ASSESSMENT OF THE UNGAUGE RAINFALL FORECASTING USING SDSM-GIS

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ASSESSMENT OF THE UNGAUGE RAINFALL FORECASTING USING SDSM-GIS

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ABSTRAK

An accuracy in the hydrological modelling will be effected when having limited data sources especially at ungauged areas. Due to this matter, it will not receiving any significant attention especially on the potential hydrologic extremes. Three of rainfall stations Pam Paya Pinang station, Paya Besar station and Kg. Sg. Soi across Kuantan river were considered in this research. Thus, the objective was to analyses the accuracy of the long-term projected rainfall at ungauged rainfall station using integrated SDSM-GIS model. The SDSM was used as a climate agent to predict the changes of the climate trend in Δ2030s by gauged stations. Five predictors were selected to form the local climate at the region which provided by NCEP (validated) and CanESM2-RCP4.5 (projected). According to the statistical analyses, the SDSM was successfully to produced reliable validated results with lesser % MAE (<23%) and higher R (1.0). The projected rainfall was suspected to decrease 14% in Δ2030s. These findings then used to compare the accuracy of monthly rainfall at ungauged station (Stn 2). The GIS-Kriging method being as an interpolation agent to treat Stn 2. Meanwhile, the next objective was to estimate the accuracy of the forecasted monthly rainfall using Kriging-GIS interpolation. Comparing between ungauged and gauged stations, the small %MAE in the projected monthly results between gauged and ungauged stations as a proved the integrated SDSM-GIS model can producing a reliable long-term rainfall generation at ungauged station (station 2). Based on the performance GIS interpolation, for the result its historical rainfall (JPS) and projected rainfall between gauged and ungauged stations can be accepted because the difference in percentage error of MAE is less than 30%. In July was recorded value with higher error in MAE with 26.6% for historical rainfall. While the higher error for projected rainfall is 25.81% which happened in December.

ABSTRACT

Ketepatan dalam model hidrologi akan memberi kesan apabila mempunyai sumber data yang terhad terutamanya di kawasan yang tidak mempuyai data hujan. Disebabkan perkara itu, kawasan tersebut tidak akan menerima sebarang makluman penting terutamanya berkaitan dengan keupayaan untuk meghadapi hidrologi yang ekstrem. Tiga buah stesen hujan yang merentasi Sungai Kuantan telah dipilih dalam kajian ini iaitu stesen Pam Paya Pinang, stesen Paya Besar dan stesen Kg.Sg soi. Demikian itu, objektif kajian ini adalah untuk menganalisis ketepatan ramalan hujan pada jangka masa panjang di stesen ketiadaan data hujan dengan menggunakan model SDSM-GIS. Model SDSM digunakan sebagai agen iklim untuk meramalkan perubahan polar iklim yang berlaku di stesen terdapatnya data hujan pada tahun 2030. Lima parameter telah dipilih untuk menghasilkan iklim semasa di kawasan tersebut dengan menggunakan NCEP dan CanESM2-RCP4.5. Berdasarkan statistikal analisis yang diperolehi, SDSM telah menghasilkan keputusan yang baik di mana peratusan ralat untuk proses validasi kurang dari 23% dan nilai R menghampiri 1.0. Pada 2030, hujan diramalkan berkurangan sebanyak 14%. Hasil dapatan ini seterusnya digunakan untuk membandingkan ketepatan hujan bulanan di stesen ketiadaan data hujan (stesen 2). Kaedah GIS-kringing telah diaplikasikan sebagai agen interpolasi bagi mendapatkan data hujan di stesen 2. Sementara itu, objektif seterusnya adalah untuk menganggarkan ketepatan ramalan jumlah hujan bulanan yang telah diperolehi dengan menggunakan kaedah interpolasi GIS-kringing. Berdasarkan perbandingan diantara stesen hujan dan stesen ketiadaan data hujan, nilai ralat yang kecil dalam meramalkan hujan bulanan di antara dua stesen tersebut membuktikan bahawa model SDSM-GIS dapat menghasilkan ramalan hujan dalam jangka masa panjang dengan baik di stesen ketiadaan data (stesen 2). Berdasarkan hasil interpolasi GIS, data hujan JPS dan hujan yang diramalkan antara stesen terdapatnya data hujan dan ketiadaan data hujan dapat diterima dengan ralat lebih kurang dari 30%. Bagi data JPS, ralat paling tinggi dicatatkan pada bulan Julai dimana ralat terhasil sebanyak 26.6%. Manakala ralat paling tinggi untuk ramalan hujan berlaku pada bulan Disember mencatatakan ralat sebanyak 25.81%.

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LIST OF SYMBOLS

^{o}C	Celsius
cm	Centimetre
R	Correlation
CO_2	Carbon dioxide
km	Kilometre
m	Metre
mm	Millimetre
$E103^{0}$ 08’	North Coordinate
%	Percentage
$N3^{0}$ 54’	South Coordinate
R^2	Variance

LIST OF ABBREVIATIONS

ANN	Long Ashton Neutral Network
ArcCatalog	Arc Catalog
ArcGIS	Arc Geographical Information System
ArcMAP	Arc Mapp
ArcView	Arc View
DD	Dynamical Downscaling
DID	Department of Irrigation and Drainage
EDSS	Environmental Decision Support Systems
GARR	Gage-Adjusted Radar Rainfall
GCM	Global Circulation Model
GHG	Greenhouse Gases
GIS	Geographical Information System
HadCM	Hadley Center General Circulation Model
LARS-WAG	Long Ashton Research Station Weather Generator
MAE	Mean Absolute Error
METEOSAT	Meteorological Satellites
MLR	Multiple Linear Regression
MMD	Malaysia Meteorology Department
NCEP	National Centre for Environment Prediction
NEM	North East Monsoon
NEXRAD	National Weather Service
NWP	Numerical Weather Prediction
PRECIS	Providing Regional Climates for Impact studies
R	Correlation
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
SD	Statistical Downscaling
SD	Standard Deviation
SDSM	Statistical Downscaling Model
SWG	Stochastic Weather Generator
SWM	South West Monsoon
TIN	Triangulated Irregular Network
U.K	United Kingdom

CHAPTER 1

INTRODUCTION

1.1 Background of Study

National Weather Service Weather Forecast Office stated that flood can be explained as an overflow of water onto normally dry land. The inundation of a normally dry area caused by rising water within an existing waterway, like a river, stream, or drainage ditch. Ponding of water at or nearby the point where in fact the rain fell. Flooding is a longer term event than flash flooding, it could last days or weeks. In Malaysia, flood event usually happens during end of the year, during the North East Monsoon season from October to January. High frequency of rainfall causes high flow rate in a river, and when the existing drainage system unable to cope with the high flow rate and volume of runoff, flood occurs.

Therefore, increasing frequency of floods due to changing rainfall pattern is a growing concern in the east coast of peninsular Malaysia. Ungauge rainfall catchment prediction are techniques used to extrapolate by hydrological information proceed of contiguous ungauged catchment from gauged data through, hydrological model simulation, and other relevant methods. However, runoff data were not available in many catchments appealing. Therefore, it is required to forecast runoff hydrographs of ungauged catchments from other information within that catchment or from other catchments. Many methods have been developed and applied in several parts.

However, prediction in ungauged catchment remains a significant problem in hydrology. As not all the streams are gauged long time for ungauged catchments has to be assessment using relationships of the physical characteristics of the gauged catchments and the long-time derived from streamflow and rainfall data. For this purpose, an integrated between SDSM-GIS. Statistical Downscaling Model and GIS have been formulated to generate the long term rainfall pattern at ungauged area.

1.2 Problem Statement

In Pahang River basin, the station rainfall data were limited and cater only small parts of the entire basin. For the big catchment area Kuantan river, this will make the estimation of become inaccurate. Thus, the potential impacts of climate change on hydrologic extremes, like floods, in small watersheds and medium, have not received significant attention especially ungauge catchment because no accurate data may be due to inadequate equipment. Apart from that, there was lack of sufficient development and application of suitable water resources design techniques in the context of climate change. So, that need interpolation data using GIS to analyses the reliability of the forecasted ungauge rainfall it can reduce the impact of flooding by taking extra precautions in ungauge catchment and provided the most accurate surface.

Nowadays the global warming is unavoidable and main factor due to the emission scenarios based on the countrys development and expected level of greenhouse gases. The greenhouse gases consist of carbon dioxide. Akhbari (2014) wrote that river in Malaysia as a main factor that caused to the flood event due to the continuous rainfall and this incident occur repeatedly over the past decades and it is believed that the climate changes is related to the fluctuated weather especially in the rainfall variability. Thus, the performances of SDSM climate model to present Pahang climate variability to generate the long term rainfall trend using SDSM from the past 30 years of historical data and GIS.

The were 2 techniques have been used to downscale information from GCMs to regional scales Dynamical Downscaling (DD), Statistical Downscaling (SD). The DD uses Regional Climate Models (RCMs) to simulate finer-scale physical processes consistent with the large-scale weather evolution prescribed from a GCM (Giorgi, 2001; Mearns, 2004). Meanwhile SD adopts statistical relationships between the regional climate and carefully selected large-scale parameters (Storch, 1993 ; Wilbyet, 2004 ; Goodess, 2005). DD methods are extremely computationally intensive and have data requirements which may not be easily available.

In this study, SD has been proposed due to computationally cheap and requires few parameters contrast with dynamical downscaling (Fowler,2005). Statistical Downscaling Model (SDSM) developed by (Wilby,1999) was used as the basic model to present the initial view of how significant the projections of climate change scenarios will affect the precipitation variability for the sites under study. SDSM is well documented and has been successfully tested in numerous studies (Wilby, 2003 ; Nguyen, 2005 ; Diaz-Nieto, 2005 ; Haylock, 2006 ; Khan, 2006). The model permits the spatial downscaling of daily predictor-predictand relationships using multiple linear regression techniques and generates synthetic predictand that represents the generated local climate scenario.

However, rainfall information is often needed at ungauged catchments especially when the stream gauge network is not dense. One conventional approach to estimate streamflow at an ungauged catchment is to transfer streamflow measurements from the spatially closest stream gage, commonly referred to as the donor or reference gage using the drainage-area ratio method. By using GIS, it can interpolate data because the probably is the fact could never sample adequately for any locations that want in. In addition, recent advances in GIS software, allow the spatial variation of model parameters and processes to be considered at a reasonably small scale. The older and more precise method of measurement involves rainfall gauges that need to be inspected at various points during a rainfall.

1.3 Objective

The purpose of this study is to generate the long term rainfall trend at ungauge area using integrated of Statistical Downscaling Model (SDSM) – GIS modelling. Therefore, this study covers the following objectives:

i. To estimate the accuracy of the forecasted monthly rainfall using Kriging-GIS interpolation.
ii. To generate the long term rainfall ($\Delta 2030s$) at ungauged area using SDSM-GIS Models.

1.4 Scope of Study

This study covered the whole area within the Kuantan river. As mentioned, Pahang river overflow during the high rainfall volume due to the uncertainly in rainfall pattern because of the climate change. Therefore, climate prediction is the main focus in this case to generate the long term rainfall trends. The historical rainfall and temperature was provided data by the Department of Irrigation and Drainage (DID) and Malaysia Meteorological Department (MMD). Validated and calibrated results had been being compared with the historical data to analyses the SDSM performances.

The GIS interpolation used to produce the rainfall patterns at ungauged area. Rainfall station can be as a control in generating result for the ungauged area. This study aims to determine the pattern of 10 years rainfall distribution length using GIS.

For this purpose, a using Statistical Downscaling Model and GIS have been developed model can be suitably in this study. Available rainfall data along with other catchment characteristics from gauged catchments were used to develop the model and were follow applied to the poorly gauged or ungauged catchments with the study area for prediction of ungauge rainfall forecasting.

1.5 Significance of Study

The climate changes occurred more often in time especially if the greenhouse gases (GHGs) emissions are not controlled. Due to the climate changes, there are so many factors affected and some of it is the rainfall pattern and the variability. It is making it even harder to predict the weather and disable us to prepare for any disaster that occur in a flash light. Therefore, the future rainfall trend can be as a significant data to planning and managing the water resources and flood mitigation. The climate prediction also is important to determine the rainfall rate and the changes along with the line to avoid an of the flood disaster occurred. The disaster is affected so much by the climate change and the effect are badly unwelcome by the humans.

To solve the lacking data and missing data problem especially at ungauged area. Usually lack of data keeping due to the wrong technique used when measuring the rainfall, relocation of the rain station and malfunctioned of instrument. While missing data problems may be due to the inadequate record data from DID. Based on the previous research based on Pahang, the percentage missing value around 20-50%. Therefore, this one of the challenging problems which need to be faced by the researchers to analyses rainfall data.

In addition, the GIS interpolate method is a better method than the Arithmetic method of rainfall areas based on station rainfall because GIS interpolate it include a whole wide area and not just based on point location. It can know the suitability of the method missing rainfall data developed by GIS interpolate may be appropriate in this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

However, unavailability of the hydrological data storage is one of the major constraints in the hydrological. The coastal and river areas of the eastern Peninsular Malaysia are exposed to the hydrological disaster especially during North-cost monsoon. This scenario becomes worse year by year strongly consistent to the green gases (GHGs) rises and the climate change impact. Many studies have been conducted in effort to reduce the island effect from this events. In recent year, climate change more rapidly and become global issues very seriously. Emissions and concentrations of carbon dioxide and greenhouse gases affect the temperature rise, and thus lead to global warming.

While, the greenhouse gases (GHGs) consist of carbon dioxide, methane, nitrous oxide, hydrofluorocarbon, perfluorocarbon, and sulphur hexafluoride. These gases normally exist in the atmosphere in minimal concentration. The contaminant of these gasses depends on the population growth, urbanization, level of pollutions and land development in the region. These gasses could stay in the atmosphere in a long period of time and are well-mixed to form higher concentration levels. So that, the world community is concerned about the impact of climate change and extreme time series that may affect the global climate system. In the projection of climate, the emission levels are taken into account in the physical of atmosphere, ocean, cryosphere, and land surfaces known as GCM. Wilby (2002) wrote that these models are especially helpful in investigating and predicting future changes in climate, output of these models based on large-scale grid (250 to 600 km). Due to their abrasive resolution, the output should not be used successfully to investigate the environmental impacts and hydrology of climate change on a regional scale.

In addition, the El Nino occurrences during this period are also indicate the improve to improve the impact of these events on the rainfall patterns of Malaysia. The majority of the El Nino occasions starting 1970 have brought about extremely dry years of Peninsular Malaysia. The three driest years for Peninsular Malaysia (1963, 1997 and 2002) have been recorded amid El Nino occasions. All things considered, the El Nino phenomena alone cannot be in charge of drought over Peninsular Malaysia as a significant number of just as generally dry years have been recorded during the absence of the El Nino.

Based on the study done by (Leiserowitz, Kates & Parris, 2005; Brechin,2003), several countries have surveyed some of the less information people about climate change. The most majority of the world believe that human activity is a major cause of climate change, but many continue to confuse and conflate global warming with thinning of the ozone layer, which in turn leads to a lot of support ineffective solutions, such as the aerosol spraying cans.

The climate uncertainties can be analysed based on the climate variability and climate changes. Climate variability refers to the fluctuation of the seasonally or yearly average or climate variables range. The measurement of climate variability is used to analyse and simulate the probability of climatic event in the future year as imperative information for the system designing tools. Meanwhile, climate change refers to the continuous changes of the climate variability in the long term to observe the climate transition in a general manner.

The study of rain predictions is very important for a country like Malaysia where there is a lot of rain. In Malaysia, the average annual rainfall is 2500mm year meanwhile for east coast of Malaysia is 5080mm year with the temperature changes between 20^{o}C to 30^{o}C. The northeast monsoon is the major rainy season in the east coast states of Kelantan, Terengganu, Pahang and east Johor in Peninsular Malaysia are flooded annually from November to March. The average monthly rainfall in this area ranges from 230 mm to 760 mm. At the same time, land or area protected by mountain ranges are often free from the effects of heavy rain. Referring to Tangang (2008), the influences of whirlwinds in Borneo and the Indian Ocean also most important in contributing to the massive floods during that period. While for the South West monsoon is generally dry season in the states of Kedah, Penang, Perlis and south Perak in Peninsular Malaysia. The average monthly rainfall in this area ranges from 200 mm to 350 mm.

The trend of rain from in year 1960 to 2010 in the western region of Peninsular Malaysia in terms of monthly, seasonal and annual rainfall trends to identify the variations that existed and the factors that influenced them. Dale (1959) divides Peninsular Malaysia into five rainy areas, West, West, East, West-Daya and Port-Dickson-Muar Beach. Western-Sea region receives less rainfall than 2540 mm, West (> 2540 mm), East (> 2794 mm) and Port Dickson-Muar Beach (2032-2540 mm). Meanwhile, the South West region is considered a dry area that receives rain less than 2286 mm a year. The region is considered a dry area because it does not receive high rainfall. This rainforest has been instructed by the Malaysian Meteorological Department (MMD) and the Department of Irrigation & Drainage (DID) to categorize rainy areas as well as planning water sources for irrigation and other domestic purposes.

In the year 2016, the majority part of east coast of Peninsular Malaysia has been flooded after a couple weeks of continuous rain started on November 2016. There is a weakness of too much rain causing injuries or adverse human health. Several parts in Pahang including Kuantan the affected due to the flood which was originated from the Pahang River. It occurred at the end of the year which was usually normal to be receiving such amount of rainfall because during that period, the northeast monsoon occurred but in that year, an extreme weather brought a disaster to the whole east coast Malaysia. Malaysian Meteorological Department (MMD) and the Department of Irrigation & Drainage (DID) stated that for station Ladang Kuala Reman, Kuantan, Pahang have been receive in average 2010mm/year and total average temperature is 26.7^{o}C. To compare November 2014 until January 2015, Kuantan have been receiving in average 2735mm/year. The heaviest rainfall happens in with November 2014 and December 2014 with 310mm and 878mm respectively. With this factor along with the massive high tide from the sea, it had caused the increment in water level resulting the flood disaster. Thus, the results of the developed multivariate equations revealed the model to be capable of predicting the desired flow parameter at ungauged catchments in the area under consideration with reasonable accuracy.

2.2 Analysis of Rainfall Distribution in Malaysia

Malaysia is situated on a stable plate, a geographical region that being protected from most major natural disasters, earthquakes and volcanoes. Malaysia is less likely to be hit by tsunamis due to the surrounding landmasses and free from typhoons as it is not in the tropical cyclone basins. However, flash flood and drought are the two extreme contrary of natural disasters that are likely to occur in Malaysia within the same year in the recent years. This phenomenon gives huge impact especially to the Malaysia's economy which can cause million ringgits to recovered the losses, the destruction of the agricultural plantation and exposed to the water born decreases. Besides, the landslide is also one of the destructive disasters that caused by the heavy rain as there was a strong correlation between the rainfall and landslides (Ratnayake and Herath, 2005). Therefore, by understanding the characteristics of the rainfall, precaution steps to overcome or reduce problems can be planned and done earlier (Suhaila, 2011).

The rainfall trend in Malaysia is greatly affected by these two monsoons. Two different monsoon seasons there are north east monsoon (NEM) season from November to March, and the south west monsoon (SWM) season from May to September. The northeast monsoon (NEM) brings heavy rainfall, particularly to the east coast states of Peninsular Malaysia and western Sarawak, while the southwest monsoon (SWM) normally signifies relatively drier weather. Hence, a monsoon does not necessarily mean rain, it is just the name of the prevailing winds blowing at a certain time. The findings from the study showed that NEM season brought the most rainfall during the end of year as general. On average, there was 55% and 31% of rainfall received at the east coast region during NEM and SWM season respectively. On the other side of Peninsular Malaysia, the west coast regions had 37% and 41% of the average rainfall during NEM and SWM seasons. Meanwhile, the inland region received 80% of its average yearly rainfall during the monsoon seasons. A study carried out by Wong (2009) to examine the rainfall spatial pattern and time-variability in Peninsular Malaysia over 3 regions from 1971 to 2006 year.

The northeast monsoon is the major rainy season in the east coast states of Kelantan, Terengganu, Pahang and east Johor in Peninsular Malaysia are flooded annually from November to March. The small islands on the east coast such as Perhentian, Redang and Tioman is unsuitable to visit, as the heavy winds and strong rains affect beachside activities usually shut down for the season. Based on the results of the Mann-Kendall test, the rainfall intensity increases at most of the stations due to the trend of the total amount of rainfall and the frequency of wet days. High pressure areas are formed in low temperatures in the Asian continent where low temperatures are formed in high temperatures in the Australian continent. Winds leading to Australia's low pressure area from high pressure areas of Asia. the wind moves from the northeast of Peninsular Malaysia at a speed of 10-20 knot and when crossing the equator, it needs to be upgraded towards Australia.

