ASSESSMENT THE IMPACT OF THE CLIMATE CHANGE ON THE DRYNESS INDEX AT KEDAH STATE

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ASSESSMENT THE IMPACT OF CLIMATE CHANGE ON THE DRYNESS AT KEDAH STATE TITLE

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Thesis submitted in fulfillment of the requirements
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ABSTRACT

The issue of climate change and its effect on various aspects of the environment has become more challenges for society. It is desirable to analyses and predict the changes of critical climate variables, such as rainfall, temperature and potential evapotranspiration affect in the content of global climate change. This paper assessed the potential dryness index in the long term with considered the impact of the climate changes. To achieve the objective, statistical climate model (SDSM) has been applied to stimulate the changes of the climatic trend at the study area. In this study, the long term climate has been predicted using atmospheric variables which provided by National Centre for Environmental Prediction (NCEP) and General Circulation Model (GCM). Then the Standard Precipitation Index (SPI) used to estimate the dryness index at study area. The dryness index was measured based on the rainfall amount according to cumulative 3-month and 12-month cumulative period. The rainfall amount changed into normal distribution to get a zero SPI mean value for each selected stations and period time scale. The positive value of SPI shows the greater precipitation than median while negative value shows the lesser precipitation than the median. The purpose was to classify the precipitation into dry and wet conditions at Kedah state. Based on the results obtained, SDSM produced good performance in calibration where the average error for all stations was below 20%. Meanwhile, the performance of validation shows the result of error was above 20% but below 40%. The less consistent rainfall historical data at Kedah state given from DID might be the reason for high percentage of error. The rainfall projection at all selected station shows the different prediction compared to historical data. RCP2.6 agreed that Kedah Peak and Kg Gajah Puteh expected to receive lesser annual rainfall compared to historical with 5.58% and 32.92% decrement respectively. All RCPs claim Kg Jelutong expected to receive more rainfall because all RCPs shows increment in predict the future annual rainfall. Meanwhile, RCP8.5 claim Kota Sarang Semut will receive lesser annual rainfall with 7.49% decrement. In order to estimate the dryness index, SPI 3-month and 12-month was analysed for all stations at study area. At least all stations expected to experience three times of extreme dry within the year 2019 until 2040.

ABSTRAK

Perubahan iklim serta kesannya terhadap alam sekitar merupakan suatu isu yang telah menjadikan masyarakat terdedah dengan lebih banyak cabaran. Kajian yang dijalankan adalah bersesuaian untuk menganalisis dan meramalkan perubahan bentuk iklim yang kritikal seperti hujan, suhu dan potensi evapotranspirasi yang mampu menjejaskan keadaan perubahan iklim global. Kajian ini mengkaji tahap kekeringan dalam jangka masa panjang yang memberi kesan terhadap perubahan iklim. Untuk mencapai objektif tersebut, iklim statistik model (SDSM) telah digunakan bagi mengkaji polar dan perubahan iklim di kawasan kajian. Dalam kajian ini, perubahan iklim jangka masa panjang telah diramal dengan menggunakan parameter yang didapati daripada National Centre for Environmental Prediction (NCEP) dan Model Edaran Umum (GCM). Kemudian, piawai indeks hujan (SPI) digunakan untuk menjangkakan indeks kekeringan di kawasan kajian. Tahap kekeringan itu diukur berdasarkan jumlah hujan dalam jangka masa kumulatif 3 bulan dan 12 bulan. Jumlah hujan ditukarkan kepada taburan normal untuk mendapat nilai purata SPI untuk stesen terpilih dan jangka masa kumulatif. Nilai SPI positif menunjukan penerimaan hujan yang lebih berbanding purata manakala negative menunjukkan penerimaan hujang yang kurang dari purata. Tujuannya adalah utk mengkelaskan taburan hujan dalam menentukan tahap kering dan lembap di Kedah. Berdasarkan keputusan yang didapati, SDSM telah mengahsilkan keputusan yang baik dalam kalibrasi di mana ralat yang terhasil kurang dari 20%. Sementara itu, keputusan validasi menunjukaan ralat melebihi 20% tetapi masih kurang dari 40%. Data yang kurang konsisten yang diperolehi dari Jabatan Pengairan dan Saliran (JPS) mungkin antara punca ralat yang besar. Ramalan hujan di semua setesen menunjukkan ramalan yang berbeza dibandingkan dengan data yang lepas. RCP 26 besetuju bahawa Kedag Peak dan Kg Gajah Puteh dijangka akan menerima kurang hujan sebanyak 5.58% dan 32.92% penurunan. Semua RCP menyatakan Kg Jelutong akan menerima lebih hujan. Sementara itu, RCP 8.5 menyatakan Kota Sarang Semut akan menerima kurang hujan sebanyat 7.94% penurunan. Dalam meramal tahap indeks kekeringan menggunakan jangka masa kumulatif 3 bulan dan 12 bulan, kesemua stesen dijangka akan mengalami kering yang ekstrem dari tahun 2019 sehingga 2040.

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LIST OF SYMBOLS

°C	Celsius
%	Percentage
mm	Millimetre
23’22’’N	North coordinate
100’33’’E	East coordinate
km	Kilometre
m	Metre
cm	Centimetre
R^2	Variance
CO_2	Carbon dioxide

LIST OF ABBREVIATIONS

IPCC	Intergovernmental Panel on Climate Changes
MMD	Malaysian Meteorological Department
SPI	Standard Precipitation Index
DID	Department of Irrigation and Drainage
GCMs	General Circulation Model
SRI	Standardize Runoff Index
SDI	Streamflow Drought Index
IDI	Integrated Drought Index
SSFI	Standardized stream flow Index
DHR	Drought Hazard Rate
DEI	Drought Extent Index
ADI	Agriculture drought intensity
SEDI	Socioeconomic drought Index
MWR	Minimum in-stream water requirement
VIC	Variable Infiltration Capacity
WSL	Water shortage level
RSP	Reservoir storage percentage
LCWD	Largest cumulative water deficit
DDL	Drought Duration Level
PDSI	Palmer Drought Severity Index
SPEI	Standard Precipitation Evapotranspiration Index
SC-PDSI	Self-Calibrated Palmer Drought Severity Index
MAM	March-April-May
JJA	June-July-August
SON	September-October-November
DJF	December-January-February

NE	Northeast
SW	Southwest
GHG	Greenhouse gas
NGO	Non-Governmental Organisation
NCEP	National Centre for Environmental Prediction
SP	Super predictor
PRP	Partial correlation
MCM	Multi correlation matrix
MAE	Mean absolute error
NSE	Nash Sutcliffe Efficiency
RMSE	Root mean square error
RCP	Representative Critical Pathway

CHAPTER 1

INTRODUCTION

1.1 Introduction

Situated between 1° and 6°N, the whole of Malaysia has a classic equatorial climate, with high temperatures and wet months throughout the year. The weather in Malaysia is hot and humid year round, interspersed with tropical rain showers. The wet season on the east coast is between November to February, which is when the west coast experiences sunny and dry weather. Conversely, the wettest months on the west coast are April to October, which are the driest months on the east coast.

In Malaysia, climate changes is one of the big issues that have been discussed among authorities. Heading towards as a developing country, many factors influencing climate change in Malaysia such as logging, construction, agriculture and an extreme climate event. Climate change refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change refers to the major change in temperature, precipitation, or wind pattern, among other effects, that occur over several decades or longer.

The temperature in Malaysia has uniformly distributed over the peninsular. The mean temperature at low area is in range of 26°C to 28°C. Meanwhile, the annual variation of the daily mean temperature may be small where the ranges about 2°C to 3°C and the diurnal variation may be as large as 12°C. Seasonal variations in climate are more evidently marked by rainfall patterns. The rainfall patterns was influenced by the monsoon and strength of the winds blow at different times of the year. The north-eastern monsoon is dominant from November to March, bringing moisture and more rain during south-western monsoon with high winds blow from June to September. Therefore, the average annual rainfall in Malaysia 3550mm/year.

The rainfall projection was widely estimating using Statistical DownScaling Model (SDSM). Statistical downscaling is a downscaling approach that utilizes statistical relationships between the large-scale climate (predictor) and the local climate (predictand) to simulate the climate at a local scale (Benestad et al. 2007)

1.2 Problem of the Statement

Rainfall distribution and temperature are very important role in the determination of climate conditions. Therefore, various initiatives have been undertaken to overcome the problem associated with rain due to a variety possibility will happen if not done vigorous. In addition, increasing the temperature at maximum and minimum readings will also affect all activities that made at study area.

Extreme precipitation leads to serious disasters that cause large human and economic losses because it tends to bring natural hazards such as floods, landslides, and debris flows (Easterling et al, 2000). The global increase in the frequency and intensity of extreme precipitation events has been observed in numerous studies. The reasons behind the extreme precipitation changes have been widely discussed in the past decades. The extreme precipitation events was influenced by combination of natural and human factors (IPCC, 2013). Global warming and anthropogenic aerosols are considered to be the major components affecting extreme precipitation changes (Liu et al, 2015).

The problem of natural occurrence of disasters related to rainfall also occurs such as flash floods and floods would recommend residents and urban areas. This is because excessive water will damage public property and claimed human lives (Arakawa, 1969).

Malaysia is one of the countries in the world which is experiencing a warming trend for the past few decades. The global land precipitation has raising about 2% since the early of the 20th century. The extremely hot temperature, heat waves and heavy precipitation events will contribute to become more frequent (IPCC,2001). Malaysia's temperature and rainfall are rapidly increasing between +0.6 to 3.4°C and -1 to +32% in 60 years repetitively and the rise of sea level is about 13 to 94 cm within 100 years respectively (INC, 2000). Thus, these will give impacts on water resources, coastal zone, public health, food supply, drainage, flooding, landslides, haze, typhoons, and others negative phenomenon that need national and international responses to face climate change.

In order to estimate the dryness index at the study area, the SPI was used as a method to estimate drought at the region. It allows an analyst to determine the rarity of a drought at a given time scale (temporal resolution) of interest for any rainfall station with historic data. SPI also can be used to determine periods of anomalously wet events.

In January 2018, almost all states in the peninsular of Malaysia recorded the SPI index from a moderate scale to a high scale of humidity. Extremely areas are around Pulau Langkawi Station, Bayan Lepas, Butterworth, Subang and Temerloh. The state of Johor and some areas on the east coast of the peninsula recorded the normal reading of the SPI index. In Sarawak, almost all areas recorded the reading of the SPI index at normal levels except for one or two places around Kuching Station which recorded the index of SPI at moderate to dry levels. Meanwhile, areas around the Sibu station indicate the SPI index at a moderate level of humidity. For Sabah, all areas recorded the SPI index at normal levels except around Labuan Station which recorded the SPI index at a moderate level of humidity (MMD,2018).

