EVALUATION OF STREAMFLOW PREDICTION WITH CONSIDERED THE CLIMATE CHANGE IMPACT AT SUNGAI KECHAU, PAHANG

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ABSTRAK

Aliran sungai pada masa kini menjadi berubah-ubah disebabkan oleh kesan perubahan iklim yang menyebabkan pelbagai bencana yang mengancam alam sekitar dan telah dikaji bahawa kesan negatif yang lebih besar akan melanda terhadap masyarakat manusia. *General Circulation Model* (GCM) menyatakan bahawa peningkatan kepekatan gas rumah hijau akan mempunyai perubahan untuk iklim pada skala serantau. Dalam simulasi ini, teknik "downscaling" digunakan untuk menggambarkan sebagai alat sokongan untuk kesan perubahan iklim setempat. *Statistical downscaling model* (SDSM) memberikan manfaat pada pembangunan pesat pelbagai, kos rendah, senario tapak tunggal bagi pembolehubah cuaca harian dan daya iklim serantau yang akan datang. Penggunaan SDSM adalah untuk mensimulasikan dengan menghasilkan suhu harian dan senario hujan untuk Sungai Kechau, Pahang pada tahun 2020-2099. Walau bagaimanapun, dalam kajian ini disokong dengan keupayaan model IHACRES di kawasan di mana data hidrologi mempunyai faktor batasan. Model IHACRES telah digunakan dalam pendekatan regionalisasi untuk menghasilkan ramalan aliran sungai. Dengan penggunaan model IHACRES, ia adalah modul kehilangan bukan linear yang mengira hujan yang berkesan dan mengarahkan modul linear yang menukar hujan berkesan ke aliran sungai.

ABSTRACT

Streamflow nowadays becomes fluctuated due to climate change impact that causes various disasters that threaten the environment and it has been measured that a greater negative impacts on human society. 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 is “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 Kechau River, Pahang for 2020-2099. 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.

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R^2	Coefficient of determination
ARPE	Average relative parameter error
Q_O	Observed streamflow value
Q_M	Modelled streamflow value
U_k	Effective rainfall
S_k	Soil moisture index
Q_k	Generated streamflow
α	Recession rate
β	Fraction of effective rainfall

LIST OF ABBREVIATIONS

USGS	United Stated Geological Survey
GHG	Greenhouse Gas
GCM	General Circulation Model
IPCC	Intergovermental Panel on Climate Change
DID	Department of Irrigation and Drainage Malaysia
MMD	Malaysian Meteorological Department
MOSTI	Ministry of Science, Technology and Innovation
NCEP	National Centres Environmental Prediction
RMSE	Root Mean Square Error
ARPE	Average Relative Parameter Error
NAHRIM	National Hydraulic Research Institute of Malaysia

CHAPTER 1

INTRODUCTION

1.1 Research Background

Streamflow nowadays becomes fluctuated due to climate change impact that causes various disasters that threaten the environment. There are many disasters that cause by climate change such as a change on radiation by sun and global warming. These phenomena have been discovered that will indicate most harmful effects to human and the natural circulation. Actually, Malaysia is a country that has the equator climate, which are hot, humid and rainy throughout the year. The climate pattern is influenced by the monsoons, there are Northeast Monsoon and Southwest Monsoon. Malaysia has a high frequency of rainfall every year from November to January and goes minimum between March and August due to drought season. However, the enhancement of climate changes issues in the natural processes due to human activities. The increasing level of carbon dioxide, (CO2) and other hear gases to the atmosphere have warmed the Earth that are causing to the rise of sea level, floods and also drought.

The impact of climate changes has been the main influences on the change of weather, temperature, rainfall and streamflow. These phenomena have been discovered that will indicate most harmful effects to human and the natural circulation. Regarding to the matter, an article from "Science for a Changing World" stated that certain human activities throughout Kansas, United Sated of America cause decreased streamflow or declining groundwater levels. Researchers assessed streamflow alteration as it relates to habitat management by analysing data from 129 USGS stream gages across the state from 1980 through 2015. Agricultural practices have one of the greatest effects on streamflow. Ongoing pumping of groundwater from the High Plains aquifer, mostly for irrigation, has resulted in an ongoing drop in groundwater levels in parts of western Kansas. In some areas, levels have declined 50 to 100 feet or more. This proved that the human activities are one of the causes of contributing to streamflow changes and will affect ecosystems in the environment. Streamflow is decreased by increasing air temperatures and increased by rising precipitation amounts. Refer to the United States Environmental Protection Agency, an annual basis when extreme climate change would be a 4℃ increase in air temperature and a 20 percent decrease in precipitation. For the 21 rural watersheds studied, mean annual flows would be reduced by about 40-50 percent if air temperature increased by 4℃ and precipitation were reduced by 20 percent. Clearly, a 103 percent increase in flow due to urbanization would offset the 40-50 percent decrease in flow due to climate change to produce a 53-63 percent net increase in flow.

The temperature changes also influenced by the continuous to rise the greenhouse gases (GHGs) due to climate change impact. This phenomenon allows incoming sunlight to pass through, but retains heat emitted from the earth's surface. Greenhouse gases including methane, nitrous oxide, and carbon dioxide are compounds in the atmosphere that absorb and emit radiation in the thermal infrared range, heating the Earth's surface. This greenhouse effect is necessary for life on Earth, but if greenhouse-gas concentrations in the atmosphere continue to increase at their current rate, Earth's surface could hit historically high temperatures as early as 2047 with enormous effects on weather, wildlife, and the way we live (Moran, 2017). The climate change is usually changing the natural system. These may be cause the global warming which sea water level will increase immediately.

Meanwhile, in Malaysia it is often the case of high floods occurring by the streamflow and is related to human life safety issues. Malaysia has long been involved in a flood disaster over the last decade when the city of Kuala Lumpur was sunk in the flash floods in January 1971. The flood was due to heavy rain that struck Klang and Gombak rivers. 32 people were killed and 180,000 were affected. Prime Minister of Malaysia Tun Abdul Razak declared a state of disasters in West Malaysia. According to a statement from the Pahang Police Headquarters Flood Operating Room Spokesman, Kuantan recorded the highest number of victims during the 2013 Big Flood in Kuantan with 32,871 victims followed by Pekan (3,464), Temerloh (839), Jerantut (519), Maran (183), Bera (117), and Lipis (53). Prime Minister Datuk Seri Najib Tun Razak then announced a grant of RM500 for every flood victims in the East Coast and Johor. The Pahang government is ready to face the Great Flood in Pahang, which will hit the state in the future with 579 evacuation centres identified with 60 percent being school buildings, while food items such as food cost about RM 1.2 million.

Hence, various modelling and simulation has been made to forecast variability and change in climate variables and parameters to predict for long term framework on climate change. The most common approach in predicting the variability and changes in climate variables by downscaling techniques that are acquired to obtain local-scale conditions and climate, particularly at the surface level, from regional-scale atmospheric variables that are supplied by a general circulation model (GCM). However, the GCMs require high resolution of regional scales to satisfy the represent of complex topographical features when there are hydrological and environmental impacts of climate changes need to be examined. To overcome the problem, downscaling model able to simulate local conditions in greater detail where a statistical relationship is established from observations between large scale variables, like atmospheric surface pressure, and a local variable, like the wind speed at a particular site. It has been exposed widely to the studies of the world climate change either in mean or extreme condition throughout the assessment. Furthermore, the IHACRES model which a catchment-scale rainfall-streamflow is modelling that function as to predict streamflow by using rainfall and temperature information.

1.2 Statement of the Problems

The natural circulation that has been created has their large roles as the earth's climate varies in some countries in accordance with the circumstances surrounding nature. The existence of climate change has resulted in various adverse effects to environment on water sources and hydrological cycles. It is very important to identify how great the changes of global climate may affect the characteristics of hydrology variables a certain watershed which can cause in 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 a country located in the tropical rainforest region where it is in the equator. Therefore, it requires optimal management resources in each major catchment area. Generally, it experienced in two different seasons which is rainy season and dry season. Ekkawatpanit, (2009) has stated on his research 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 the estimation of Malaysia's annual rainfall is more than 2500mm. However, the amount of annual rainfall received is not necessarily the same in every month as it depends on the influence of monsoon season. This is because, many Southeast Asian countries have grown rapidly, and urbanization has led to a lack of water supply. Therefore, the idea of experimenting in streamflow modelling from rain to stream flow using a mathematical algorithm gives a better idea of understanding the change in water movement.

Global climate changes are expected to alter precipitation and run-off patterns, exerting significant pressure on water resources on a regional and global scale (IPCC, 2001). Thus, potential impacts of climate change on hydrologic extremes, like floods, in small and medium sized watersheds, have not received significant attention. Consequently, there is lack of sufficient development and application of suitable techniques in the context of climate change. For the Pahang River, it floods frequently happened especially during northeast monsoon because the east coast Malaysia experienced humidity and heavy rains from November to February that brought by northeast monsoon. The Pahang River is the main channel for flowing water from a small drainage area to South China during the rainy season caused by the northeast monsoon. The idea of the forecasting the changes trend of streamflow affected by climate changes comes for predicting the future rainfall and streamflow by considering climate changes impact.

Climate models grow increasingly complex as they more accurately reflect these intricacies. Detection and attribution methods attempt to separate observed climate changes into components that can be explained either by the variability of the climate system or external changes, such as human activity (Hegerl, 2000). Most detection and attribution studies use climate models to interpret the observations. Models are used both to determine the expected 'fingerprint' of climate change and to access the uncertainty in the estimated magnitude of observations given climate variability. Professor Hegerl argued that research which does not rely on climate models makes strong assumptions about how the effects of human influence on the climate can be distinguished from the effects of the natural variability of the climate system. This research supports the conclusion that human influence has changed recent temperatures that is drawn from studies that use models. These strong assumptions do not have to be made when using physically based climate models, but because climate models are not perfect their use does introduce other uncertainties. These uncertainties are small for large-scale temperature change, but are larger and less well understood for changes related to impacts, such as regional temperatures, extremes, and precipitation.

1.3 Objectives of the Study

The main objective is to estimate the long terms changes of streamflow trends affected by climate changes at a local site. To achieve the objective, two objectives were considered, there are:

1) To generate the long terms trend of rainfall and temperature from year 2020 until 2099 by using statistical model.

2) To estimate the long terms changes of water stream concerned with climate changes impact.

1.4 Scope of the Study

This research focused on the long-term pattern of water streamflow in the context climate change impact. The historical data of temperature, rainfall and streamflow from year 1984 to 2013 were needed to generate the future changes by using these two model which is Statistical Downscaling Model (SDSM) and IHACRES model. Statistical Downscaling Model (SDSM) requires the historical daily rainfall that provided by the Department of Irrigation and Drainage Malaysia (DID), and the historical mean temperature data from year 1984 until 2013 were provided by the Malaysia Meteorological Department (MMD). Meanwhile, IHACRES model needs the historical streamflow that provided by the Department of Irrigation and Drainage Malaysia (DID). In addition, the statistical downscaling model (SDSM) and IHACRES were used to predict the climate trend in the region with considered the climate change impact. The study was focused at station Ulu Kechau, Pahang to analyse the climate change using the existing data variables.

1.5 The Significance of the Study

The importance of the study is to determine the long-term pattern streamflow in Pahang River by considering the climate change impact. This issue become very important as a guideline for the authority to manage any development close to the river and catchment area such as hydropower plant and dam with efficiently. Flood risk assessment is needed to predict the flood events especially areas that are always flooded such as Temerloh and Kuantan. It is effectively identified the difference between precipitation and temperature at the site for present and future based their changes due to the effects of environmental changes in the zone. This study gives an advantage to the authority to make a precaution for the disaster warning.

The performance of Statistical Downscaling Model (SDSM) as a streamflow statistical model at Pahang River can be measured by comparing the climate data based on the Malaysia Meteorological Department (MMD). These models are importance for management in predicting the weather in our country by determine the long terms pattern of precipitate and water streamflow. Streamflow modelling contribute an important part in water resources management including land use change, water quality assessment and generating streamflow data despite of monitoring the stations (Tan et al. 2014).

Finally, the long-term streamflow generation becomes significant information for the authority to manage Pahang River because the natural cycle plays a big role in life on earth and its effects when there is a change in its circulation. The projected future trend of rainfall provides guidance to decide appropriate new development areas in upstream, midstream, and downstream of Pahang River.

CHAPTER 2

LITERITURE REVIEW

2.1 Introduction

Climate change, whether natural or due to human activities, will have an impact on many aspects of our environment. The changing of streamflow trend will depending on the magnitude and direction of the climate change. The main climatic elements that control the streamflow are precipitation and evapotranspiration, which can be estimated from air temperature data, the sensitivity of streamflow to variations in climate can be considered through the use of plausible scenarios of climate alteration. Changes in streamflow will affect the availability of water for agricultural, human consumptive, industrial, and recreational uses. For critical areas in need of water, understanding the possible consequences of climate change on streamflow is necessary to ensure adequate supply of the future. The simple streamflow model presented here can easily be applied to other streams to evaluate the regional effects of climate change on water supply.

Thus, the changes of the global climate nowadays are no doubt because of the climate change impact. Several have already seen as an example of flash floods, droughts and thunderstorm. Since the Industrial Revolution, human alteration either inadvertently or deliberately on the concentrations of active gases that released in the atmosphere has risen to levels at which human activity may become a major cause of climate change. For this reason, studies on the effects of climate change on natural and water resources management especially for the hydrologic and agricultural systems, become significant in preparing an effective plan. Therefore, the present study focuses not on the expected response from the hydrological system to a given climate change, but rather on the sensitivity of streamflow to a range of hypothetical climate change scenarios.

To assess the impact of climate change on streamflow in the study area, many researchers applied empirical statistical models to study the effect of rainfall, temperature, and streamflow with the climate change impact. This study found that for any annual precipitation diminishes rapidly with increasing temperature, and that for any given temperature the proportion of precipitation increases rapidly with increasing precipitation. The models that involved in the study are Statistical Downscaling Model (SDSM) and IHACRES as a medium that facilitates to interpret the accepted data of temperature, rainfall and streamflow.

2.2 Climate Trend in Malaysia

Malaysia is one of the country which located at an equator. The characteristic features of the climate of Malaysia are uniform temperature, high humidity and copious rainfall. It is extremely rare to have a full day with completely clear sky even during the periods of severe drought. On the other hand, it is also rare to have a stretch of a few days with completely no sunshine except during the northeast monsoon seasons.

According to Malaysian Meteorological Department (MMD), the climate trend in Malaysia influenced by two monsoons, there are Northeast and Southwest Monsoons. The Southwest Monsoon happens from late May to September, and the Northeast Monsoon from October to March. The Southwest Monsoon rainfall where it comes from China is more often compared to the Northeast Monsoon which comes from the Australian desert. These two main monsoon regimes are specifically named the northeast monsoon as winter monsoon and the southwest monsoon as summer monsoon.

