from GCM predictors. *Journal of Hydrology*, *517*, 120–134. https://doi.org/10.1016/j.jhydrol.2014.05.016

Burns, A.W., and James, I.C., Jr., 1972, Computer simulation model of the Ipswich River Basin: Massachusetts Water Resources Commission, Boston, Mass., publication 6317, 66 p.

La, E. M., Linder, E., & Pan, Y. (2016). Statistical downscaling of regional climate model output to achieve projections of precipitation extremes, *12*, 15–23. https://doi.org/10.1016/j.wace.2015.12.001

Croke, B., & Cuddy, S. M. (2005). Redesign of the IHACRES rainfall-runoff model, (February).

Climatology, A., Hassan, Z., Shamsudin, S., Teknologi, U., & Hassan, Z. (2015). Application of SDSM and LARS-WG for simulating and downscaling of rainfall and temperature Application of SDSM and LARS-WG for simulating and downscaling of rainfall and temperature, (April 2014). https://doi.org/10.1007/s00704-013-0951-8

Nurul Nadrah Aqilah, T., & Sobri, H. (2011). The Projection Of Future Rainfall Change Over Kedah, Malaysia With The Statistical Downscaling Model. *Malaysian Journal of Civil Engineering*, *23*(2), 67–79.

Nurul Nadrah Aqilah, T., (2014). Reservoir System Modelling Using Nondominated Sorting Genetic Algorithm In The Framework of Climate Change.

Littlewood, I. A. N. (2017). Practical aspects of calibrating and selecting unit hydrograph-based models for continuous river flow simulation, *6667*(June). https://doi.org/10.1080/02626660109492871

A Precipitation-Runoff Model for Analysis of the Effects of Water Withdrawals on Streamflow , Ipswich River Basin , Massachusetts. (n.d.).

Search, H., Journals, C., Contact, A., Iopscience, M., Conf, I. O. P., Environ, E., & Address, I. P. (2010). A Review on Flood Events for Kelantan River Watershed in Malaysia for Last Decade (2001-2010), *12070*. https://doi.org/10.1088/1755-1315/32/1/012070

Merz, R., Blöschl, G., & Parajka, J. (2006). Regionalization methods in rainfall – runoff modelling using large catchment samples, 117–125.

Manual, U. (2007). SDSM 4 . 2 — A decision support tool for the assessment of regional climate change impacts User Manual, (August), 1–94.

IHACRES User Guide. Second Edition. (2017), (January 2005).

Travis, W. R. (2014). Weather and climate extremes : Pacemakers of adaptation ?, *6*, 29–39. https://doi.org/10.1016/j.wace.2014.08.001

Ahmed, M., & Ogtrop, F. F. Van. (2014). Can models help to forecast rainwater dynamics for rainfed ecosystem ? *Weather and Climate Extremes*, *5–6*, 48–55. https://doi.org/10.1016/j.wace.2014.07.001

Chung, U., Gbegbelegbe, S., Shiferaw, B., & Robertson, R. (2014). Modeling the effect of a heat wave on maize production in the USA and its implications on food security in the developing world. *Weather and Climate Extremes*, *5–6*, 67–77. https://doi.org/10.1016/j.wace.2014.07.002

Search, H., Journals, C., Contact, A., Iopscience, M., Conf, I. O. P., Environ, E., & Address, I. P. (2010). A Review on Flood Events for Kelantan River Watershed in Malaysia for Last Decade (2001-2010), *12070*. https://doi.org/10.1088/1755-1315/32/1/012070

Croke, B. F. W., & Jakeman, A. J. (n.d.). Use of the IHACRES rainfall-runoff model in arid and semi arid regions.

A Precipitation-Runoff Model for Analysis of the Effects of Water Withdrawals on Streamflow , Ipswich River Basin , Massachusetts. (n.d.).