Based on Dry Monitoring Report from Malaysian Meteorological Department (MMD) in January 2018, over the last three months from November 2017 to January 2018, the rainfall in the peninsular Malaysia showed a percentage of rain anomalies above the average. The entire northern states of Peninsular including Perlis, Kedah and Penang have experienced anomalous percentages of 60% above average. There are one or two places in the west of Perak also recorded the same percentage of rain anomalies.

In Malaysia, agricultural such paddy plantation exacerbated by a variety of factors including ranging from climate change, uncertainties market prices, inaccessibility of financial services and a lack of risk mitigation instruments. Climatic change, natural disasters, diseases and attacks from pests and insects were also seen as threats to paddy plantation. In year 2010, the floods hit several states such as Johor, Kelantan and Kedah have resulted in huge losses to nearly all the land of the peasants. This clearly shows that paddy, although highly important, was a crop exposed to high-risk factors.

Floods and droughts have caused losses amounting of millions of ringgit, the destruction of natural resources and environment. Paddy production areas that were at risk of floods and droughts have grown each year, especially in low areas and areas with improper irrigation system. In addition, the lack of early warning systems making farmers more vulnerable to disasters. The incidence of droughts had plagued six times over the period 1977 to 1992 (Mon and Chang, 2008).

Natural disasters, especially floods and droughts had led to decline in paddy production from 0.21 million metric tons in 2009 to 0.20 million metric tons in 2010, due to reduction in planted area of about 5,306 hectares (Baharuddin, 2007). Natural disasters were one of the major contributors to the decline in the productivity of agricultural commodities (Hasegawa, 2009). In general, about 12% to 22% of paddy productivity declined due to the effect of climate change in Malaysia (Rosenzweig et al, 1994). Floods and droughts not only decreased the yield, but also resulted in the destruction of crops and indirectly affect the country's food security (Ibrahim et al, 2012).

There were variety of modern and sophisticated equipment used in hydrology for the researchers. However, not all problems can be overcome but it can reduce the problems, cost and time. Consequently, each study and analysis is done not so accurate and precise. It is because of the accuracy of an analysis depending on the perfection in work and consumption data. Therefore, it is important to review and interpret the data from the analysis conducted, it was determined that a systematic method of regulating the state condition (Sarjon, 2000). If the required data is not complete and there are many defects, this situation will cause problems for researchers in the field of hydrology.

The impacts of climate change on these deposits are directly or indirectly affect the hydrologic cycle differently. Due to the uncertainties in climate change, this projection can function under various climate change scenarios. Thus, the proposed study is based on climate change scenarios present.

1.3 Objective of Study

The main objective of this study was to assess the impact of climate change on the dryness at Kedah state. Therefore, there were 2 objectives as follow:

i) To forecast the long term changes of rainfall using statistical model (SDSM)

ii) To estimate the dryness index using Standard Precipitation Index (SPI)

1.4 Scope of Study

The study was focused on the estimation of dryness index at Kedah state using Standard Precipitation Index (SPI). The historical daily rainfall (1980-2009) were provided by Department of Irrigation and Drainage, Malaysia (DID). About 4 stations have been selected around Kedah state. There were Kedah Peak, Kg Gajah Puteh, Kg. Jelutong and Kota Sarang Semut. The future climate was generated using variable provided by GCMs using SDSM model. The SDSM was applied to investigate the future climate variation for rainfall in year 2011 to 2040. This main aim of this study was to analyse the effectiveness and accuracy of rainfall data obtained was influence the climate change at the Kedah state. The projected result from SDSM was used to analyse the dryness index using SPI index. The long term dryness index was examined by SPI equation.

1.5 Significant of Study

The important of this study is to determine the long term dryness index and rainfall pattern at Kedah state which were affected by the climate changes. This research important to become a significant information for the long term planning and management water resources in future. The dryness index can be as references the drought level at the region. The application and performance of SDSM as a rainfall projection model for Kedah state can be measured by analysing result produced by Department of Irrigation and Drainage, Malaysia (DID). The dryness index at the study area was obtained by the application of SPI to analyse the long term dry pattern since Kedah receives amount of the rainfall distribution about 2970mm/year.

In addition, this research also important to identify the rainfall distribution at this region in the future year. Therefore, indirectly aware of the background environment and hydrological characteristics in the area and able to anticipate climate change the distribution of the quantity of rain will occur in the future at area of study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Drought is not only a physical occurrence that can be defined by the weather conditions. A drought is defined as an extended period of unusually dry weather that causes water shortage and crop damage. Drought is recognized as a slow-onset natural hazard that originates from a deficiency of rainfall over a prolonged period (Dubrovsky et al.,2009) and also described as inequality of water accessibility. It is known as the global costliest climatic hazard that causes destruction on the agriculture and ecosystem in term of economy, social and the nature (Wilhite, 2000).

In Malaysia, the drought can be classified as a critical issue due to the rainfall deficit, which induces with to the problems of water crisis. Most of the states in Peninsular Malaysia have experienced notable historical drought episodes that produce significant impacts to the environment, economic and social activities. Drought has caused the negative impacts with respect to the deterioration for the quality of life, conflict of water and land uses, reduction of crop yields, rising of pollution issue, outbreak of water-borne diseases, declination of aquatic biodiversity, forest or bush fires which subsequently cause erosion and sedimentation. It produces devastating consequences on regional water resources, agriculture, economic, environment and land desertification with far-reaching effects in a progressively globalized world (Liu et al., 2016). These impacts often lead to disruption of life quality and economic growth of the country. Therefore, drought analysis is very essential to enhance the ability of drought monitoring, understand the changes of drought vulnerabilities and mitigate the drought impacts (Yusof and Hui-Mean, 2012).

The drought indices can be evaluated using a weighted set of evaluation criteria to assess the severity of meteorological, hydrological, socioeconomic and agricultural forms of drought (Keyantash and Dracup, 2002). There are four types of drought which are hydrological, agricultural, meteorological and socioeconomic that were discussed in the next sub chapter.

2.1.1 Hydrological Drought

Hydrological drought is related to the impact of periods of precipitation including snowfall, shortfalls on surface or subsurface water supply. Streamflow, reservoir, lake and groundwater are some example of subsurface water supply. The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Although all drought happens due to the lack of precipitation, hydrologist is more anxious with how the precipitation deficit plays out through the hydrologic system. Hydrological droughts are typically out of phase with or lag the occurrence of meteorological and agricultural droughts. Some component of hydrological system like moisture of soil, streamflow, groundwater and reservoir levels will take more time to show the effect of precipitation shortage. These impacts will result on the economic sectors. In other word, the lack of precipitation may result in the reduction of soil moisture and almost directly noticeable to agriculturalist. However, the effect of these deficiency on reservoir levels not cause any impact to the hydroelectric power production or recreational in several months. Besides, water in hydrologic storage systems such as reservoir and river is frequently used for various and opposite purpose like flood control, irrigation, recreation, navigation, hydropower and also for wildlife habitat further complicating the structure and quantification of impacts. During drought, the competition for water in these systems may bring conflict among all water users.

Assessment of hydrological drought plays an important role in water management (Weng et al., 2015). Hydrological drought is very important because most of daily activities depend on surface water resources or ground water resources (Santos et al., 2011). Typically, stream flow data is generally used for the analysis of hydrological drought (Bao et al., 2011). Previous study has been conducted and the aim of the study is to assess hydrological drought by Standardize Runoff Index (SRI) and Stream Flow Drought Index (SDI) in study area river basin and comparison of those indices for long-term drought studies.

i) Standardize Runoff Index (SRI)

SRI is developed (Shukla; Wood., 2008) to assess hydrological drought considering only the stream flow data. It involves fitting of suitable distribution to flow records of a particular location. After that, Probability Density Function (PDF) and Cumulative Distribution Function (CDF)are calculated and then transformed it to standardized Gaussian distribution with mean zero and unit variation that gives SRI value. By using the index 3, 6, 9 and 12 months SRI is calculated.

ii) Streamflow Drought Index (SDI)

SDI developed (Nalbantis; Tsakiris., 2009) to characterize the hydrological drought by considering monthly stream flow value (Q_{ij}); where *i* represent hydrological year and *j* represent months with in the hydrological year, then the equation is given below

$$V_{ik} = \sum_{i=0}^{k} Q_{ij} \,; for\ i = 1,2,3, \dots, j = 1,2,3, \dots, 12, k = 1,2\,, \dots \qquad (2.1)$$

where, V_k gives *i*th year volume of cumulative stream flow. For 3 months SDI (July to September) the value of $k = 1$ similarly $k = 2$, $k = 3$ and $k = 4$ for 6 months, 9 months and 12 months SDI respectively. From cumulative flow values, for each *k*, SDI is defined for the *i*th hydrological year as below:

$$SDI_{i,k} = \frac{V_{ik} - V_k}{S_k} \,; for\ k = 1,2,3 \dots . i = 1,2,3, \dots \qquad (2.2)$$

where *Vk* represent mean value of cumulative stream flow for *k*th period while *Sk* represent the cumulative stream flow of *k*th period.

2.1.2 Agricultural Drought

Agricultural drought relates to the various characteristics of meteorological or hydrological drought to agricultural impacts, focusing on precipitation deficiency, differences between genuine and potential evapotranspiration, deficits of soil water, decreasing groundwater or reservoir levels, and so forth. The main weather conditions will affect the plant water demand usually in terms of specific plant biological and the period of grow. The weather conditions also influence the physical and biological properties of soil. The best definition of agricultural drought should be able account for the variable exposure of crops during different phase of crop development, from emergence to maturity. The deficiency of topsoil moisture at planting may result on the low population of plant per hectare produced and a final yield reduction. However, if in the early growth requirement had obtain sufficient topsoil moisture, the final yield will not have affected by the deficiency in subsoil moisture if the subsoil moisture is replenished as the growing season progresses or if rainfall meets plant water needs.