The Malaysia’s climates are affected by the presence of mountain ranges throughout Malaysia (Surjamanto Wonorahardjo et al., 2016). Thus, the climate is occurring from the highlands, the lowlands, and coastal regions. The coastal area has a sunny climate, with temperatures ranging between 23 and 32 °C, and rainfall ranging from 10 to 30 centimeters a month, however, the lowlands have a similar temperature, but follow a more distinctive rainfall pattern and show very high humidity levels. The highlands are cooler and wetter, and show off a greater temperature variation than lowland. A large amount of cloud cover is present over the highlands, which have humidity levels that do not fall below 75%.

As a country located that lies on the equator, Malaysia has uniform temperature throughout the year. The annual variation is less than 2°C except for the east coast of Peninsular Malaysia which are often influenced by cold surges from Siberia during the northeast monsoon. However, the annual variation is less than 3°C. The daily temperature range in Malaysia is large, which is from 5°C to 10°C for stations near the beach and ranging from 8°C to 12°C for stations inland but daily high temperatures as found in tropical continents do not ever experience. Although the days are often hot, but the nights are a bit cold. Although seasonal and spatial changes in temperature variations are relatively small, the study explains some of the ways it can be determined. For Peninsular Malaysia, there are changes in temperature during monsoon on the east coast of peninsula. April and May are the months in which the temperature is highest monthly average temperature while December and January are the months with the lowest monthly average temperature.

2.2.1 Rainfall Patterns

According to Ministry of Science, Technology and Innovation of Malaysia, the seasonal wind flow patterns and characteristics of local topographic determines rainfall patterns over the country. During the northeast monsoon season, the exposed areas such as the east coast of Peninsular Malaysia, Western Sarawak and the northeast coast of Sabah are experiencing heavy rain spells. On the other hand, inland areas or areas which are sheltered by mountain ranges are relatively free from its influence (Kripalani and Kulkarni, 1997). Over the east coast states, November, December and January are the months with maximum rainfall, while June and July are the driest months in most districts. However, the rest of the Peninsula with the exception of the southwest coastal area, the monthly rainfall pattern shows two periods of maximum rainfall separated by two periods of minimum rainfall. The main maximum usually occurs in October-November while the secondary maximum generally occurs in April-May (Tangang et al., 2012).

The average monthly rainfall (annual) for Peninsular Malaysia is shown in Figure 2.1. This figure shown that the study location is risk and potential to happen flood event.

The highest mean monthly rainfall in Peninsular Malaysia were area located at east coast which recorded more than 300mm of rain (Malaysian Meteorological Department, 2017).

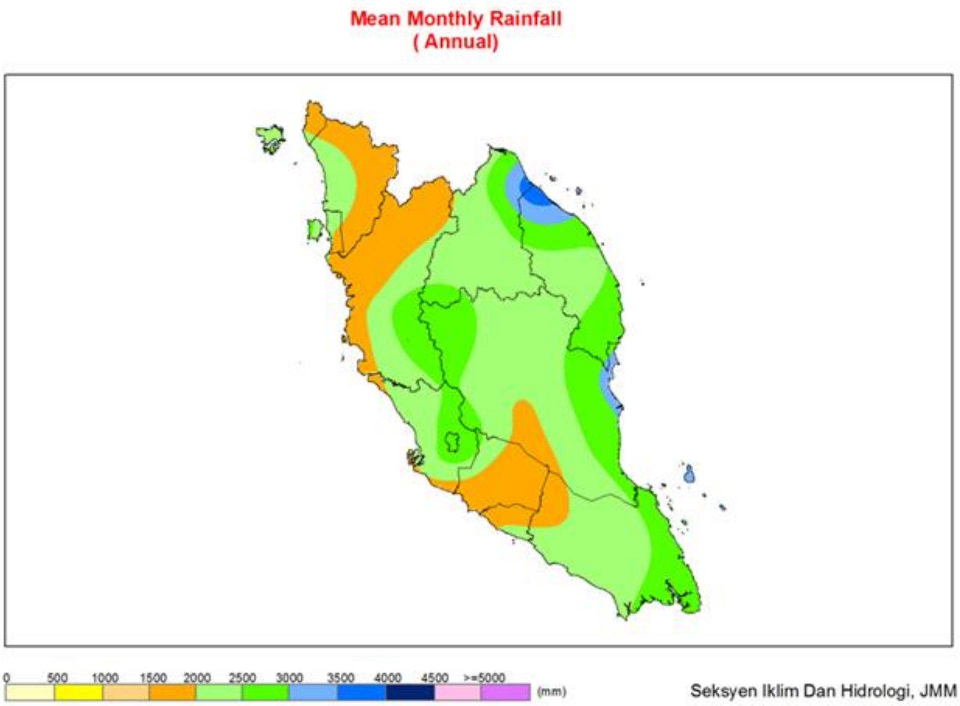

Figure 2.1: Mean monthly rainfall in Peninsular Malaysia
Source: Malaysian Meteorological Department (2017)

2.2.2 Comparison between Past and Present Climate

Climate has changed on all time scales throughout Earth's history. The investigations of the climate change impacts on the hydrologic processes in Peninsular Malaysia are limited because nowadays, climate change assessment has been an important issue. There are about 54 stations in the east coast of Peninsular Malaysia for rainfall records that can analyze the historical trends in rainfall and rainfall-related extremes, such as maximum daily rainfall, number of rainy days, average rainfall intensity, heavy rainfall days, extreme rainfall days, and precipitation concentration index for historical 40 years (1971–2010) (Mayowa et al., 2015).

There are change a lot of things regarding to symptoms happen nowadays. One of the phenomena is the concentration of carbon dioxide (CO_2) in the atmosphere has reached a record high relative to more than the past half-million years, and has done so at an exceptionally fast rate (Wei et al., 2007). Current global temperatures are warmer than they have ever been during at least the past five centuries, probably even for more than a millennium. If warming continues unabated, the resulting climate change within this century would be extremely unusual in geological terms (Wang et al., 2011). The past climate changes were natural in origin, whereas most of the warming of the past 50 years is attributable to human activities. The temperature trends for the 4 meteorological stations which represent the 4 different geographical locations were plotted as shown in Figure 2.2. The differences of temperature recorded changes very slightly since year 1984. In the fact, Malaysia has experienced severe drought around 1997 and 1998 due to the phenomenon of El-Nino. This record will increase day by day and year after year with increasing carbon dioxide levels continue to rise and various other factors that are contributing to global warming.

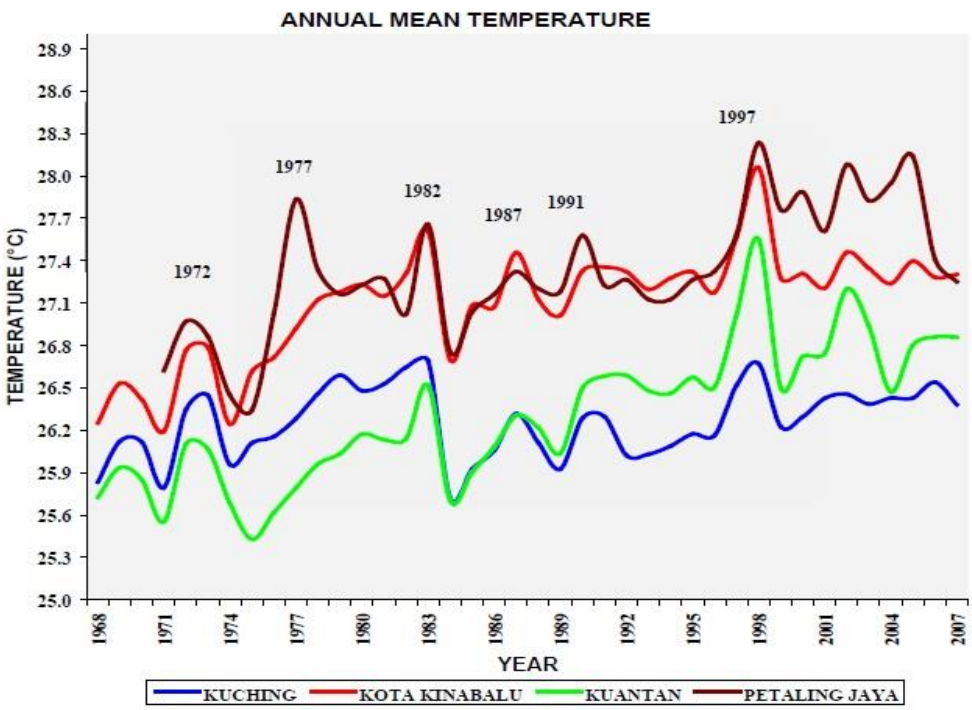

Figure 2.2: Annual mean temperature

Source: Malaysian Meteorological Department (2017)

2.3 Climate Change

Climate change is likely to have a significant effect on Malaysia, increasing sea and river water stream and rainfall, and temperature. The issue of climate change arises because of the increasing number of tragedies and disasters occurring phenomenon in Malaysia. In the past, Kedah and Johor are the worst states that experienced floods recently. Analysis of temperature records in Malaysia shows a trend of warming. The temperatures change between 0.3°C to 4.5°C and rain changes from -30% to + 30% have been used. A number of scenarios of rising sea levels within 20-90 cm in 100 years have been adopted for impact assessment on coastal resources (INC, 2000). Every 10°C temperature rise may cause 10% reduction in rice yields and prolonged drought conditions may adversely impact the current flooded rice ecosystem, putting national food security at greater risk (MOSTI, 2000).

The temperature also changes effected by the continuous to rise the greenhouse gas concentration. Figure 2.3 shows the symptoms that humans do to be the source of greenhouse gas emissions to atmosphere. Greenhouse gas emissions from sources and removal by sinks resulting from human (anthropogenic) activities such as industrial processes have been estimated and included in the inventory. However, the natural processes lie outside the scope of the inventory. The sinking causes are grouped into five categories which is namely, energy, industrial processes, agriculture, land use change and forestry, and waste. Referring to figure 2.3, the main gas of GHGs is carbon dioxide which is recorded as the highest contributing in GHGs which is about 76%. This phenomenon allows incoming sunlight to pass through, but retain heat radiated back from the planet's surface. These may be cause the global warming which sea water level will increase immediately. The climate changes happened normally in the natural processes in the changes of nature system, but it could be disaster due to human activities. There is little that humankind can do to alter the consequences of these natural occurrences except adapt to the environmental changes like the rest of the animal and plant species.

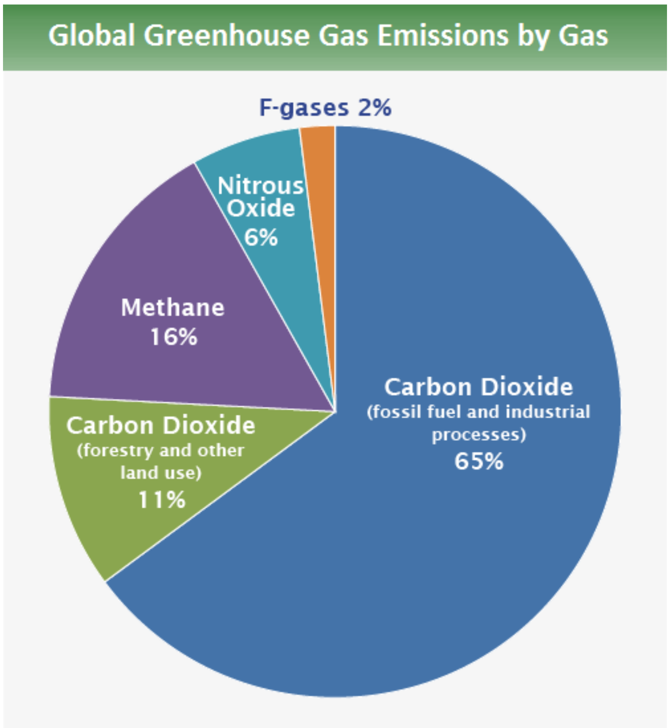

Figure 2.3: Global greenhouse gas emissions by gas

Source: IPCC (2014)

According to NAHRIM (2006) and Wan Azli (2008), modelling results illustrate that temperature in Malaysia may warmer in the mid and end of the century. The significant increase in monthly rainfall over the North East Coastal region and decrease in monthly rainfall in West Coast of Peninsular Malaysia may be expected. Future river flows in several watersheds in East Coast of Peninsular Malaysia were simulated as increases in hydrologic extremes when compared with their historical level. These refer to the occurrence of floods and droughts which cause significant socioeconomic impact on the country when landslides occur due to excess rain and strong winds occurring in hilly areas.

Malaysia's national policy on sustainable development is based on a balanced approach such that environment and development complement each other. While existing national and past policies and initiatives may indirectly address climate change issues under the context of sustainable development, the need to develop a dedicated climate change policy is increasingly recognizable. Therefore, the Ministry of Natural Resources and Environment Malaysia in collaboration with the Institute for Environment and

Development (LESTARI), Universiti Kebangsaan Malaysia (UKM), had conducted the Policy Study on Climate Change. The aim of the study was to develop a national policy and strategies on climate change in fostering sustainable development in Malaysia to meet the needs of the country and respond to the United Nations Framework Convention on Climate Change (UNFCCC). The other stakeholder consultants regarding to climate change issue are Ministry of Science & Technology and Ministry of Natural Resources and Environment, DOE, Ministry of Health and Institute of Medical Research, Environmental Protection Society of Malaysia, SIRIM, Maritime Institute of Malaysia and Business Council for Sustainable Development.

2.4 Future Climate Changes in Malaysia

Climate change assessment has also been an important topic in Peninsular Malaysia recently. However, investigations of the climate change impacts on the hydrologic processes in Peninsular Malaysia are limited. Historical trends in rainfall and rainfall-related extremes, such as maximum daily rainfall, number of rainy days, average rainfall intensity, heavy rainfall days, extreme rainfall days, and precipitation concentration index for historical 40 years (1971–2010) in the east coast of Peninsular Malaysia were analyzed using the rainfall records from 54 stations (Mayowa et al., 2015). This study estimated the spatial variation of the sea level change along the Malaysian coastlines by assimilating the global mean sea level projections from the coupled Atmospheric and Oceanic GCM (AOGCM) simulations to the satellite altimeter observations (Ercan et al., 2013). He assessed the effects of future climate change on Peninsular Malaysia's water resources during the 2025–2034 and 2041–2050 periods in comparison with the historical period of 1984–1993 based upon one realization of future climate change projection from one global climate model (the Coupled General Circulation Model of the Canadian Center for Climate Modeling and Analysis, CGCM1) (Shaaban et al., 2011).

The findings of this study can be helpful in the identification and quantification of the potential hazards due to the potential future extreme events, such as floods that may occur in the study areas due to climate change. This was due to the limited availability of the GCM projection data for the 21st century, and limited computer resources at the time of that study. Shaaban et al. (2011) found that the overall mean monthly streamflow increases significantly during the future period in Kelantan and Pahang watersheds due to climate change impacts. Moreover, in the future, high flow conditions will increase in the Kelantan, Terengganu, Pahang, and Perak River watersheds during the wet months, whereas monthly flows will be significantly lower in the Selangor and Klang watersheds during the dry months. Shaaban et al. (2011) assessed the effects of future climate change on Peninsular Malaysia's water resources during the 2025–2034 and 2041–2050 periods in comparison with the historical period of 1984–1993 based upon one realization of future climate change projection from one global climate model (the Coupled General Circulation Model of the Canadian Center for Climate Modeling and Analysis, CGCM1).