Ahmed, M., & Ogtrop, F. F. Van. (2014). Can models help to forecast rainwater dynamics for rainfed ecosystem ? *Weather and Climate Extremes*, *5–6*, 48–55. https://doi.org/10.1016/j.wace.2014.07.001

Mahmood, R., & Babel, M. S. (2014). Future changes in extreme temperature events using the statistical downscaling model (SDSM) in the trans-boundary region of the Jhelum river basin. *Weather and Climate Extremes*, *5–6*, 56–66. https://doi.org/10.1016/j.wace.2014.09.001

Chung, U., Gbegbelegbe, S., Shiferaw, B., & Robertson, R. (2014). Modeling the effect of a heat wave on maize production in the USA and its implications on food security in the developing world. *Weather and Climate Extremes*, *5–6*, 67–77. https://doi.org/10.1016/j.wace.2014.07.002

Travis, W. R. (2014). Weather and climate extremes : Pacemakers of adaptation ?, *6*, 29–39. https://doi.org/10.1016/j.wace.2014.08.001

Liberato, M. L. R. (2014). The 19 January 2013 windstorm over the North Atlantic : large-scale dynamics and impacts on Iberia. *Weather and Climate Extremes*, *5–6*(January 2013), 16–28. https://doi.org/10.1016/j.wace.2014.06.002

Ruy, J., Carvalho, P. De, Delgado, E., Fortes, A., Oliveira, D., & Silveira, H. (2014). Annual maximum daily rainfall trends in the Midwest , southeast and southern Brazil in the last 71 years. *Weather and Climate Extremes*, *5–6*, 7–15. https://doi.org/10.1016/j.wace.2014.10.001

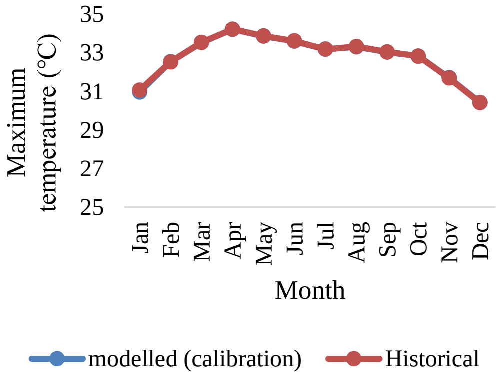
Ogungbenro, S. B., & Eniolu, T. (2014). Rainfall distribution and change detection across climatic zones in Nigeria. *Weather and Climate Extremes*, *5–6*, 1–6. https://doi.org/10.1016/j.wace.2014.10.002

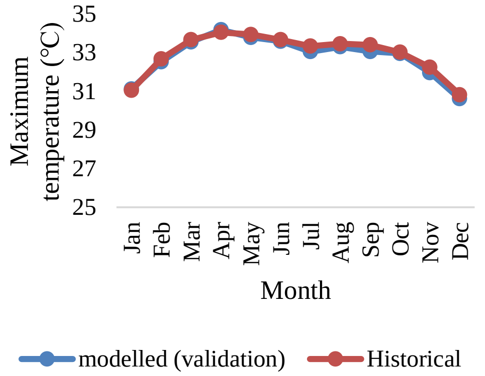
Thevasiyani, T., & Perera, K. (2014). Statistical analysis of extreme ocean waves in Galle , Sri Lanka. *Weather and Climate Extremes*, *5–6*, 40–47. https://doi.org/10.1016/j.wace.2014.07.003

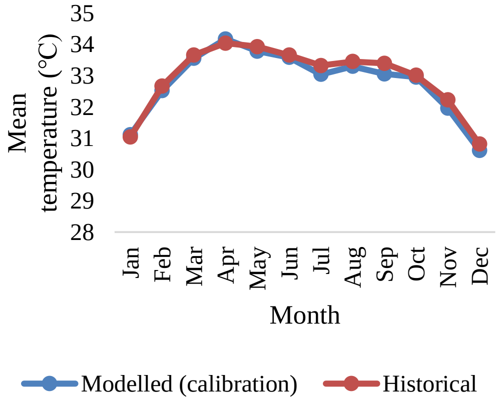
IPCC (2017). *Scenario Process For AR5*. Retrieved from http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