Previous research applied the variable fuzzy set theory to develop an Integrated Drought Index (IDI) combining meteorological, hydrological, and agricultural factors (Huang et al., 2015). The IDI has a better performance compared with SPI and Standardized stream flow Index (SSFI) because it is more sensitive and effective to capture drought onset and persistence. However, drought indices that are related to soil moisture are inappropriate in humid regions is the main crop. Therefore, there are several alternative drought indices were defined that will be discussed.

i) Drought Hazard Rate (DHR)

DHR is defined as the ratio of the crop planting area affected by droughts (A_{da}) to the crop planting area covered by droughts (A_{dc}). The crop planting area affected by droughts where the area in which crop yield is reduced over 30% by droughts. The crop planting area covered by droughts where the area in which crop yield is reduced over 10% by droughts (Yan et al., 2009) in the same year. DHR is given by

$$DHR = \frac{A_{da}}{A_{dc}} \times 100\% \quad (2.3)$$

The DHR can be used to describe the degree of actual damage from droughts.

ii) Drought Extent index (DEI)

The drought extent index (DEI) is definerd as the ratio of A_{dc} divided by the crop planting area A_s in the same year.

$$DEI = \frac{A_{dc}}{A_s} \times 100\% \quad (2.4)$$

A_s was derived from the study area statistical bureau. DEI can be used to describe the actual intensity of droughts. Both DHR and DEI are based on statistical data.

iii) Agricultural drought intensity index (ADI)

$$\text{ADI} = \Delta WB_r = \frac{WB_r - WB_r}{WB_r} \times 100\% \quad (2.5)$$

where WBr = [(P – ET_0) / ET_0] is the relative difference between the water supply from precipitation (P) and the crop water demand or requirement as measured by evapotranspiration (ET_0). WB_r is the average of WB_r over the period. ADI reflects the degree to which water requirements are met. A large negative ADI indicates a local water deficit and an inability to meet water demands for normal crop growth and development. ADI can be divided into four levels

Table 2.1 ADI value indicator

Level	Description
ADI ≥ −20	No drought
(−20 > ADI ≥ −45)	Mild drought with no obvious crop effects
(−45 > ADI ≥ −70)	Moderate drought that produces some crop damage
(ADI < −70)	Severe drought that reduces crop yield

2.1.3 Meteorological Drought

Meteorological drought is defined as the basis of the degree of dryness and the period of the dry period usually compare to some normal or average amount. The definitions of meteorological drought must take as consideration in order to specific the region since the atmospheric conditions may result in shortage of precipitation are highly variable from one area to other area. For example, some definitions of meteorological drought are used to identify periods of drought on the basis of the number of days with precipitation less than some specified threshold. This measure is only suitable for regions characterized by a year-round precipitation regime such as a tropical rainforest, humid subtropical climate, or humid mid-latitude climate.

One of the most commonly used indices for meteorological drought is the Standardized Precipitation Index (SPI), which has been studied by many researches due to its simplicity, standardized nature and flexibility (e.g., Hayes et al., 1999). Since SPI index is based on precipitation data, drought evaluation will be relative easily and it could be explained on multiple time scales. A nonparametric framework can be used for deriving np-SPI that describes drought more effectively. However, the other method to determine meteorological drought is by using precipitation percent normal and precipitation percentiles.

2.1.4 Socioeconomic Drought

Socioeconomic drought is the drought relate to the supply and demand of some economic good with components of meteorological, hydrological, and agricultural drought. It differs from the meteorological, hydrological and agricultural drought because the occurrence is affected by the spaces processes of supply and demand in order to categorize droughts. Weather is influence many economic goods supplier like water, forage, food grains, fish, and hydroelectric power. Because of the climate change nowadays, water supply may sufficient in some years but it does not guarantee that water supply would meet human and environmental needs in other years. When the demand for economic good exceeding the supply the socioeconomic drought will occur. It is as a result of a weather-related shortfall in water supply.

Drought may reduce the hydroelectric power because in order for power generation, some power plant is depending on the streamflow rather than storage. When the hydroelectric power production is reduced, the government need to import petroleum and implement stringent energy conversation to fulfil the nation's power needs. In most cases, the increasing population and per capita consumption will increase the demand for economic goods. Regarding that, the supply also may increase due to production efficiency improvement, technology or the construction of reservoirs that may result on surface water storage capacity. When both supply and demand are increase, the critical factor is the relative rate of change.

Based on the previous study, in order to identify socioeconomic drought events on different severity levels through evaluating the impacts of water shortage and drought duration under climate change, a few methods were developed which is heuristic method and socioeconomic drought index (SEDI). Historical drought analysis was conducted using the observed data, which can validate the applicability of the heuristic method and SEDI. The future drought analysis was conducted using different datasets of climate change scenarios, which can reflect a variety of drought conditions in future. The heuristic method and the SEDI are developed as follows

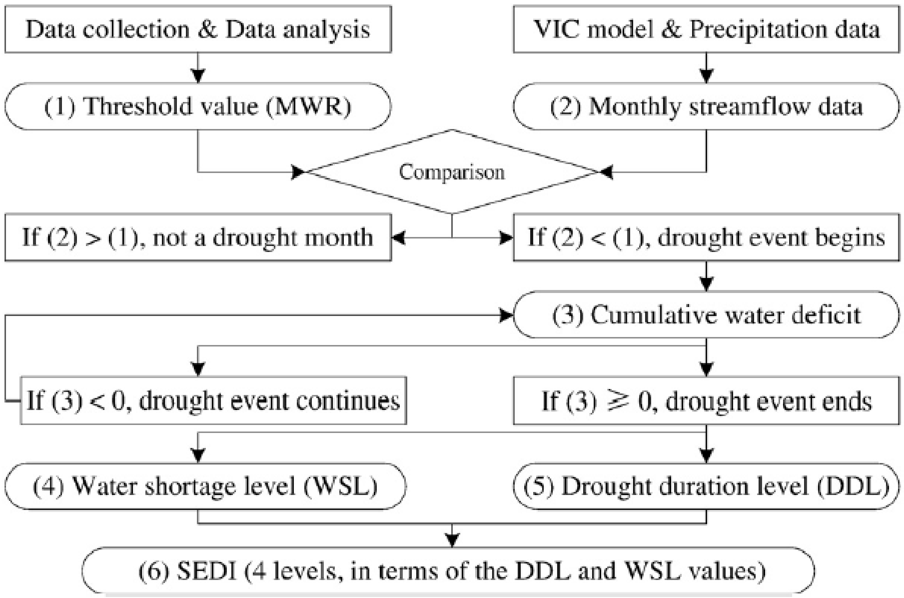

Figure 2.1 Flowchart of the development of the heuristic method and the SEDI

First, the minimum in-stream water requirement (MWR) of the river basin which is enough to sustain and support the different functions in this river basin, is adopted as the threshold value through comprehensively considering a number of factors such as water quality, ecology, navigation, and water supply. Second, the monthly streamflow data, either the observed data recorded at the hydrological stations or the simulated data derived from the Variable Infiltration Capacity model (VIC) (Liang et al., 1994) are used to identify drought month. Then, the monthly difference calculated by minus the monthly streamflow data and the MWR value.

It is worth noting that a socioeconomic drought event will continue until the cumulative water deficit turns into a non-negative value. Finally, for each identified socioeconomic drought event, the SEDI value can be calculated through integrating the impacts of water shortage and drought duration, which are classified into four different levels represent in table 2.2. It is worth noting that the indicators related to experiment procedures; the MWR value may vary with land use and land cover dynamic, catchment geomorphology and scale, and even some climate-related events occurred in a particular region. Therefore, the heuristic method and SEDI are region-dependent, which indicates that the values of the indicators should be recalculated for different regions.

In addition, the four water shortage levels (WSL) are defined by a typical reservoir storage percentage (RSP). The typical reservoir storage (TRS) refers to the total manageable storage capacity of the reservoirs in a study area. The RSP can be calculated as the absolute value of the largest cumulative water deficit (LCWD) divided by the TRS (Denver Water, 2002).

$$\mathrm{RSP} = \frac{\mathrm{Abs\ (LCWD)}}{\mathrm{TRS}}$$

Where Abs () is the function of taking the absolute value. The WSL value will be 1, 2, or 3 if the RSP value is 40%, 60% or 80%, respectively, and if the RSP value is greater than 80%, the WSL value will be 4. Therefore, for each identified socioeconomic drought event, the SEDI is defined in terms of the DDL and WSL values as follows

$$\mathrm{SEDI} = \max \{\mathrm{DDL}, \mathrm{WSL}\}$$

For example, if the WSL and DDL values are 2 and 3, the SEDI value will be 3, which means it is a severe socioeconomic drought event. TABLE shows the ranges of different SEDI values classified by different levels of water shortage and drought duration.

Table 2.2 Definitions of the SEDI based on Water Shortage Level and Drought Duration

SEDI		**Water Shortage Level (WSL)**		**Drought duration level (DDL)**	
Value	**Definition**	**Value**	**Definition**	**Value**	**Definition**
1	Slight	**1**	RSP < 40%	**1**	Quaterly (1-3 month)
2	Moderate	**2**	40%<RSP<60%	**2**	Semi-annual (4-6 month)
3	Severe	**3**	60%<RSP<80%	**3**	Annual (7-12 month)
4	Extreme	**4**	RSP>80%	**4**	>12 month

2.2 Drought indices

Drought indices are widely used for identify the moisture conditions. However, because of the complexity of drought characteristics and definitions, it is difficult to have a single index to adequately capture the intensity and severity of drought and its potential impacts (Vicente-Serrano et al., 2012). The type of drought indices used will be discuss in the next sub chapter.

2.2.1 Standard Precipitation Index(SPI)

SPI is a common tool utilized to monitor current drought conditions, which is far more functional than raw data during decision making (Belayneh and Adamowski, 2012). The SPI is a multi-timescale drought index that totally depending on precipitation data. The SPI represents abnormal wetness and dryness with user defined time durations by comparing precipitation departure from the cumulative probability distribution of precipitation over the same region and period (McKee et al., 1993). The SPI has widely used because simple data, simple calculation and flexible time duration. The SPI result employed is enable to be used as drought monitoring at variables timescales and water supply management (Guttman, 1999). However, it is limited in its ability to represent drought conditions when other environmental components like temperature are not stationary (Vicente-Serrano et al, 2010) because the SPI only based on the precipitation record. Nevertheless, studies have shown that drought conditions are mainly determined by the variability of precipitation, and the SPI is reasonably correlated with the Palmer Index at time scales of 6–12 months (Heim 2002; Redmond 2002).

The SPI is considered as the most appropriate index for monitoring the variability of droughts since it is easily adapted to local climate, has modest data requirements and can be computed at almost any time scale (Ntale and Gan, 2003). In Asia, many researches have adapted SPI as an effective tool for their countries drought monitoring (Yusof et al, 2014) and applied SPI to assess rainfall characteristic over Peninsular Malaysia and concluded that the whole peninsular is predicted to have an increasing trend during drought events (Z hang et al, 2014).