The current unprecedented rate of rising atmospheric CO_2 raises concerns about melting ice sheets, rising sea level, major climate change, and biodiversity loss - all of which were evident more than 300 million years, the only other time in Earth's history when high CO_2 accompanied ice at the polar regions. By the end of 2017, global emissions of carbon dioxide from GHG and industry are projected to rise by about 2% compared with the preceding year, with an uncertainty range between 0.8% and 3%. The news follows three years of emissions staying relatively flat.

The Malaysian government and industry are working hand in hand to reduce the CO_2 emissions produced by the manufacturing industry. In 2014, the World Bank reported that CO_2 emissions from manufacturing industries and construction (based on% of total fuel combustion) reduced 13% compare to 1971 (The World Bank, 2014). Malaysia's commitment to lowering CO_2 emissions also has an impact on productivity gains. In April 2017, Malaysia’s Index of Industrial Production (IPI) increased by 4.2% and the increase was also in line with manufacturing sales. The manufacturing sub-sectors have contributed significantly to manufacturing sales (80.1% out of total manufacturing sales) including Electrical Products, Petroleum, Chemical, Rubber and Plastic Products. Each sector increased by 17.3%, 18.2% and 12.3% respectively from 2016 to 2017 (Department of Statistics Malaysia, 2017). Despite the decline in CO_2 emissions and the rise in production index, no recent data is available about how manufacturing companies manage the CO_2 emissions in production and link it with manufacturing performance

(Thollander et al., 2007). The government has already offered various energy efficiency programs but industry interest in disclosing energy usage remains low.

Figure 2.4 shows the increment of CO_2 concentrations that released at atmosphere with difference scenarios. However, the changes of concentration are increases for all scenarios. It shown the emission of CO_2 at atmosphere is critical for the future. The projector was recorded based on past data which is from year 1990 and projected for the future prediction of CO_2 concentration by referring to the climate changes impacts. The concentration is predicted that CO_2 rises year by year this has been the result of factors such as lack awareness for identifying the potential benefits of energy saving (Bunse et al., 2011), lack of motivation by decision makers to break predefined processes that risk operational losses (Tonn and Martin, 2000).

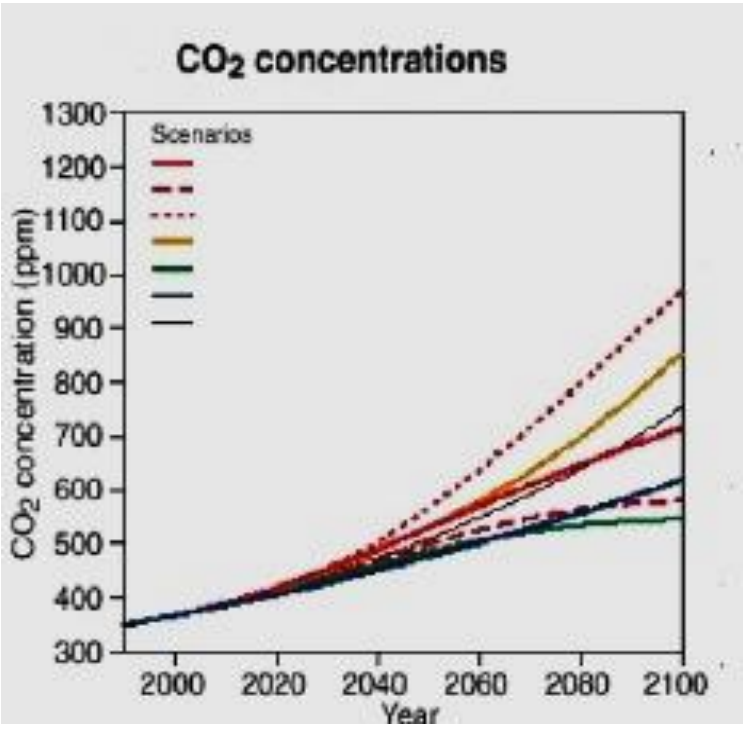

Figure 2.4: Carbon dioxide concentrations

Source: Knorr et al. (2009)

2.5 Downscaling Techniques

Global climate models (GCMs) are the primary tool for understanding and projecting changes in the global climate and their outputs have been widely used in impact studies (Maraun et al., 2010). GCM outputs are of too coarse a scale to be directly used in catchment-scale impact studies (Fowler et al., 2007). Numerous downscaling techniques have been developed to derive local climate change information from large scale GCMs outputs (Maraun et al., 2010). Different downscaling techniques yield differences in local climate change characterizations, and these differences affect the evaluation of changes to the hydrological regime (Mpelasoka and Chiew, 2009). The two primary categories of downscaling techniques are dynamic downscaling, which obtains regional information by nesting a high resolution regional climate model within a GCM, and statistical downscaling, which relates large scale climate variables to local scale climate variables (Trzaska and Schnarr, 2014).

The need to consider both GCMs and downscaling techniques on issues related to catchment hydrology has been well recognized. However, in ecological impact studies, although the uncertainty from GCMs has been considered, the influence of downscaling methods has not previously been assessed. Although uncertainties from GCMs have been recognized, the influence of downscaling methods remains unclear. This paper evaluates the influence of applying different downscaling methods of increasing complexity in annual scaling, monthly scaling, quantile scaling, and weather generator method) on the assessment of ecological outcomes.

Various methods have been developed to bridge the gap between what GCMs can deliver and what society/businesses/stakeholders require for decision making. The derivation of fine-scale climate information is based on the assumption that the local climate is conditioned by interactions between large-scale atmospheric characteristics (circulation, temperature, moisture, etc.) and local features like water bodies, mountain ranges, land surface properties (Roy et al., 2001; Loukas et al., 2002; Whitfi eld et al., 2002). It is possible to model these interactions and establish relationships between present-day local climate and atmospheric conditions through the downscaling process. It is important to understand that the downscaling process adds information to the coarse GCM output so that information is more realistic at a finer scale, capturing sub-grid scale contrasts and inhomogeneities (Department of the Environment, 1996). Figure 2.5 presents a visual representation of the concept of downscaling. Downscaling can be performed on spatial and temporal aspects of climate projections. Spatial downscaling refers to the methods used to derive finer-resolution spatial climate information from coarser-resolution GCM output. For example, 500 kilometers grid cell GCM output to a 20 kilometers resolution, or even a specific location. Temporal downscaling refers to the derivation of fine-scale temporal information from daily rainfall sequences from monthly or seasonal rainfall amounts as a coarser-scale temporal GCM output. Both approaches detailed be to downscale monthly GCM output to localized daily information.

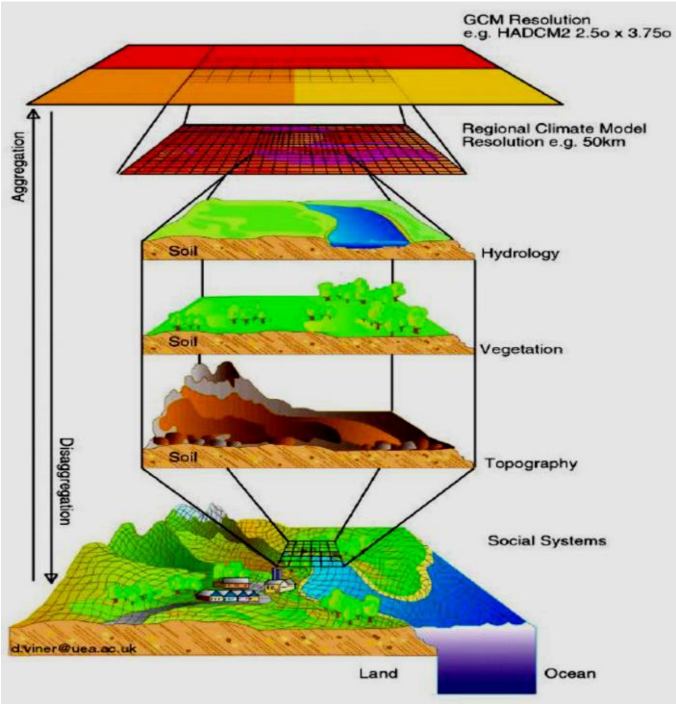

Figure 2.5: Downscaling view

Source: Maraun et al. (2010)

2.5.1 Statistical Downscaling

Statistical downscaling (SD) methods which are based on some established statistical relationships between large-scale atmospheric variables (predictors) and local climate variables (predictands) are most widely used as they are computationally inexpensive but as powerful as the dynamic downscaling (Sahar, 2016). Under the broad category of statistical downscaling, there are several methods from the simplest constant scaling method to more sophisticated regression models and weather generator methods. SD adopts statistical relationships between the regional climates and carefully selected large-scale parameters (Storch et al., 1993; Wilby et al., 2004; Goodess et al., 2005). It involves the establishment of empirical relationships between historical large-scale atmospheric and local climate characteristics. Once a relationship has been determined and validated, future large-scale atmospheric conditions projected by GCMs are used to predict future local climate characteristics. In other words, large-scale GCM outputs are used as predictors to obtain local variables or predictands (Trzaska, 2014). These methods are computationally inexpensive in comparison to RCMs that require complex modelling of physical processes. Thus, they are a viable and sometimes advantageous alternative for institutions that do not have the computational capacity and technical expertise required for dynamical downscaling. Unlike RCMs, which produce downscaled projections at a spatial scale of 20–50 kilometers, statistical methods can provide station-scale climate information (Schnarr, 2014).

Statistical Downscaling Model (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).

The main strength of SDSM performance is computationally cheap and only requires very few parameters compare to dynamical downscaling modelling (Fowler et al., 2005). Moreover, most of methodologies of statistical downscaling have various advantages than studies of dynamical downscaling. Statistical downscaling is currently provided more options in a situation of low-cost and require fast valuation of impacts on high climate change localized. The present study is reviewed a several of the evaluation and comparison between SDSM and the Long Ashton Research Station Weather Generator (LARS-WG) in terms of their ability to simulate extreme precipitation frequency using a parametric distribution at a watershed scale (Wilby et al., 2002). (Semenov and Barrow 1997). The SDSM-downscaled data suggest that a 100-year event will become a 20-year event and a future 100-year event will be around 1.5 times that of the 100-year event now. However, the Generalized Extreme Value (GEV) estimate based on the LARS-WG-downscaled data suggests an increase in magnitude of low-return period precipitation events, while a decrease is projected for the high return period events (Hashmi et al., 2010). Precipitation downscaling in LARS-WG is performed using the relative change factors (RCFs). According to Hashmi et al. (2010), RCFs are derived using the two times series of HadCM3 precipitation output for the twentieth century run and future run based on SRES A2 scenario. The SDSM makes use of the changes in atmospheric circulation patterns in terms of the large-scale predictors, as suggested by a GCM which can be considered more reliable. On the other hand, LARS-WG uses the RCFs derived from the direct precipitation output of a GCM.

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 relating 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 scopes s 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.

2.6 Climate Change Affecting the Runoff Trend

Climate change due to increment of the carbon dioxide in the atmosphere and its possible impacts on the hydrological cycle are a matter of growing concern. Hydrologists are specifically interested in an assessment of the impacts on the runoff, evapotranspiration, and soil moisture and their temporal and spatial redistribution. The study area has been subjected to repetitive flooding caused by either relatively short duration with high intensity event or a longer duration rainfall event with lower intensity for several days. The long duration rainfall which may causes flood on the main streams and it becomes worse when backwater effects due to tidal intrusion. Therefore, the main causes of the flood event due to heavy rainfall and the large concentration of runoff, which exceeds river capacity. In the coastal areas, flood could be attributed to high tides, occasionally aggravated by heavy rain or strong winds.

Major floods recorded in the study area, especially at the downstream areas are the floods of December 1948, December 1969, Nov 1979, Dec 1982, Dec 1983, Jan 1987, Nov 1989, Dec 1991, Jan 2004, Mar 2004, Dec 2006, Jan 2007 and Dec 2007. Most of the floods events occurred during the northeast monsoon which brought large volume of runoff to the relatively large catchment areas. Typically, flood occurs at low areas and could be aggravated by shallow river sections coupled with high tidal level. The recent Dec 2006 and Jan 2007 floods in Johor, considered as the costliest flood events in the Malaysian history, were due to the incredible rainfall events leading to disastrous floods that caused an estimated total damage of RM 1.5 billion.

Although the monsoon rainfall which happen at east coastal area is the main cause of flood events along Pahang River and thus has been giving impact to flow pattern changes, anthropogenic factor could not be neglected (Fu and Wen, 1999). Urban climate is commonly controlled by the regional natural climate system but in some cases, it is affected by local urbanization (Ntelekos et al., 2010). Urbanization could significantly affect the precipitation climatology relating to flood events (Shepherd, 2005; Tuncay and Esbah, 2006). Archer et al. (2010) and Baris and Karadag (2007) believe that there is a relationship between timing of land use and hydrological change. Jung et al. (2011) mention that in 2050, changes in flood frequency will be more sensitive to climate change compare than land use change. However, the percent change in mean annual runoff and evapotranspiration as a function of precipitation change for different temperature change scenarios for these basins.

2.6.1 The Relationship between Rainfall and Runoff

The rising of greenhouse gases concentration is expected to change the radiative balance of the atmosphere, resulting in increased temperature and changes in precipitation patterns and other climatic variables (Bolin et al., 1986; IPCC, 1990; Pearman et al., 1989). These changes have important implications for the hydrological cycle, the design of water systems and the management of water resources. For example, larger reservoir spillways and drainage waterways are required where the runoff is expected to increase, and bigger water supply storage needed where runoff is expected to decrease. Impacts on soil moisture and evapotranspiration will have important implications on irrigation and agricultural crop and land management. This research describes the simulation of the potential impacts of climate change on runoff and rainfall. A conceptual daily rainfall runoff model is first applied to the catchments, with the model parameters optimised against 8-20 years of historical streamflow data. The historical input data are then altered by increasing the temperature and scaling precipitation to reflect the climate changes. The simulations from the altered data, using the same optimised parameter values, are then compared with the historical runoff and rainfall to provide an estimate of the potential changes.

The huge in changes in the precipitation is because of the increment of CO_2. The temperature increases are causes increased rates of precipitation and evapotranspiration, but here, the observed precipitation and temperature series were modified according to these scenarios and, considering these modified series and calibrated parameters of the model, climatically affected runoff, evapotranspiration, and soil moisture series were obtained as output of the water balance model. The estimated runoff series corresponding to observed temperature and precipitation series (base run) is used for comparison purposes.

2.7 Streamflow

Streams or rivers play a critical role in the hydrologic cycle that is essential for all life on Earth. These are major aquatic landscapes for all manners of plants and animals. It even helps keep the aquifers underground full of water by discharging water downward through their streambeds. In addition to that the oceans stay full of water because rivers and runoff continually refreshes them. Streamflow is the main mechanism by which water moves from the land to the oceans or to basins of interior drainage. In a fact, Sg Pahang is the longest river in Peninsular Malaysia and it have many stream connections along Sg Pahang.