C.A. Chen (1998) stated that the east coast states of Peninsular Malaysia such as Terangganu, Kelantan and Pahang are more affected by this monsoon because of that has wind speeds that can reach up to 30 knots. This season, before coming to Malaysia there will be a wind blow across the South China Sea. In the rainy season the direction and movement of the winds bring heavy rain especially on the eastern and southern coasts of Peninsular Malaysia as well as the central part of the Titiwangsa Ranges (H. Jantan, 1981). The direction and the movement of the wind in this monsoon brings heavy rain, especially to the eastern, southern coasts of Peninsular Malaysia and the center of Titiwangsa Ranges (H. Jantan, 1981). The rainy season takes place around the end of every year in the east coast states.

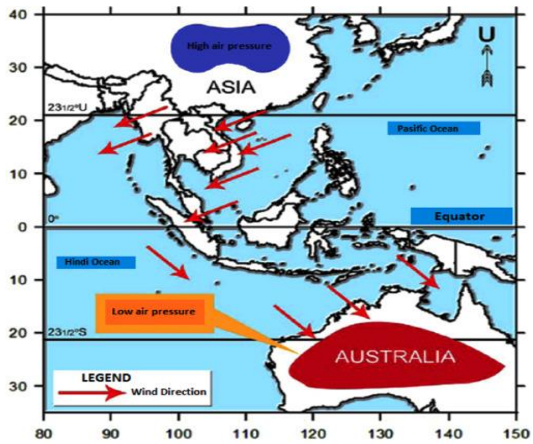

Figure 2.1: The process of the formation of the Northeast monsoon winds in Malaysia

For the South West monsoon is generally dry season in the states of Kedah, Penang, Perlis and south Perak in Peninsular Malaysia. Hence there is very little rain to kill the fires, so an unpleasant level of pollution can appear at some point between June and November. This pollution can last between 2 weeks to 2 months in 2015. This season is relatively stable atmospheric conditions in the equatorial region. This season flow average is usually the wind is blowing at 15 knots (Capslock, 2013). The rate temperature during the monsoon reached 30°C to 35°C. In the night the temperature rate is 28°C to 29°C (Capslock, 2013). In May to September, the condition of the atmosphere of the southwest monsoon will start blowing during the northen hemisphere are experiencing summer conditions. At the interior Asia will happen under which the air pressure from a condition with low.

However, at the same time also the situation at the Australian continent and the ocean area around is going to be in a condition of high air pressure. This situation occurs because of circumstances with temperature reading at low levels. This situation makes the difference in pressure between the two places will give rise to the existence of a slope between the two point of pressure. The Australian continent and the oceans around it would in the circumstances of cool air. The cold air will begin to move out toward the low air pressure area and would recommend the interior of Asia. The wind conditions originally a southeast monsoon wind system as refracted to the left by Coriolis Force. The wind will start to move towards the equator line. When the movement of the wind across the equator, this will be deflected to the wind right again by the same Coriolis Force, which is the same hemisphere north. This wind is known as the southwest monsoon. This situation will take considerably less wind bringing rain. This wind will through towards the west coast of peninsular Malaysia. This happen because the wind blowing is blocked by the mountain ranges on the island of Sumatra.

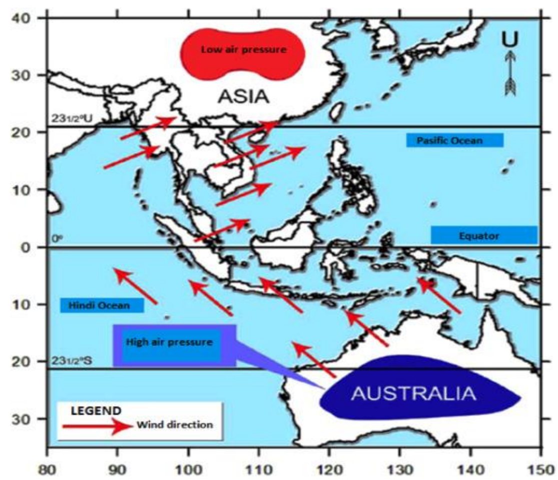

Figure 2.2: The process of the formation of the Southwest monsoon winds in Malaysia

2.2.1 The Hydrological Cycle

Catchment modelling requires a clear understanding the hydrologic cycle at catchment scale. The main process can be involving in catchment hydrologic cycle. Some hydrologists investigate this cycle by some studies. The hydrologic refer to the process beginning with the water falling to the earth either in liquid form or solid form through the precipitation. Precipitation is needed generate the water runoff at a catchment scale. The distribution of precipitation is varying to the spatial and temporal characteristic. Dews, snow, hailstones and rain made from precipitation. In Peninsular Malaysia precipitation is rain only.

In Canada, spatial and temporal characteristics of heavy precipitation events are examined for the period year from 1900 to 1998. In southern Canada, the total precipitation comes from rainfall events is 71%. In northern Canada, total precipitation comes from snowfall events is more than 50%. Total rainfall in heavy events and non-heavy events apply a several part (<20%) stations This result for not rain, it is snow because the total of precipitation falling in heavy and non-heavy events increases or decreases.

In peninsular Malaysia, humid tropical have a very low distribution temporal and spatial. Based on previous studies, rainfall runoff behaviour and to regulate the rate of wet canopy evaporation shallow water table fluctuation is a feature for tropical rain (Schellekens, 1999; Chapell, 2001; Bidin, 1993). Kumar (2007) studied the distribution of rain intensities in different parts of the tropical region and found that temporal distribution of rain intensities in different places showed a low intensity class from 65% to 90% at the time which may indicate the prevalence of strati shape and cumuliform clouds. There are also rain temporal features such as diurnal changes. Showing short temporal changes such as diurnal and monsoon seasons changes due to the amount rainfall in this region is highly (Tick and Samah 2004). In addition, the terrain of Peninsular Malaysia is highly variable from coastal to highlands.

Each catchment area is a different direction. Due to the vegetation, it is largely bypassed by canopy plants. Depend on vegetation type, vegetation density can due to a loss function to catchment runoff describe by interception. The rest of rainfall moves down the vegetation as stem flow, drip off the leaves or directly falls to the ground as through fall. The rainfall stays on the surface of the depressant soil and loads evaporate, infiltrate or discharge as a ground stream. During the day, it returns to the atmosphere by evaporation process or evapotranspiration process which is from the plant and restart the cycle again.

Unsaturated subsurface flow and recharges the saturated zone occurs due to the water moving downwards when infiltration of rainwater occurs. This process is natural and fills the groundwater aquifer system. In some instances, at the shallow subsurface level where in fact the lateral hydraulic conductivity is greater than vertical one, the direct infiltration partly moves toward the route through interflow or through stream.

The main topographic factors of the catchment, before being discharge to the channel network system is the groundwater pattern can be influenced by the catchment characteristics. The groundwater across the catchment boundary can discharge by aquifers of the groundwater system. The decrease of water storage in the subsurface occur by evaporation and transpiration at the land surface. As an impact, unsaturated stream in upward direction is made that is named capillary rise.

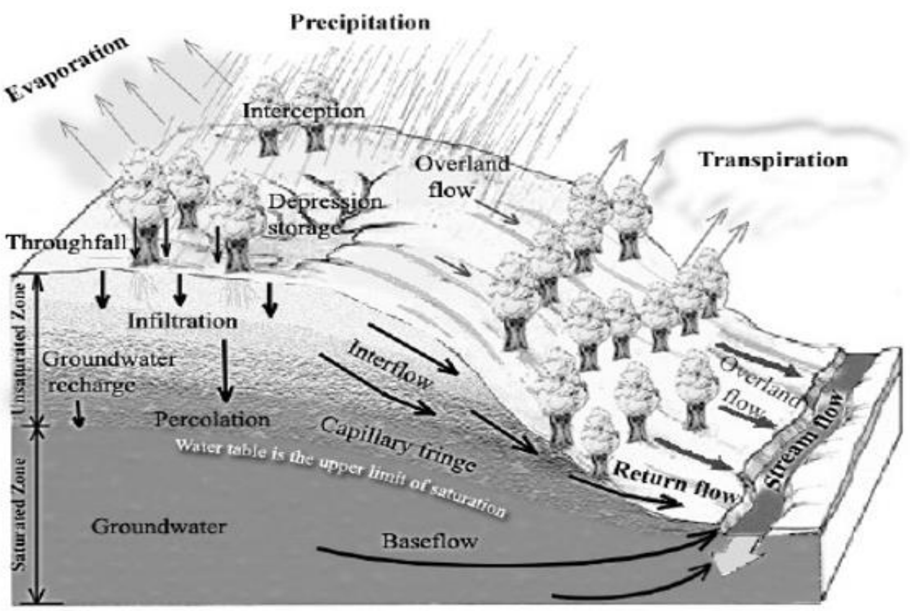

Figure 2.3: Physical processes involved in runoff generation (Tarboton, 2003)

2.2.2 Ungauged Rainfall Catchment

In the process of hydrology, the most important thing is the runoff hydrograph prediction. There are several functions for example hydrological disaster risk management, hydropower operations, hydraulic structure design, water resource planning and management and assessing the effects of environmental changes. Transfer of adjacent unsaturated catch hydrological information from the data measured through simulation of hydrological model extrapolated from river flow forecast. The effects of anthropogenic and climate change reinforce this issue in some areas involved. Hence, predictions of poorly gauged or ungauged catchments under these conditions are highly uncertain (Sivapalan, 2003).

In addition, there are some interesting areas that data cannot get. So, that needs to predict runoff hydrographs of ungauged catchments from other information within that catchment or from other catchments. Various places have been developed using various methods. More challenges in hydrology remain of prediction in ungauged catchment. A lot more challenging in tropical regions where almost all of the catchments are ungauged including the need for increase knowledge of flow variability in such areas become very immediate, especially in the context of growing hydrological disasters and changing hydrological processes due to climate change. On the east coast of peninsular Malaysia, changes in rain patterns will result can increasing the severity and frequency of floods. Major problem in hydrological studies in area is a reliable and long-term flow of data streams in almost all catch interesting. Sivapalan (2003) wrote that ungauge catchment can be describe a drainage catchment which has insufficient records of various hydrological observations in terms of both quantity and quality for analysis at the appropriate spatial and temporal scales and up to a good level of accuracy for application in practical fields.

According to definition, both the quantity and quality of data known as ungauged catchment are one with inadequate records. Hydrological observation to enable computation of interesting hydrological variables on appropriate space and time scale, and acceptable accuracy for practical applications. Raining, run, sub-surface flows, infiltration and evaporation referenced from hydrological variables. However, many interesting processes from a hydrological point of view are difficult to observe on a regular basis and are not clear. Streamflow measurement is a variable that can be measured at a measurement site of a basin with confidence. Need to measure and record inadequate flow flows and scanty or no streamflow records at the site is limited for ungauged catchment. In India, some medium and small catchments are mostly ungauged and only the main river catchment has been gauged. Kothyari (2004) stated that a several parts of the country that have not yet been gauged for measurement of runoff, sediment. Due to economic constraints that do not allow hydrological research and meteorological investigations at each new site for long-term climate change. The method for the ungauged catchment use for realistic hydrological variables.

The ungauged catchment area may have different data availability. Ungauge catchment is interpreted as no river level measurement at the catchment. The presence of rain measurements in catchment areas usually will not affect any classification. R.J Moore (2007) wrote that this guideline recognizes different degrees of ungauged, including consideration of: stage-discharge relations for flow estimation, the presence of telemetry for real-time data access and availability of data from neighboring catchments and past historical records but no current ones.

In addition, the major challenge with rainfall-runoff modeling in ungauged catchments is the lack of local runoff data that could be used for calibrating model parameters. Firstly, there is no unique hydrological equation that can be derived from first principle with the exception of the water balance equation, so most of the model equations are empirical in nature and tend to depend on the hydrological setting. Calibration can account for the effects of the hydrological setting in a particular catchment. Second, boundary conditions and these are often poorly defined depending on hydrological models. Calibration can adjust for biases in the inputs, for example, as a result of orographic effects and instrument biases. Third, and probably most important, the media properties (both soil and vegetation) are highly heterogeneous and essentially always unknown or at least poorly known. Soil properties can change dramatically in space but change very little with time, so parameter calibration can significantly enhance the performance of rainfall-runoff models. While the calibration of runoff data has served a good hydrology in the past, this is not an option in the ungauged catchment area. The model parameters and perhaps the model structure from analogue in region and more catchments that one can expect to behave similarly to the catchment of interest is the best option in overcoming the problem of ungauged catchments. Rainfall-runoff models use two broad categories of model parameters: physically based parameters that in principle can be observed or estimated directly from measurements in a catchment; and calibration parameters that appear in empirical relationships and need to be back-calculated from rainfall and runoff data. Even in ungauged catchment no runoff data is available, other hydrological response data is available and can be used as an alternative to model calibration and testing (Gunter Blocshl,2006).

2.3 Global Climate Model

Global circulation models (GCM) or otherwise known as General circulation models (GCM) which from the name itself is to generate the circulation of the atmosphere. GCM also function to explain how the environment, the seas, the geographical features, living organisms, and solar energy influence one or the other as well as Earth's atmosphere by using a lot of mathematical equations in the computer. GCM have been designed to simulate the planet's future climate. Global climate to have significance impacts on water basins and regions, such as in a runoff and hydrological system. For example, floods or droughts may happen due to the decrease or increase of total volume of flow caused by change in climate change. Therefore, there are many studies have been done to investigate the relationship between the climate change impact and the water basins. The large grid size scale of the model output is only about 250 to 600 km. Thus, grid scales on environmental studies and climate change hydrology are inaccurate (Wilby, 2002).

GCM have three main group there are Atmospheric GCMs coupled with a simple slab ocean (the ocean represent by single fixed layer) and simple land-surface parameterization schemes. Second point is the ocean system represent by a three-dimensional representation in Atmospheric GCMs coupled (represent of one in which ocean currents and heat transport) and with simple land-surface parameterization schemes. A three dimensional terrestrial biosphere model and Atmospheric GCMs coupled to a three-dimensional representation of the ocean occur at the last point.

The history of these models is closely connected to the history of advances in computing power, and the current generation of high-end GCM are among the most computationally-intensive programs in existence. Mathematical ideas motion simulates the atmosphere, to help forecast the weather, beginning in 1920. But the numerical weather forecasting to be very practical in 1950 using electronic digital computer. By the end of the forecaster in 1950 in the United States and parts of Europe combines computer-generated weather maps into their work routine. The power and utility of these model is that they can show how climate changes on a regional scale, which is of utmost importance in planning for our future.

In the 1970, we are probably going to be the most effective in dealing with climate change on the scale of regions, so having a model that shows us what those regional changes are likely to be is a very important tool. At that time, scientists believe that GCM is crucial to analyzing the effects of climate change, especially long-term possibilities due to the accumulation of carbon dioxide in the atmosphere.

GCM is divided into two types which are Transient Climate change and Equilibrium Climate change experiments often used on for equilibrium climate change experiments of the first generation of climate change experiment. Added atmospheric carbon dioxide concentration used when applicable the equilibrium response of the climate system to an instantaneous increase. Besides that, these experiments can only be carried out to simulate the short term and the results cannot be repair because of the absence of the ocean, and because only a slow computer available.

The emergence of high technology computers in addition coupled ocean atmosphere-biosphere GCM, this climate change experiments could be performed with coupled ocean-atmosphere for Transient Climate Change. It is possible to investigate the reaction of the climate system to a different scenario of force rendering. One of the great implications of this experiment is that decisions can be fixed.

Gao (1995) wrote that it is classified that GCMs are divided into three distinct types which is atmospheric, oceanic and coupled. Generally, the atmospheric type is to predict the physical characteristic of the atmosphere so does to the oceanic type which representing the physics the ocean. Meanwhile, coupled GCMs which researches see as the most developed of the models, physically join these two types of GCMs and threat the advancement of the climate in both areas. To enhance expectations of the future climate, modelers are additionally endeavoring to join, and some to the certain extent have joined the land surface to the atmosphere and the atmosphere.

Climate models is typically used to simulate the climate change numerically in the future, given decades of year ahead with certain factors such as concentration in greenhouse gasses (GHGs) that produce a result of changes in low pace enables these researchers to learn the climate by the means and the variability. However, it often been mistaken with Numerical weather prediction (NWP) models. These two models use the same motion equations but, NWP model is used to forecast the weather in shorter in range 1-3 days and medium in range 4-10 days. GCM are run much longer, for years on end, long enough to learn about the climate in a statistical sense. NWP model is related to the prediction of the motion and development of disturbances that is tropical cyclones as well as frontal system. Meanwhile, GCMs is more related to the quality of the occurrence of disturbances whether tropical or extratropical, NWP and its relations are applicable to GCMs, the models are bound to make error after a while, give it 2 weeks to the point it becomes not useful from weather foresight perspective. NWP do not affect by the error in temperature for the sea surface by small margin of different in degree Celsius because this factor matters a little in weather forecasting. Unlike NWP, this factor the most to GCMs over a long term. Other that than, based on the definitions and functions of both types model, it can be concluded that GCMs are not both with oscillate conditions when taking into account the endless changes and NWP models do not affected by the slow processes. In the long-term changes, GCM ignore fluctuating conditions. The NWP model is not suitable compare to the dynamic ocean model as opposed to GCM which is most suitable for use dynamic models of sea ice and conditions on land. There is comparison between GCM and NWP as summarized in Table 2.1.

Table 2.1: Comparison between NWP models and GCM.

	NWP	**GCM**
Main function	Weather prediction	Climate prediction
Area covered	Regional or Global	Global
Time range	Days	Years
Area resolution	Variable (20-100 km)	Usually coarse
Relevance of initial conditions	High	Low
Relevance of clouds, radiation	Low	High

Relevance of surface (land, ice, ocean)	Low	High
Relevance of ocean dynamics	Low	High
Relevance of model stability	Low	High
Time Dimension	Essential	Ignored
	NWP & GCM	
Physics	equations of motion	
Method	Finite difference expression of continuous equations, or spectral representation	
Output	State variables and motion of the atmosphere in 3 dimensions	
Maximum Time Step	Controlled by spatial resolution (CFL condition)	

Source: Geerts and Linacre (1998).

The GCM output cannot directly be used for hydrological assessment due to their coarse spatial resolution. Hydrological models deal with small catchment scale processes, where GCMs of the climate system are limited in their helpfulness for parameter many regional. It is the series of actions whereby the outputs by the GCMs are more favor to the coarse resolution hence its function to translate them into finer resolution of information climate in order to produce better outcomes for influences in regional climatic like local topography (Climate Change in Australia, 2007-2015). By using the GCM climatic output variables, only certain station data may be used to convert the coarse spatial resolution of the GCM output into a fine resolution known as downscaling. The two main approaches for downscaling that can be used, namely DD (dynamical downscaling) which involves a nested RCM (regional climate model) and SD (statistical downscaling) model which employs a statistical relationship between the large scale climatic state.

2.3.1 Features of Global Climate Model

Global climate models use for simulating the response of the global climate system to the increasing greenhouse gas concentrations. All three dimensional atmospheric and ocean dimensions have been used to study the effects of changes in atmospheric composition to global climate. The sensitivity to small changes in surface or radiation input and long-term stability is a major problem in GCM. The newer GCM can make a difference between the greenhouse gas reminder effect and the regional aerosol sulphate cooling effect. Many GCM experiments are now available for use in climate change studies.

The main features of General Circulation Models such as the main goal is to predict the future climate, they have a global spatial coverage, they have a temporal range of years to centuries, they have a very coarse resolution of several hundreds of kilometres, they are based on the conservation law of mass, momentum, energy and water vapour and controlled by spatial resolution. They method used to run GCM is finite different expression of continuous time and space equation, or a spectral representation.

2.4 Downscaling Model

Outputs from GCMs can be useful in getting an overview of possible climate scenarios, but are typically too coarse in scale to be useful in practical comprehensive water resource planning situations (Durman, 2001). Extreme rain patterns like long rain and drought are described in hydrology applications. Thereby climate change impact studies need to reproduce the important patterns in observed precipitation simulations using the multisite precipitation. The use of scenario outputs in local water management can solve problems to downscale the output from GCMs to a higher resolution in space or time.

The efforts of climatologists and hydrologists have developed Downscaling techniques. More recently, downscaling has found wide application in hydro-climatology for scenario of construction, simulation and prediction of regional precipitation (Kim et al., 2004), low-frequency rainfall events (Wilby, 1998), mean, minimum and maximum air-temperature (Kettle and Thompson, 2004), runoff (Arnell, 2003), stream flows (Cannon and Whitfield, 2002) and ground water levels (Bouraoui, 1999).