Table 2.3 Classification of Drought Severity Level Based on SPI Scores

SPI score	Level of
>2.00	Extremely wet
1.50 – 1.99	Very wet
1.00 – 1.49	Moderately wet
0.01 – 0.99	Mildly wet
-0.99 – 0.00	Mild drought
-1.00 - -1.49	Moderate drought
-1.50 - -1.99	Severe drought
<-2.00	Extreme drought

2.2.2 Palmer Drought Severity Index (PDSI) and Z index

The PDSI and Z-index were developed in 1965 (Palmer, 1965). The PDSI and Z-index are calculated using a water balance model that requires air temperature and precipitation data also information on the available water content (AWC) of the soil. Based on these data, the PDSI calculates evapotranspiration, runoff, recharge and soil moisture (Zargar et al., 2011). PDSI represents longer-term moisture conditions over approximately 9 months, while the Z-index is an intermediate term in the PDSI calculation and it represents monthly moisture anomalies.

In the different climate, the PDSI is the first procedures to validate success at quantifying the severity of drought (Palmer, 1965). In particular, the PDSI does not perform well in regions where there are extremes in term of rainfall variability or run-off, such as in Australia and South Africa (Burke et al., 2006). PDSI indicates the severity of a wet or dry spell; the greater the absolute value, the more severe the dry or the wet period.

2.2.3 Standard Precipitation Evapotranspiration Index (SPEI)

The SPEI combines the PDSI's sensitivity to changes in evaporation demand caused by temperature fluctuations and trends, with the multitemporal nature and straightforward to calculations of the SPI. SPEI uses the basis of SPI but includes a temperature component and allowing the index to account for the effect of temperature on drought development through a basic water balance calculation. SPEI has an intensity scale in which both positive and negative values are calculated; identifying wet and dry events.

The advantages of the SPEI is similar to the SPI. It can be calculated over different time scales to monitor droughts with respect to severity, duration, onset, extent, and completion. The SPEI (Vicente-Serrano et al., 2010) is similar to the SPI, but it is produced by standardizing the difference between water supply in form of precipitation and demand; potential evapotranspiration. Since the SPEI accounts for potential evapotranspiration, thus it can account for the influence of air temperature, wind speed, solar radiation and humidity (Wang et al., 2015). In the other hand, the primary advantage of the SPEI is it combines the multi-timescales aspects of the SPI with information about evapotranspiration, making it a more physically realistic drought index.

2.2.4 The Self-Calibrated Palmer Drought Severity Index (SC-PDSI)

SC-PDSI mechanically calibrates the behaviour of the index at any location by exchange empirical constants within the index computation with dynamically calculated values (Wells et al., 2004). SC-PDSI is more spatially compared to the PDSI. The use of different time scales by the SPI permits the consequences of rainfall deficit on different water-resource elements to be accounted for, creating it more vigorous. However, since it does not consider water balance, it is highly recommended in data-limited areas for pragmatic reasons.

2.2.5 Precipitation Percent Normal

Precipitation percent normal (Keyantash and Dracup, 2004), hereafter referred to as percent normal that used as an indicator of the precipitation deficit. It can be calculated for any location and time period of interest by comparing observed precipitation to normal precipitation for the location and time period. Usually, normal precipitation is based on a 30- year record.

2.2.6 Precipitation Percentile

Precipitation percentiles (Gibbs, 1967), referred to as percentiles, are another method to represent moisture conditions. Percentiles can be determined empirically by ranking the monthly precipitation data in order from lowest to highest; with the 0th percentile being the driest condition and 100th percentile being the wettest condition (Quiring, 2009). Percentile is same with SPI and percent normal because only requires precipitation data and can be calculated for any time scale of interest. Precipitation percent normal, precipitation percentiles and the SPI are commonly used to describe meteorological drought and they are all based on precipitation data.

Table 2.4 Median Correlations Between Drought Indices and Soil Moisture (n = 133).

	PDSI	**Z INDEX**	**SPEI**	**SPI**	**PERCENTILE**	**PERCENT NORMAL**
MAM	0.32	0.49	0.52	0.43	0.35	0.42
JJA	0.37	0.58	0.63	0.62	0.70	0.59
SON	0.30	0.54	0.58	0.55	0.47	0.52
DJF	0.32	0.54	0.55	0.45	0.44	0.40

2.3 Rainfall Distribution of Malaysia

Rainfall is formed when saturated air is heated (air that cools down at dew point) and rises either by a mountain, conventional currents or frontal action. The rising saturated air or water vapour cools down as it rises. It attaches itself to tiny particles of dust, salts, seeds or smoke in the atmosphere. Clouds are formed as the rain drops developed. As the cloud develops further, they become heavy and unstable, but cooling down at the dry adiabatic rate. This adiabatic rate means that for every 1,000 m rise, temperature of the water droplets reduces by 10°C.

The rainfall comes to the ground when about 300 m above the earth's surface and the cloud rises further. The rising clouds become warmer than the surrounding air. This makes it unstable. As it develops further, it becomes very heavy and falls to the ground as rain. The type of rain that falls depends on the factors responsible for rising of the saturated air. Each type of rainfall requires a different mechanism that triggers the vertical movement of unstable air. The amount of rainfall recorded at a place is measured by an instrument called rain gauge. Rain gauge is a copper cylinder with a collection Jar inside and a funnel on top. The gauge is placed into the ground leaving only 30 cm of the top above the ground level to prevent splashing water from entering it. Rain falls through the funnel on top of the copper cylinder and is collected into the jar. The water is collected after 24 hours, and then poured into a measuring cylinder for measurement to be taken.

Malaysia is geographically separated into Peninsular Malaysia and west Borneo. The rainfall maximum in the former region occurs during November to December. Since rainfall is primarily produced by severe weather systems, the formation of a climatological rainfall centre is explored through synoptic activity and the rainfall amount of this centre is estimated through contributions by rain-producing disturbances (Chen, 2013).

Malaysia's climate is categorised as equatorial due to its location near the equator. Thus, the weather is being hot and humid throughout the year. The average rainfall is 2500 mm/year and the average temperature is 27 °C. The climates of the Peninsular and Sabah Sarawak is differ as the climate on the peninsula is directly affected by wind from the mainland, as opposed to the more maritime weather of the East. Malaysia is exposed to the El Nino effect, which reduces rainfall in the dry season.

Malaysia country is rich in water resources as it receives a high precipitation over the year. In 2016, Kuching station recorded the highest annual rainfall of 5,423 mm with an increase of 877.5 mm as compared to 2015 which is 4,545.5 mm. Meanwhile, the lowest annual rainfall was recorded at Temerloh station with 1,397.8 mm in 2016 and 1,193.2 mm during 2015. In addition, Malaysia also experienced a warm and humid climate in 2016 where the lowest temperature was recorded at Cameron Highland station which is 16.2°C while the highest temperature was recorded at Jerantut station is 34.2°C. These readings increased as compared to 2015 where the lowest temperature recorded was 15.9ºC at Cameron Highland while the highest temperature recorded was 33.8ºC at Temerloh (Department of Statistics Malaysia, 2017).

Kedah experienced a tropical climate and received a significantly rainfall that classified in the equatorial rainforest and fully humid. Even in a dry season the state is still experiencing rainfall. As other peninsular state of Malaysia, Kedah face the changes of the wind flow pattern that can be distinguished as Southwest monsoon, Northeast monsoon and inter-monsoon seasons. Because of some local topographic features, the rainfall distribution pattern in Kedah is affected and there was a previous study done showed that during NE monsoon, Kedah was one of the driest regions in Malaysia (Othman et al, 2016).

2.3.1 Convectional Rainfall

Conventional Rainfall is formed when air on the surface of the earth and few metres above it is heated by the sun. As the air is heated, it becomes lighter and called as water vapour. The lighter air rises, cools down, and then condenses on the condensation focusses in the atmosphere. When water vapour rises further, it converges and moves gradual upwards. This is due to the fact that there are few areas to be covered by the converging air. As the air converges, it condenses to form thick cumulous clouds. The rising clouds become heavier and unstable. This unstable cloud then drops to the ground as raindrops or rainfall. This type of rainfall is common in West Africa and is followed by lightning and thunderstorms as its associated character.

In other words, convectional rainfall as the name indicates it is due to convection. When the temperature at certain places heats up the air on the earth surface, the air gets warms up and its density increases as water vapour content in air increases and this hot air now tries to go up because of high density and low denser cool air comes down on to surface of air and now as the hot air goes up its temperature gets reduced as a consequence water vapour in air reduces and it condenses to form clouds and subsequently rains.

When these convectional rains occur as hot air goes there is low pressure created in system hence air from surrounding regions enter with high speed (as pressure is low at this place when conferred with surroundings due to which wind speed increases)

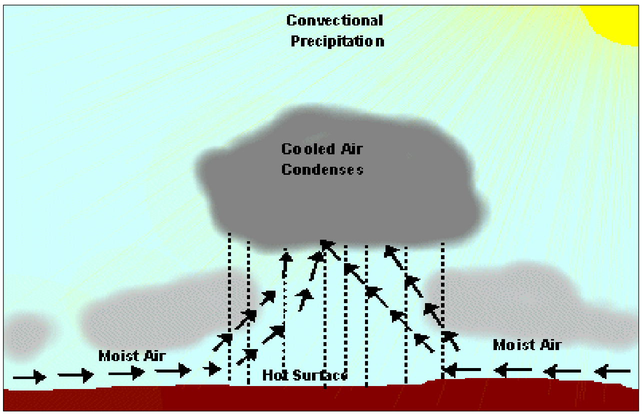

Figure 2.2 Flow of convectional rainfall

2.3.2 Orographic (Relief Rainfall)

When wind forces moist air landwards towards mountainous terrain, the mountain lifts the moist air masses high into the atmosphere. Once the air rises, it cools and allows precipitation to occur. As the wind or water vapour rises, they become unstable and heavy. They develop around condensational process and form thick clouds. They rise further and become unstable water droplets. They fall to the ground as raindrops. This type of rainfall mostly occurs at the areas facing the hill or mountain called the windward side.

The opposite side or leeward side receives the descending dry air and low or no rain. At times, it comes as droplets or in a form shower. Characteristically, orographic rainfall occurs in mountainous areas and along slopes of hills. The mountain or hill blocks and forces the rain bearing winds or water vapour to rise. Notably, it is the mountain that serves as an obstacle that forces the vapour to rise and then gives us orographic rainfall.