Then, global climate change is nowadays a key issue in water management all over the world. As reported by Intergovernmental Panel on Climate Change (IPCC, 2013), precipitation regimes are changing under changing climate. Precipitation peaks are also getting more intense in many regions of the world. These changes in precipitation are leading to changes in flow discharge. Therefore, climate change impacts on hydrologic processes have to be taken into account for a robust and resilient water management approach under the changing climate.

2.7.1 Changes in the Streamflow Trend

There is some analysis can define the relationships between streamflow and climatic factors, but it is difficult to interpret the physical mechanism behind the changes. Hydrological modelling is a useful method to understand different variables and their interactions through physically based mechanism; however, model performances differ due to model structure, data requirements, calibration and validation (Bronstert et al., 2002).

The combined effects of these changes have contributed to streamflow reduction. Considering the variations in soil, climate and land use, interpreting the spatiotemporal variations in the attributions of hydrological changes can provide useful information for water resources management. Recently, although streamflow variations and attribution have been demonstrated in some studies (Liang et al., 2015; Zhang et al., 2008; Zhao et al., 2014), the temporal variability has not been studied.

Refer to the Intergovernmental Panel on Climate Change (IPCC, 2013), precipitation regimes are changing under changing climate. That's mean the global climate change is a primary issue in water management nowadays. As reported by IPCC, precipitation peaks are also getting more intense in many regions of the world. These changes in precipitation are leading to changes in flow discharge. Therefore, climate change impacts on hydrologic processes have to be taken regarding to manage the Pahang River streamflow due to climate change.

2.7.2 Hybrid Conceptual Matrix Model-IHACRES Model

By increasing pressure on water sources in Malaysia, the use of rainfall-runoff models can be part of the solution to manage and maintain the water sector. Therefore, rainfall-runoff modelling as one of the most important hydrological processes plays a key role in flood forecasting and water resources studies (Jakeman and Pittock, 1996). Application of rainfall-runoff models to the catchments can be used to generate streamflow data. The model IHACRES was chosen because it requires only catchment area, streamflow data and a surrogate variable representing evaporation such as temperature (Kim et al., 2010).

One of the main advantages over other models is the small number of parameters needed and its high predictive accuracy. In the fact, these parameters can describe the essential dynamics of the hydrological response of a catchment. Such relationships improve our understanding of catchment behaviour and have the potential to be used to predict streamflow in ungauged catchments in the study region (Jakeman and Hornberger, 1993). Another hydrological model such as the Water Evaluation and Planning (WEAP) model suffer from a number of disadvantages in the needs of this study. They are complex, over-parameterised, data demanding and expensive to use. IHACRES is a lumped conceptual rainfall–runoff model based on unit hydrograph principles. This model requiring minimal input data, is less limited by these problems, and has the potential to advance our understanding of streamflow patterns and predict how these may be altered by land-use change (Jakeman, 1999).

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 included 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 has a greater complexity to methods that target streamflow alone.

In addition, it has only two parameters to be varied during calibration. The model consists of a nonlinear module to convert rainfall to effective rainfall and a linear module to route this effective rainfall to streamflow. IHACRES is capable of simulating daily streamflow given concurrent daily rainfall and temperature data and offers a possibility of infilling missing data or generating a long series of streamflow data for water resources management in the Upper Pahang River basin. Simulated streamflow was compared with the observed streamflow for these catchments and the goodness of fit evaluated.

The model output may be sensitive when the monitored flood is relatively small. The optimum parameter value is based on the length of the calibration data and event specific changes. The model has been previously used in both land use and climate change studies, as well as in regionalization to ungauged catchments (Post and Jakeman, 1999). In this study, the metric conceptual IHACRES model is applied to Pahang River catchment. Flood estimation was performed based on daily scales and storm events scales. The model was extended for rainfall to cope with such extreme events. Although the best performance of the IHACRES model daily is poor, the performance on storm events scale showed a good agreement between observed and simulated streamflow.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The main purpose 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 pattern and then the IHACRES model were applied to generate the streamflow pattern. SDSM is categorized as a hybrid model, which utilized a linear regression method and a stochastic weather generator. IHACRES model has been used to achieve more accurate and less bias comparing between the modelled streamflow with the observed streamflow which parameterically efficient rainfall-runoff model that has been applied to a large number of catchments covering a diverse range of climatologies.

The schematic diagram of the methodology has been illustrated in Figure 3.1. In the beginning, SDSM was used to perform the local pattern of climatic variability for future trend which is the provided data by MMD is consists of rainfall intensity, temperature, dry and wet spell length. The model 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 additional, NCEP predictor variables that used in SDSM for this site which is available in the period of 1948 to 2015. Statistical Downscaling is assisting 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 on land use can change the hydrological cycle in our daily life.

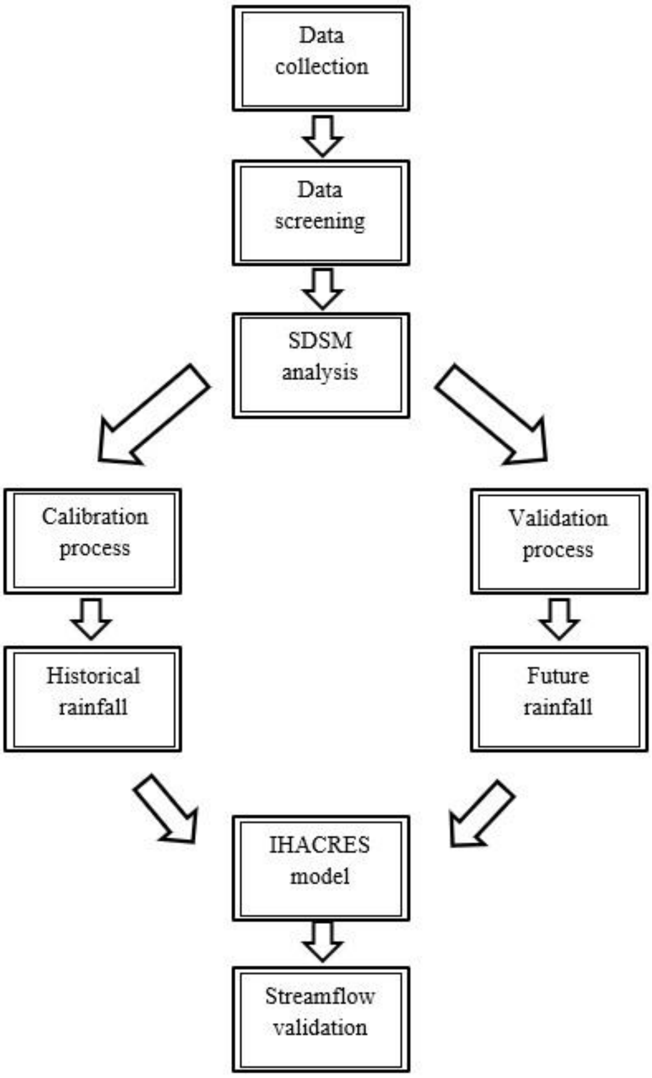

Figure 3.1: The Schematic diagram of methodology of the study

3.2 Statistical Downscaling Model (SDSM)

The Statistical Downscaling Model (SDSM), developed by Wilby et al. (2002). This model is a combination of Multiple Linear Regression (MLR) and the Stochastic Weather Generator (SWG). MLR generates statistical and empirical relationships between NCEP predictors and predictands during the screening process of predictors, and the calibration process of SDSM results in some regression parameters. These parameters, along with NCEP and GCM predictors, are used to generate a maximum of 100 daily time series to fit closely with the observed data during validation, and twenty-time series are considered as the standard, a precedent set by other studies as well (Wilby etal., 2002; Gagnonetal., 2005; Chuetal., 2010).

In SDSM, various indicators-partial correlation, correlation matrix, explained variance, P-value, histograms, and scatter plots can be used to select some suitable predictors from a multitude of atmospheric predictors. SDSM has the ability to transform the data into different forms such as the logarithmic, square root, and fourth root to make it normal before the said data can be used in regression equations (Khan etal., 2006). To develop SDSM, two kinds of daily time series are needed: NCEP predictor daily time series and observed daily time series (Huang etal., 2011). The mathematical details of this model are provided in the study by Wilby etal. (1999).

SDSM version 4.2 is a decision support tool for the assessment of regional climate change impacts. This study uses SDSM version 4.2.9 to downscale the GCMs outputs into finer scale resolution. SDSM Version 4.2 was supported by the Environment Agency of England and Wales as part of the Thames Estuary 2100 project (Wilby & Dawson, 2007). SDSM 4.2 model facilitates the rapid development of multiple, low–cost, and single–site scenarios of daily surface weather variables under present and future climate forcing. In this study, the statistical downscaling method allows the setting up of climate change scenarios at daily time steps by using the GCMs output. The SDSM software reduces the task of statistically downscaling daily weather series into seven discrete steps: 1) quality control and data transformation; 2) screening of predictor variables; 3) model calibration; 4) weather generation (using observed predictors); 5) statistical analyses; 6) graphing model output; 7) scenario generation (using climate model predictors). These key elements of SDSM will be outlined using observed and climate model information for a theoretical station (Sg.Kechau), looking at downscaled daily rainfall precipitation in the year of 1986 to 2015 and temperature arrangement in the year of 1985 to 2014 with future climate trend in the year of 2020 to 2099.

In the scientific classification of downscaling procedures, SDSM is considered as the best combination of a hybrid model of the stochastic weather generator and transfer function methods. This is due to the atmospheric moisture variables and the large–scale circulation patterns are used to condition local–scale weather generator parameters such as precipitation occurrence and intensity. Furthermore, stochastic techniques are used to artificially inflate the variance of the downscaled daily time steps to better accord with historical observations. At this time, the downscaling of SDSM has been linked to the study of meteorological, hydrological and ecological appraisals as well as a range of geographical contexts including Asia, Europe, North America and Africa. The following figure illustrates the SDSM Version 4.2 climate scenario generation.

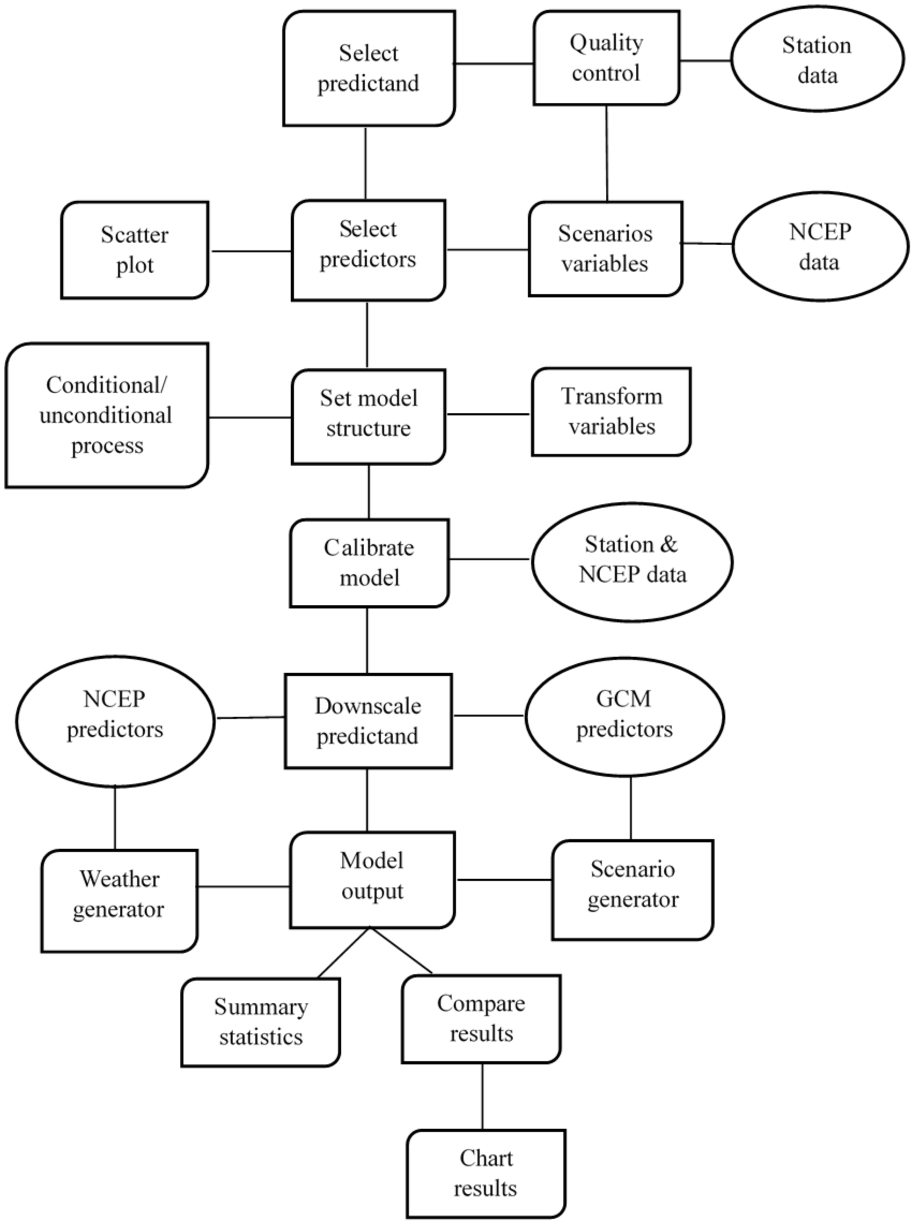

Figure 3.2: SDSM model climate scenario generation methodology
Source: Wilby and Dawson (2007).

3.2.1 Quality Control and Transformation

In this stage, the recovering process of missing and imperfect data is required to check a daily meteorological data have the expected number of days and values for most practical situations because there are not all the meteorological stations have fully accurate data sets. Simple Quality Control checks in SDSM enable the identification of gross data errors, specification of missing data codes and outliers prior to model calibration. In many situations, it may be appropriate to transform predictors or the predictand prior to model calibration. The transform facility takes chosen data files and applies selected transformations such as logarithm, power, inverse, lag, and binomial. Therefore, SDSM enables both quality control and data transformation.

3.2.2 Screening of Downscaling Variables

The screening of large scale variables is the most important process in all types of statistical downscaling (Wilby etal., 2002; Huang etal., 2011). There are many indicators that can be used in this process. The selection of the first and the most appropriate predictor is relatively easy, but the selection of the second, third, fourth and soon is much more subjective. Therefore, a more quantitative procedure, also used by Mahmood and Babel (2013), was applied for screening the predictors for each local climate variable and at each climate station in this study.

Screening works as 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 atmospheres 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. The SDSM proposed screening process in the Screen Variables stage to measure the performance level of the selected predictors with single- site of predictand in order to obtain a good agreement in term of statistical relationship between predictor and predictand.

At the end, the predictor with the least PR is selected as the second most suitable predictor. Similarly, the third, the fourth and further predictors are chosen by repeating the procedure outlined above. It can be seen in different studies (Wilby etal., 2002; Chuetal., 2010; Mahmood and Babel, 2013) that mostly 1–3 large scale variables are believed to be enough to capture the variation of a predict and during calibration. It is better to use a smaller number of predictors during calibration because as the number of predictors increases in the regression equation, the chances of multiple co-linearity also increase. So, the fewer the predictors, the lower is the chance of multiple co-linearity during calibration.