There are two main approaches called statistical downscaling (SD) and dynamical downscaling (DD), it is display methods similar level at estimate surface weather variables under current climate condition for downscaling outputs of a GCM. Some of the problems in the statistical downscaling (SD) method are due to the assessment of the future climate change scenario and the recognition of inter-variable biases in host GCMs. This is because uncertainties exist in both GCMs and downscaled climate scenarios. For example, precipitation changes projected by the U.K. Future changes in atmosphere humidity to add with ocean atmosphere model HadCM2 in Meteorological Office (Murphy, Wilby, and Wigley, 2000). The SD method is easier than the DD method as it reduces the size of the GCM output. Besides, Wetterhall (2006) stated that global-scale climate variables such as mean sea level pressure, zonal wind, temperature, geo-potential height, etc. are linked with local-scale variables (regional-scale variables) such as observed temperature, precipitation and humidity, and this is done by producing some statistical/empirical relationships when using SD.

2.4.1 Dynamical Downscaling Method (DD)

There are several functions such as to highly understanding of the atmospheric physical behaviour and regional interactions and feedback involving the development of regional climate models in Dynamic Downscaling (DD). Principle GCM similar with the use of a regional climate model (RCM) but with high resolution in Dynamical downscaling. DD is applied by using the RCM, but there are certain limitations that hold back that the effectiveness of using RCM. They are restricted in the size of the possible area, the number of repetitive experiment along with the timeframe of the simulation process. When the variables are restricted with such level, it could affect the outcomes and would not be as consistent and precise as statistical downscaling. Apart from that, the outcomes of the RCM can also be easily affected by the selection of the limit conditions like the moisture of the soil that is function to begin the experiments. However, despite the limitations of the RCM, there are still certain valuable advantage that researcher could benefit from that is RCM beyond the bounds of GCM can definite the fine scale of the atmosphere characteristics such as jet stream in the lower level and also one of the specific types of orographic precipitation. Moreover, RCMs can be utilized to investigate the relative centrality of various outside forcing for example earth like ecosystem. To generate realistic climate information at a spatial resolution of approximately 20–50 kilometres, RCM take the large-scale atmospheric information supplied by GCM output at the lateral boundaries and detailed descriptions of physical processes.

Seaby (2013) wrote that the tied to the accuracy of the large-scale that force GCM to rely on quality of dynamically downscaled RCM. Despite recovering important regional-scale but less known features in GCM resolution. Paolo (2013) stated that RCM outputs are still subject to systematic errors in the seasonal timescales lower 10 mm/month and therefore often require a wrong correction as well as further downscaling to a higher resolution.

The completion process atmospheric process such as topographic precipitation and consistency with GCM that are advantages of dynamical downscaling answered correctly in physically consistent ways to different external forcing. It can model changes that have never been observed in historical record and captures feedbacks. However, there are some weakness of dynamical downscaling such as it dependent on the realism of GCM boundary forcing initial boundary conditions affects results and requires significant computing resources. Problems with drifting of large scale climate and limited amounts of model, run and timescales. Among the aspects of dynamical downscaling techniques is determining whether the high resolution scenarios actually lead to significantly different calculations of impacts compared to the coarse resolution GCM that the high resolution scenario was partly derived.

2.4.2 Statistical Downscaling Method (SD)

Statistical downscaling or empirical downscaling is a tool for downscaling climate information from coarse spatial scale to fine scales. Statistical Downscaling (SD) of nonlinear and linear relationship between large scale atmosphere variables known as predictors and local climate variables known as predictand (Wilby and Dawson, 2007). The predictor characteristics were considered the emission level of GHGs an aerosol forcing in the earth spaces. Meanwhile, the predictand climatic series were taken from the local climatic stations consists of temperature and rainfall stations in the region.

Due to the higher on demand and cost, SD method. Wliby (2002) believed that DD are too expensive, SD on the other hand offer much lower cost and in the requirement of the fast evaluation of notably high localize climate change impacts thus making it more reliable as a downscaling option. Unlike dynamical, SD requires minimum demand in computational wise which encourage the time of group of climate acknowledge to assess equivalent scenarios (Wilby, 2002). NCEPs are available for limited area and studies.

Moreover, the outputs of NCEPs are in grid resolution for NCEPs is 50km for most practical applications, such like hydrological studies. SD method are development to overcome these challenges but it is more user friendly with efficient cost in implementation.

The use to lower the RCM output to a finer resolution only involves the use of RCM for the lower GCM output before the statistical equation in decreasing Dynamic statistics. Guyennon, (2013) stated that is statistical downscaling to high-resolution output due to better forecasters and specific regional climate modeling within the DD. To compare DD, the statistical-dynamical downscaling is a better performance because of less calculation but its use is rather complicated. Fuentes and Heimann, (2000) stated that this method statistically pre-filters GCM outputs into a few characteristic states that are further used in RCM simulations.

SD method need a strong relationship and adequate data to prove this theory for the predictor-predictand connection. If the relationship does not take account into the crucial climatic characteristics such as the circulation of large scale. So that, SD is better sub-GCM grid scale information on extreme events such as heavy precipitation (Diez, 1999). There are several advantages of Dynamical Downscaling procedures which are flexible adaptation to specific study purposes, and inexpensive computing resource requirements in Statistical Downscaling Methods. The selection of this downscaling method is majorly control by the data availability for the calibration of the model as well as requirement variable. Majority used model SD by Statistical Downscaling Model (SDSM) and this model early to widen group of the effect of the climate changes. These studies utilized various strategies to downscale and correct the error GCMs and RCMs. The comparison between these downscaling method can be observed on below the Table2.2.

Table 2.2: Comparison between Statistical Downscaling and Dynamical Downscaling

Characteristic	**SD**	**DD**
Provides	➢ Any scale, down to station-level information	➢ 20–50 km grid cell information ➢ Information at sites with no observational data

	➢ Daily time-series (only some methods) ➢ Monthly time-series ➢ Scenarios for extreme events (only some methods) ➢ Scenarios for any consistently observed variable	➢ Daily time-series ➢ Monthly time-series ➢ Scenarios for extreme events
Requires	➢ Medium/low computational resources ➢ Medium/low volume of data inputs ➢ Sufficient amount of good quality observational data ➢ Reliable GCM simulation	➢ High computational resources and expertise ➢ High volume of data inputs ➢ Reliable GCM simulations
Applications	➢ Country or regional level (e.g., European Union) assessments with significant government support and resources ➢ Future planning by government agencies across multiple sectors ➢ Impact studies that involve various geographic areas	➢ Weather generators in widespread use for crop-yield, water, and other natural resource modeling and management ➢ Delta or change factor method can be applied for most adaptation activities
Factor affect	➢ Predictor variable	➢ Initial boundary condition

	➢ Empirical transfer scheme	➢ Selection of cloud/ precipitation
Advantages	➢ Based on consistent, physical mechanism ➢ Resolves atmospheric and surface processes occurring at sub-GCM grid scale ➢ Not constrained by historical record so that novel scenarios can be simulated ➢ Experiments involving an ensemble of RCMs are becoming available for uncertainty analysis	➢ Computationally inexpensive and efficient, which allows for many different emissions scenarios and GCM pairings ➢ Methods range from simple to elaborate and are flexible enough to tailor for specific purposes ➢ The same method can be applied across regions or the entire globe, which facilitates comparisons across different case studies ➢ Relies on the observed climate as a basis for driving future projections ➢ Can provide point-scale climatic variables for GCM-scale output ➢ Tools are freely available and easy to implement and interpret; some methods can capture extreme events
Disadvantages	➢ Computationally intensive	➢ High quality observed data may be unavailable

	➢ Due to computational demands, RCMs are typically driven by only one or two GMC/emission scenario simulations ➢ Limited number of RCMs available and no model results for many parts of the globe ➢ May require further downscaling and bias correction of RCM outputs ➢ Results depend on RCM assumptions; different RCMs will give different results ➢ Affected by bias of driving GCM	for many areas or variables ➢ Assumes that relationships between large and local-scale processes will remain the same in the future (stationarity assumptions) ➢ The simplest methods may only provide projections at a monthly resolution
Quality of data	High	Low
Cost	Low	High
Computer Technology	Low	High
Physical consistency	No	Yes

Source: STARDEX, 2005 ; Fowler, 2007 ; Wilby, 2009 and Daniels, 2012.

2.4.3 Statistical Dynamical Downscaling (SDD)

Statistical dynamical downscaling links global and regional model simulations through statistics derived for large-scale weather types. The regional simulations are initialized using representative vertical profiles for each weather type and then run for a short period without lateral forcing by the global model (Heinmann and Sept, 1998). The statistical-dynamical approach combines advantages of the other two methods. As in dynamical downscaling, a regional model is used and as in statistical-empirical downscaling, the computational effort does not depend on the length of the period to be downscaled. Statistical dynamical downscaling consists of three steps which are a multi-year time series from a GCM simulation is classified into an adequate amount of large-scale weather types characteristic for the region of interest. These weather types are defined on a scale which is well resolved by the GCM. The frequency of the weather types is used as the probability of their occurrence in the climate simulated by the GCM. Next, regional model simulations are carried out once for each weather type. The regional model calculates the mesoscale deviations from the large scale state due to the impact of the regional topography. The model domain is situated within the area in which the frequencies of the large scale weather types are derived. The last part, the regional model output is weighted with the respective frequencies of the weather types and then is statistically evaluated to yield regional distributions of climatological parameters (mean values, or frequency distributions) corresponding to the global climate represented by the GCM data.

2.4.4 Statistical Downscaling Model (SDSM)

Precipitation scenarios at a fine temporal and spatial resolution are needed in order to improve the design and evaluate the future performance of urban drainage systems (Bardossy, 2005). Statistical downscaling method is the only method that requires very few parameters and this makes it attractive for many hydrological applications (Wilby, 1999). Statistical downscaling techniques were applied based on the daily precipitation series and downscaled the HadCM2 greenhouse experiment results to a scale relevant for hydrologic impact empirical methodology based on modelled monthly changes from for the time of horizon 2050 years. These research aimed at a problem faced by hydrologists undertaking impact studies on flooding at Severn at Haw Bridge, a catchment of 9895 km2 situated in Wales in western England due to the inappropriate scales of the climatic output provided by Current GCMs. It is found that these scenarios show an overall change of the flood regime both in terms of increase of magnitude and frequency of the extreme events (Prudhomme, 2002).

Charlton (2006) stated that the GCM output using statistical techniques to provide precipitation for the baseline period of 1961-1990 and future in years 2041-2070. The results proved that the statistical downscaling technique was able to give significant result for climate change impact assessment on water supply and flood hazard. The results of these simulations indicate a decrease in annual runoff that is most marked in the east and southeast of the country, whereas an increase is likely for extreme northwest. It is also found that increasing trend in runoff is suggested for the western half of country which could have implication for flood frequency.

Meanwhile Huth (2000) evaluated local daily temperature produced by two GCM, several statistical downscaling methods and a weather generator, distribution of day-to-day temperature changes and characteristics of heat and cold waves, while the latter in terms of extreme value distributions and return periods. It is also shown that the spatial behaviour of precipitation is dependent of time scale, precipitation is more intermittent for shorter time periods (Huth, 2000).

Khan (2006) used that SDSM, Long Ashton Neutral Network (ANN) and Long Ashton research station weather generator (LARS-WAG) to compared the Various Uncertainty assessments exhibited in their downscaled results of daily precipitation, daily maximum and minimum temperatures. The study has been carried out using 40 years of observed and downscaled daily precipitation, daily maximum and minimum temperature data using National Centre for Environmental Prediction (NCEP) reanalysis predictors starting from 1961 to 2000. The uncertainty assessment results indicate that the SDSM is the most capable of reproducing various statistical characteristics of observed data in its downscaled results with 95% confidence level, the ANN is the least capable in this respect, and the LARS-WG is the between SDSM and ANN. However, Hassan (2013) wrote that the SDSM output is better achieve compared to LARS-WG because SDSM approximate higher change of annual rainfall.

Compare to Providing Regional Climates for Impacts Studies (PRECIS), it is only dependent on the realism of GCM boundary forcing and choice of domain size and location affect results. The limitation of PRECIS also is the initial boundary conditions will affect and choice of cloud/convection scheme affects precipitation results. Lastly, this is not ready transferred to new regions. PRECIS is currently used to produce the projection of climate scenario for peninsular Malaysia, Sabah and Sarawak.

2.5 GIS Operation and Implementation

Geographic Information System (GIS) applications are commonly used to generate rainfall patterns in visual formation with a combination of characteristics of rainfall data and then can be used by stakeholders to facilitate the process of analysis and forecasting rainfall (Mohd Zambri,1999). It has a long history and has been through main version and changes. Originally developed for large mainframe computers, in the last 10 years it has appear from system based on typed command to a graphical user interface, which makes it much easier to use because of the size and user have come to depend on certain aspect of the software, much the code is carried forward and include in new version. The reason is that GIS have contributed critical information as input of the models.

In addition, GIS process become a critical step in hydrological modelling since it contributes to generate model parameter distribution in spatial manner. In these applications, the GIS processing step such as data store, map overlaying, map analysis has help to derive hydrologic parameters from soil, land cover and rainfall maps (Schumann, 2000). Knowing this background helps a student of ArcGIS understand the nature of the ArcGIS system and helps explain some characteristics. ArcGIS release 2001, is the powerful Arc/Info system with the easy to use interface of ArcView, update to use the latest advance in desktop computing and database technology. It contains two programs collectively referred to as ArcGIS Desktop which are ArcMAP and ArcCatalog. ArcMap provides the means to display, analyse, edit spatial data and data table. Similar in appearance to its ArcView predecessor, it nevertheless contains powerful new functionality.

There are have four application GIS which are environmental planning and management, hydrology and water resources, urban planning and socioeconomics, and urban growth modeling. Various applications have different user requirements based on vendor specifications. Environmental planning and management requires the spatial data analyses and management capabilities of environmental decision support systems (EDSS), which integrate monitoring data and, through modeling, enhance solutions to particular problem areas including environmental impact assessments, which include soil erosion and pollution hazards and their underlying factors. Applications in hydrology and water resources couple GIS with specific models of spatial attributes such as land use and precipitation patterns, usually for response prediction of, say, floods and sediment yields. This model can be useful in the support of management and water resources operations including improved understanding of hydrological process dynamics. Other applications are the reduction of the risk of property damage in settlements, urban planning and modeling, and other socioeconomic applications (Ondieki C.M. and Murimi S.K, 2006).

A GIS is required for creating awareness of environmental conditions for various applications including policy making. This involves the use of data. A GIS will in general have a means of inputting data into a database, editing the data, displaying information stored in the database, and performing certain calculations including sorting of the data in the database. The nature of the data stored and the analytical and modeling capacity of a GIS will determine the solution to particular problems related to floods or land use planning or other potential needs.

The role of a GIS is to enable the capture, storage, and manipulation of data in a structured form, therefore allowing the use of analytical techniques on the spatial dimensions of problems. With a GIS, analysis and depiction of spatially referenced information as well as dissemination of results of analysis using thematic maps is possible. Environmental science and other disciplines have generated enormous amounts of data of many different types, and this is bound to increase in future.

For the previous research in Batu Pahat, to determine the pattern of rainfall in the area of Batu Pahat in the form of mapping based on information and criteria required in the use of GIS applications. GIS application effectiveness is determined by using the analysis result of the rainfall distribution pattern based on cause and effect of the highest rainfall identified during the review period. For the result, GIS in determining the distribution patterns of rainfall in Batu Pahat area have proved their effectiveness where the analysis have shown that 2006 and 2007 were the years of the heavy rainfall occurrence and the application has proved the existence of massive flooding event caused by heavy rains that year (Kadir et al. 2016). GIS applications are also suitable model of hydrological processes.

In this studies, the method of GIS interpolation technique can build an isohyet line using ArcMap software to developed for all the above procedures to process the projected daily rainfall data and spatially interpolate them into 100 m grids. A rainfall filter is applied such that any daily rainfall event above a maximum threshold 350 mm/day is replaced by that value. To save computation time, only wet days were selected for spatial interpolation and calculation of monthly and annual rainfall. A threshold of 0.1 mm was chosen to define wet days. Other thresholds could also be chosen 0.2 mm, but a previous study showed that it is reasonable to choose the threshold in the range 0-1 mm (Hindawi, 2015). While ungauged catchment, an exploration on data sources from satellite images. Especially potential sources contributed from public domain satellite data have been utilized in many applications, for example SRTM (Rabus et al.2003) for DEM generation, METEOSAT (Barrbera, 1995) for rainfall estimation.

2.5.1 Climate Interpolation Using ArcMAP

A GIS is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map. This enables people to more easily see, analyses, and understand patterns and relationships. With GIS technology, people can compare the locations of different things in order to discover how they relate to each other (Mohd Zambri, 1999).

GIS Statistical Analyst has the capability to apply many types of spatial interpolation to input point data. Depending on the spatial variability, some types are not necessary or appropriate. Part of this study was to determine the most appropriate interpolation method for the data provided. The data presented for analysis has already been normalized to a 2km grid, for example some surface interpolation methods may not truly come into play. Rarely in science is there a truly homogeneous surface like the study data which is only thus because it has already been interpreted from rain gauges. It should interpolate data because the most likely is that could never sample adequately for all locations that are interested in. Think of rainfall measurements. The older and more precise method of measurement involves rainfall gauges that need to be inspected at various points during a rainfall event. Because of data collection issues, such as the time to travel to each gauge and check the rainfall amounts, a limited number of rain gauges are used. Because there is a spatial correlation between rainfall amounts in various locations, it is assumed that rainfall gauges near each other have similar rainfall and that the rainfall amounts between rain gauges is similar to the rainfall amounts at the gauges. The further you are from a gauge, the less certain you are about the amount of rainfall at that location. Predicting rainfall, elevation, or anything else, between locations where you have measurements, is spatial interpolation. It is possible to do this in ArcMAP and other GIS software.

It will interpolate data using two of the three interpolation procedures available in ArcMAP. You should look at the help system to see how these work. Additionally, there is much information in the literature on spatial interpolation. The choices you have in the software are using are commonly found in most commercial GIS packages.

Traditionally, rainfall data were obtained from local authorities at meteorological stations rain gauges data collection. Using Kriging interpolation method data in each rain gauge was measured to gain its total volume of rainfall on the area. How accurate the rain gauge in predicting rainfall volume is depends on how consistent the gauge estimates where it is actually represent the rainfall distribution between each gauge. It is hardly to get the accurate results using rain gauge alone, therefore it was not surprising that many hydrologic analyses frequently exhibit large uncertainties (Hoblit, 2013). Thus, the usage of GIS applications to produces the rainfall patterns in the form of visual and combined with the attribute data of rainfall can be used by stakeholders to facilitate the process of analysis and forecasting rain. Consequently, would help to solve the problems associated with rainfall data. The method of Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location (ESRI, 2016). This method gives more accuracy in interpolation results because it gives values close to the minimum and maximum values of the sample data.

Interpolation is the procedure used to predict cell value for location that lack sample points. The Kriging method, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in Kriging, the weight, depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location (ESRI, 2016)

Hydrologic modelling requires climatological data is an important variable. However, most of the weather data rainfall is collected using rain gauges, hence point data in nature. However, more often than not spatially explicit rainfall data are required by the hydrologic models. The spatially explicit data are often obtained using interpolation methods. The representation of rainfall data in the digital world and its accuracy is controlled by the spatial distribution of the weather stations and the spatial interpolation methods used which may or may not reflect the reality actual spatial pattern of rainfall. Actual patterns intensity, duration and spatial distribution of rainfall affects the hydrology of a watershed. In a given watershed, weather patterns can vary from low intensity-short duration or low intensity and long duration rainfall to high-intensity-short duration rainfall. Digital presentation of the variability of rainfall pattern is affected by the interpolation methods used as well as the nature of original data.

Historically, rainfall data are collected using rain gauge stations. These site specific data were then interpolated to create continuous surface for the rainfall data. Needless to say interpolation methods more often than not fail to represent the variability of the rainfall pattern. In more recent years, the usage of Next Generation RADAR (NEXRAD) has become more widespread and gained appreciation in the hydrologic modeling community as a source of input data to hydrologic models as these datasets provide continuous spatial coverage, hence captures the rainfall variability with less uncertainty than simple point data and its derivative interpolated surfaces. Although, the temporal resolution of the NEXRAD data is very fine (every 15 minutes is available), the spatial resolution of the cells that contain rain information are generally very coarse (2km) compared to other available GIS data layers. Therefore, some issues of error propagation with hydrologic models cannot be ignored. One solution to such issues is the use of Gage-Adjusted Radar Rainfall (GARR), which combines rain gage estimates at a point with the spatial distribution information from the National Weather Service NEXRAD (Hoblit & Curtis, 2005).