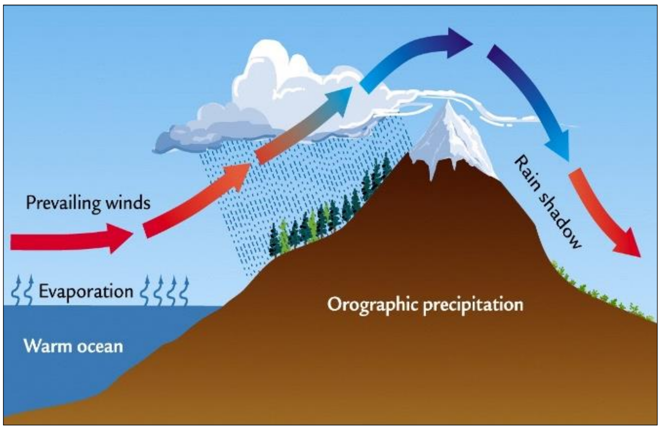

Figure 2.3 Flow of Orographic Rainfall

2.3.3 Cyclonic Rainfall

Finally, Cyclonic Rainfall is the last type of rainfall and it is also known as frontal rainfall. This occurs when two air masses of different characteristics meet or come together. For instance, when a warm maritime air mass (lighter) meets a cold air mass (heavier), the warm air mass is under-cut by the cold air mass. The warm air mass is forced to rise because it is lighter. The warm water vapor cools down as it rises. The rising air condenses or condensation takes place, and clouds are formed on the condensation nuclei (particles in the air) in the atmosphere. As the clouds rise further they become unstable due to more water droplets accumulating. They fall to the ground as cyclonic rainfall.

The characteristic feature of this rainfall is that, it is common in the Tropics (Latitude 23% Degrees North and South of the Equator), and the Temperate Zone (Latitude 66% Degrees North and South of the Equator)

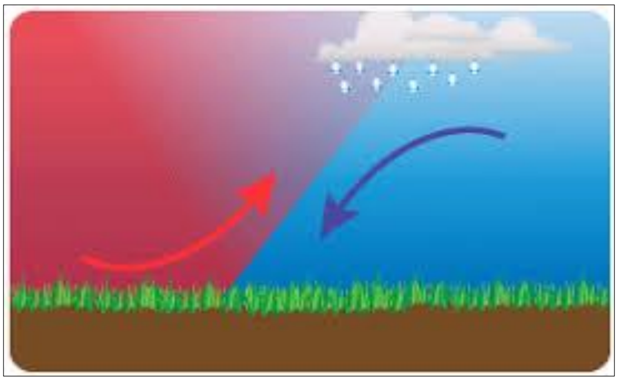

Figure 2.4 Flow of cyclonic Rainfall

2.4 Monsoon

Seasonality is caused by the tilting of the Earth, while the monsoon weather systems are a result of the land-sea temperature differences caused by solar radiation (Huffman et al, 1997). When the Earth rotates and revolves around the Sun, different seasons occur due to the different land masses of the northern and southern hemispheres. To understand this phenomenon, it is useful to note that the land surface area at the northern hemisphere is larger than the southern hemisphere. Therefore, the northern hemisphere is warmed greater. This causes opposing seasons between the northern and southern hemispheres. During summer, the southwest monsoon rainfall is controlled by the warming of the northern hemisphere, where the heated air will rise, and be transported by the monsoon wind towards the southern hemisphere (Wolfson, 2012). Monsoonal areas receive summer rainfall maximums and most of double rainfall maximums. Monsoon not only influences Asian countries, but also breaches beyond the tropical latitudes. Monsoon rainfall can also affect regions that were not originally considered as monsoonal (Serreze and Barry, 2010).

The weather in Malaysia is characterised by two monsoon seasons; namely the Southwest Monsoon from late May to September, and the Northeast Monsoon from November to March. The Northeast Monsoon brings heavy rainfall, particularly to the east coast states of Peninsular Malaysia and western Sarawak, whereas the Southwest Monsoon 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.

What is called heavy rain in Malaysia, more often than not qualifies as a storm in other parts of the world. But because the rains come almost daily, Malaysians handle the rain with nonchalance. For example, Kelantan and Terengganu are flooded annually by the Northeast Monsoon from November to March; and the small islands on the east coast such as Perhentian, Redang and Tioman essentially shut down for the season. Conversely, the Northeast Monsoon is the best time to visit the north western part of the Peninsula, as the monsoon does not affect the states of Penang, Kedah or Perlis as much from December to March.

2.4.1 Northeast Monsoon

The northeast monsoon is the major rainy season in the country. Monsoon weather systems that develop in conjunction with cold air outbreaks from Siberia produce heavy rains that often cause severe floods along the east coast states of Kelantan, Terengganu, Pahang and East Johor in Peninsular Malaysia, and in the state of Sarawak in East Malaysia.

While it frequently pours throughout the Northeast Monsoon, it is sometimes a welcoming change for many Malaysians as it cools down the daily hot and humid temperatures. As this monsoon wind is particularly strong, it often brings heavy rain to the west side of Peninsular Malaysia as well during this period. However, daytime is usually warm and sunny, with heavy rains only occurring in the evenings onward. This makes most destinations, especially cities, suitable to be visited throughout the year. It is only the coastal cities and islands on the east coast that may become unsuitable to visit, as the heavy winds and strong rains affect beachside activities. Malaysia itself is virtually free of major natural disasters, such as tornados, hurricanes, volcanic disruptions and earthquakes, making it a very safe destination. Winds are often light, bringing a gentle cooling effect on the climate.

On the other hand, it is found that the lowlands areas such as the eastern part of the Peninsula are strongly characterized by the northeast monsoonal flow. Based on the results of the Mann-Kendall test, as the trend of the total amount of rainfall and the frequency of wet days during the southwest monsoon decrease at most of the stations, the rainfall intensity increases. In contrast, increasing trends in both the total amount of rainfall and the frequency of wet days were observed at several stations during the northeast monsoon, which give rise to the increasing trend of rainfall intensity. The results for both seasons indicate that there are significantly decreasing trends in the frequency of wet days during the extreme events for most of the stations on the peninsula. However, a smaller number of significant trends was found for extreme intensity.

The low temperature of the Asian continent forms a high-pressure area, while the high temperature of the Australian continent forms a low pressure area. As a result, the wind moves from the high pressure area of Asia to the low pressure area of Australia. In this season, the wind comes from the east or northeast of Peninsular Malaysia with a speed of 10–20 knots and is then deflected towards Australia when crossing the equator. The east coast states of Peninsular Malaysia such as Kelantan are more affected by this monsoon, which has wind speeds that can reach up to 30 knots (C.A. Chen, 1998). During this season, the winds blow across the South China Sea before coming to Malaysia. The direction and the movement of the wind in this monsoon brings heavy rain, especially to the eastern and southern coasts of Peninsular Malaysia as well as the central part of the Titiwangsa Ranges (H. Jantan, 1981). This rain causes flooding, especially around the end of every year in the east coast states.

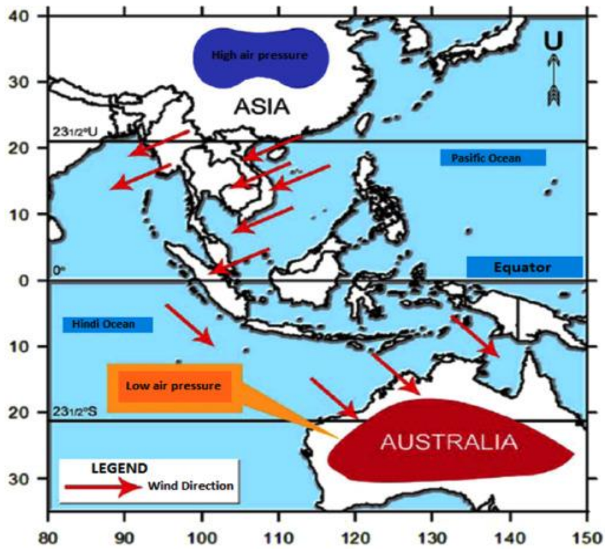

Figure 2.5 The process of the formation of the Northeast monsoon winds in Malaysia

2.4.2 Southwest Monsoon

The South West monsoon is generally dry, 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 (the record-length was in 2015). At the best it is not noticeable, at worse it gives a heavy dense haze with little visibility which can be dangerous to heath. The impact will solely depend on the areas being burnt and the direction of the prevailing winds. Southwest monsoon is the dry season in all states except Sabah in East Malaysia. 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 northern 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

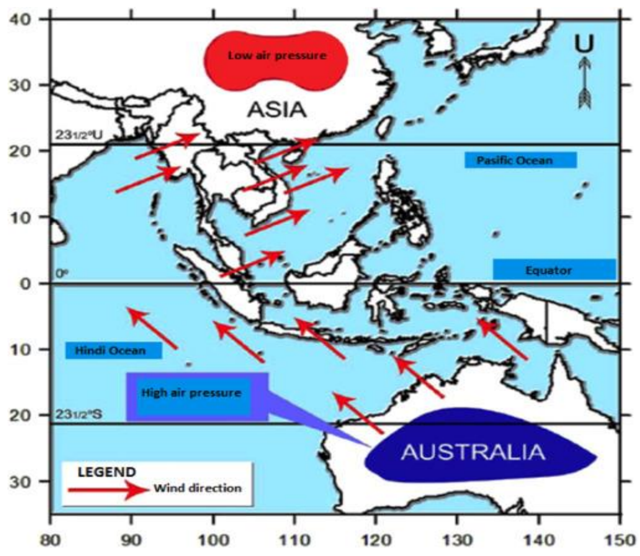

Figure 2.6 The process of the formation of the Southwest monsoon winds in Malaysia

2.5 Climate change of Malaysia

Climate change is rapidly increased and become very serious global issue. Usually, the occurrence of global warming is due to the emission and concentration of carbon dioxide and rising in global temperature due to greenhouse gases. Many community is very worried with the effect of climate change. Meanwhile, the current series of extreme weather also could possibly affect the global climate systems. Some developed countries like USA, Europe, and Japan have been aware about global climate change and supportive of a wide range of mitigation and adaptation policies. But, they are less of knowledge about international public opinion or behaviour regarding climate change (Leiserowitz, Kates, & Parris, 2005). Majorities over worldwide believe that climate change mostly occur because of human activities. Human activity continue to confuse and conflate global warming with depletion of the ozone layer, which in turn leads many to support ineffectual solutions, such as the banning of aerosol spray cans.

Malaysia is one of the countries in the world which is experiencing a warming trend for the past few decades. The global land precipitation has raising about 2% since the early of the 20th century. The extremely hot temperature, heat waves and heavy precipitation events will contribute to become more frequent (IPCC,2001). In the past few years, the frequency of long dry period tended to be higher with significant increase in the mean and variability of the length of the dry spells. All the indices of wet in these areas show a decreasing trend. Increasing temperature with long dry periods would give variable result of weather and climate (Deni et al., 2008).

Malaysia's temperature and rainfall are rapidly increasing between +0.6 to 3.4°C and -1 to +32% in 60 years repetitively and the rise of sea level is about 13 to 94 cm within 100 years respectively (INC, 2000). Thus, these will give impacts on water resources, coastal zone, public health, food supply, drainage, flooding, landslides, haze, typhoons, and others negative phenomenon that need national and international responses to face climate change. Realizing the importance of reducing and combating the impact of climate change and GHG's emissions, the Malaysian government has taken concerted efforts towards this issue by introducing the mitigation programs in the Ninth Malaysian Plan.