3.2.3 Model Calibration

The Calibrate Model operation takes a user-specified predictand along with a set of predictor variables, and computes multiple linear regression equations (forced entry method). The model specifies the model structure: whether monthly, seasonal or annual sub-models are required; whether the process is unconditional or conditional; and whether a lag-1 autocorrelation function is required. The parameters of the regression model are obtained via the efficient dual simplex algorithm and it is written to a standard format file (*.PAR) (Wellington, 1977). Unconditional models assume a direct link between the regional-scale predictors and the local predictand. For example, local wind speeds may be a function of gridded airflow indices such as the zonal or meridional velocity components. Conditional models, such as for daily precipitation amounts, depend on an intermediate variable such as the probability of wet-day occurrence. In this case, the two-state occurrence process either wet or dry day is first modelled as a function of the regional forcing. Then, if precipitation occurs, the wet-day amount is modelled conditional upon a different set of predictor weights (see below). Similarly, daily sunshine might be modelled conditional on the presence or absence of precipitation. Wet-day precipitation amounts are assumed to be exponentially distributed and are modelled using the regression procedure of Kilsby et al. (1998). The expected mean wet-day amount is empirically constrained by the algorithm to equal the observed mean wet-day amount of the calibration period. Therefore, precipitation amounts are a special case in which an autocorrelation function is not explicitly included by the regression equation. Instead, serial correlation between successive wet-day amounts may be incorporated implicitly by lagged predictor variables. This maximizes the availability of precipitation data for calibration by including wet-days that are preceded by dry-days.

Finally, the calibration algorithm reports the percentage of explained variance and standard error for each regression model type (monthly, seasonal or annual averages). These data should inform assessments of the significance of climate changes projected by the statistical downscaling (see below). For example, if the standard error of the model's maximum daily temperature is 4°C, and projected future temperature changes are smaller than this, then the model sensitivity to future climate forcing is less than the model accuracy (i.e. the temperature change could be an artefact of the model parameters rather than regional forcing).

Similarly, the percentage of explained variance indicates the extent to which daily variations in the local predictand are determined by regional forcing. For spatially conservative variables such as temperature 70%+ explained variance is not unusual; for heterogeneous variables such as daily precipitation occurrence/amounts <40% is more likely. Unfortunately, it is not possible to specify an 'acceptable' level of explained variance since model skill varies geographically, even for a common set of predictors. For example, precipitation models tend to be most skilful for locations on western seaboards where zonal airflows transport moisture directly from the ocean (McCabe and Dettinger, 1995).

3.2.4 Weather Generator

The parameters established during the calibration process that explains the statistical agreement between observed and simulated data are then used for model validation. The 15 years data (1999-2013) were used to validate the performance of the model. For precipitation, the mean daily precipitation, average wet and dry spell lengths are used as statistical performance evaluation criteria.

The Weather Generator generates ensembles of artificial daily weather series given observed atmospheric predictor variables. The process allows the verification of calibrated models by applying independent data and the synthesis of synthetic time steps for present climate conditions. The user will choose a calibrated model and SDSM automatically links all importance predictors to model weights. The user must also select the period of record to be synthesised as well as the desired number of ensemble members. Synthetic time steps are coded into specific output files for statistical analysis graphing or impacts modelling.

3.2.5 Scenario Generation

The Generate scenario operation produces ensembles of synthetic daily weather series given observed daily atmospheric predictor variables supplied by a GCM either for current or future climate experiments. The procedure is identical to that of the synthesize operation in all respects except that it may be necessary to specify a different convention for model dates. For example, HadCM2 assumes 12 months, each with 30 days, giving a fixed year length of 360 days. Alternatively, the Canadian Climate Center's CGCM1 model has 365 days in every year (i.e. does not recognize leap days). Note that there is a facility in the settings screen to de-activate leap years for downscaling using GCM data of this format for both the synthesize and generate options need not be the same length as those used to obtain the regression weights during the calibration phase.

3.3 Hybrid Conceptual Model-IHACRES Model

IHACRES is a catchment-scale rainfall-streamflow modelling methodology. It's aimed to assist the hydrologist or water resources engineer to assess the dynamic relationship between basin rainfall and streamflow. The main purpose of IHACRES model includes the identification of unit hydrographs, continuous time series streamflow modelling, runoff event modelling and infilling missing streamflow data (Croke, et al., 2005). The IHACRES model is using the simplicity of the metric model to reduce the parameter uncertainty inherent in hydrological models while at the same time attempting to represent more detail of the internal processes than is typical for a metric model. In the projection of future streamflow by using IHACRES rainfall-runoff model, the principal three components structure of IHACRES are data and its preparation, calibration and simulation of the projected streamflow pattern.

Figure 3.3 shows the generic structure of the IHACRES model. It contains a non-linear loss module which converts rainfall into effective rainfall (that portion which eventually reaches the stream prediction point) and a linear module which transfers effective rainfall to stream discharge. The linear relationship between effective rainfall and streamflow sets up the application of unit hydrograph theory which conceptualises the catchment as a configuration of linear storages acting in series or parallel. All the non-linearity commonly recorded between rainfall and streamflow is applied in the non-linear loss module which converts rainfall to effective rainfall. The conceptualisation of spatially distributed processes in both the non-linear and linear modules is restricted. An advantage of this spatially approach is the model needs only a little number of parameters, typically six (3 for the non-linear loss module and 3 for the linear unit hydrograph module). Despite this structural simplicity, the IHACRES methodology performs well for almost types of catchment.

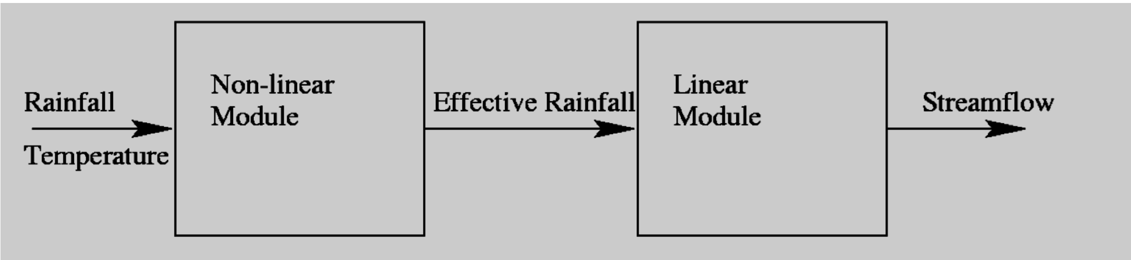

Figure 3.3: Generic structure of the IHACRES model

3.3.1 Data Requirements

In the projection of IHACRES model, it is indicating the current the three state of 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 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 successful, the substance of the information document is 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 notice to the time corresponding to the first-time step of a time series that is being imported. The start time is specified by modifying the Year, Month, Day, Hour and Minute list boxes so as the correct start time is shown. The Time Step parameter refers to the time between each time step of a time series that is being imported. The time step is specified by selecting the units using the list box (Minutes, Hours or Days) and determining an amount using the text field.

Based on the data requirement in the import procedures, there are four main processes to be carried out. Firstly, choose a cell on the Import File Data table that is within the column corresponding to the time series that is to be imported. Clicking a table cell will select the table column. A table cell that is chosen has a yellow border. In addition, select the type of the time series that is being imported by clicking on the appropriate tab – Obs. Rain (observed rainfall), Temperature or Obs. Stream. (Observed streamflow). Next, select the unit of the time series being imported using the Unit list box. The contents of the unit list box are dependent on the type of the currently selected time series. Lastly, press the Import button. If the select unit requires a catchment area value, the user will be asked to indicate the catchment area value using a dialog box after the Import key is pushed. It is possible to import data for different data types from various raw data files. If the time series have been initialised, these data will be synchronised.

3.3.2 Calibration and Validation

The very important phase in calibration is establishing the calibration period which is for this projection the selected period which is from year 2005 to 2009. Another stage that needed for calibration is defining the linear module and non-linear module. IHACRES approach enables the user to choose multiple calibration periods for a project. As an example, the user may determine two calibration periods and then specify a different calibration for each period and analyse the simulation data for each calibration period separately. Each period has its own set of tabs to accommodate multiple calibration period. The contents of each calibration period tab are functionally identical each period has its own set of variables and actions. For example, by applying the Unit Hydrograph Linear Module Calibrator peaks can only be chosen from the calibration period corresponding to the current selected calibration period tab. Furthermore, when a calibration is ultimately specified, it is only applied to the calibration period corresponding to the current selected calibration period tab. The current calibration period refers to the calibration period corresponding to the currently selected calibration period tab.

The calibration and validation processes for the streamflow by using IHACRES model are analysed for the period of the year 2010. The best calibration is based on the highest value of Coefficient of Determination (R^2) with the lowest value of Average Relative Parameter Error (%ARPE). The equations are as follows:

$$R^2 = 1\frac{\sum(Q_o - Q_M)^2}{\sum(Q_o - \bar{Q}_M)^2} \qquad 3.1$$

$$\%ARPE = \frac{1}{n}\sum\frac{(Q_o - Q_M)^2}{Q_o} \times 100 \qquad 3.2$$

Where; Q_O= observed streamflow value

Q_M= modelled streamflow value

$\bar{Q}$= mean of observed streamflow

n= total number of streamflow

3.3.3 Equation of Generated Streamflow

The original structure of the IHACRES model uses exponential soil moisture drying rate index. In this study, the classic redesign version has been used to improve the performance of the model. IHACRES model was divided into two modules which were non-linear and linear. Rainfall (r_k) is converted into effective rainfall (u_k) in the non-linear loss module. In order to obtain the streamflow, the first step is to determine the drying rate, which is given by:

$$\tau_{w}(t_k) = \tau_{w(const)} \exp((20 - t_k)f) \quad 3.3$$

Where; $\tau_w (t_k)$ = the drying rate at each time step

$\tau_{w\ (const)}$ = time constant

t_k = temperature at time step, k

f = temperature dependence of drying rate

Soil moisture index, S_k is computed for each time step on the basis of recent rainfall and temperature records:

$$S_k = cr_k(1 - \frac{1}{Tw\ (tk)})S_{k-1} \quad 3.4$$

Where; S_k = soil moisture index

c = mass balance

r_k = observed rainfall

Finally the effective rainfall (u_k) in the model is given by:

$$u_k = r_k \text{ x } S_k \quad 3.5$$

In the linear routing module, the effective rainfall is converted into streamflow (Q_k). The storage configurations of two parallel storage components have been applied

$$Q^q_{(k)} = -\alpha_q Q^q_{(k-1)} + \beta_q u_{(k)} \quad 3.6$$

$$Q^s_{(k)} = -\alpha_s Q^s_{(k-1)} + \beta_s u_{(k)} \quad 3.7$$

$$Q_{(k)} = Q^q_{(k)} + Q^s_{(k)} \quad 3.8$$

Where; Q^q = quick streamflow
Q^s = slow streamflow
α = recession rates
β = fraction of effective rainfall

This formulation enables the gain of the transfer function to be directly related to the value of the parameter c, thus simplifying model calibration. In order to get a representative value, the rainfall dataset was averaged from Kechau station in the catchment area for the same period as archived streamflow data.

3.4 Site Description

The site for this study is located at Kechau River (Station ID no: 4320066), Pahang. Pahang is the largest state in the Peninsular of Malaysia. Pahang River is the longest river in Peninsular Malaysia. The length of this channel is 61.5 km. Based on Figure 3.4, Kechau River is located at central of Kuala Lipis. Kechau River connected with Jeram River at equivalent of Jerantut and Lipis. Kechau River is the main river at Lipis area as a water resources. In the fact, Pahang River is Pahang River Basin serves to drain rainfall from this watershed to South China Sea.

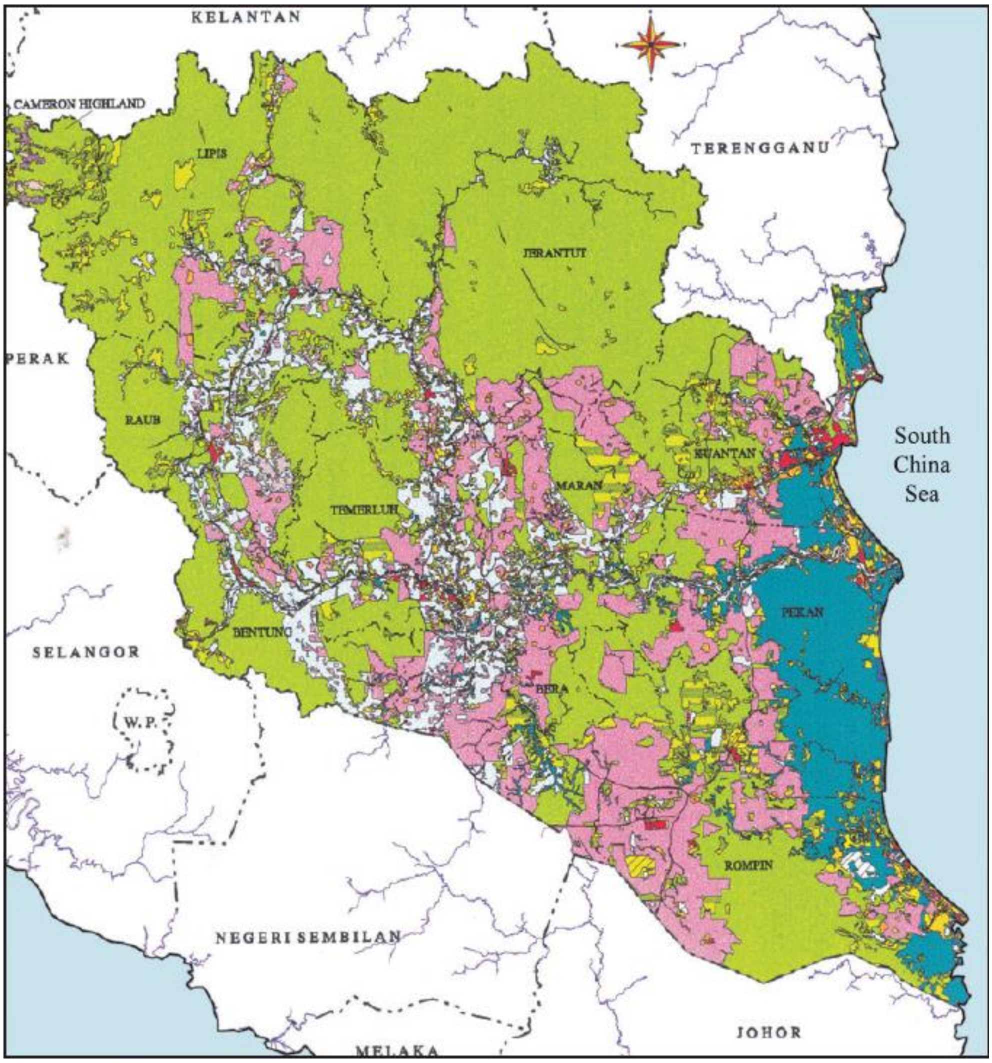

Figure 3.4: Hydrological in Pahang

Source: Department of Irrigation and Drainage of Malaysia

3.4.1 Rainfall Characteristics at Sg. Pahang

The statistics of rainfall at Pahang River Basin from 1972 to 2016 were recorded by Department of Irrigation and Drainage (DID). As discussed in DID (2001), Kechau Rainfall Station recorded the highest monthly total rainfall on December which was 658.00 mm and the lowest was 26.00 mm on Jun. Meanwhile, Lubok Paku has the lowest monthly rainfall which was 79.81 mm on February and the highest was 324.57 mm on December. Lastly, Temerloh Rainfall Station recorded the highest monthly total rainfall on November which was 219.83 mm and the lowest was 93.75 mm on February. Based on the given data, all the stations received highest rainfall from October to December every year. This is because the occurrence of the northeast monsoon season starting from

November to March every year. Due to this, water level also showed highest reading every December. This is the reason for the overflow of water that caused floods from Pahang River.