For the previous research, the method of GIS interpolation technique uses to compare rainfall interpolation methods. Based on the annual rainfall record for 4 years 2005-2008 of 21 rainfall station across the mountainous leeward portion of the island of Oahu, Hawaii. Using the Geostatistical interpolation methods, including Thiessen polygon, Inverse Distance Weighting (IDW), linear regression and Kriging. The Thiessen method produced the highest error, whereas Kriging method produced the lowest error in all but one period. The Kriging method produced more accurate predictions than linear regression of rainfall against elevation when the correlation between rainfall and elevation is moderate (R<082). Comparison of the Kriging method interpolation map with gridded isohyet data indicate that the areas of greatest rainfall deficit were confined to the mountainous region of west Oahu (Mair & Fares, 2011).

Overall, the application of GIS is one of the appropriate tools in handling information and involved operation such as planning, observation, collection, storage, management and analysis of data to produce information that can used in the decision-making process. Kadir (2016) wrote that GIS applications are also able to create a better performance in term of hydrological processes rather than using rain gauges alone.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Observed daily historical rainfall data of these rain gauge stations were collected from the DID Pahang. Firstly, the annual rainfall data across the state of Kuantan for a period of 30 years was analyzed based on the three stations selected. This studies use two methods which are SDSM and GIS for assessment of the ungauge rainfall forecasting. This aim for this study is to evaluate the performance of SDSM as climate agent and also to predict the long term rainfall trends in 30 years in Kuantan district at ungauge area. Therefore, the integrated of SDSM-GIS Model have been used to solve the ungauged problem.

The GIS analysis through the ArcMAP application. The three stations were registered in the GIS map and the average annual rainfall value for each station will be used as an additional input into the GIS attribute file for interpolate data. This interpolation is the procedure used to predict cell value for location that lack of sample points. After that, the isohyet maps that represented the annual rainfall for each year was predicted by using the interpolation of Kriging method in GIS software. This is a more practical way to discuss rainfall patterns in the Kuantan area with limited rainfall stations especially ungauged rainfall.

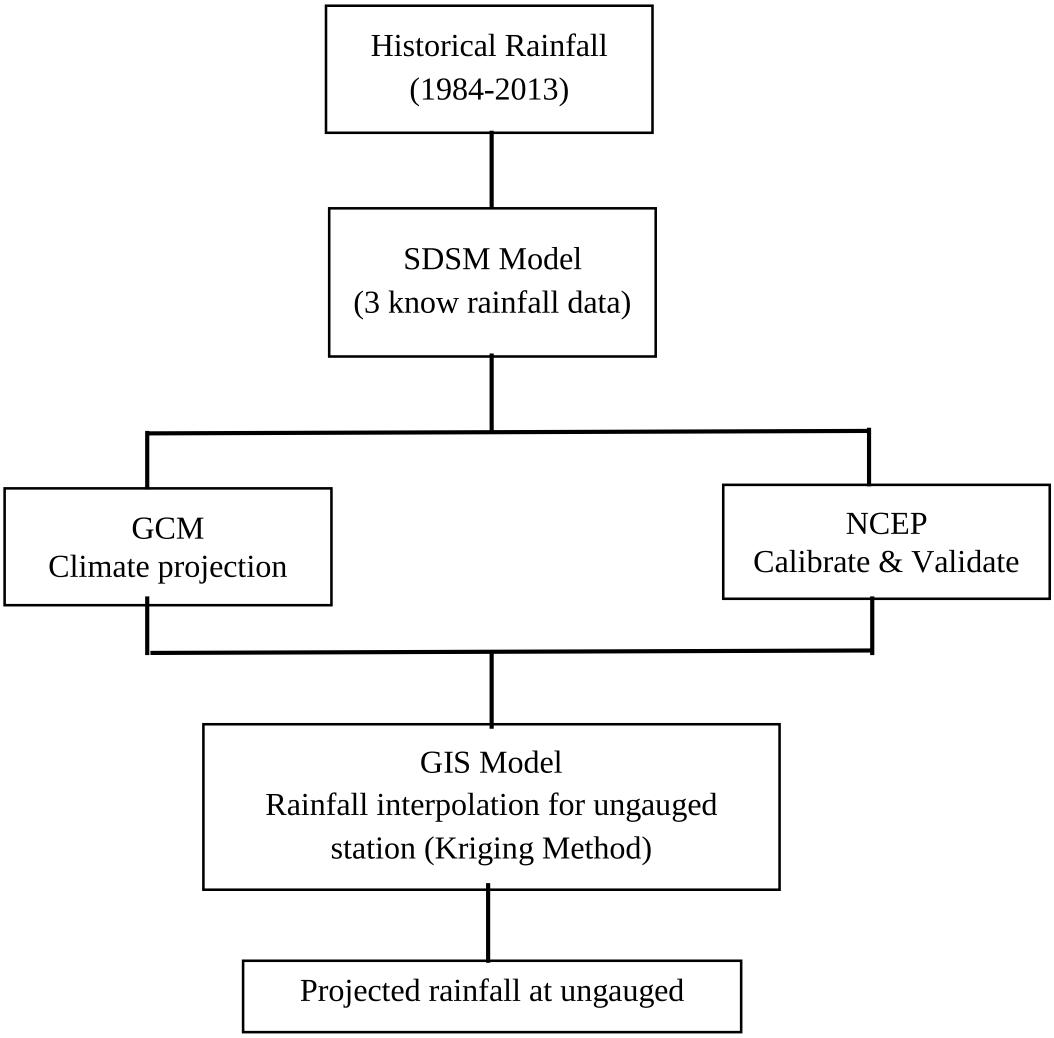

Figure 3.1: Methodology of the study

3.1.1 Site Study

The study is focused on Pahang state, its located on the East Coast of Peninsular Malaysia with its boundaries covering averaging 102^o 23'T to 103^o 30'T and a 3^o 53'U line up to 4^o 38'U. The total area of the state is 35965 km^2, which is 9.8% of the total area of Peninsular Malaysia and consists of 11 districts, Temerloh district, Bera district, Rompin district, Pekan district, Raub district, Maran district, Kuantan district, Lipis district, Jerantut district, Bentong district and Cameron Highland district. The state of Pahang consists of a diverse surface area of the sea level 0 meters up to 3000 meters above sea level. Approximately 70% of the country comprises low-density land less than 200 meters above sea level. However, only about 30% of the territories of Pahang are flooded. The average wind speed is 6 mph and average humidity is 80%. The rainfall distributions at this region is influenced by the wind direction and 2 monsoons pattern known as Northeast (October - March) and Southwest (Jun - August) monsoons and result in almost every part of the state in Pahang in the catastrophic floods in November and December. Malaysian Meteorological Department (MMD) and the Department of Irrigation & Drainage (DID) stated that for Pahang have been receive in average 2000mm/year until 4000mm/year and total average temperature is 27°C to 32°C. The average monthly rainfall in this area ranges from 200 mm to 790 mm. Three (3) rainfall stations at surrounding Kuantan district were selected based on the availability of 30 years length data records. A 30-years period or more as standard reference was recommended for climate change and climate variability study or trends in climatology (Gulacha and Mulungu, 2017).

3.2 Statistical Downscaling Model (SDSM)

SDSM 4.2 is one of the downscaling models that applied the multiple linear regression (MLR) and the stochastic weather generator (SWG) analysis to interpret the relationship between GCMs characteristics with local climatic records (Wilby, 2002). The correlation matrix, scatter plots, P value, histograms, and partial correlation are functions of use multiple linear regression model in the atmospheric predictors. A statistical/empherical relationship between National Center for Environmental Prediction (NCEP), large-scale variables (predictor), and local scale variables (predictand), and produces some multiple regression techniques has been fixed by MLR. Moreover, prediction (NCEP), large-scale variables (predictor), and local scale variables (predictand), and produces some multiple regression techniques. Calibrated parameters, together with NCEP and GCM predictors, were then used by SWGs to simulate up to 100 series of time each day to create better relationships with the time series observed. To develop the downscaling relationship, should be reanalysis data calibrates and validates in the period year 1984 - 2013 from daily rainfall data and daily atmospheric predictors NCEP. At that point, the GCMs data are applied to generate future trend for interval year periods of 2050.

Despite these variables were credible to project the climate change but the spatial resolution presented by GCMs are coarse 250km to 600km and the changes of climate in general trending (Ghosh and Mujumdar, 2007). Wigley (2000) stated that the ability of GCMs output would be suspicious because some climatic condition especially precipitation features are critically well correlated with the atmosphere condition at specific sub-grid scale.

Before applying the calibration and validation, the raw data need to transform into standard predictor variables to produce nonlinear regression and the data series can also be shifted forward and backward by any number of time steps to produce lagged predictor variables. Annual sub-models drive the same kind of regression parameters for 12 months and the monthly sub-model represents 12 regression equations, to get different calibrated parameters for each of the 12 months.

There were also two types of sub-models namely as conditional and unconditional. Both of them can be used according to the local-scale variables. The independent or unconditional variables such as temperature used for unconditional sub-model. Variables such as precipitation and evaporation used for conditional sub-model (Wilby, 2002 and JT Chu, 2010). Usually, temperature data is distributed normally but in the case rainfall data is not distributed normally. This case uses the rainfall data at station area Kuantan was presented in daily time series and was converted into month and annual period for analysis. SDSM can transform the data to make it normal before using the data in regression equations (MS Khan, 2006). For example, (AG Barnett and C.Huang, 2011 ; MS Khan, 2006) used the fourth root for precipitation to render it normal before using it in a regression equation.

SDSM has two types of daily time series, the first is daily historical site data and second is NCEP daily predictors. The outputs of this model are daily time series, which can be produced by forcing the NCEP or Hadley Center General Circulation Model (HadCM3) predictors under A2 and B2 scenarios were used as the predictor to simulate climate trend (AG Barnett and C. Huang,2011; MS Khan, 2006). HadCM3 model was a modified version of HadCM2, made to improve the accuracy of the climate projection results without the application of flux adjustments. It has wider coarse spatial resolutions of 2.5° x 3.75° (latitude by longitude) which can be applied in many climatic regional studies. Samadi, (2010) considers HadCM3 as the best GCM model that is superior to other models such as CCSNIES, CSRIO, and GFDL. The A2 scenario was chosen to capture the future rainfall trend at this region because by providing medium-high emission scenarios it would be more suitable with the study area. Hence, the A2 scenario was applied widely in the study area due to the efficiency of the climatic projection results

(Chu, 2010; Horton, 2005). The projection results produced by this model were used as data input for hydrological analysis, crop water requirement, and optimization model.

3.2.1 SDSM Climate Scenario

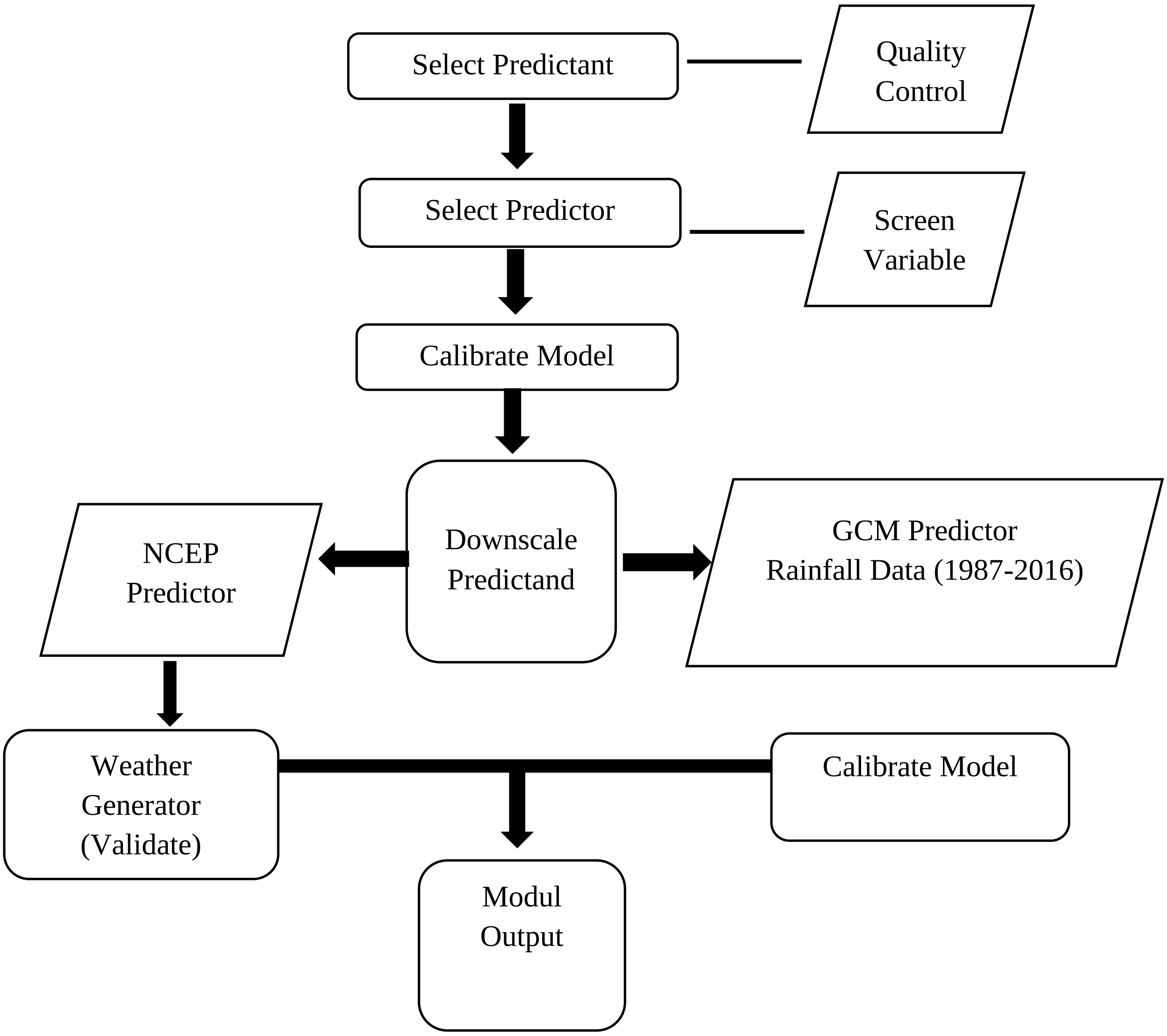

Figure 3.2: Methodology of SDSM

Figure 3.2 represent the methodology of SDSM model. To downscale the local climate change two sorts of information were required and those incorporated the rainfall and temperature station known as predictant and two sets of predictor at the matrix box 34X x 38Y. Apply SDSM to GCMs data, both observed predictand and GCMs data should ideally be available on the same grid spacing. However, observed and GCMs predictor variable are seldom available at the same grid solution, required interpolation and regridding of at least one of the data sets. Wilby and Wigley (2000) state that the grid box nearest to the target site does not always yield the stronger predictor-perdictant relationships. In this study, three of historical rainfall stations were utilized as predictand. The choice of rainfall stations depends on the lesser rate of missing information to control the quality and creativity of information collection. This information was displayed in daily and was changed over into month and yearly period for the examination purposes.

Downscaling is justified when GCMs simulations of the required surface variable are unrealistic at the temporal and spatial scales of interest either because the impact scales are below the climate model resolution or because of model deficiencies yet are consider realistic or other related variables. The indicators set were given by NCEP reanalysis information to be utilized for adjustment and approval process and approval process and GCMs factor to create the future climate trend in view of expected increment of GHGs at the local region.

NCEP reanalysis is the atmospheric variables in the regional scale to construct the linear relationships with the local climate. The data were provided by the NOAA-CIRES Climate Diagnostics Centre which consists of air temperature, sea level pressure, geopotential height, specific humidity, and relative humidity between 500 hpa and 850 hpa. The NCEP data were applied directly in the screening process to select the appropriate predictors as downscaling agents. Then, the predictor selections were used in the calibration and validation by weather generator. The NCEP variables provide a guideline to the decision makers to view the predictor responses in the regional scale before simulating with the coarse scale resolutions (GCMs).

All input and output files text only format. Individual predictor and predictant file one variable to each file, time series data only are denoted by the extension *.dat. The *PAR file records meta-data associated with the model calibration, model weights, and measure of “goodness-of-fit” (percentage explained variance and standard error of the model). The *.SIM file records meta-data associated with every downscaled scenario such as number of predictor variables, ensemble size period and the *.OUT file contains an array of daily downscaled values one column for each ensemble member, and one row for each day of the scenario. Finally, *.TXT files are created whenever statistical analyses are undertaken by SDSM. These files record summary statistic for individual ensemble members or for the ensemble mean, and are accessed by bar/line chart options. The data format also enables convenient export to other graphing software and spreadsheets.

Table 3.1: SDSM File Names and Directory Structures

Extension	Expansion	Directory
*.DAT	Observed daily predictor and predictand file employed by the Calibrate and Weather Generator operations (input).	SDSM/ Calibration
*.PAR	Meta-data and model parameter file produced by the calibrate operation (output) and used by the Weather Generator and Generator Scenario operations (input).	SDSM/ Scenario/ Calibration
*.SIM	Meta-data produced by the Weather Generator and Generator Scenario operations (output).	SDSM/ Scenario/ Results
*.OUT	Daily predictant variable fiel produce by the Weather Generator and Generator Scenario operations (output).	SDSM/ Scenario/ Results
*.TXT	Information produced by the Summary Statistics and Frequency Analysis operations (output).	SDSM/ Scenario/ Results

3.2.2 Screening Variable

The screening process is important for the creation of reliable and credible downscaling scenarios. SDSM provides quantitative tools to assists in choosing a realistic set of predictors, even though local climate knowledge is part of best practices. Monthly percentage of explained variance show to capability of a given predictor to explained local climate variability. Gagnom (2006) wrote that the partial correlation coefficient applied to the most suitable predictors help eliminate those for which the weight is not important enough to influence the regression equations

In SDSM technical part, screening process is still the most challenging issue due to the selecting the best predictors in regression based downscaling techniques because different sets of predictor selection will likely give different result. It is crucial to make the choice especially in SDSM model to use the quantitative test which by using variance and partial correlation. Nonetheless, the steps in determine the most suitable predictors contain a certain level of subjectivity as per one judgements, one must decide whether a predictor is significant enough to avoid rejection. A possible solution to further reduce the level the subjectivity is the use of stepwise regression, as suggested by Hessami (2004) in their eastern Canada application. They initially included all available predictors in the regression model and the least significant terms was eliminated at every step until the remaining terms were statistically significant.

3.2.3 Selection of Predictor

One of the major challenges in climate downscaling, especially in downscaling technique is the selection of appropriate predictors. It is expected that predictors should be highly correlated with extreme rainfall indicates. However, Cavazos and Hewitson (2005) wrote that a wide range of predictor variables has been employed, making comparative evaluation problematic. Indeed, it is often uncertain that the chosen predictors are the most climatologically meaningful in terms of their relevance for the site-specific predictand. Furthermore, the predictor should be accurately projected by available GCMs for future project climate trend. There were no general guidelines for the selection of predictor is necessary. 26 NCEP variables that was usually projected by various climate models, including the Hadley Center Model (HadCM), were used in the present study for the selection of predictor. The description of 26 NCEP variables is given in Table 3.2.

The climatic system is influenced by the combined action of multiple atmospheric variable in a wide tempo-spatial space. Any single circulation predictor or small tempo-spatial space are unlikely to be sufficient for climate projection, as they fail to capture key rainfall mechanisms based on thermodynamics and vapor content. Following the suggestions of Wilby and Wigley, the regional synoptic circulation patterns that contributes to the irregular rainfall pattern in Malaysia were considered in the selection of the spatial domain of each predictor. The NCEP predictors that have high and strong correlation that have high and strong correlation values with rainfall at chosen station will be used to downscale.

Table 3.2: List of 26 Predictors

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

3.2.4 Calibration and Validation Processes

The calibration and validation processes are necesssily to ensure the accuracy and realibilty of the projected results. The goals were to identify the fundamental rules and the predictand-predictors relationship. In this study, the period ranges from year 1987 to 2016 were provided by Department of Irrigation and Drainage (DID). During calibration (1987-2001) and validation (2002-2016) processes each model used different approaches in controlling the accuracy of the model ouput.