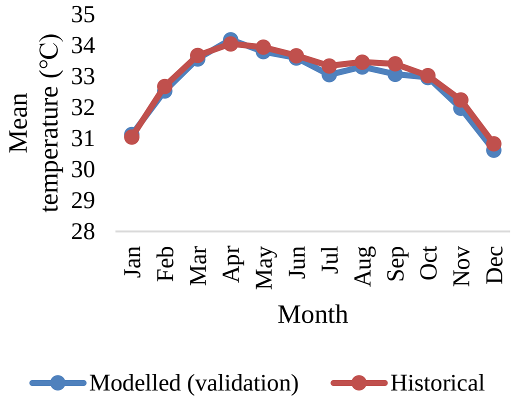
APPENDIX A

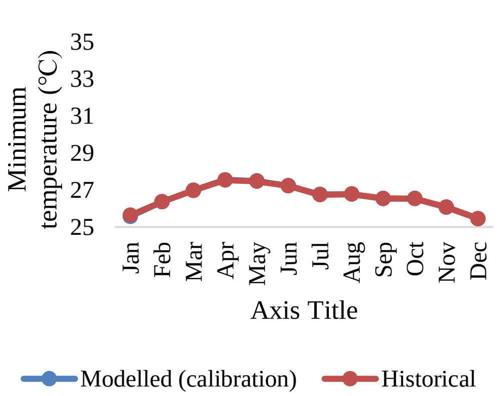
Results of calibration (1984-1998) and validation (1999-2013) maximum, mean and minimum temperature at Temerloh station using SDSM model