3.4.2 The Streamflow Trend at Sg. Pahang

According to Department of Irrigation and Drainage (DID), Kechau River recorded 58.18 m^3/s of streamflow for period from 1980 to 2009. Meanwhile at Temerloh station, it was 1008.50 m^3/s of discharge. Lastly at the downstream which was Lubok Paku Station showed a streamflow value of 1184.46 m^3/s. Based on the record, the rating curve between discharge and water level showed positive relationship for Kechau and Temerloh. In short, the higher the rainfall intensity, the higher the water level at the gauging stations. In conclusion, the streamflow of water discharge also increases. If the discharge continues to increase and heavy rainfall occurs, overflow of water and flood will take place.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the result of the study were analysed and presented in two main objectives as follow:

a) The projected of long term climate variation (rainfall and temperature) using SDSM.

b) The streamflow generation with considered the climate changes using IHACRES model.

The 30 years length historical climate records at Kechau have been considered in purpose to generate the long term climate trend during year 2020 to 2099. To generate climate trend, the calibration and validation process in the SDSM have been applied to obtain the relationship between local climate pattern and information of the atmosphere features at specific sub-grid. Then, the equal atmosphere features provided by GCMs were used to generate the upcoming 80 years length records. The SDSM was generated the rainfall and daily temperature for a single hydrological station at Kechau (4320066).

The IHACRES was considered the historical streamflow records at Sg. Kechau in year 2010 to generate the long term climate trend from year 2020 to 2099. The calibration and validation process in the IHACRES have been applied to obtain the rainfall-runoff relationship with other factors such as parameters value and catchment area. The IHACRES was generated the streamflow for Sg Kechau station (4320401).

4.2 Climate Analysis

The climate for Kechau station was analysed using the SDSM model. The monthly correlation values between predictors and predictand were used as guideline to select software to select the predictors which provided by NCEP. The purpose was to present the relationship between the predictor-predictand in a single-shot analysis.

4.2.1 Performances Predictand-Predictors Relationship

The climate simulation in the SDSM model began with the process of screening variables to measure the performance by correlation values for predictors-predictand relationships. There were 26 NCEP predictors and a local predictand that involved in the screening section, which was analysed directly applied in the SDSM model. The purpose of the correlation was to screen the predictor-predictand relationship in a single-shot analysis.

The rainfall simulation was directed as the site station at Kechau. The analysis were started with the screening data to select the predictors affected by the rainfall volume. Then, the calibration and validation stages were conducted between the selected predictor with the 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 climate changes that regarding with potential phase of greenhouse gases.

The reliability of the SDSM model was depending on the workability of the selected atmospheric variables with local climates in Kechau station. Based on 26 of NCEP predictors with the station of local predictand at Kechau were presented in a single correlation matrix form by monthly. The selected predictors was chosen based on the correlation value in the SDSM model. The most highest and consistent average range of correlation value for monthly was the most affected to the change of climate which is influenced to the amount of annual precipitation. Predictors which selected shows that these relationships were necessarily to associate them together in projection for the future climate trend because it is estimated to produce the most value of correlation and contributed to the projection in rainfall stations.

Therefore, there were five of 26 predictors have been chosen which yielded better correlation with a predictands. In other words, these five predictors suggest that they have better potential in forming the local climate trend. Based on the selected predictors, the rainfall equation can be formed and produced good results in the calibration and validation processes. Table 4.1 shows the selected of 5 predictors which most affected to the pattern of projection for rainfall trend at Kechau**.**

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

No	Predictor Variable	Predictor Description	Correlation Values
1	p850	850 hpa geopotential height	0.177
2	r500	Relative humidity at 500 hpa	0.307
3	r850	Relative humidity at 850 hpa	0.105
4	shum	Near surface specific humidity	0.187
5	temp	Near surface air temperature	0.196

4.2.2 Calibrated and Validated Performances

For the calibration and validation performances, the calibration process was referred to the 1st 15 years (1984-1998) and validation process was referred the remaining 15 years (1999-2013). The selected NCEP predictors were used to analyse the performance of the simulated result compared to the historical data. Then, the GCM-derived predictors were used to generate the daily weather series using similar NCEP predictor variable for the future year.

The historical rainfall data was referred to the hydrological rainfall station at Sg. Kechau. Meanwhile, the historical temperature was referred to Kuantan station based on 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.

4.2.3 Historical Rainfall Trend at Sungai Kechau

Figure 4.1 and 4.2 show the performances of calibrated and validated resulted between observed and simulated. Based on the results, the simulated rainfall at Kechau station was successfully to produce good agreement with the historical rainfall. The minimum error occurred in calibration process during December which was less than 0.2mm/month. The simulated rainfall reflects the reliability of the model. The difference between historical and modelled values was obvious in validation process during June and August which in range between 20.0 to 27.0 mm/month.

It was suspected that the error might be influence the projection of future rainfall for Kechau station. It is expected that the projected rainfall at Kechau 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 Kechau 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 as a treatment method. However, the results would not significantly affect the analysis at Kechau station.

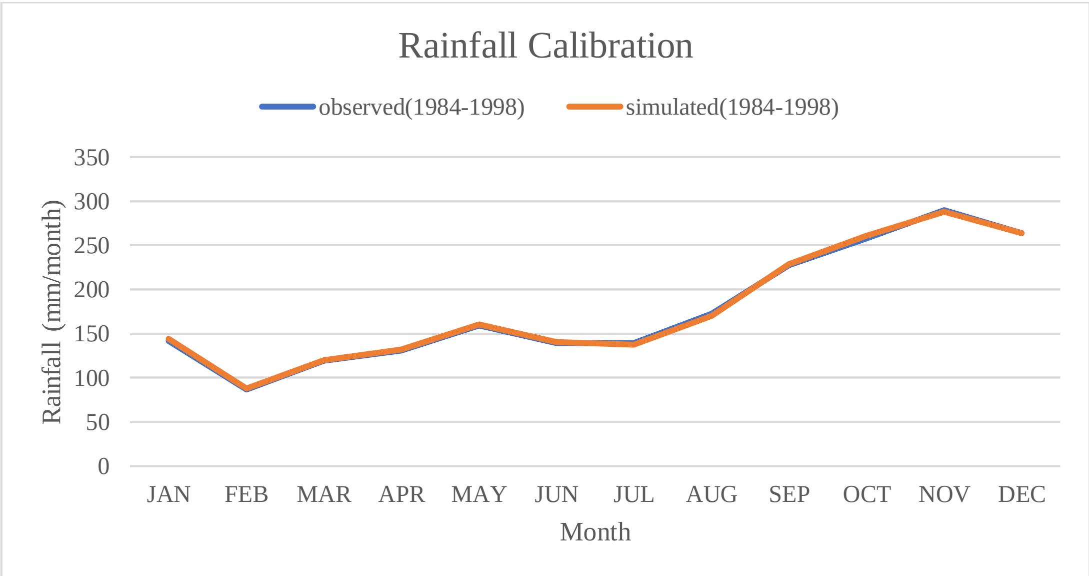

Figure 4.1: Result of calibration (1984–1998) at Kechau station by using SDSM

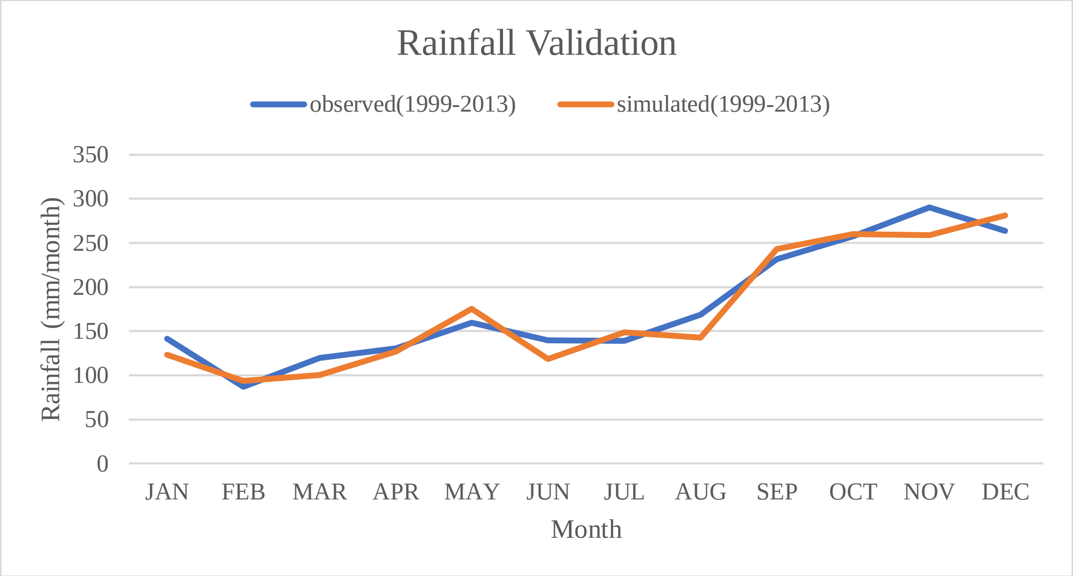

Figure 4.2: Result of validation (1999-2013) at Kechau station by using SDSM

The performance of the predictors selection to react with the local climate was evaluated using the statistical parameters that measure the monthly discrepancies between historical and modelled data at Kechau rainfall station. The statistical parameters are mean absolute error (MAE). Table 4.2 summarizes the MAE results for monthly mean rainfall of modelled and historical values. The correlation value was in good result with 1.00 and 0.97. However, the errors for calibrated and validated was closed to zero.

Table 4.2: Performance of calibration and validation results using SDSM

	Calibration	Validation
r	1.00	0.97
MAE	0.04	0.50

4.2.4 Projection of Rainfall Trend at Sungai Kechau

The analysis of climate changes at Kechau station is significant information for the water resources and reservoir management in long term. The projection of rainfall in this area can be as beneficial information 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 4.3 shows the long term projected rainfall at Kechau station for the year of 2020 to 2099 by using GCM predictors type RCP26, RCP45 and RCP85 scenarios. The projected rainfall potentially to sustain the historical rainfall pattern with very minimum increment. The simulated rainfall result produced by RCP26 scenario was expected to generate higher rainfall intensity though a year. The average annual rainfall was expected to rise about 0.22% every year. The greatest percent increment of rainfall was expected in month of December in average 36% to 41%. Based on the graph, the increment of the projected rainfall was started from May until December. These results were due to the northeastern monsoon that lasts from October until March. In this research, the factor of climate changes were considered since the maximum rainfall intensity was not on monsoon circulation timeline. For the RCP26, RCP45 and RCP85 it rise at 16.7%, 16.4% and 15.1% respectively. Whereas, the greatest percent of reduce from the historical data was in the month of March which in range 1.0% to 6.3%.

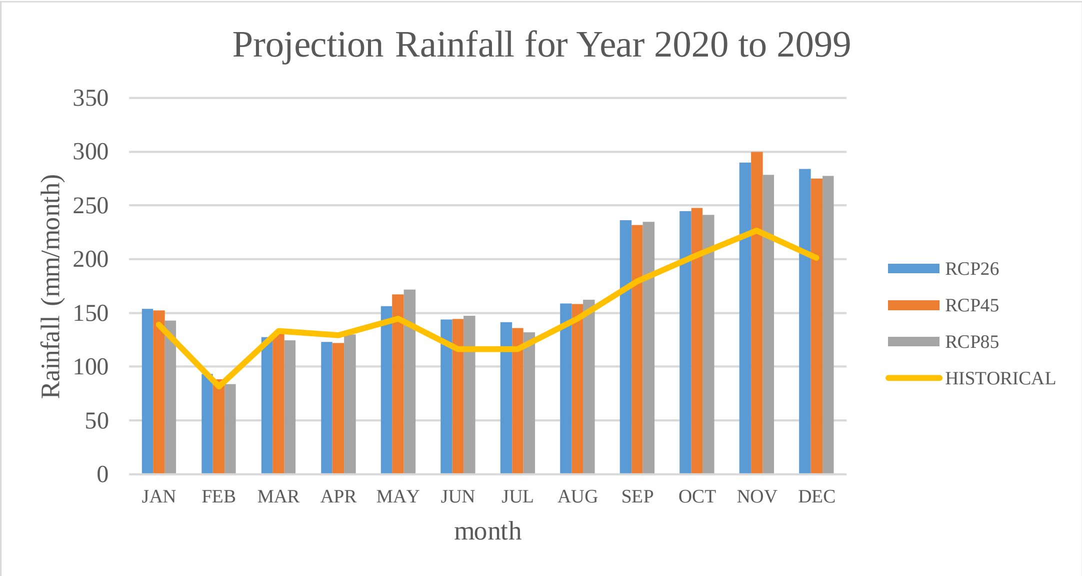

Figure 4.3: The comparison historical and projection rainfall for year 2020 until 2099 (RCP26, RCP45, RCP85)

4.3 Predictors Selection for Temperature

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 duration of historical period was similar as historical rainfall period. However, the simulation of historical temperature data refers to the meteorological station at Kuantan. 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, Table 4.3 shows the best 5 predictors has been selected for projecting the temperature trend at the site study.

Table 4.3: The selected predictor variable in SDSM model of historical temperature

No	Predictor Variable	Predictor Description	Correlation Values
1	p_z	Surface vorticity	0.021
2	r500	Relative humidity at 500 hpa	0.014
3	r850	Relative humidity at 850 hpa	0.012
4	p500	500 hpa geopotential height	0.035
5	temp	Near surface air temperature	0.082

4.3.1 Calibrated and Validated Results for Temperature

Based on Figure 4.4 and Figure 4.4, the results present the simulated temperature at Kechau station was well to produce good agreement with the historical temperature with 0.0012% minimum error that occurred in calibration process during February. The simulated temperature follows the reliability of the model. The difference between historical and modelled values was obvious in validation process during April which was

0.93%. It was suspected that the error might be influence the projection of future temperature for Kuantan station. However, the minimum resulting errors were not give a high effect for generated temperature.