Multiple regression equation based in downscaling models here be constructed in the calibration model process with given daily weather data act as the predictand and a regional scale atmospheric variables act a predictor (Wilby, 2007). Regression models for every month of the year was constructed with the relationship between predictand and selected predictors used calibrate the SDSM. The calibration of the SDSM was referred to the first 15 years of daily rainfall data and reanalysis predictors data sets reserving the last 15 years for evaluation of the calibration processes.

After the calibration process, validation process was required. Validation manages to deliver engineered current daily climate information in light of contributions of the observed time series data, and multiple linear regression parameters created utilizing observed data, which disregarded during calibration process. In this research, daily rainfall from the first 15 years of 30 years rainfall data ranges various from each station has been used to do calibration meanwhile the second 15 years from the 30 years period was used for the validation process. In this calibration and validation process the result that can be obtained is the percentage of absolute error between these two processes and the correlation value. Addition information included the variance of the generated scenario daily time series to compensate for the regression that does not explain all observed variance of the predictand, given to the user in the form of percentage of mean absolute error (MAE), correlation value (R) and standard deviation (SD) for the model. Moreover, the SDSM is capable of modelling both unconditional processes using the regression relationships and conditional processes such as precipitation.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|Xi - X\right| \tag{3.1}$$

Where,

n = the number of errors

Xi - X = the absolute errors

$$R = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{\sqrt{\left[n\sum x^2 - \left(\sum x\right)^2\right]\left[n\sum y^2 - \left(\sum y\right)^2\right]}} \quad 3.2$$

Where,

X = calibrated or validated data

Y = historical data

$$SD = \sqrt{\frac{\sum\left|x - \bar{x}\right|^2}{n}} \quad 3.3$$

Where,

X = calibrated or validated data

$\bar{X}$ = sample mean

n= the number of sample

3.3 GIS Interpolation Processes

A GIS was basically a computerized information system like any other database, but with an important difference which mean all the information in GIS should be linked to a geographic spatial references such as latitude and longitude, or other spatial coordinates. According to the Environmental Protection Agency a GIS works by combining database functions with computer mapping to map and analyses geographic data. It uses a layering technique to combine various types of data. Special GIS software was used to analyses layered data and create new layer of data. Geographical was a geographic reference, means it referred to data of spatial coordinates on the surface of the earth map. Information system data base of attribute data corresponding to spatial location and procedure to provide information for decision making.

GIS consists of two components which were spatial component and attribute component. Spatial component defined as the location of an information. Basically it was constructed from three forms which were lines, points, and polygons. Spatial data was categorized into two which were lines, points and polygons. Spatial data was categorized into two which were in raster and vector. Individual cells in a matrix, or grid, format was used in the raster data to represent real world entities. It was obtained from satellite from satellite imagery, aerial images of space, and a map scan. Meanwhile, the coordinate was used in the vector data to store the shape of spatial data object. It was performing in CAD software, Shapefile, Map info table, delimited text file with coordinates, Triangulated Irregular Network (TIN). Attribute component was the information in the database. The information that was mentioned before was related to geographic information, the position and size of plots of land, the systems network of road, and railways, drainage, sewerage, ranked rivers and building.

3.3.1 Interpolation Method Scenario

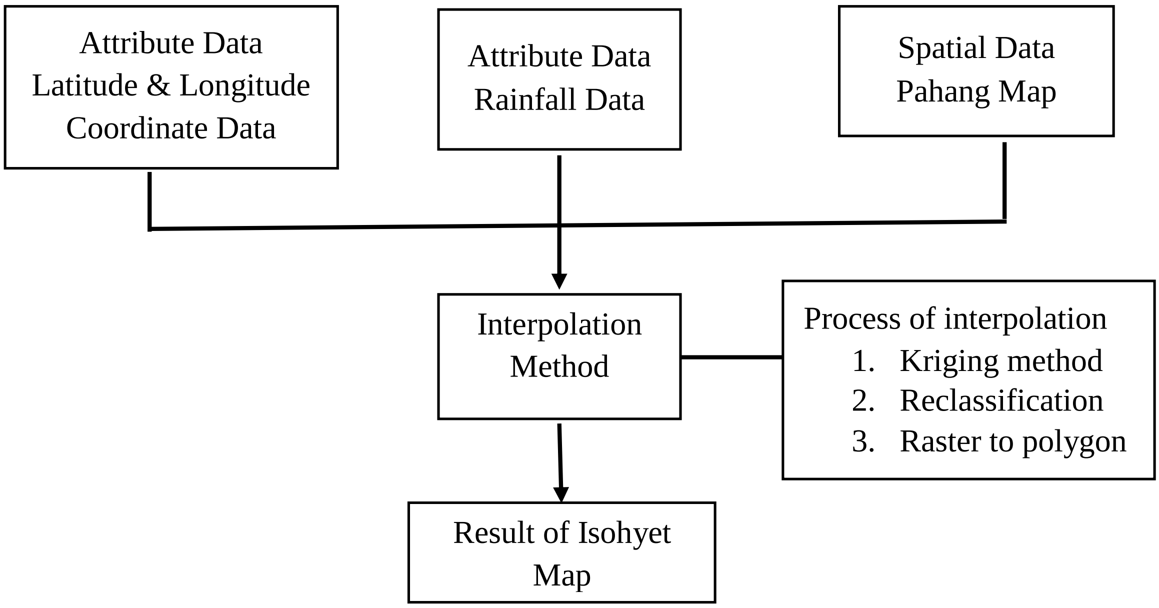

Figure 3.3: Methodology of interpolation method using GIS

The monthly rainfall data were used in this study. For each climatic zone, a cluster of 1 to 3 rain gauging stations was selected considered for the study. Stratified random sampling method was used to select rain gauging stations for the study. The monthly rainfall data of selected stations were estimated using selected techniques based on the observations of surrounding stations. In the analysis, all those years were excluded for all the stations within that cluster. In the instances where none or only station 2 had missing values, the averages of those particular months were used in place of missing data. In order to test the accuracy of methods used in estimation of missing data, a rain gauge station 2 and neighbouring stations, for which data are available, are selected and assumed that observations from station 2 are missing. Then using each method, observations for station 2 are estimated and compared with the actual observations.

Interpolation is the procedure used to predict cell value for location that lack sample points. The Kriging method, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in Kriging method, the weight, depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location (ESRI, 2016). The basic equation used in the Kriging is as (Eq.3.1) (ESRI, 2016).

$$\overline{Z}(so) = \sum_{i=1}^{N} \lambda i . Z(si) \qquad 3.4$$

where,

$Z(s_i)$ = the measured value at the location

λ_i = an unknown weight for the measured value at the location

S_0 = the prediction location

N = Number of measured values

Analysis of rainfall data was based on the analysis of space and time. For the analysis of space, location of rainfall stations was plotted by using GPS, then the amount of annual rainfall was plotted by each rainfall station. After that, the isohyet maps that represented the annual rainfall for each year was predicted by using the interpolation of Kriging method in GIS software. This interpolation is the procedure used to predict cell value for location that lack of sample points. The aim of isohyet map development using GIS was to identify the distribution of rainfall patterns and to compare the rainfall distribution between years. In addition, the changing patterns of rainfall from year to year can also be analysed. Other than that, the analysis of changes in rainfall per year was analysed by using the graph changes in rainfall for each station. The analysis was then performed to identify the highest rainfall received during the review period and then the causes and effects of the highest rainfall were identified.

3.3.2 Step usage GIS

1. Open Google Earth Pro to create a file with three columns: one for longitude, one for latitude, and one for the variable that wish to map. Input x and y coordinates correspond to the x and y coordinates of the rainfall station of the data frame. Pam Paya Pinang station (X:03 50 30, Y:103 15 30), Paya Besar station (X:03 46 20, Y:103 16 50) and Kg. Sg. Soi station (X:03 43 50, Y:103 18 00). Input x and y coordinates for four locations as a boundary map.

2. Open your map in ArcMap, and go to File, Add Data (or click on Add Data icon in the Standard Toolbar), click the folder icon on the top right, and browse through the folders to find the .csv file that it just created. Then hit OK. New layer should appear in the Layers column on the left. It will also display the layer as individual points on map and rename file is rainfall station.

3. Firstly, click start editing and right click the folder rainfall station then click open attribute tables to input historical rainfall data and projection rainfall data based on monthly rainfall data and boundary for three stations.

4. Select Geostatistical Wizard on the Spatial Analyst toolbar. Click to interpolation and choose Kriging method. Select the input rainfall station data to krige and the attribute variable, as well as the 'Kriging' method. Then choose 'Next'.

5. Filled value from historical data to input point features and insert monthly rainfall data to Z value field, then rename file to save at output surface raster. Click Ordinary Kriging method then hit OK.

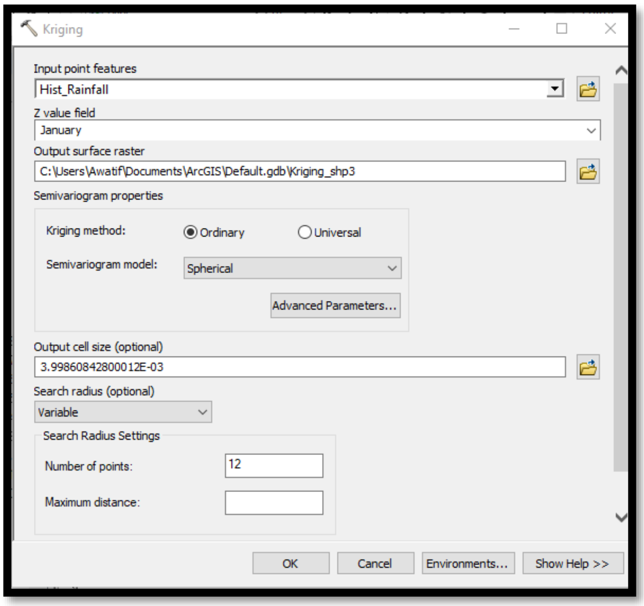

Figure 3.4: Input data for Kriging method

6. Select Spatial Analyst toolbar and click extraction. The function extraction is to obtain the exact map of Kuantan district. Filled value from interpolation value by month to input raster and insert boundary of district file to input raster or features mask data, then rename file to save at output raster then click OK.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results are represented and discussed on the performance of ungauged rainfall forecasting using SDSM model. It is very significant to ensure the reliability of the long term climate projection at ungauged station. It is a support tools that facilitates the regional climate assessment considered with the global warming impact. The model carries out subordinate work of predictor variable, pre-screening, model calibration, linear regressions and charting of climate information (Dawson, 2015).

Generally, observed daily historical rainfall data of these rain gauge stations were collected from the DID Pahang. Firstly, the annual rainfall data across the state of Kuantan for a period of 30 years was analyzed based on the three stations selected. Next, using SDSM model to analysis future climate change to get a result for calibration and validation based on historical data. In this calibration and validation process the result that can be obtained is the percentage of absolute error between these two processes and the correlation value. In GCM data, it used for future climate projection based on three different forcing data scenarios which are RCP2.6, RCP4.5 and RCP8.5. Selected the best RCP to use in GIS model. Lastly, use GIS interpolation to analyses the accuracy of forecasted ungauged rainfall. Using Kriging method to observe for station 2 are estimated and compared with the actual observation. Based on the methodology, it can see that the process validation and calibration to predict of trend for the long term of climate change until to get a good result for this chapter. This chapter, it can know the performance of rainfall modelling which has been used.

4.2 Calibrated and Validated of The Predictors Group

Table 4.1 shows the calibration and validation periods of 3 rainfall stations at surrounding Kuantan district. All the historical rainfall data were simulated from the year 1984 to 2013. In this study, there were 30years length record of historical data were considered. Then, the data were divided into two periods of times, for calibration and validation processes. For rainfall, 1984-1998 has set as a calibrated period and 1999-2013 has set as validated period.

Table 4.1: Calibration and Validation year on each station

Bill	Station Number	Station Name	Calibration Year	Validation Year
1	3832015	Rancangan Pam Paya Pinang	1984-1998	1999-2013
2	3732020	Paya Besar	1984-1998	1999-2013
3	3732021	Kg. Sg. Soi	1984-1998	1999-2013

Before the calibration process began, all the raw data had been screened to identify the best predictors variable that influenced the formation of the local rainfall. In method of screening, firstly select predictand file from raw data DID for 30 years, then select predictor file from NCEP, repeatedly filtering up to 5 predictors. Next, select conditional as a rainfall data and significance of 0.9. Finally choose a correlation to run the data after completed the 5 predictors. It will produce a partial correlation and P value. Table 4.2 along with corresponding p-value ($0 \leq p \leq 0.05$) and partial-r ($r \pm 1$), then those were used for calibration of SDSM.

In the predictor selection stage, the 26 of NCEP variables in the grid box 38X and 34Y were individually correlated with local rainfall events. Higher monthly R^2 and partial correlation show good association among selected atmospheric variables with the local climates. Gagnon (2005) stated the selected predictors were significant stage in determine the strength of single predictor-predictand relationship and it can be analyzed by the variance and partial correlation coefficients.

From the 26 predictors, there were 5 predictors have been selected for these 3 rainfall stations. For all stations, the same predictors were used because all the stations were in the nearest each other and in the same climate boundaries. Thus, the atmospheric influencers were also expected to be similar. The predictors variables were surface zonal velocity of the (p_u), the surface vorticity (p_z), temperature (temp), relative humidity of the (r500) and relative humidity at the height 850 hpa (p850). The best five correlated predictors variables were selected for each stations predictand.

Each selected predictors has their own relation with the local weather formation. Like in the geopotential height at 850hpa, it shows approximately the actual height of a pressure surface above mean sea-level where the location of the rainfall stations were near to the South China Sea. Meanwhile, the relative humidity of the r500 is the amount of water vapor represent in air expressed as a percentage of the amount needed for the saturation at the same temperature. The temperature in Pahang was influenced by relative humidity at the height 850 hpa. The selection predictor is surface zonal velocity of the p_u, and the surface vorticity p_z. represents the velocity component near the surface. From Table 4.2 show the strongest correlation between single predictand and set of predictors was identified. ‘temp’ was dominating over other four predictors. Meanwhile, ‘p_u’, ‘p_z’ and ‘r500’ were in good correlation for rainfall with 0.72, 0.75 and 0.81. Thus, for all station of five predictors to produce with range 0.01 to 0.056 except for r500 and p850 recorded the highest p-value at Paya Besar station.

Table 4.2: Correlation predictors in three stations

Predictors / Stations	Station 1 Pam Paya Pinang		Station 2 Paya Besar		Station 3 Kg. Sg. Soi	
	Partial r	p-value	Partial r	p-value	Partial r	p-value
p_u	0.720	0.010	0.783	0.013	0.692	0.024
p_z	0.770	0.027	0.612	0.034	0.759	0.005
temp	-0.998	0.056	-0.921	0.056	0.896	0.035
r500	-0.890	0.054	-0.643	0.332	0.659	0.015
p850	0.680	0.056	-0.635	0.123	-0.525	0.02

4.3 Rainfall Analysis using SDSM model

The simulation of rainfall data was referred to these 3 of hydrological stations at Kuantan. The calibration and validation processes were performed using the selected predictors by NCEP reanalysis. There were five predictors were selected; surface zonal velocity (p_u), and the surface vorticity (p_z), relative humidity at 500 hPa (r500), 850 hPa geopotential height (p850) and mean temperature at 2m height (temp). The performances of the calibrated and validated results as shown in Figure 4.1.

For the Pam Paya Pinang station, the calibrated result was very closed with the historical record in all months with very minimum error. The MAE was in average of 2.22% for calibrated. The bigger error happened in November which the simulated rainfall intensity was predicted higher 20.14mm, 5.83% of MAE. Differ in the validated result where the simulated value may varies with higher values compared to the historical in January is 127.5mm. However the simulated result was successfully to produced similar monthly trend to the historical. The average MAE was 21.30% for validated. Which still can be acceptable for this analysis.

Meanwile for the Paya Besar station, the calibrated result was very closed with the historical record in all months with very minimum error. The MAE was in average of 2.66% for calibrated. The bigger error happened in December which the simulated rainfall intensity was predicted higher 36.88mm, 5.96% of MAE. Differ in the validated result where the simulated value may varies with higher values compared to the historical in April is 58.82mm. However the simulated result was successfully to produced similar monthly trend to the historical. This station is better than other stations because to produce small errors is below 13.71%. Which still can be acceptable for this analysis.

Refer to the Kg. Sungai Soi station, the calibrated result was very closed with the historical record in all months with very minimum error. The MAE was in average of 6.28% for calibrated. The bigger error happened in February which the simulated rainfall intensity was predicted higher 37.44mm, 30.87% of MAE. Differ in the validated result where the simulated value may varies with higher values compared to the historical in December is 286.9mm and the percentage error of MAE with 52%. The analysis can be derived that the simulation data is fluctuating the year and does not have the same trend as the historical. However the simulated result was successfully to produced similar monthly trend to the historical. This station recorded to produce the highest average MAE was 23.24% from other stations but it still can be acceptable for this analysis.

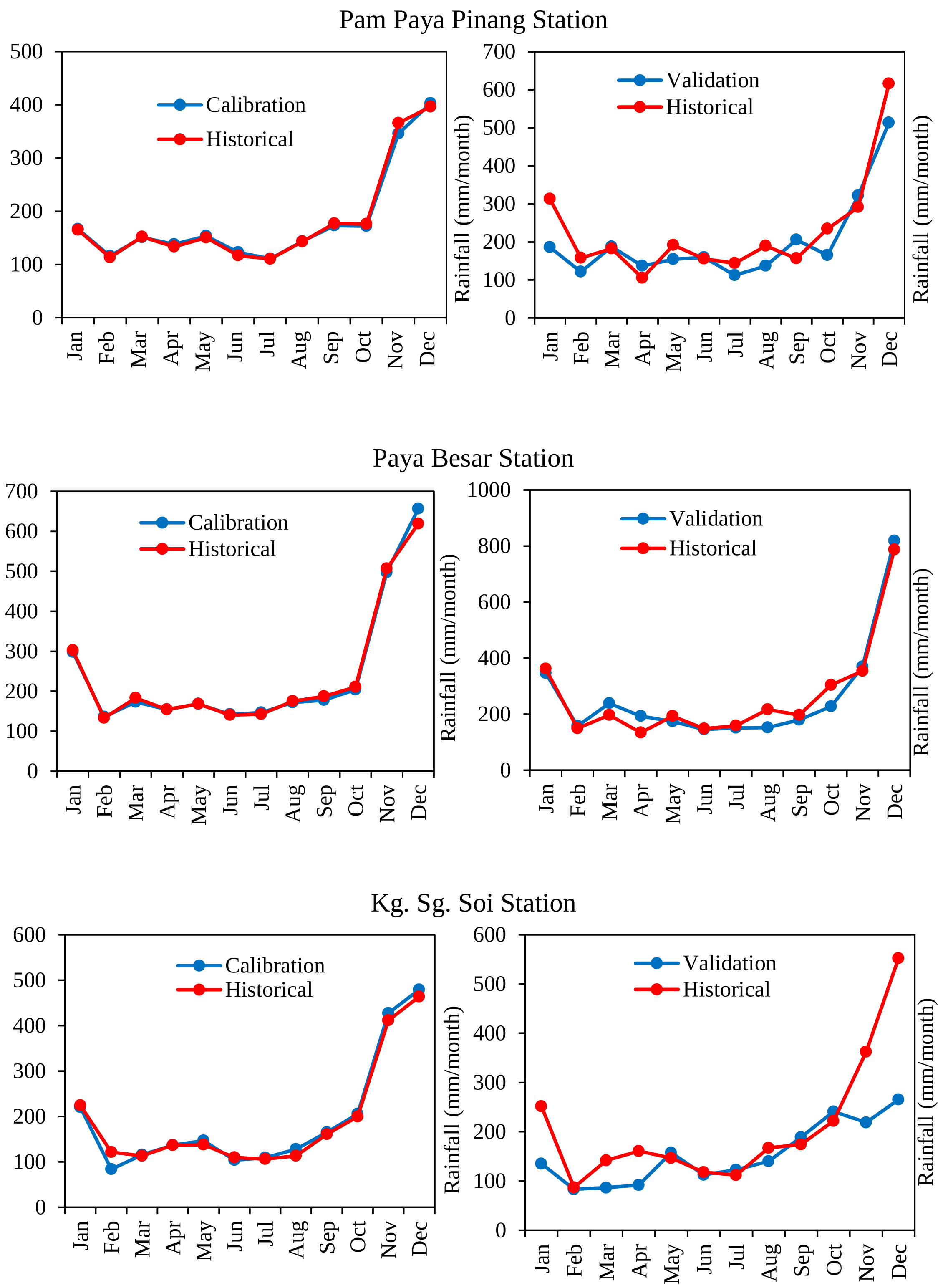

Figure 4.1: Comparison the performance of calibrated and validated for three station.