Due to the increasing number of tragedies and disaster phenomenon in Malaysia, it will bring Malaysia to climate change. Kedah and Johor are the worst states that experienced floods recently. An analysis of temperature records in Malaysia shows a warming trend.

Malaysia's desire to achieve the status of a developed country by the year 2020 will require rapid economic growth and expansion, especially in the urban, industrial and commercial sectors. Economic growth is guided by the principles of sustainable development. The extent to which sustainable development is achieved will ultimately depend on the ability of the country to monitor and manage the impacts of economic activities on the environment. NGOs continue to advocate national efforts to address such issues as the economics of climate change, the compilation and publication of timely data on GHG emissions, and projections of energy consumption by different end-users.

Most Malaysian is not aware of the effects of global warming. Being in a hot climate country and most likely holed up in their air conditioned offices, most did not notice the changes in daily temperatures. Rising temperatures from global warming are creating violent storms in Malaysia for the past few years. A disaster caused by climate change or global warming could be defined as a serious disruption to the functioning of a community or a society causes widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources.

Prediction about impact of climate change on public health are general, there are no specific region scenarios is available. Nevertheless, Malaysia can expect significant impact mainly because of its tropical weather with high rainfall and temperatures that make dangerous combinations for air factor, food diseases, and illness due to air pollution. In Malaysia public perception on climate change is not well documented. Hence, this objectives, want to discover the perception on climate change.

Malaysia is considered as a free zone from climate related disaster. However, mild climate-disasters are quite frequent to happen lately. These refer to the occurrence of floods and droughts that caused significant socio-economic impacts to the nation while the occurrence of landslides due to excessive rainfall and strong winds happened at the hilly and the latter, at the coastal areas caused minimal damage. The floods incidence happened in the southern states of Malaysia, such as Negeri Sembilan and Johor. There are many obstacles remaining, including our limited understanding of the current status of Malaysian public opinion and the unknown potential for rapid social change to dramatically reduce global greenhouse gas emissions at a rate fast enough to forestall large-scale climate disruptions.

Malaysia's national policy on sustainable development is based on a balanced approach such that environment and development complement each other. While the past and existing national policies and initiatives may have indirectly addressed climate change concerns under the context of sustainable development, the need to formulate a dedicated climate change policy is increasingly recognized.

2.6 Climate Model

Nowadays, human activities such as land use and the dependence upon fossil fuels has resulted in global warming. Hence, this kind of activities will increase the concentration of greenhouse gases in the atmosphere. (Huang et al, 2011). Fourth Assessment Report (4AR) of the Intergovernmental Panel on Climate Change (IPCC) had stated there are rising 0.74 °C in the global mean temperature in the last hundred years between 1906 to 2005. In addition, for the last 50 years, the temperature rate was increase to 0.13 °C each 10 years. During the twenty – first century, the global mean surface temperature is projected to increase approximately from 1.1°C to 6.4 °C (IPCC, 2007). Global warming gives a large impact to the hydrological cycle, water resources, public health, industrial and municipal water demands, water energy exploitation, and the ecosystem (Chuet al. 2010). Climate models have provided new tools in the last 30 years. In any climate model it has been attempted to simulate the processes that affect climate, and subsequently forecast the climate for the upcoming years. As the exact prediction of the future climatic conditions is not possible, different scenarios with different possibilities have emerged as an alternative solution. In order to analyse the impact of climate variables (precipitation) climate model have been introduced such as Statistical Downscaling Model (SDSM). In this paper the scope only focus on SDSM to downscale the important of climate variables.

2.6.1 SDSM Model

SDSM is using the multiple linear regression model to statistically recognize the connections between huge scale predictor like GCM and local scale predictands which could be derived in reliable hours of series of rainfall in daily either or and temperature in relation to the climate condition from the outputs of the GCMs due to climate scenarios from the GCMs output. It is a compromise bolsters tools for evaluating local climate change effects utilizing a vigorous SD technique. It encourages the fast development of numerous with minimal cost and single site situation of daily surface climate factors under current and future territorial climate forcing. Other than that, the model carries out subordinate work of predictor variable pre-screening, model calibration, essential analytic testing, and linear regressions and charting of climate information (Dawson, 2015).

SDSM has been recognize as one of the main SD methods (Koukidis and Berg, 2009) and has been prescribed by Canadian Climate Impacts and Scenarios (SSIS, 2006) as a fitting downscaling model. Furthermore, the SDSM is the earliest downscaling model offering to the more extensive, less specific climate change group such as preservation authorities or non-government consulting organizations. Correlations among SDSM and different SD techniques have shown that SDSM is a very much helpful as a downscaling method, equipped for imitating the observed variability in climate. Various studies have been carried out to assess the model for the output from GCM to be used in numerous applications hydrologically.

SD can be divided into three major types which are weather typing, regression based and weather generators. In spite of the fact that these wide downscaling classifications may seem to contrast profoundly in their operation, they for the most part exemplify three fundamental suppositions (Hewitson and Crane, 1998, 2006) in which chosen predictor variables are applicable to the review and the host GCM can re-enact them sensibly, the experimental connections created under the current climate conditions are additionally legitimate for future and chosen predictor factors can obtain the climate change flag (Hashmi *et al.*, 2009).

There are various models for statistical downscaling and in the comparison in the performances of SDSM that use the regressions model with other model which in this case, a model that has been developed by Semenov and Barrow (1997), Long Ashton research station weather generator (LARS-WG) technique is used. As a part of measuring the impact of climate change condition in a local scale, The LARS-WG and SDSM models clearly are attainable techniques to be utilized. However, SDSM produces a superior outcomes and performance as to LARS-WG, aside from SDSM is somewhat thought little off for the wet and drought lengths. Albeit these models don't give indistinguishable outcomes, the time arrangements created by both strategies demonstrate a general expanding pattern in the mean daily temperature values. In the meantime, the pattern of the day by day precipitation is not like each other, with SDSM giving a moderately greater change of yearly precipitation in contrast with LARS-WG.

SDSM as compared to the other models has the ability to obtain between yearly fluctuations better to other SD techniques like weather generators and weather typing (Hashmi et al., 2009). These three SD methods has been compared by (Khan et al., 2009) in ways of the assessment that is uncertain in their downscaled outcomes for both precipitation as well as temperature and it can be concluded that SDSM showed the most convincing technique in imitating the essential of the data that has been observed. Other than that, the common advance in SDSM is low cost and does not require computational expertise and easy to obtain. It is very flexible and easy to be altered to achieve several of variables. SDSM provide vast application to many GCMs and compatible to regional modelling as well as the ability to carry out uncertainty analysis and finally, one of the simplest models to use hence become accessible way over the community in research (Brown, 2003).

Nonetheless, the precision of the simulation of the climate in the SDSM relies on upon the selection of the predictors. The predictors ought to have better relationship with the local surface atmosphere to produce great assertion during calibration and validation process. A few criteria that are basic for the predictors to be dependably mimicked by GCM are promptly accessible to accomplish from GCM output, and firmly related with the surface variable of interest (Wilby *et al.*, 1999).

CHAPTER 3

METHODOLOGY

3.1 Introduction

The phases of work of study are identified. The aim for this study is to forecast the long term changes of rainfall using SDSM and also to estimate the dryness index using SPI in the year 2011-2040 at 4 stations in Kedah state. Therefore, SDSM is used as the model to generate the climate trend. Kedah state generally receives about 2970mm of rainfall annually with average temperature of 26°C to 33°C and average humidity of 77% throughout the year. In this study, a total of ten stations in Kedah consists of rainfall details has been selected to carry out this study. Figure 3.1 shows a methodological project which involve with 2 stages in achieving the objective of study. First stage includes the process to do simulation to all the data input. Meanwhile, the second stage was to analyse the findings produced from the data input. SDSM model was used to project the future trend of rainfall for Kedah state. A further brief about SDSM will be discussed in the next subtopic.