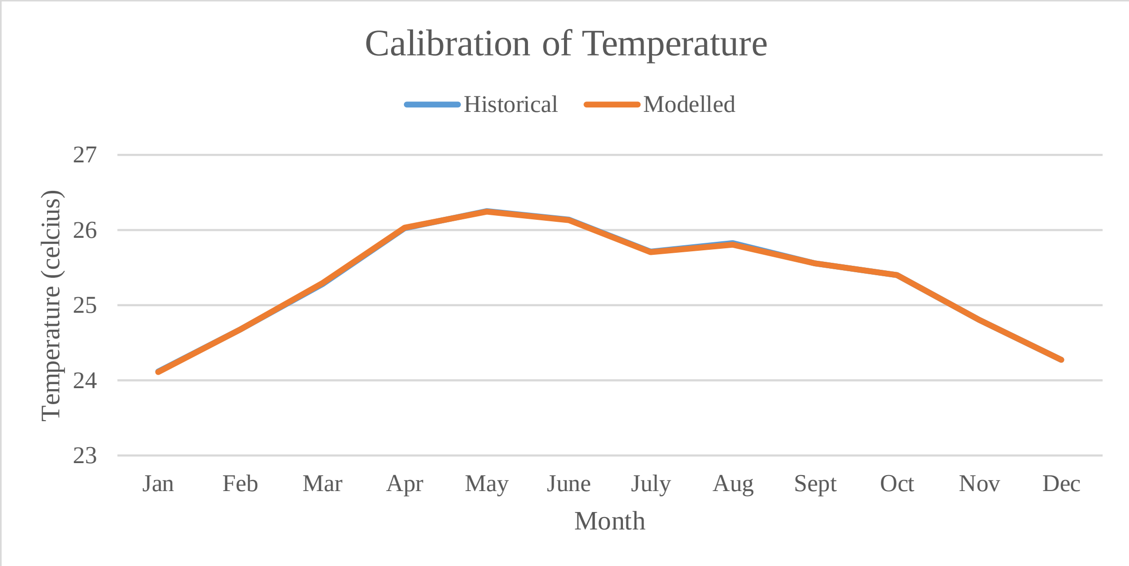

Figure 4.4: Calibrated temperature result (1999-2013) at Kechau station by using SDSM

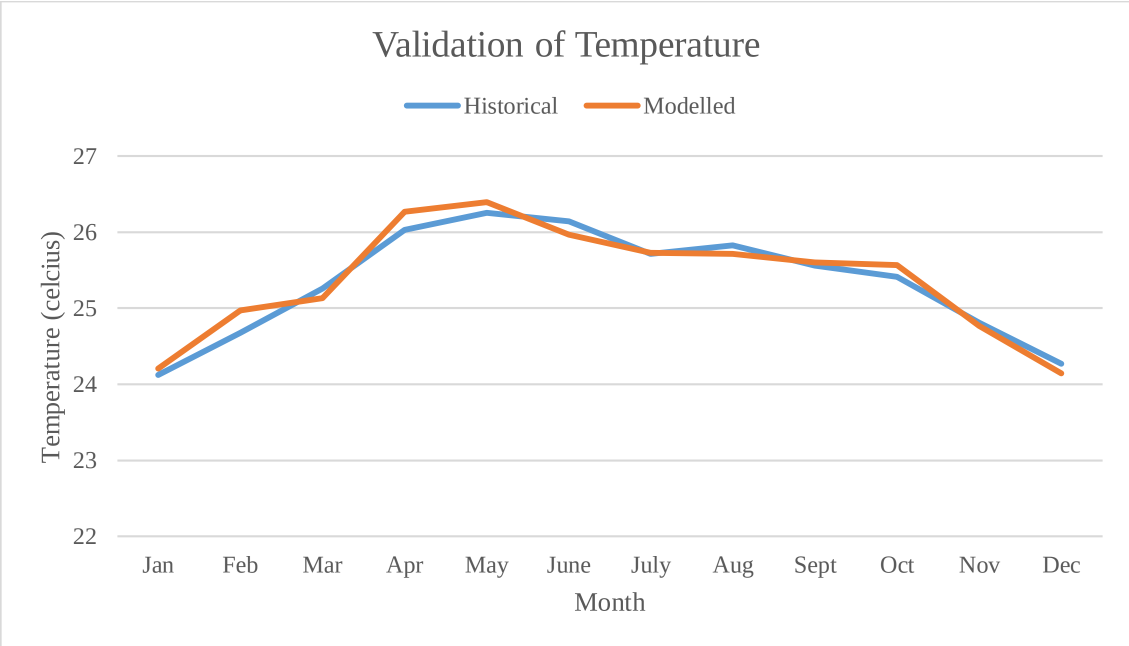

Figure 4.5: Validated temperature result (1999-2013) at Kechau station by using SDSM

The performance of the predictors selection to react with the local climate was evaluated using the statistical parameters that measure the monthly discrepancies between historical and modelled data at Kuantan station. The statistical parameters are mean absolute error (MAE). Table 4.4 outlines the MAE results for monthly maximum temperature of modelled and historical values. The correlation value was in good result with 1.00 and 0.98. Then, the errors for calibrated and validated was closed to zero.

Table 4.4: Performance of calibration and validation results using SDSM

	Calibration	Validation
r	1.00	0.98
MAE	0.01	0.13

4.3.2 Temperature Generation for the Long Term Trend

Figure 4.6 shows the projection of maximum temperature in year of 2020 to 2099 by using GCM predictors type RCP26, RCP45 and RCP85 scenarios. The projected temperature potentially to sustain the historical temperature pattern with very obvious increment. The results show that the average annual temperature will continue to increase for another 80 years with 0.3%. The simulated temperature result produced by RCP85 scenario was expected to generate higher temperature though a year with a minimum difference with RCP26 and RCP45 scenarios. Based on the monthly average temperature, it shows that the highest temperature will rise on May with 24.2% which during the transition monsoon. Based on the MMD report (MMD, 2016), the increment of temperature may be affected the interchange of east coast monsoon. For the RCP26, RCP45 and RCP85 it rise in every year at 0.273%, 0.275% and 0.279% respectively. Whereas, the lower percent of increment from the historical data was in the month of December which in range 17.6% to 18.4%.

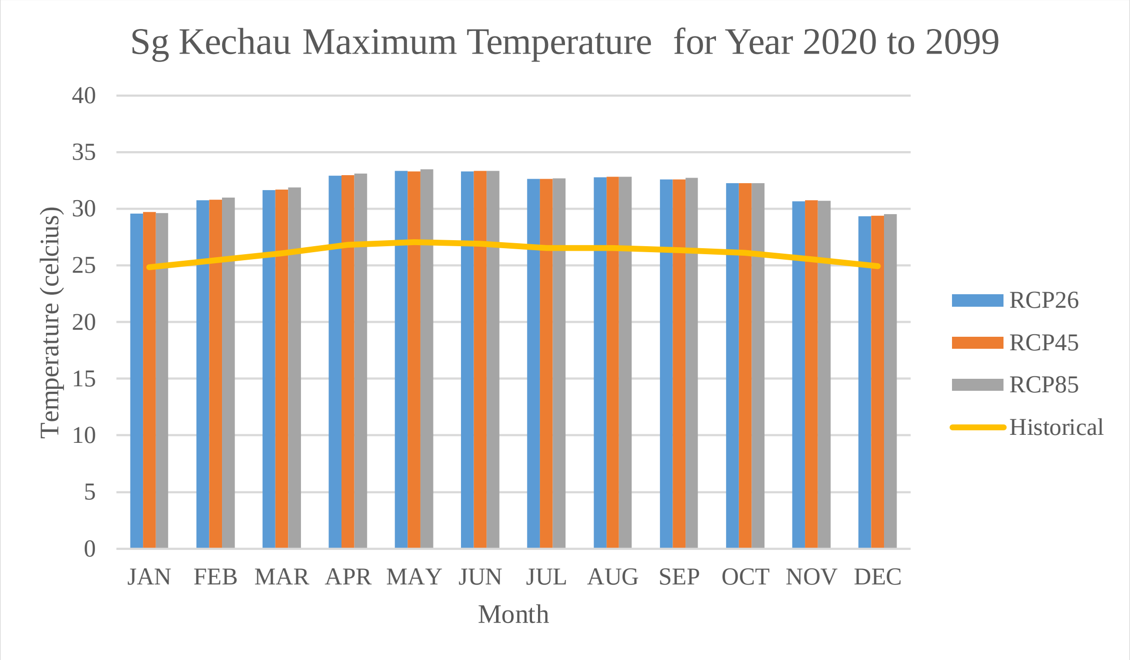

Figure 4.6: The comparison historical and projection temperature for year 2020 until 2099 (RCP26, RCP45, RCP85)

4.4 Streamflow Prediction

The streamflow prediction were generated for the year of 2020 until 2099 using IHACRES model. For IHACRES model input, it was considered with historical data of rainfall, temperature, and streamflow which all in same period without any missing data. It also related with the catchment area of local site study and the six parameters values. In general, the application of rainfall-runoff model outputs of simulated value should be closer to observed data by supported with the selected parameters which consists of mass balance (c), drying rate at reference temperature (Tw), temperature dependence of drying rate (f), reference temperature (tref), and moisture threshold for producing flow (l). The projected streamflow was also influenced by temperature and rainfall at local area. This outcome will shows the relationship of rainfall-runoff either the streamflow will resulting the increment or decrement.

4.4.1 Performances of Parameter Selection in IHACRES Model

In preparing water balance for Kechau station, predictions was made for the year of 2020 to 2099 for the time series of monthly runoff that will be used to simulate the river water level. The IHACRES model were used for making the analysis of streamflow as it affected by the rainfall and streamflow pattern at the Kechau station. Table 4.5 shows the parameters values which has been used in this study. The parameters value were referred to local area condition. Based on the calibrated value of parameter in IHACRES model, it shows that the percentage of ARPE is quite low which is at 0.07%. However, the values of correlation r of parameters is at 0.196. It is shows that the data is still in a good range of correlation parameters.

Table 4.5: The selected parameters value for IHACRES model

Parameters	Values
Mass Balance (c)	0.0378
Drying rate at reference temperature (Tw)	90
Temperature dependence of drying rate (f)	2
Reference temperature (tref)	20
Moisture threshold for producing flow (l)	0
Correlation Coefficient (r)	0.196
Average Relative Parameter Error (% ARPE)	0.07

4.4.2 Calibrated and Validated Result in IHACRES Model

The simulation of streamflow data were referred to the hydrological streamflow station at Sg. Kechau. The observed streamflow data were simulated from 1 January until 31 December 2010. The calibration process started from 1 January 2010 to 31 August 2010 and validated for the 6 months remaining started from1 September 2010 to 31 December 2010. The calibrated and validated results will compare with the selected parameters to analyse the performance of the simulated result compared to the historical data.

Figure 4.1 and 4.2 show the performances of calibrated and validated results for streamflow at Sg. Kechau. The simulated streamflow at Kechau station was successfully to produce an equality with the historical streamflow. The minimum error occurred in calibration and validation processes during February which 1.04%. The decrement between historical and modelled values was obvious in calibration and validation process during March which was from 5.29m^3/s deduce to 2.25m^3/s. Although, the greatest increment between historical and modelled values was in month of May which rise about 5.56 m^3/s. It was suspected that the error might be influence the generated streamflow for Kechau station. The projected streamflow at Kechau station was expected to be underestimated.

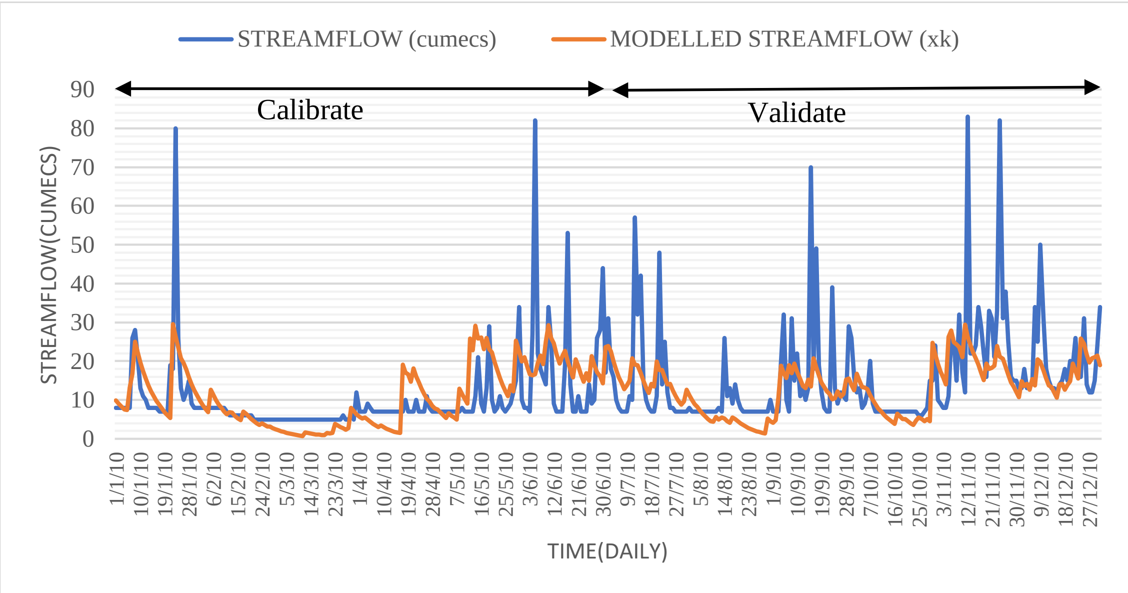

Figure 4.7: The calibration and validation in daily for streamflow by using IHACRES

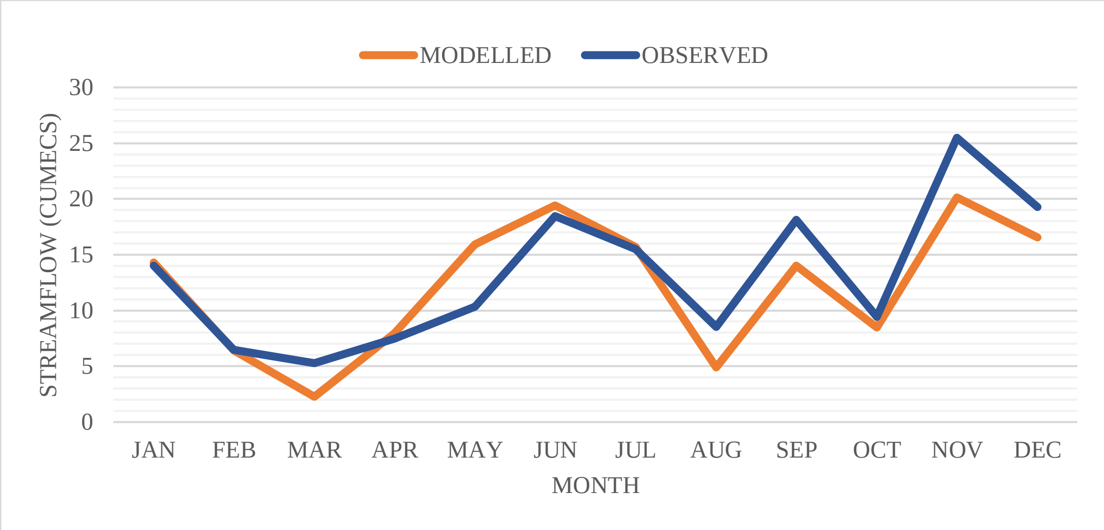

Figure 4.8: The calibration and validation in monthly for streamflow by using IHACRES