In the case study, each rain station needs to make difference data through statistical analysis between calibrated and validated to evaluate the performance data. Table 4.3 show the performance of the predictor selection to inter react with the local climate was evaluated based on standard deviation, mean absolute error (MAE) and correlation value (R). The selected predictors are primary important to ensure the accuracy and reliability of projected rainfall. Correlation indicates the relationship between the observed and modelled data. This parameter ranges between zero and one, and an correlation value of 1 indicates strong relationship between the two groups of data (Zehtabian et al. 2016).

Table 4.3: Statistical analysis for rainfall

Bill	Stations	Std. D		MAE (%)		R	
		Calibrated	Validated	Calibrated	Validated	Calibrated	Validated
1.	Pam Paya Pinang	0.546	0.591	2.220	21.304	0.998	0.921
2.	Paya Besar	0.857	0.928	2.657	13.705	0.998	0.978
3.	Kg. Sg. Soi	0.651	0.251	6.277	23.243	0.995	0.791

For a calibrated, all station was estimated to produce small errors below 6% in MAE but slightly higher in the validation analysis. The best simulated result was at Pam Paya Pinang station because it produced the smallest MAE with 2.22%. Besides, the rainfall pattern was also consistent with the historical record. The highest MAE was recorded at Kg. Sungai Soi station with 6.28%. For the validation analysis, Pam Paya Pinang station and Kg. Sungai Soi station produced greater MAE with 21.304% and 23.243% but slightly lower MAE at Paya Besar station with 13.705%. There were bigger error during validation process which might cause of the predictors selection efficiency and inconsistent trend in the local climates between calibration and validation periods. However, the pattern of the simulated rainfalls were still consistent with the historical as proved the selected predictors can be used and suitable as climate influencer for this region.

In general, the % of MAE for each stations were still under reasonable and acceptable. In more information, R above 0.80 generally are accepted as high correlations while for R between 0.50 and 0.80 are usually considered as medium moderate correlations and R below 0.50 are typically regarded as low correlations (Wang, 1990). From the analysis, the highest R were produced for every rainfall stations which closer to 1.0. For the standard deviation result, to produce above 0.5 for every rainfall station except Kg. Sg. Soi station recorded lesser SD among other station with 0.25 for validated. However, it shows that the calibrated and validated values is reliable and acceptable for this study. Based on the graph above, it can be seen that the rainfall trend remains the same where higher rainfall value during northeast monsoon especially in January, November and December.

4.3.1 Projected Rainfall using GCMs predictors

The GCMs predictors were used to project and generate the local climate trend in the future year. Normally, hydrological cycle occurs affected by GHGs. Higher temperature on the earth surface will evaporates more water surface than normal condition to form water vapor in the atmosphere and then condensate as heavy rainfall. Kevin (2011) wrote that the water vapour has potential to increase about 7% for every 1^{o}C warming and encourage more intense precipitation event.

Figure 4.2 to 4.4 show the projected rainfall for 3 rainfall stations during year 2020 to 2049 by GCMs parameters. There were 3RCPs have been considered; RCP2.6, RCP4.5 and RCP8.5 scenarios. The projected annual rainfall were predicted to produce lesser annual rainfall compared to the historical. The highest rainfall was projected at Paya Besar station which expected to produce 2995mm/year compare to historical data is 3060mm/year. While the lowest rainfall was projected at Rancangan Pam Paya Pinang station of 2120mm/year compare to historical data is 2469mm/year. Normally, lesser rainfall intensity was focused on February to July as a dry season and higher rainfall intensity was expected to occur on October to December as a wet season.

Comparing between RCPs scenario, there were inconsistent results and being fluctuated throughout a year. The months Feb until Aug are predicted to have reasonable amounts of rainfall in all scenarios and are more significant under the most severe scenario RCP4.5 due to the Southwest monsoon, which normally dominates the dry season period. Pam Paya Pinang station of RCP4.5 recorded the least receive rainfall among other stations has decrease to 2120mm/year with the percentage decrement with -

14.11%. Meanwhile, Paya Besar station with 2995mm/year increasing of rainfall recorded to have +2.14% increment in rainfall projected of RCP2.6. However, Kg. Sungai Soi station show that the rainfall pattern is very close between projected data and historical data among other stations.

Referring to the projected rainfall at Pam Paya Pinang Station in Figure 4.2 and Table 4.4, the projected rainfall pattern was similar with the historical trend where lower rainfall focused on January to September then became higher started from Oct to Dec. From the total annual rainfall of 2469mm/year from historical data, the projected result has decrease to 2120mm/year. The obvious difference was expected to occur during Northeast monsoon especially in November and December. In November, the monthly rainfall was expected to increase to 343.13mm and +4.46% of RCP2.6. Meanwhile in December, the total monthly rainfall was expected to decrease to 443.41mm and -12.39% of RCP2.6. February of RCP4.5 was a critical month which recorded to receive the least rainfall and expected to decrease to 90.44mm with the percentage decrement -33.29% differ to historical in the future year. However, RCP8.5 agreed the highest increment of rainfall intensity is expected to occur in Apr +20.72% but RCP4.5 claimed in Jan expected to decrement with -35.41% among other months.

Based on the RCPs, RCP 4.5 shows the least rainfall changes in the long term compared to other RCPs. The annual decrement of the projected rainfall is -12.17% for RCP 2.6, -14.11% for RCP 4.5 and -3.84% for RCP 85. Therefore, the projection analysis results are lowest compare to historical.

Meanwhile for the Paya Besar station in Figure 4.3 and Table 4.5, the projected rainfall pattern was similar with the historical trend where lower rainfall focused on Feb to Oct then became higher started from Nov to Dec. From the total annual rainfall of 3060mm/year from historical data, the projected result has decrease to 2714mm/year. The obvious difference was expected to occur during Northeast monsoon especially in November and December. In November of RCP2.6, the monthly rainfall was expected to increase to 469.19mm from projected result and 430.34mm from historical data and differ both result is +9.03%. Meanwhile in December of RCP2.6, the total monthly rainfall was expected to decrease to 646.09mm from projected result and 702.74mm from historical data and differ both result is -4.57%. October was a critical month which recorded to receive the least rainfall and expected to decrease to 178.41mm with the percentage decrement -30.63% of RCP4.5 differ to historical in the future year. Meanwhile, RCP8.5 agreed the highest increment of rainfall intensity is expected to occur in Jan with +15.91% among other months.

In additional, RCP 8.5 shows the least rainfall changes in the long term compared to other RCPs. The annual decrement of the projected rainfall is -2.14% for RCP 2.6, -7.17% for RCP 4.5 and -11.32% for RCP 85. Therefore, the projection analysis results are lowest compare to historical.

Referring to the projected rainfall at Kg. Sungai Soi Station in Figure 4.4 and Table 4.6, it can be observed from the graph is the rainfall pattern is a bit different than the pattern from the historical data. The projected rainfall pattern was similar with the historical trend where lower rainfall focused on Feb to Aug then became higher started from Nov to Dec. From the total annual rainfall of 2397mm/year from historical data, the projected result has decrease to 2350mm/year. Rainfall is predicted to increase during the wet season months especially from November to December due to the Northeast monsoon. In November, the monthly rainfall was expected to increase to 394.75mm from projected result and 487.13mm from historical data and differ both result is +1.97% of RCP2.6. Meanwhile in December, the total monthly rainfall was expected to decrease to 427.72mm from projected result of RCP8.5 and 507.99mm from historical data and differ both result is -15.80%. The months Feb until Aug are predicted to have reasonable amounts of rainfall due to the Southwest monsoon, which normally dominates the dry season period, but has a marked influence during these months. February was a critical month which recorded to receive the least rainfall and expected to decrease below 72mm with the percentage decrement below -36.52% differ to historical in the future year for all RCPs. Differ in RCP2.6 agreed the highest increment of rainfall intensity is expected to occur in Apr with decrement +15.63% among other months.

For information, RCP 8.5 shows the least rainfall changes in the long term compared to other RCPs same with the Paya Besar station. The annual decrement of the projected rainfall is -1.96% for RCP 2.6, -6.33% for RCP 4.5 and -6.50% for RCP 8.5. Therefore, the projection analysis results are lowest compare to historical.

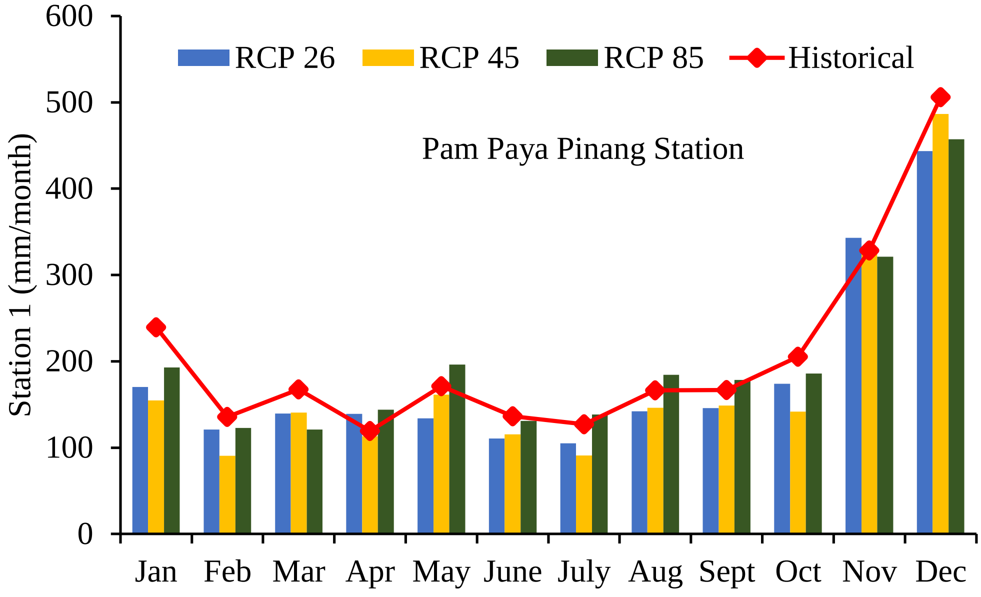

Figure 4.2: Comparison between projected monthly rainfalls by all RCPs with the historical at Pam Paya Pinang station

Table 4.4: Projected monthly rainfall at Pam Paya Pinang station

Month	Historical	RCP 2.6		RCP 4.5		RCP 8.5	
		Rainfall (mm)	%	Rainfall (mm)	%	Rainfall (mm)	%
January	239.306	170.141	-28.90	154.556	-35.41	192.718	-19.47
February	135.58	121.126	-10.66	90.439	-33.29	122.858	-9.38
March	167.404	139.526	-16.65	140.456	-16.10	121.140	-27.64
April	119.31	139.324	+16.77	113.007	-5.28	144.035	+20.72
May	171.074	134.112	-21.61	161.546	-5.57	196.290	+14.74
June	136.253	110.697	-18.76	115.501	-15.23	131.148	-3.75
July	126.963	104.918	-17.36	90.973	-28.35	138.291	+8.92
August	166.219	142.283	-14.40	146.238	-12.02	184.261	+10.85
September	166.737	145.647	-12.65	148.714	-10.81	178.552	+7.09
October	205.227	173.874	-15.28	141.605	-31.00	186.025	-9.36
November	328.478	343.129	+4.46	330.565	-0.64	321.126	-2.24
December	506.113	443.405	-12.39	486.659	-3.84	457.310	-9.64

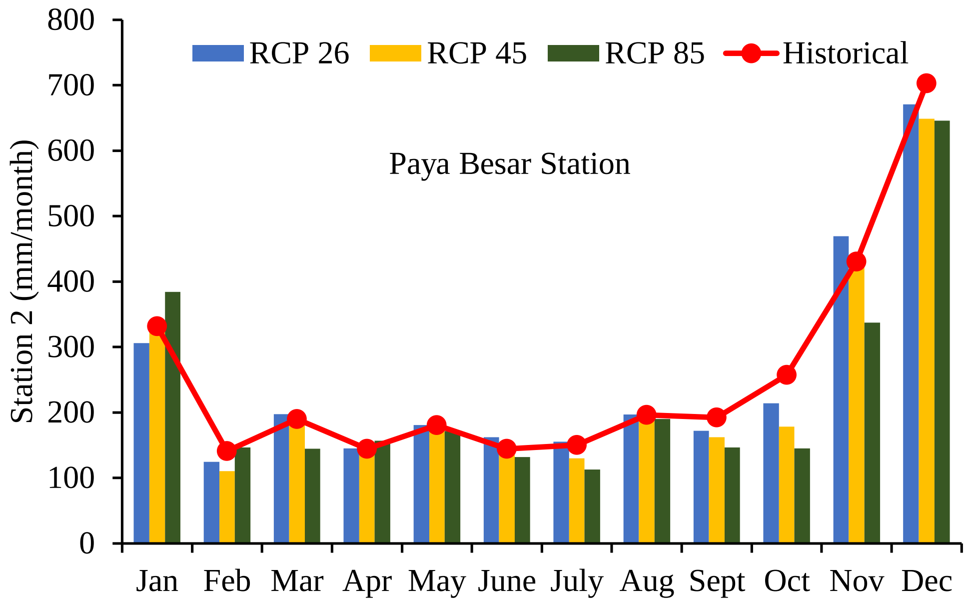

Figure 4.3: Comparison between projected monthly rainfalls by all RCPs with the historical at Paya Besar station

Table 4.5: Projected monthly rainfall at Paya Besar station

Month	Historical	RCP 2.6		RCP 4.5		RCP 8.5	
		Rainfall (mm)	%	Rainfall (mm)	%	Rainfall (mm)	%
January	331.563	306.257	-7.63	326.665	-1.48	384.324	+15.91
February	140.985	124.612	-11.61	110.547	-21.59	146.387	+3.83
March	189.94	197.527	+3.99	187.460	+1.31	144.642	-23.85
April	144.186	145.070	+0.61	141.930	+1.56	156.666	+8.66
May	180.673	180.953	+0.15	184.093	+1.89	171.415	-5.12
June	144.287	162.252	+12.45	145.240	+0.66	132.147	-8.41
July	150.233	155.375	+3.42	130.052	+13.43	112.941	-24.82
August	196.177	196.858	+0.35	187.368	+4.49	189.973	-3.16
September	192.117	172.033	-10.45	162.461	-15.44	146.807	-23.58
October	257.176	214.234	-16.70	178.413	-30.63	145.073	-43.59
November	430.34	469.191	+9.03	438.161	+1.82	337.569	-21.56
December	702.737	670.649	-4.57	648.690	-7.69	646.085	-8.06

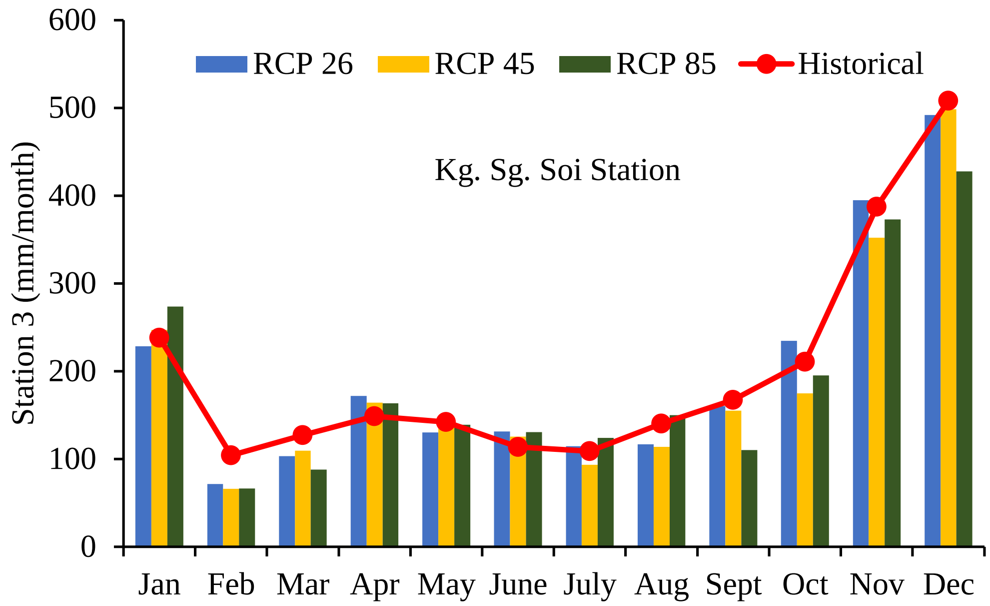

Figure 4.4: Comparison between projected monthly rainfalls by all RCPs with the historical at Kg. Sungai Soi station

Table 4.6: Projected monthly rainfall at Kg. Sungai Soi station

Month	Historical	RCP 26		RCP 45		RCP 85	
		Rainfall (mm)	%	Rainfall (mm)	%	Rainfall (mm)	%
January	238.099	228.531	-4.02	247.109	+3.78	273.777	+14.98
February	104.074	71.5585	-31.24	66.064	-36.52	66.467	-36.14
March	127.285	103.072	-19.02	109.567	-13.92	87.992	-30.87
April	148.654	171.885	+15.63	164.234	+10.48	163.297	+9.85
May	142.233	130.339	-8.36	145.316	+2.17	138.846	-2.38
June	113.741	131.196	+15.35	125.332	+10.19	130.501	+14.74
July	108.978	114.692	+5.24	93.230	-14.45	123.959	+13.75
August	140.270	116.842	-16.70	113.649	-18.98	149.984	+6.92
September	167.411	160.095	-4.37	155.158	-7.32	110.200	-34.17
October	210.707	234.762	+11.42	174.674	-17.10	195.164	-7.38
November	387.134	394.749	+1.97	352.010	-9.07	372.950	-3.66
December	507.994	491.835	-3.18	498.442	-1.88	427.715	-15.80

4.4 Performance Comparison using GIS Interpolation

The Kriging method has been used widely to produce interpolation between rainfall stations using spatial autocorrelation. It allows the interpolated cells to exceed the boundaries of the sample range. In this case study, the Kriging method was used as interpolation agent to treat ungauged rainfall station. Monthly rainfall data of three station were estimated using the data of surrounding stations so that ungauged station and the gauged station can be compared for the station 2. GIS interpolation method in finding missing data because it does not take a long time to obtain the value compared to other methods which is Arithmetic Mean method, Quadrant method and Normal Ratio method.

Different types of landform and density values of height measurement were considered in the ungauged treatment. Irrespective of the surface area, landscape morphology and sampling density, few differences existed between the employed interpolation techniques if the sampling density was high (Setianto & Triandini,2013). At the lower density of the station area, in contrast, the performance of the techniques tended to vary. This proves that in the northern monsoon the difference between the two mapping to produce very different value especially in November and December. It will cause wetlands and become ramps. In addition, the position of the station near the sea will interrupt the value of the interpolation. Figure 4.5 and 4.6 represent the comparison of monthly rainfall trend between ungauged station with gauged station.

Figure 4.5 shows that the period of the comparison was in between of 1984 until 2013. The highest different error between ungauged station and gauged station based on range in Table 4.7 for historical rainfall was 16.12% in February but the trend pattern is similar. In more detail, the result monthly rainfall for ungauged station with range 101.56mm until 107.19mm compared to the gauged station was 118.13mm until 127.79mm. Meanwhile in April, it was produced the lowest error with 0.1% compared to the rest months. For the ungauged rainfall was recorded with range 135.43mm until 148.7mmm compared to the gauged station is 132.86mm until 148.38mm. March, May, and June were also produced the lower percentage error because with less than 5%.

In additional, the lowest monthly rainfall for ungauged station was 101.56mm in February while for the highest monthly rainfall was 527.17mm in December. For the gauged station, it was recorded the lowest monthly rainfall is 127.79mm in February. In December was produced that the highest monthly rainfall is 580.12mm. Based on the performance GIS interpolation for station 2 as ungauged station in Table 4.8, in July was recorded value with higher error in MAE with 26.6% while the lowest error was 0.22% occur in April among other months.