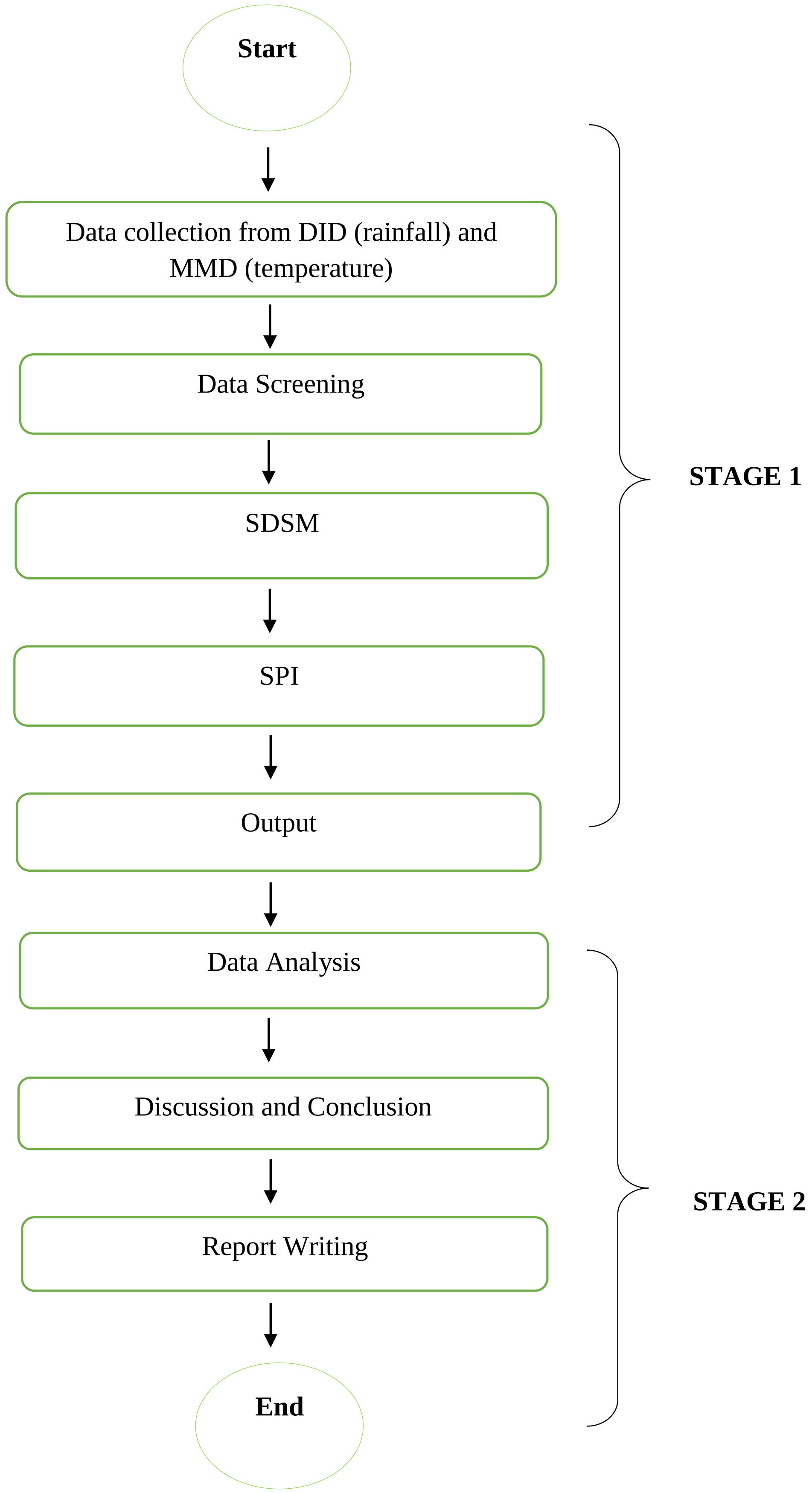

Figure 3.1 Methodological of the study

3.2 Study area

This study is focused on Kedah State. Kedah coordinates is 5° 23' 22.0200" N and 100° 33' 48.3516" E. The land area covered about 9,000 km². Kedah located in the north western part of Peninsular Malaysia. To the north, Kedah borders the state of Perlis and shares an international boundary with the Songkhla and Yala provinces of Thailand. It borders the states of Perak to the south and Penang to the southwest. Kedah state has been chosen to forecast the long term changes of rainfall and estimate the dryness index at the region. The selected of Kedah because of its drought record from year. The wind flow pattern at the region was influenced by Southwest monsoon, Northeast monsoon and inter-monsoon seasons. Because of some local topographic features, the rainfall distribution in Kedah is affected and there was a previous study done showed that during NE monsoon, Kedah was one of the driest regions in Malaysia (Othman et Al, 2016). Kedah state generally receives about 2970mm/year and 248mm/month with average temperature of 26°C to 33°C. Meanwhile, the average humidity of 77% throughout the year.

Figure 3.2 Kedah State Mapping

Table 3.2 Station list

Station			**Coordinate**
Location	**ID Number**	**Station Name**	**Lat. / Lon**
Pendang	5904051	Kota Sarang Semut	05°58°10 N 100°24°05 E
Kubang Pasu	5806065	Kg. Gajah Puteh	05°53°55 N 100°38°45 E
Kuala Muda	5704055	Kedah Peak	05°47°45 N 100°26°20 E
Sik	6005044	Kg. Jelutong	06°02°45 N 100°30°15 E

3.3 Statistical Downscalling Model (SDSM)

SDSM is utilizing the multiple linear regression model to measurably perceive the connections between bigger scale predictor like GCM and local scale predictand which could be inferred in dependable hours of series of rainfall in every day either or and temperature in connection to the climate condition from the outputs of the GCMs because of climate conditions from the GCMs output. It is a bargain support device for assessing local climate change using SD method. The GCMs factors spoke to the physical procedure which comprised of climate, sea, cry sphere, and land surface in term of numerical models with thought of GHGs increment (IPCC, 2007). Regardless of these factors are sound to extend the climate change, yet the spatial determination exhibited by GCMs are coarse (250 - 600 km) and the progressions of climate in general trending.

The capacity of GCMs output would be suspicious on the grounds that some climatic condition particularly precipitation elements are basically very much related with the environment condition at particular sub-framework scale (Wilby and Wigley, 2000). The SDSM model infers that the measurable connections to downscale the large scale resolutions of GCMs signified as indicators into the local climate factors known as predictand. It enabled the raw data to change into standard predictor variables to create nonlinear regressions models before applying the adjustment and approval. The information arrangement can likewise be moved forward or in reverse by any number of time ventures to create slacked indicator factors.

The rainfall occurs on each day t or not (W_t) is defined as:

$$W_t = \propto_0 + \sum_{j=1}^{n} \propto_j \widehat{U_t} + \propto_{t-1} W_{t-1} \qquad (3.1)$$

In which t is time (days), W_t is the conditional possibility of rain occurrence on day t, $\hat{U}_t$ is the normalized predictor, αj is the regression parameter deduced by an ordinary least square method, the conditional probabilities of rain occurrence on day t-1 and lag-1 day regression parameter, respectively. These two parameters are optional, depending on the studied region and predictand. Uniformly distributed random number rt (0≤rt≤1) is used to determine the rain occurrence and the possibility that the rain would happen if wt≤rt.

In the second step, the estimated value of rainfall on each rainy day is determined. This can be represented with a z score:

$$Z_t = \beta_0 + \sum_{j=1}^{n} \beta_j \ \widehat{U}_t + \beta_{t-1} + \varepsilon \qquad (3.2)$$

In which, Zt is the z-score on day t, is the calculated regression parameter, and βt-1 and Z_{t-1} are the regression parameter and the z-score on day t-1, respectively. Simply, rainfall Y_t on day t can be written as:

$$Y_t = F^{-1}\left[\emptyset(Z_t)\right] \qquad (3.3)$$

In which, ϕ is the normal cumulative distribution function, and F is the empirical function of Y_t. A transformation of the fourth root was applied, to take account for the skewed nature of the rainfall distribution. In the case of temperature (Tmax and Tmin), only equation 1 and 3 were used for the model development. Equation 1 was not applied, since the stochastic amount is not considered in temperature analysis. During the model development (calibration) of SDSM, some parameters such as event threshold, bias correction and variance inflation were adjusted in order to obtain the best statistical agreement between observed and simulated climate variables.

3.3.1 Screening of Predictors

The screening process is important for the creation of reliable and credible downscaling scenarios. SDSM provides quantitative tools to assist in choosing a realistic set of predictors, even though local climate knowledge is part of best practices. Monthly percentages of explained variance show the capability of a given predictor to explain local climate variability. Partial correlation coefficients applied to the most suitable predictors help eliminate those for which the weights are not important enough to influence the regression equations (Gagnon *et al.*, 2006)

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 predictors 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 determining the most suitable predictors contain a certain level of subjectivity as per one's judgments, one must decide whether a predictor is significant enough to avoid rejection. A possible solution to further reduce the level of subjectivity is the use of stepwise regression, as suggested by Hessami *et al.* (2004) in their eastern Canada application. They initially included all available predictors in the regression model and the least significant term was eliminated at every step until the remaining terms were statistically significant. Below was the step that describe the entire procedure where predictor is selected for precipitation at the selected climate station.

3.3.2 Selection of the best predictors

It is obvious that selecting appropriate set of predictors is the most challenging in downscaling technique. In order to know if the selected set of predictors is the most suitable, higher correlation value must be taken into account to see if the predictors chosen can be reliable to project future trend. This is due to different local region has different predictors that could be the factors of the climate change.

Furthermore, the selected predictors must be accurately projected and has the same predictors as GCMs for projecting future climate trends. There is basically no specific instruction on how to select the best predictors. It is down to the higher correlation value but must parallel to the consistency of the value in every month throughout the year. Twenty-six NCEP variables that are usually projected by various climate models were used in the present study for the selection of predictors. The description of 26 NCEP variables is given in Table 3.1 below.

Table 3.1 NCEP Predictors Used In The Screening Process

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

How climate system works basically by the influence of several predictors combine together and affects the climate hence produce some changes in climate. The climate couldn’t possibly be changed by any singular predictor because it is insufficient for climate projection because they fail to capture key rainfall mechanisms based on thermodynamics and vapour content. The NCEP predictors that have high and strong correlation values with rainfall or temperature at the chosen station will be used to downscale the corresponding rainfall event at that station (Hadipour, 2014). The process of selecting the best predictors were summarized in figure below.

1. Make a correlation matrix between 26 NCEP predictors. Then select the predictors with high coefficient.
2. For example, 12 of predictors are selected out from 26. Arrange it in descending order.
3. Select the predictor with highest correlation coefficient compared to all predictors. It can be called as super predictor (SP).
4. The correlation between them is defined as a super correlation coefficient
5. Select the SP for the study area.

↓

6. After that, the absolute correlation coefficient between the predictor and predictand, the absolute correlation coefficient between individual predictors, absolute partial correlation, and P value will be obtained by regressing.

↓

7. Remove the predictors which have p value greater than α (0.05) in order to render the results statistical.

8. remove the predictors which are highly correlated (0.5 in this study) in order to remove any multi-co-linearity.

↓

10. Calculate the percentage of reduction in an absolute partial correlation (PRP) for each predictor with respect to absolute correlation using equation below:

$$\text{PRP} = \frac{P.r - R1}{R1}$$

PRP = percentage reduction in partial correlation with respect to the correlation coefficient

P.r = the partial correlation coefficient

R1 = correlation coefficient between the predictor and predictand.

11. Select the most suitable second predictor which has minimum PRP in partial correlation.

Repeat step 6-11 to the third, fourth and following predictors.

**In the second repetition, there will be two super predictors. It is seen that mostly

Figure 3.3 Step of Selecting Predictor

3.3.3 Calibration and Validation Process

Multiple regression equations based in downscaling models will be constructed in the calibration model process with given daily weather data act as the predictand and a regional scale atmospheric variables act as predictors (Wilby *et al.,* 2007). It was done in view of the chosen predictors that were gotten from the NCEP data set. NCEP reanalysis dataset derives the observed large scale predictors (Kalnay *et al.,* 1996). The transient resolution of the downscaling model for rainfall and temperature downscaling are indicated as month to month for each station. A portion of the SDSM setup characters for bias correction and variance inflation were balanced during calibration to get a decent factual assention between the observed and reenacted climate factors. For event threshold, an estimation of 0.5 was utilized.