4.4.3 Formation of Streamflow Equation

The formation of streamflow equation was determined from parameters value before calibration and validation process to form the generated streamflow considered with rainfall and temperature data. The equation was produced the similar result as IHACRES model did by fill the parameters value in the equation. The calculation was filled with parameters value which was referred from Table 4.5 by following the steps below. Firstly, the drying rate at each time step was given by:

$$\mathrm{T_w(tk)} = \mathrm{T_w}e^{((20-\mathrm{tk})\mathrm{f})}$$

$$\mathrm{T_w(tk)} = 90e^{((20-\mathrm{tk})\,2\,)}$$

Soil moisture index, S_k was computed for each time step on the basis of recent rainfall and temperature records:

$$\mathrm{S_k} = \mathrm{cr_k}\left(1 - \frac{1}{\mathrm{Tw\ (tk)}}\right)\mathrm{S_{k-1}}$$

$$S_k = 0.0378\, r_k \left(1 - \frac{1}{90e^{((20-tk)\,2\,)}}\right) S_{k-1}$$

Finally the effective rainfall (u_k) in the model was given by:

$$U_k = r_k \, x \, S_k$$

$$U_k = 0.0378\, rk^2 \left(1 - \frac{1}{90e^{((20-tk)\,2\,)}}\right) S_{k-1}$$

4.4.4 Future Inflow Trend

The inflow time series was generated for the future year of 2020 to 2099 with the historical streamflow. The generated inflow time series was depends on the rainfall depth and the local temperature at Kechau station area in the future using SDSM projection. Figure 4.9 shows the projection streamflow for 3 scenarios will decrease in a several months compare with the historical streamflow. The inflow is probably estimated to become lower at end of the century because the consistency of the increment of temperature and uncertain rainfall at this area was estimated due to the climate change impact. The projected streamflow potentially to sustain the historical streamflow pattern with very obvious decrement. The results show that the streamflow will sustain to decrease for another 80 years with 0.22%. The simulated temperature result produced by RCP85 scenario was expected to generate higher decrement of streamflow though a year compare with RCP26 and RCP45 scenarios. Based on the graph, it shows that the highest decrement of streamflow was in June which in range 56.0% to 60.0%. Meanwhile, the greatest increment of future streamflow was in October which in range 50.0% to 56.0% of error. Based on the MMD report (MMD, 2016), the interchange of east coast monsoon was affected the streamflow that influenced by the local rainfall and temperature.

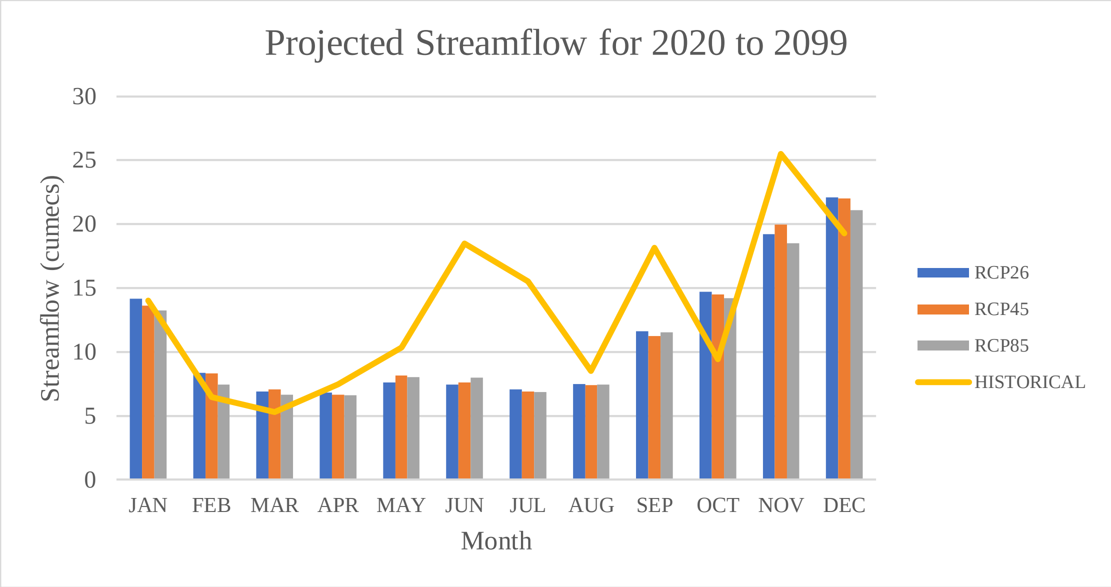

Figure 4.9: The comparison between historical and projection streamflow (RCP26, RCP45, RCP85) for 2020 until 2099

CHAPTER 5

CONCLUSION

5.1 Introduction

The study was to generate the long terms trend of rainfall and temperature from year 2020 until 2099 by using statistical model. Besides, the rainfall and temperature were used to estimate the long terms changes of water stream concerned with climate changes impact. Therefore, a useful and accurate software was needed to perform a good projection of climate change as 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. The second software that involved in this study was rainfall-runoff model which purposing to give a stronger and precise results with supported of the results from SDSM which was 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.

5.1.1 Projection of Rainfall Trend at Sungai Kechau

The projection of rainfall for Kechau station for the year of 2020 and 2099 with the constant predictors used for GCM data type RCP26, RCP45 and RCP85 scenarios. Based on the result, the projection of rainfall trend was consistent to the historical trend with inconsistent increment. The average annual rainfall was expected to rise about 0.22% every year. The selected predictors were showed the pattern closed with the historical rainfall correlated to the local predictand. The rainfall on December was expected to get higher rainfall amount than the historical in end of century with 38.6%. Whereas, the rainfall on March was expected to get lower rainfall amount than the historical in end of century with 3.8%. Based on the relative error of the performance, the highest rainfall projection was RCP26. Therefore, these results suggest that the projection analysis results is reliable and acceptable for future use.

5.1.2 Projection of Temperature

The projection of temperature for Kechau station for the year of 2020 and 2099 with the constant predictors used for GCM data type RCP26, RCP45 and RCP85 scenarios. The result shows the simulated temperature was consistent to the historical trend with inconsistent increment. The average annual temperature was expected to rise about 0.3% every year. The selected predictors were produced the similar pattern with the historical temperature correlated to the local predictand. The temperature on May was expected to get higher temperature amount than the historical in end of century with 23.9%. Whereas, the temperature on December was expected to get lower temperature than the historical in end of century with 17.5%. For the RCP26, RCP45 and RCP85 it rise respectively. But, the highest rainfall projection was RCP85. Therefore, these results propose that the projection analysis results is logic and acceptable.

5.1.3 Generation of Streamflow

The generation of streamflow was determined for the future year of 2020 to 2099 with the historical streamflow for data type RCP26, RCP45 and RCP85. The generated future streamflow was depends on the rainfall depth and the local temperature at Kechau station area in the future using SDSM projection. It was predicted to become consistent to the historical trend with inconsistent decrement for 80 years to come because the consistency of the increment of temperature and rainfall at Kechau area was estimated due to the climate change impact. The average annual streamflow was expected to reduce about 0.22% every year. The streamflow on October was expected to get higher streamflow amount than the historical in end of century with 53.0%. Whereas, the streamflow on June was expected to get lower streamflow than the historical in end of century with 8.0%. The scenario which predicted to reach the highest decrement of streamflow trend in the future was RCP 26. In addition, the monthly streamflow volume is un-synchronize affected by the local monsoon disturbance.

5.2 Recommendation

There are several guidance and recommendations that needed in improving the prediction of trend for the long term of climate change purpose;

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

b) 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.

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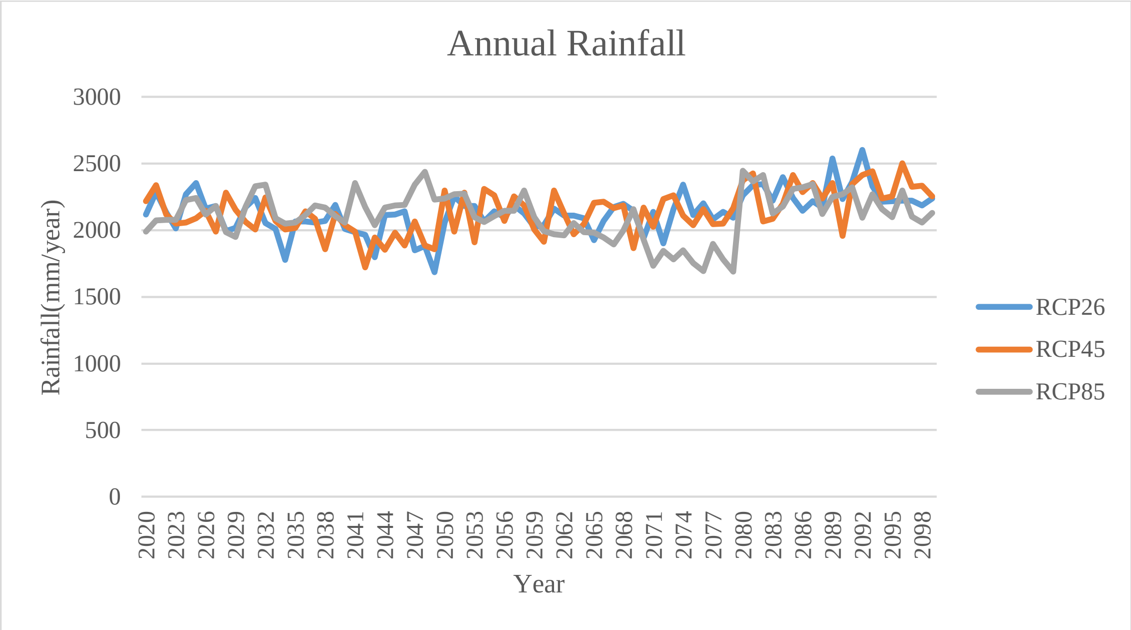
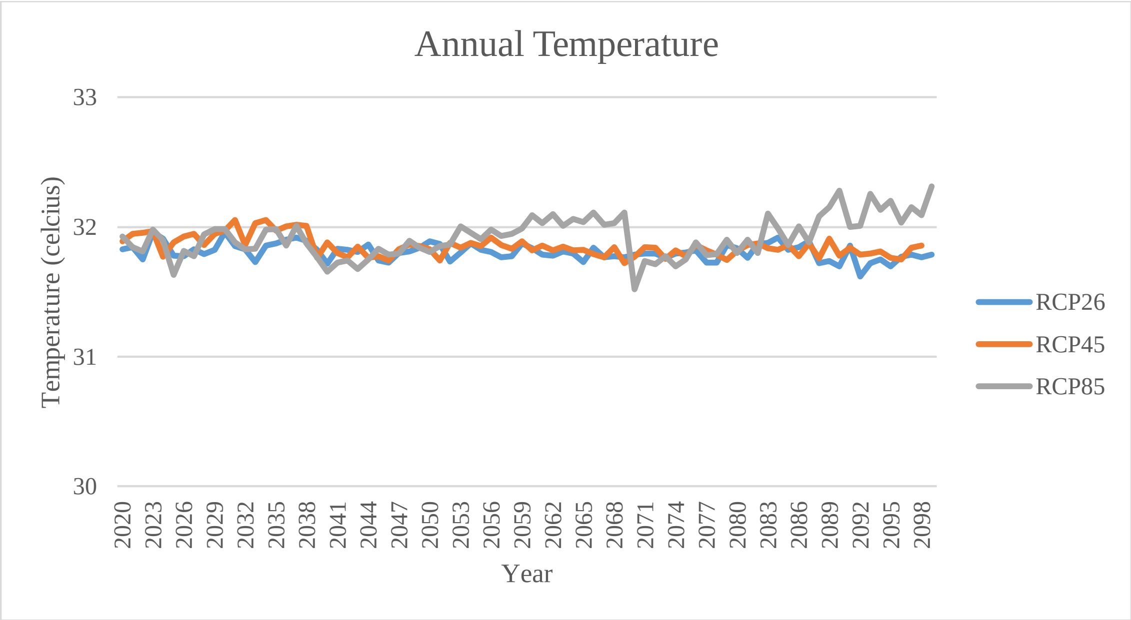
APPENDIX A

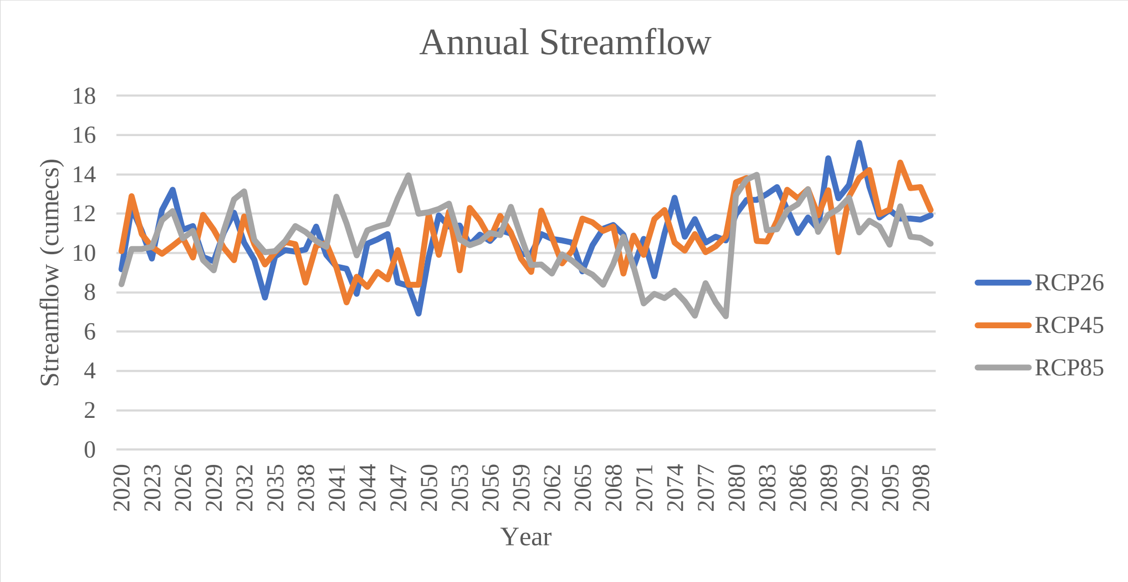
Result of annual rainfall comparison between 3 scenarios of projection rainfall (RCP26, RCP45, RCP85) for 2020 until 2099



Result of annual rainfall comparison between 3 scenarios of projection temperature (RCP26, RCP45, RCP85) for 2020 until 2099



Result of annual rainfall comparison between 3 scenarios of projection streamflow (RCP26, RCP45, RCP85) for 2020 until 2099



Result of monthly mean temperature comparison between historical and projection temperature (RCP26, RCP45, RCP85) for 2020 until 2099