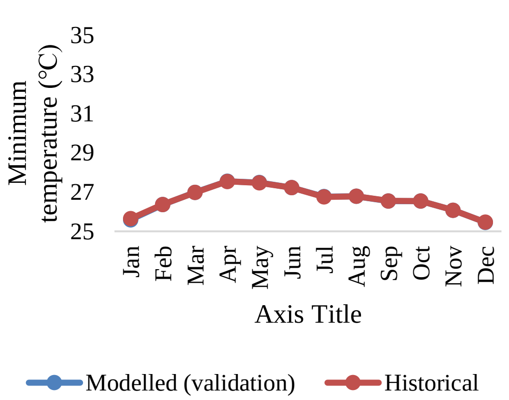




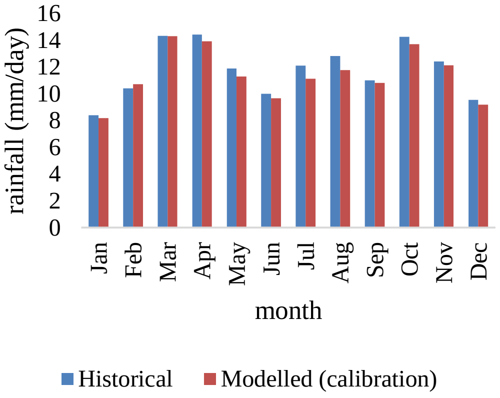


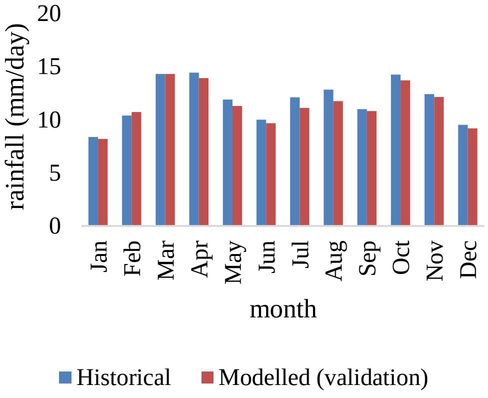






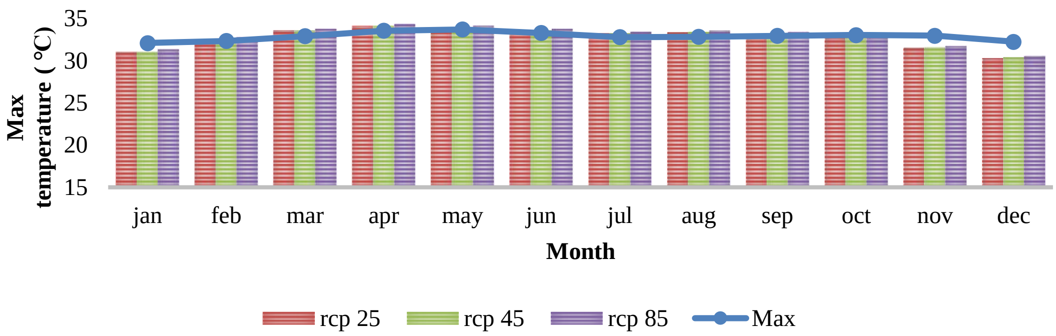
Results of calibration (1975-1989) and validation (1990-2004) of historical rainfall at Temerloh station using SDSM model