The Figure 4.6 shows the projected monthly rainfall by RCP 4.5 for the interval year of 2020 until 2049. The selection of RCP4.5 as a projected rainfall because produced closer simulated result compared to the rest RCPs. The RCP4.5 is referred to the radiative forcing at 4.5 Wm^{-2}. It provides a common platform for climate models to explore the climate system response to stabilizing the anthropogenic components of radiative forcing (Thomson,2011). The best performance and result are produced by interpolating the value of ungauged station and gauged station based on range in Table 4.7 for projected rainfall of RCP 4.5. The result produced very small error, which is less than 1% for every month and all of the rainfall trend patterns are very close to historical data. The lowest error of MAE recorded in months was in the month of October, which is 0.1%. The values recorded for ungauged rainfall is in the range of 167.58mm to 199.05mmm, while for gauged station, the range of recorded values is between 167.33mm and 198.99mm. There were also recorded values in other months which are in May, June, July and Sept that produced the percentage error of lower than 5%.

The highest error are produced in the months of February and December, which has the percentage error of 15%. In December, the percentage error between ungauged station and gauged station is 15.33%, which considered the highest error produced among other months. The result of monthly rainfall for ungauged station in December is within 479.67mm to 547.37mm compared to the gauged station which is between 538.38mm and 646.50mm. Second highest recorded error is in the month of February, which is 13.97%. The monthly rainfall for February for ungauged station is between 85.89mm and 99.79mm compared to the gauged station, which is between 98.68mm and 116mm. There is a large difference between ungauged station and gauged station, but they still follow the trend pattern rainfall.

Based on the performance GIS interpolation for station 2 as ungauged station in Table 4.8, in Dec to produce the higher error in MAE with 25.81%. While the lowest error recorded 0.06% occur in Sept among other months. The lowest monthly rainfall for ungauged station is 85.89mm, which happened in February, While the highest monthly rainfall is 547.37mm which happened in December. For the gauged station, the lowest monthly rainfall recorded is 98.68mm, which was in February. The month of December gave the highest monthly rainfall, which is 646.5mm. Normally, the months of November and December give higher rainfall value due to the northeast monsoon occurrence.

However, the results of GIS interpolation between the ungauged station and gauged station for every month, its rainfall and projection rainfall, can be accepted because the difference in percentage error between obtained value of average MAE is less than 20% and the trend pattern produced is similar. GIS interpolation is the best method for researches to find missing data because it does not take a long time to obtain the value compared to other methods. However, if missing data must be determined from a lot of rainfall stations which involve in many districts and it needs a very long time to be determined, different pattern and high variation of rainfall trend might be produced. Thus, more precise of interpolation values must be determined based on types of landform and density values according to measured height. If each rainfall station has different topography, it will be clearer and visible to conduct interpolation and more accurate values can be obtained.

Table 4.7: Performance of GIS interpolation between ungauged station and gauged station in monthly based on range.

		Historical Rainfall			Projection Rainfall RCP4.5		
Station / Monthly		Ungauge (mm)	Gauged (mm)	Error (%)	Ungauge (mm)	Gauged (mm)	Error (%)
January		239.21	265.36	9.86	313.59	332.56	5.70
		216.17	234.43	7.79	266.90	284.60	6.22
		194.87	211.30	7.78	220.20	236.65	6.95
		173.56	188.17	7.76	173.498	188.696	8.05
February		107.19	127.79	16.12	99.79	116	13.97
		101.56	118.13	14.03	85.89	98.68	12.97
		97.04	109.51	11.39	77.42	87.98	12
March		159.52	165.33	3.52	218.21	236.61	7.76
		141.19	148.20	4.73	182.33	192.53	5.30
		129.72	133.97	3.17	161.44	166.82	3.23

April		148.70	148.38	0.10	224.20	252.67	11.27
		135.43	132.86	6.63	182.46	197.94	7.82
		122.67	120.21	6.05	156.64	166.01	5.64
May		170.61	180.55	5.50	179.09	183.78	2.58
		150.54	157.77	4.58	145.82	151.72	3.89
		135.24	140.70	3.88	122.94	127.77	3.78
June		135.91	144.18	5.74	149.47	149.37	0.06
		122.49	128.37	4.58	122.11	122.66	0.45
		112.43	116.91	3.83	102.32	103.02	0.67
July		126.68	149.93	15.50	128.45	129.52	0.83
		110.05	122.29	10.01	101.39	103.85	2.27
		96.74	104.09	7.06	84.42	86.72	2.65
August		165.80	178.87	6.26	157.53	168.60	6.56
		146.72	155.26	5.50	129.46	142.47	9.13
		132.19	139.34	5.13	112.67	123.47	8.75
September		174.01	191.78	9.26	186.06	186.01	0.03
		156.69	164.99	5.03	155.84	155.93	0.06
		142.07	146.62	3.10	135.03	135.22	0.14
October		225.6	256.48	12.04	199.05	198.99	0.03
		202.02	212.74	5.04	167.58	167.33	0.15
		183.48	184.66	0.64	143.62	143.63	0.01
November		397.59	428.96	7.31	383.55	436.7	12.17
		342.5	352.45	2.82	337.89	366.38	7.78
		293.39	297.57	1.40	302.59	325.5	7.04
December		527.17	580.12	9.13	547.37	646.5	15.33
		472.53	505.26	6.48	479.67	538.38	10.9
		426.44	451.36	5.52	428.23	477.49	10.32

Table 4.8: Performance GIS interpolation in MAE for station 2.

Monthly / Station	Historical Rainfall			Projection Rainfall RCP4.5		
	Ungauge (mm)	Gauged (mm)	Error (%)	Ungauge (mm)	Gauged (mm)	Error (%)
Jan	239.21	265.36	9.85	220.2	188.696	16.70
Feb	107.19	127.79	16.12	85.89	98.68	12.96
March	141.19	165.33	14.60	161.44	166.82	3.23
April	148.7	148.38	0.22	156.64	166.01	5.64
May	150.54	180.55	16.62	145.82	183.78	20.66
June	122.49	144.18	15.04	122.11	149.37	18.25
July	110.05	149.93	26.60	101.39	129.52	21.72
Aug	146.72	178.87	17.97	129.46	168.6	23.21
Sept	174.01	191.78	9.27	155.84	155.93	0.06
Oct	225.6	256.48	12.04	167.58	167.33	0.15
Nov	342.5	428.96	20.16	337.89	436.7	22.63
Dec	527.17	580.12	9.13	479.67	646.5	25.81

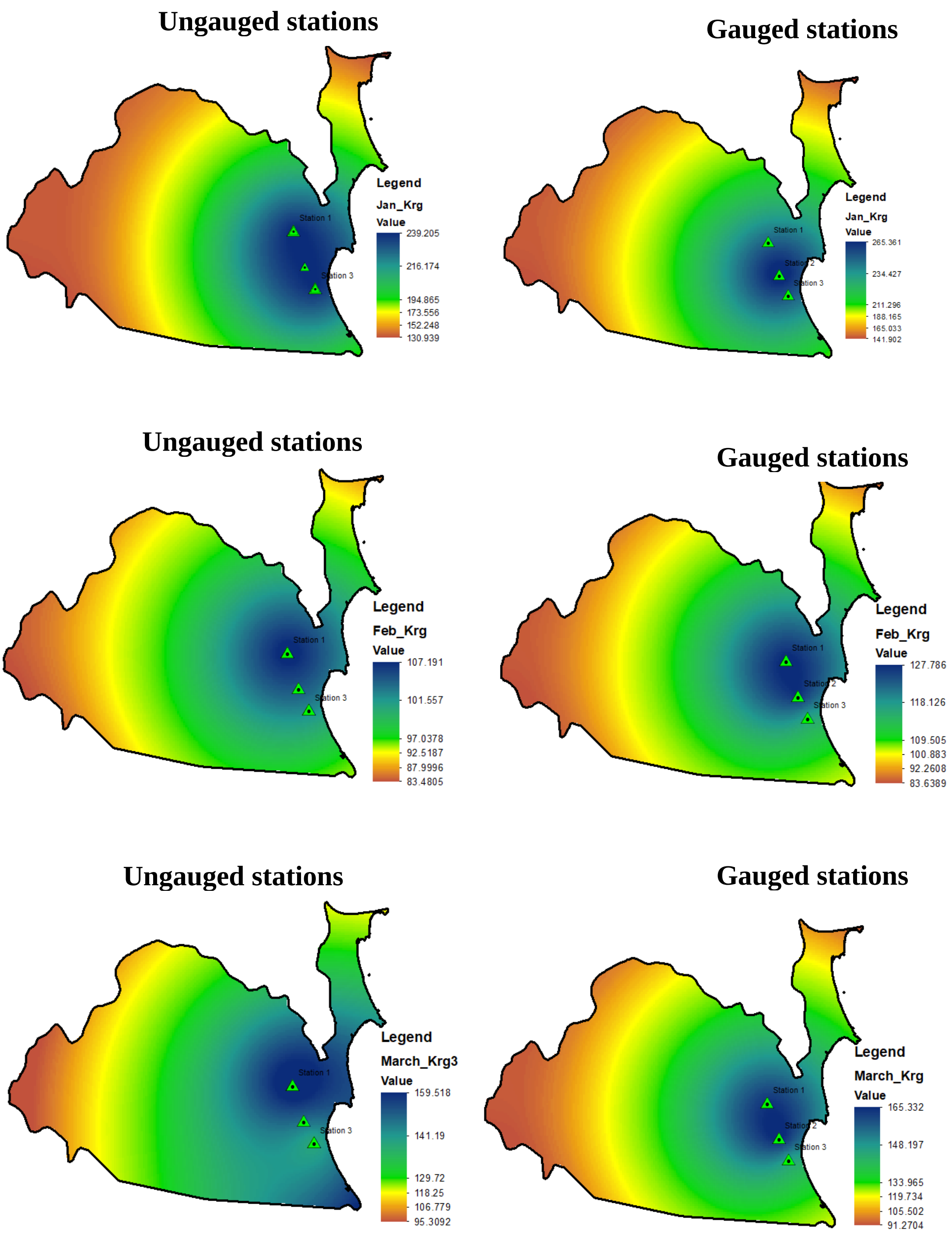

Figure 4.5: Annual average of historical rainfall for ungauged station and gauged station (cont.)

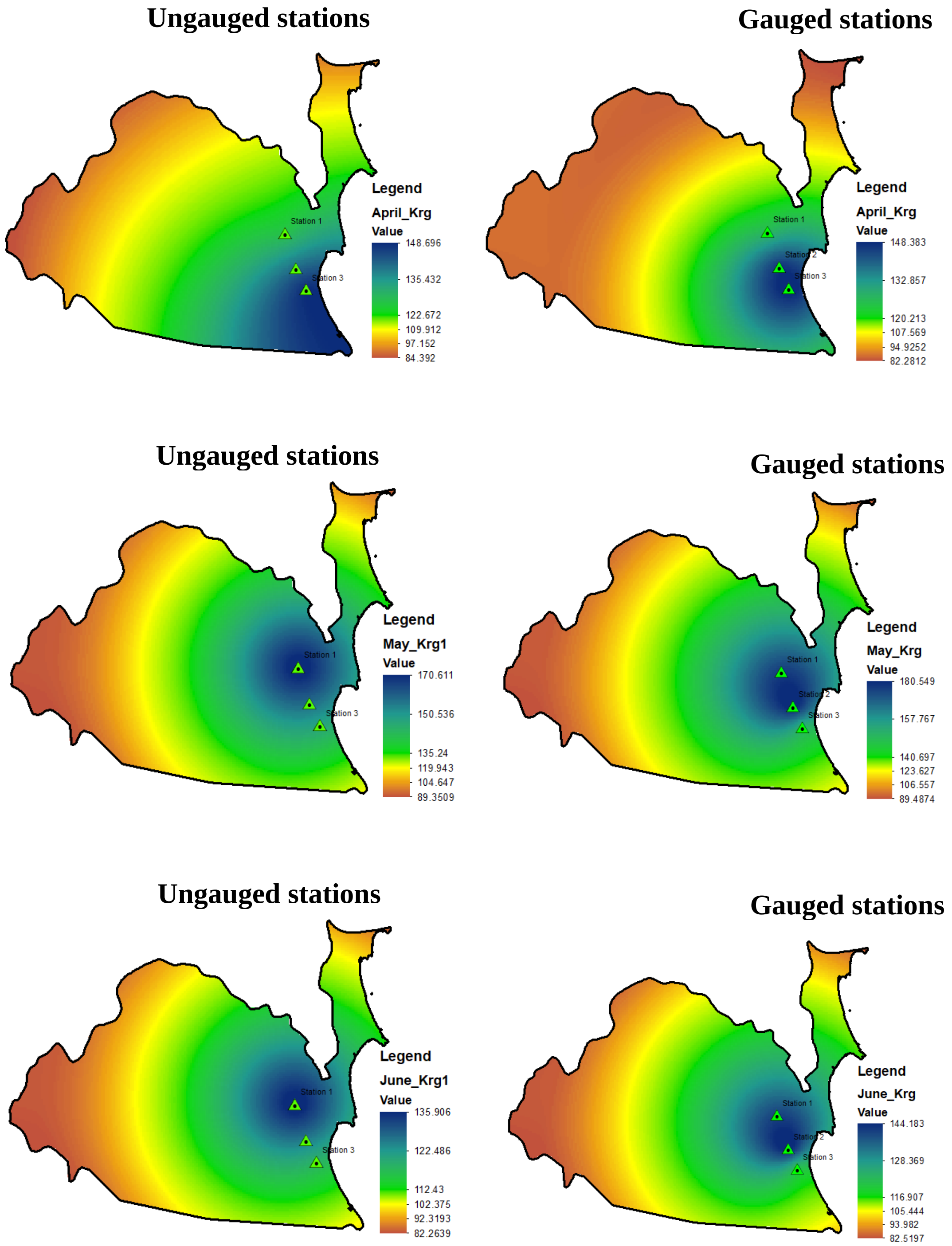

Figure 4.5: Annual average of historical rainfall for ungauged station and gauged station (cont.)

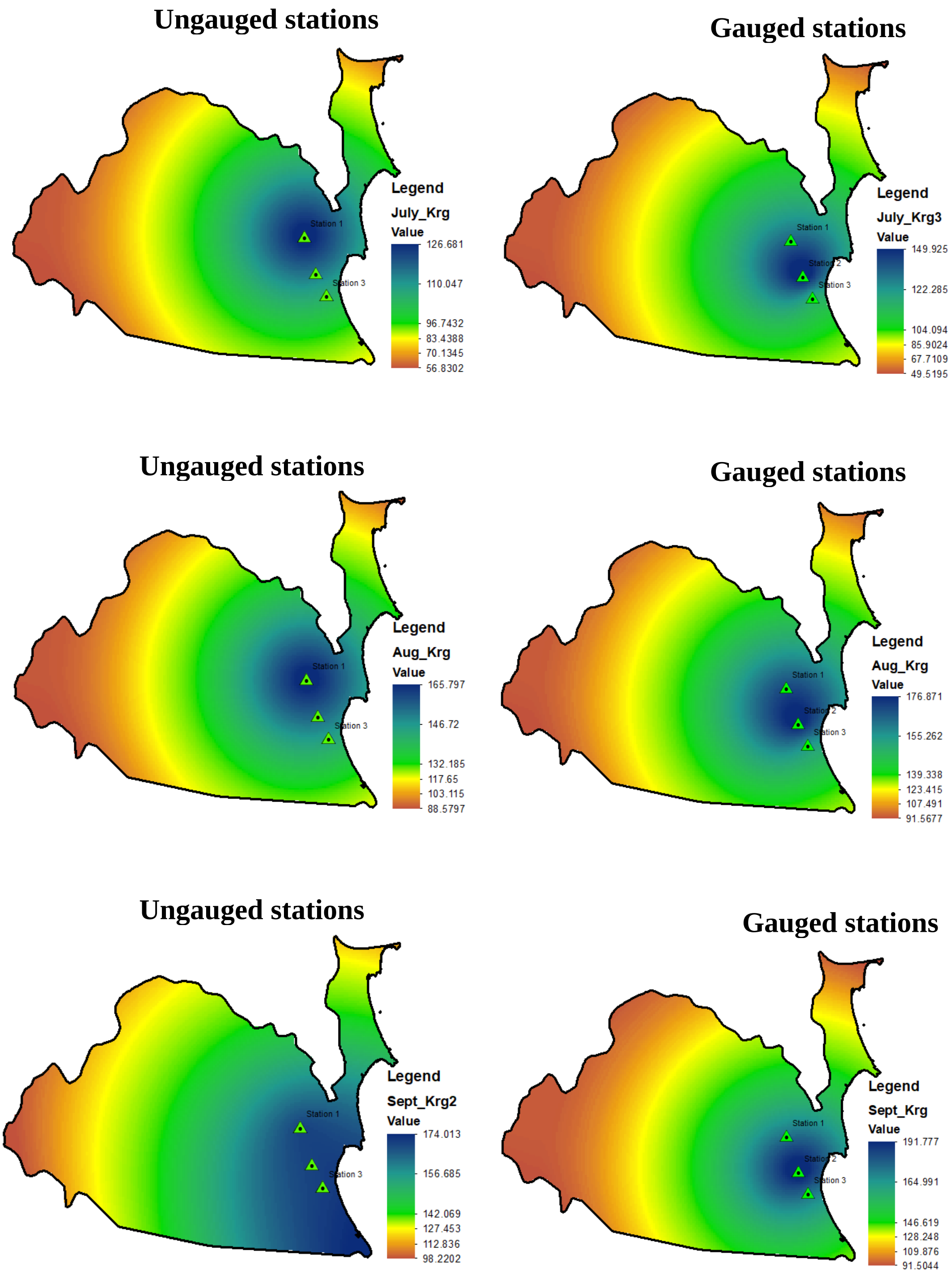

Figure 4.5: Annual average of historical rainfall for ungauged station and gauged station (cont.)

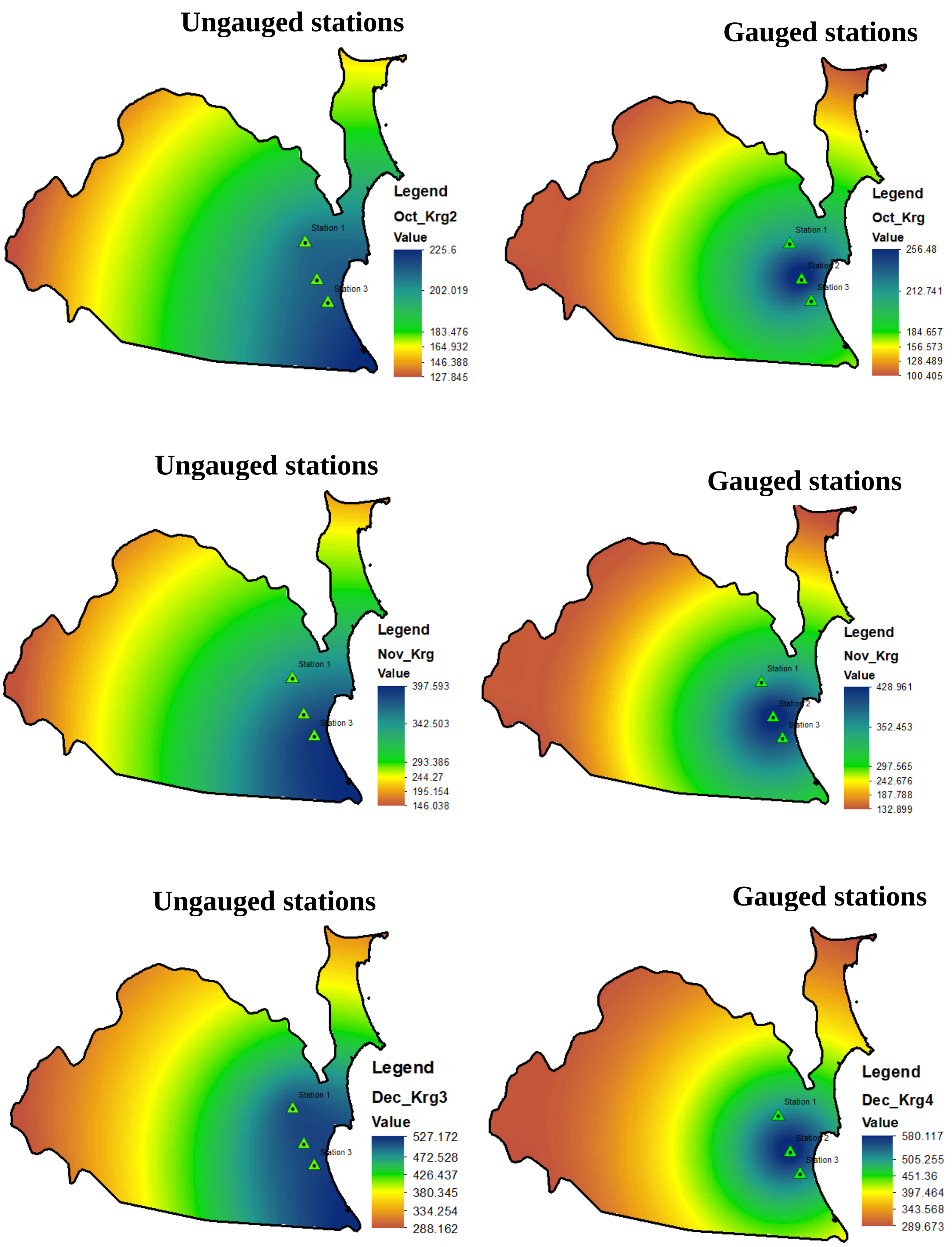

Figure 4.5: Annual average of historical rainfall for ungauged station and gauged station.