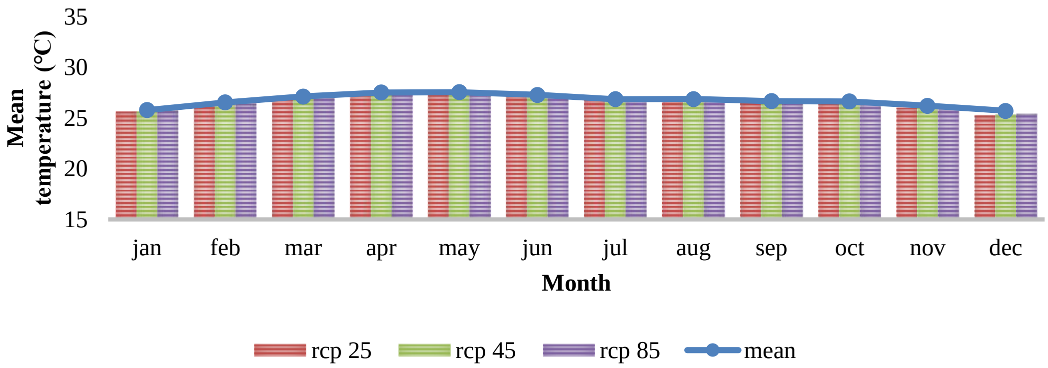


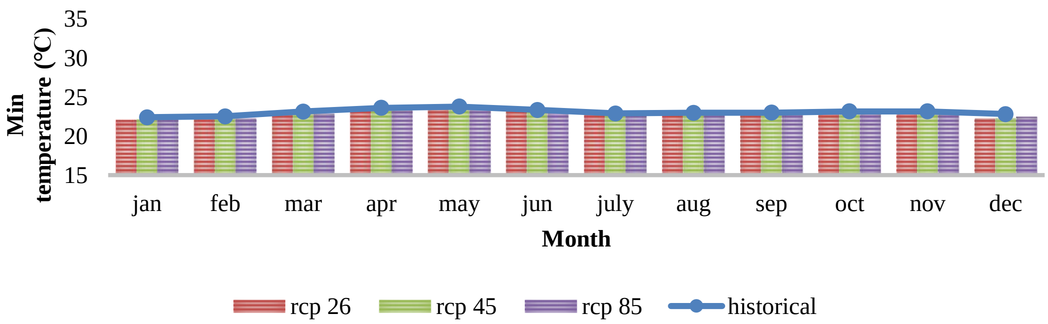


APPENDIX B

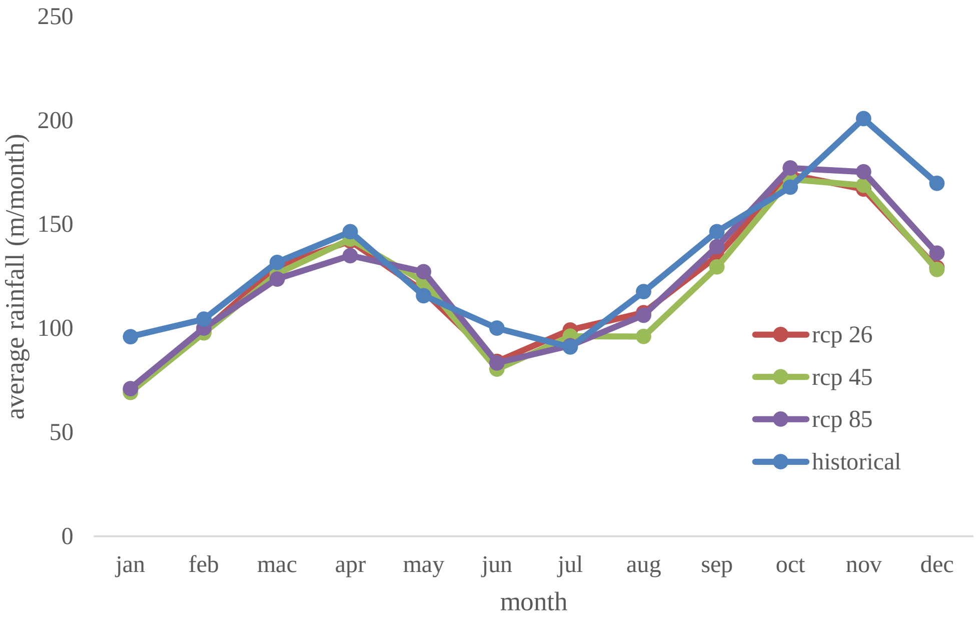
Projection of maximum,mean and minimum temperature pattern with the GCM projection by RCP26, RCP45 and RCP 85 scenarios during 2040 to 2069





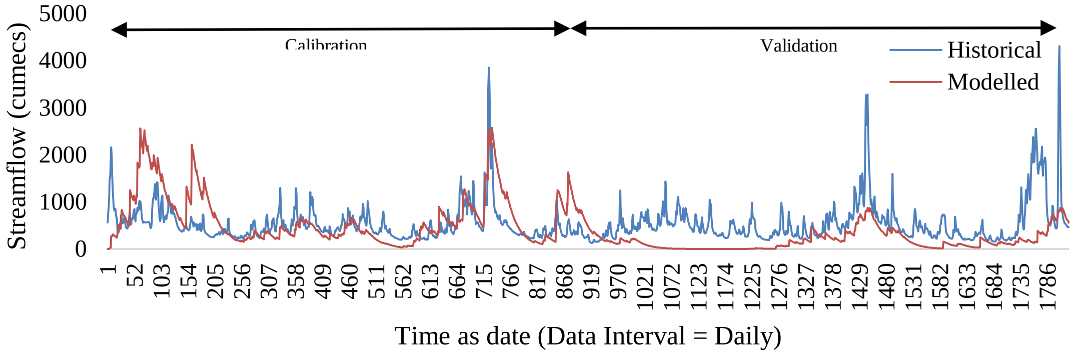


Result of simulated rainfall at Temerloh station with the GCM projection by RCP26, RCP45 and RCP 85 scenarios during 2040 to 2069

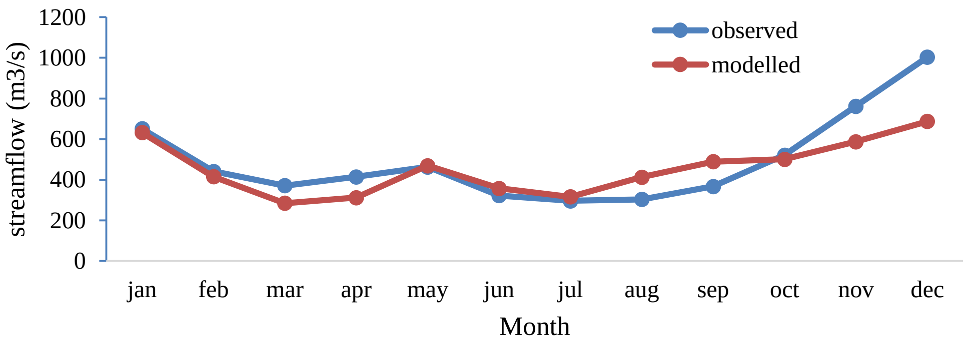


APPENDIX C

Result of calibration (2000-2002) and validation (2002-2004) for streamflow simulation using IHACRES model



Comparison between mean observed and modelled result during 2000 to 2004



The comparison between monthly generated inflow with the historical inflow at Temerloh station