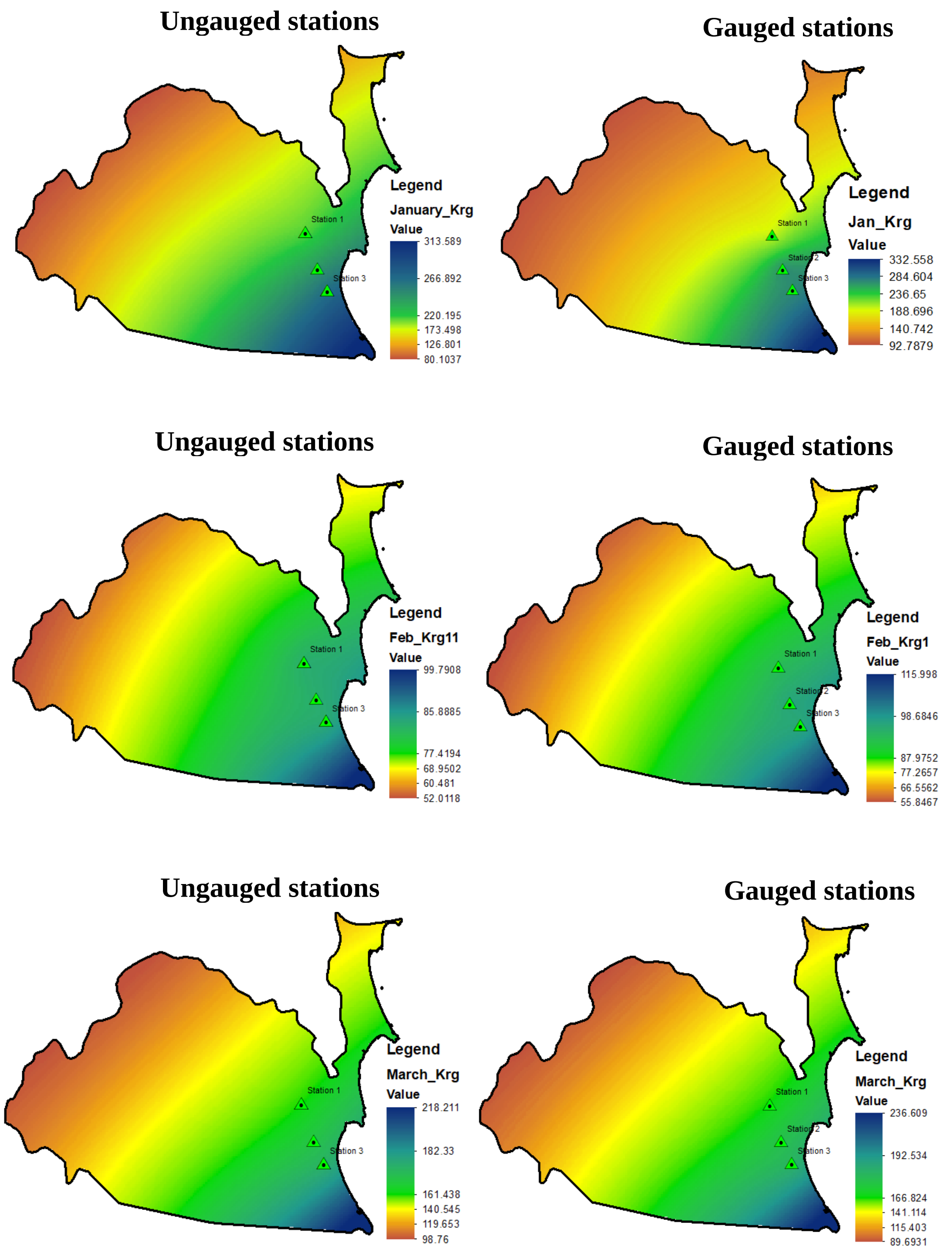

Figure 4.6: Annual average of projection rainfall RCP45 for ungauged station and gauged station (cont.)

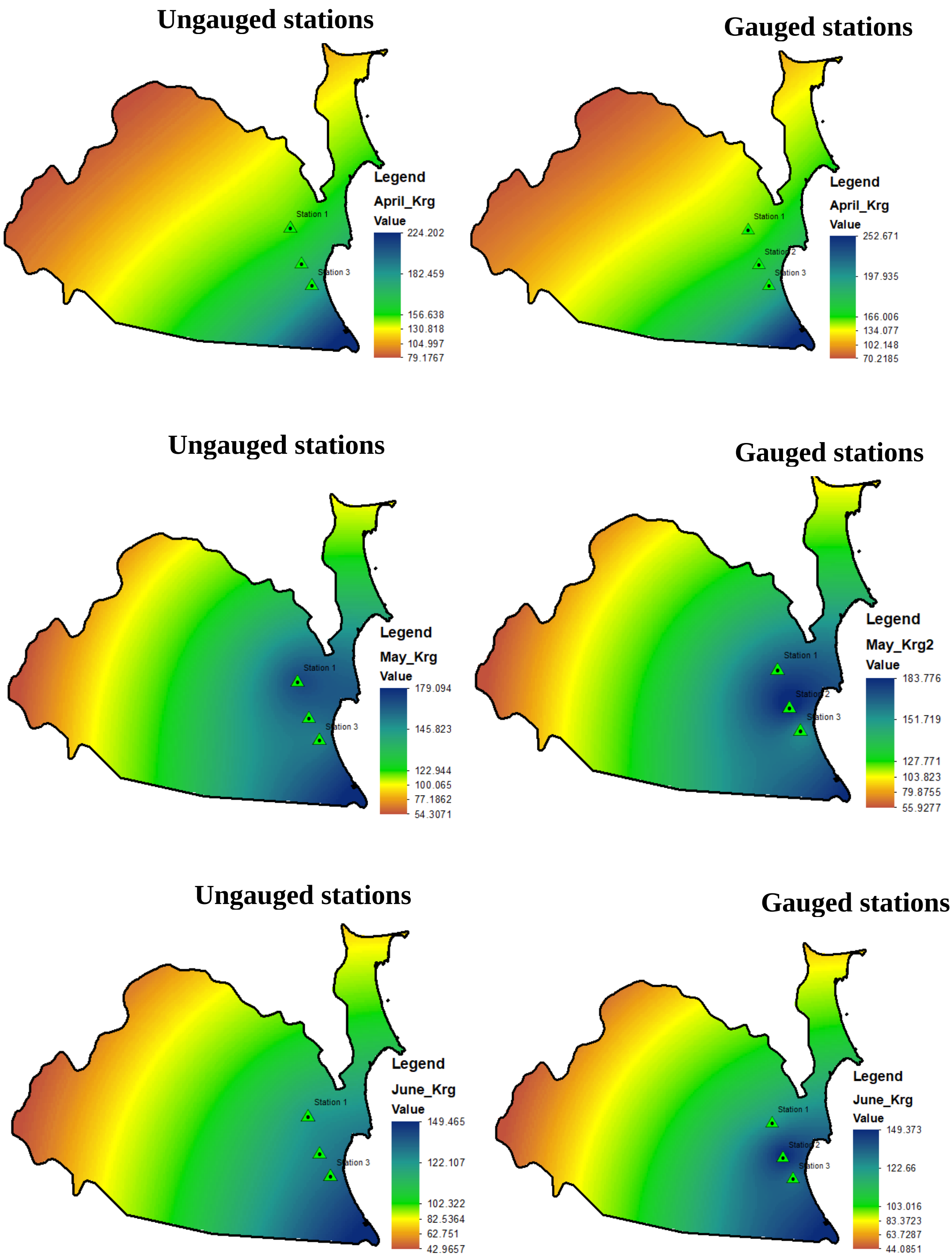

Figure 4.6: Annual average of projection rainfall RCP45 for ungauged station and gauged station (cont.)

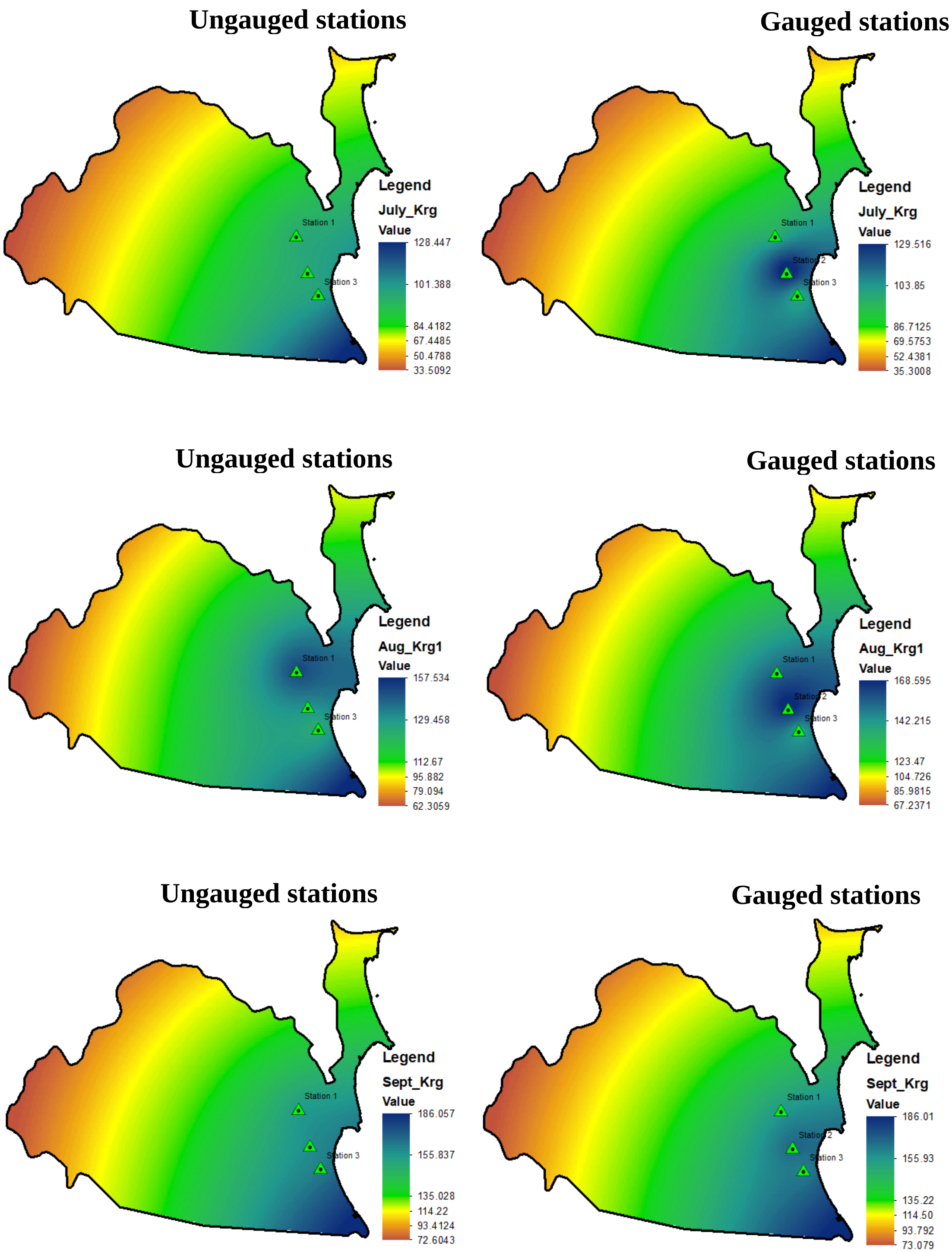

Figure 4.6: Annual average of projection rainfall RCP45 for ungauged station and gauged station (cont.)

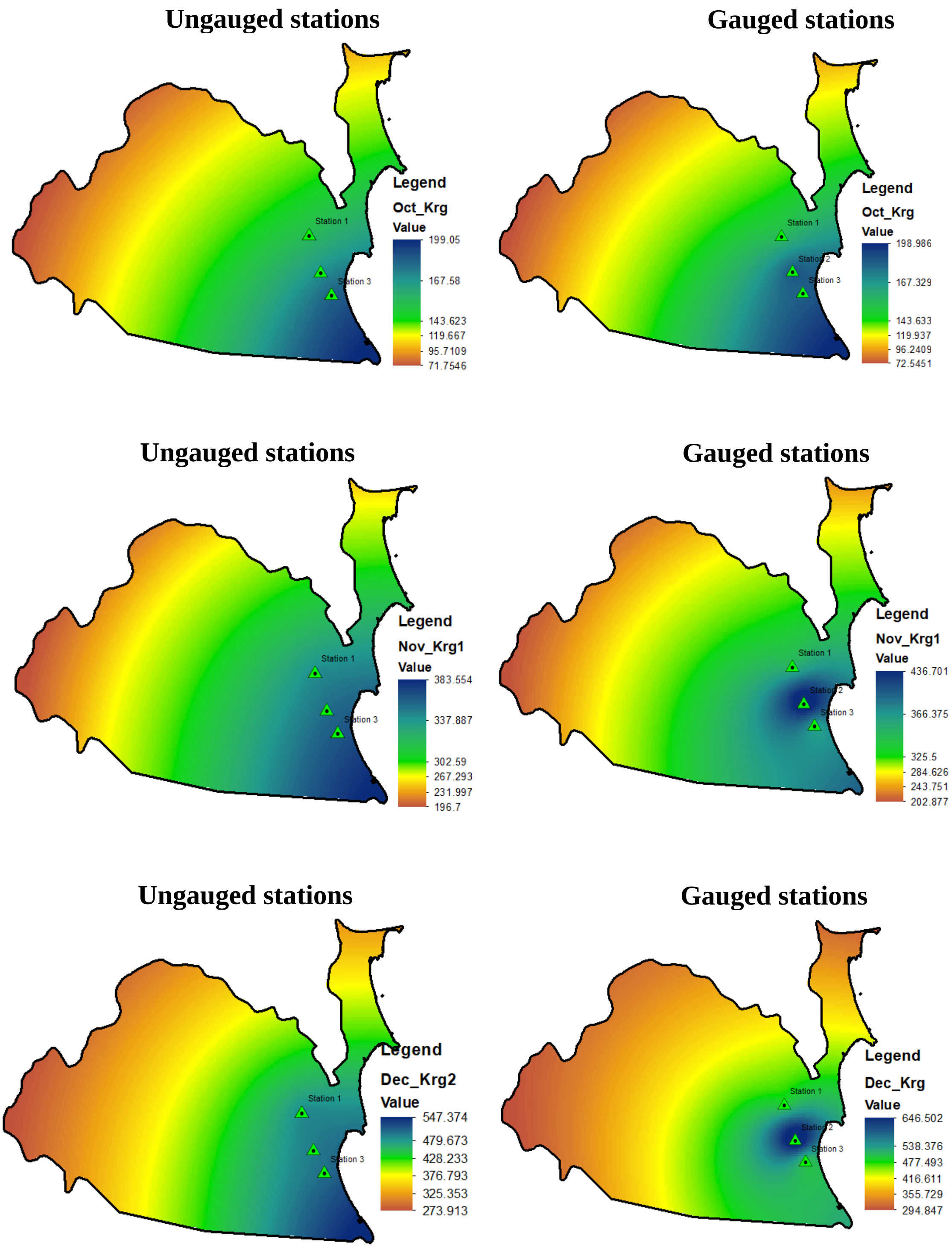

Figure 4.6: Annual average of projection rainfall RCP45 for ungauged station and gauged station.

CHAPTER 5

CONCLUSION

5.1 Introduction

The potential impact of climatic change on the occurrence of extreme precipitation events in the three rainfall station such as Rancangan Pam Pinang station, Paya Besar station and Kg. Sungai Soi station located in Kuantan, Pahang at the East Coast region of Peninsular Malaysia has been investigated. The study is show the performance of the software which contributes to the advancements tools in the operations for a long term and maintainable in order to manage the flow of hydrological cycle at site study. Therefore, a useful and accurate software is needed to perform a good projection of climate change so a step on safety precaution can be taken seriously. The Statistical Downscaling Model (SDSM) has contributed to the good projection of average rainfall of the research study. Meanwhile for the GIS model has been introduced to give an accuracy results of the forecasted ungauged rainfall as a missing data. This chapter were discussed on the main conclusion for the study. Based on discussion from previous chapter, a several specific conclusion as listed in the following section.

5.2 Prediction of Future Rainfall

SDSM model has been established good selection predictors in data screening processes. The best five correlated predictors variables were selector each rainfall stations to obtain a good result of calibration and validation. Each predictor has a different characteristic which is contributed to the change of climate change. ‘temp’ is the strongest correlation for rainfall.

The result of SDSM model for calibration and validation of rainfall represent that the graph pattern was similar between the historical and the simulated result for all station. The best simulated result was at Paya Besar station because it produce the smallest MAE with 2.66% from calibrated and 13.71% from validated. Although some of the rainfall station which are station Kg Sg. Soi station show that the validation part has a slightly different in rainfall pattern trend and the highest MAE was recorded with 6.28% from calibrated and 23.24% from validated among other stations but still acceptable because percentage of MAE are lower 40%. Meanwhile, the highest R were produced for every rainfall stations which closer to 1.0. It shows that the calibrated and validated values is reliable and acceptable for this study.

The projected annual rainfall were predicted to produce lesser annual rainfall compared to the historical for three station. The months Feb until Aug are predicted to have reasonable amounts of rainfall in all scenarios and are more significant under the most severe scenario RCP4.5 due to the Southwest monsoon, which normally dominates the dry season period. Meanwhile the projected rainfall result was expected to increase to occur during Northeast monsoon especially in November and December. For more information, Paya Besar station of RCP2.6 recorded the highest receive rainfall among other stations has decrease to 2995mm/year compare to historical data is 3060mm/year and the differ percentage is very small with -2.14%. While the lowest rainfall was projected of RCP4.5 at Pam Paya Pinang station among other stations has decrease to 2120mm/year compare to historical data is 2469mm/year with the percentage decrement with -14.11%. For the Paya Besar station and Kg. Sungai Soi station, RCP 8.5 shows the least rainfall changes in the long term with -11.32% and -6.5% compared to other RCPs.

5.3 Performance of GIS interpolation

The Krigging method was used as interpolation agent to treat ungauged rainfall station. Monthly rainfall data of three station were estimated using the data of surrounding stations so that ungauged station and the gauged station can be compared for the station 2 based on statistical analysis. Using the historical data of the comparison was in between of 1984 until 2013 and the projected monthly rainfall by RCP 4.5 for the interval year of 2020 until 2049.

From the analysis of historical data, the highest different error between ungauged station and gauged station for historical rainfall was 26.6% in July but the trend pattern is similar. In more detail, the result monthly rainfall for ungauged station with 110.05mm compared to the gauged station was 149.83mm. Meanwhile in April, it was produced the lowest error with 0.22% compared to the other months.

However, from the analysis of RCP4.5 show the result produced very small error, which is less than 26% for every month and all of the rainfall trend patterns are very close to historical data. The lowest error of MAE recorded in months was in the month of September, which is 0.06%. While the highest error recorded 28.51% occur in December among other months.

In conclusion, the results of GIS interpolation between the ungauged station and gauged station for every months, its rainfall and projection rainfall, can be accepted because the difference in percentage error between obtained value of MAE is less than 20% and the trend pattern produced is similar. GIS interpolation is the best method for researches to find missing data because it does not take a long time to obtain the value compared to other methods which is Arithmetic Mean method, Quadrant method and Normal Ratio method.

5.4 Recommendations

Several guidance and recommendation are provided in enhancing for study purpose:

a) In selecting predictors, the selection must be done with suitable specific method to produce the highly correlation values among different other predictors because since this is the most important part of SDSM, it thus however could affect the whole projections result.

b) If missing data must be determined from a lot of rainfall stations which involve in many districts and it needs a very long time to be determined, different pattern and high variation of rainfall trend might be produced. Thus, more precise of interpolation values must be determined based on types of landform and density values according to measured height. If each rainfall station has different topography, it will be clearer and visible to conduct interpolation and more accurate values can be obtained.

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