After the calibration process, validation process is required. Validation manages to deliver engineered current daily climate information in light of contributions of the observed time series data, and the 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 the calibration meanwhile the second 15 years from the 30 years period was used for the validation process. In this study, two period ranges from 1960-1974 and 1975-1989were chosen based on the data availability taken from Department of Irrigation and Drainage (DID). 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. Additional information included the variance (R2) and also root mean standard error (RMSE)

$$\mathrm{R}^2 = \left[\frac{\frac{1}{n}\sum_{i=1}^{n}(s_{i-}s)(o_{i-}o)}{\sigma_s+\sigma_o}\right]^2 \qquad (3.4)$$

$$\mathrm{RMSE} = \left(\frac{1}{n}\sum_{i=1}^{n}(s_{i-}s)(o_{i-}o)\right)\frac{1}{2} \qquad (3.5)$$

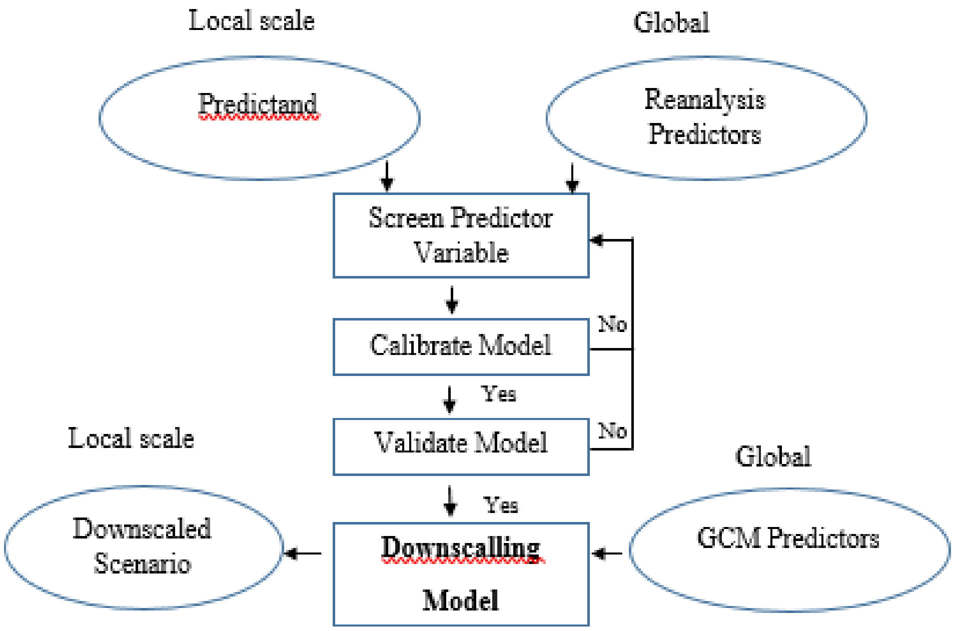

Figure 3.4 Schematic Diagram of SDSM Process

3.4 Standard Precipitation Index (SPI)

SPI is a method to identify and monitor the dryness at the region. SPI can be used in order to determine the period of anomalously wet events. Mathematically, the SPI is based on the cumulative probability of a given rainfall event occurring at a station. Gamma distribution is fitted as the historic rainfall data at certain station. The precipitation distribution would be fitted very well by using the gamma distribution. This is done through a process of maximum likelihood estimation of the gamma distribution parameters, α and β.

$$G(x_k) = \int_0^{xk} g(x_k)\, dx_k = \frac{1}{\beta^\alpha \Gamma(a)} \int_0^{Xk} x_k^{a^{-1}}\, e^{-xk/\beta} dx_k \qquad (3.6)$$

$$H(x_k) = q + (1 - q)G(\, x_k) \qquad (3.7)$$

In other word to explain the process above is the effective of rainfall distribution can be presented by using mathematical cumulative probability function. Thus, the analyst would report what is the probability of the rainfall; either less than or equal to a certain amount based on the historic rainfall data obtained. So, the probability of rainfall to get either small than or equal to the average rainfall for the area will be around 0.5. Meanwhile, for the probability of rainfall obtained either less than or equal to an amount or much smaller than the average, will be also be lower.

Likely drought event can be identified if the value for particular rainfall event is low probability on the cumulative probability function. If the value of cumulative probability function for rainfall event is high, then the event can be state as an anomalously wet event. In the instance described above, rainfall is the variate in a gamma distribution function. The function will have a standard deviation and a mean which depends on the rainfall characteristics of that area. The probability function is not same for each area. Take two example of area. After calculated, it will give most likely very different standard deviation and a different mean. Therefore, it is a little bit difficult to differentiate rainfall events for two or more different areas in terms of drought, as drought is really a "below-normal" rainfall event. For "normal rainfall" in one area can be surplus rainfall in another area, speaking strictly in terms of rainfall amounts.

The value for standard normal distribution is zero for mean, while for the standard deviation is one. The SPI is a representation of the number of standard deviations from the mean at which an event occurs, often called a "z-score". The unit of the SPI can thus be considered to be "standard deviations". Usually, standard deviation commonly used to describe the value along a distribution at which the cumulative probability of an event occurring is 0.1587. In a like manner, the cumulative probability of any SPI value can be found, and this will be equal to the cumulative probability of the corresponding rainfall event. Table 1. below give the cumulative probabilities for various SPI values.

Table 3.3 Cumulative Probabilities for SPI Values

SPI	**Cumulative Probability**
-3.0	0.0014
-2.5	0.0062
-2.0	0.0228
-1.5	0.0668
-1.0	0.1587
-0.5	0.3085
0.0	0.5000
0.5	0.6915
1.0	0.8413
1.5	0.9332
2.0	0.9772
2.5	0.9938
3.0	0.9986

Therefore, the SPI can effectively represent the amount of rainfall over a given time scale. Other than that, the advantage of SPI is it would provide not only information on the amount of rainfall, but SPI also can be indicator of what is amount in relation to the normal, that would be leading to the classified of whether at a certain station either experiencing drought or not. When the period used to calculate the distribution parameters is more longer, then possibility to get the better result is higher. For example, 50 years is better than 20 years. Therefore, in order to get better output, the very long time period must be taken as consideration to calculate the parameters of the distribution and then extract the SPI values for only a given time period. It could be one year or a number of years to give a time series.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The research results conducted will be discussed in three main sections as follows:

a) Evaluation of the projected hydrological climate pattern to rainfall for the long term using the Model Downscaling Statistics (SDSM) version 4.2 at Kedah state.
b) Evaluation of the projected dry period pattern in the long term by using 3 different scenario which are RCP 2.6, RCP 4.5 and RCP 8.5.
c) Projection of dry period pattern in the long term with analyzing the performance of rainfall pattern in order to assess the dryness index at Kedah state using Standard Precipitation Index (SPI).

There were 4 historical rainfall stations with 30years length records had been used to achieve the objectives of this study. Supported by WMO (2000) stated that at least 30 years length records or more can be as a standard reference for the studies which related to the climate change assessment and climate variability. In this study, the SDSM has been used to downscale the local climate changes and trend which was downloaded freely from http://www.sdsm.org.uk. It was used to develops quantitative relationship between the large scale GCM (predictor) and local surface variables of rainfall (predictand). In this study all the missing data was treated using Thiessen method to ensure the accurancy and reliability of projected result. The Thiessen method was selected because it consider the nearest located of rainfall station.

This is another graphical technique which calculates station in the Thiessen polygon network. Only 10% of missing data records were considered for this analysis to control the quality and reliability of the long term dryness index at the region.

4.2 Rainfall simulation using SDSM model

In measuring the long term dryness index at Kedah area, there were 4 rainfall stations had been selected based on the data qualities. The stations were Kedah Peak, Kg Gajah Puteh, Kg Jelutong and Kota Sarang Semut. The raw data obtained from DID in the range of period from 1960 until 2010. Kedah Peak and Kg. Gajah Puteh show the same percentage of missing data which are 8.1%. Meanwhile for Kg. Jelutong and Kota Sarang Semut, the percentage of missing data were 9.2% and 4.6% respectively. Overall the percentage of missing data for all stations was acceptable since the percentage of missing data was below than 10%. Other than that, the period choosen for calibrate was from 1980 to 1994 (first half 15 years). While for the validation period, the period choosen for second half 15 years was from 1995 to 2009. The data for each station was tabulated in Table 4.0 below.

Table 4.0 List of selected stations and period consideration.

Stations	Data period	Data period for calibrate	Data period for validate	Percentage missing (%)	Projected period
Kedah Peak	1960-2010	1980-1994	1995-2009	8.1	2011-2040
Kg. Gajah Puteh	1960-2010	1980-1994	1995-2009	8.1	2011-2040
Kg. Jelutong	1960-2010	1980-1994	1995-2009	9.2	2011-2040
Kota Sarang semut	1960-2010	1980-1994	1995-2009	4.6	2011-2040

4.2.1 Predictand Quality Control

As recommended by Wilby and Dawson (2007), the raw meteorological data need to be checked to increase the quality of model output. Thus in the SDSM, the stage of quality control becames significant in order to identify all missing values or outliers and suspected imperfect data in the raw data provided. The selected predictants data were filtered and transformed into format .DAT files. The minimum rainfall in all stations was zero meaning that in one period of time, these 4 stations don't accept rainfall in several months over the year. Meanwhile the maximum rainfall was different for each stations. The monthly maximum rainfall at Kedah Peak was 384 mm and 144 mm for Kg. Gajah Puteh. The amount of monthly maximum rainfall for Kg. Jelutong and Kota Sarang Semut were 237 mm and 225 mm respectively. The maximum and minimum rainfall for all stations as shown in Table 4.1 below.

Table 4.1 Quality output for all rainfall stations

Stations	Min Rainfall (mm/month)	Max Rainfall (mm/month)	Number of Record (day)	Number of Available Record (day)
Kedah Peak	0	384	1098	1098
Kg. Gajah Puteh	0	144	1098	1098
Kg. Jelutong	0	237	1098	1098
Kota Sarang semut	0	225	1098	1098

4.2.2 Selected predictors for the rainfall simulation

After the data qualities were checked, the predictand and predictors data were screened in the screening variables. The function of this process was to select the predictor variables like mean sea level, surface vorticity, relative humidity and etc which influenced the formation of the local rainfall. The selection of predictor variables was based on the monthly correlation (R) between single predictor and single predictand. For the rainfall, the conditional process was used and the R value was depending on wet-day occurrence. Besides, the default values were significance level of $p < 0.05$ and partial correlation of r ±1 (Wilby and Dawson, 2007). The predictor variables were selected based on the explained variance and R between predictor-predictand relationships. Therefore, sets of predictor variables which have p-value ($0 \leq p \leq 0.05$) were taken as best correlated predictors with individual predictand. This screening process involves a forecast NCEP daily data that has been aligned according to the uniformity four local forecast data to assist in selecting variables which corresponding to the current situation.

At this stage, the analysis process in a multiple-correlation matrix (M-CM) has been used to enable every forecaster can be identified with the current climate scenario. The M-CM process is repeated until each forecaster is high accuracy and high precision. The results obtained show was derived can be concluded that 5 best predictions have been selected to be simulated with the local climate. There is some reason for M-CM process being chosen for rainfall and temperatures stations as stated below:

i. Selection of predictors based on the best analysis value compared to other predictors.
ii. The analysis process of predictors is reviewed based on the current climate relationship with rainfall and temperature stations.
iii. Screening the uniformity of predictors to give a stable and strong projection analysis.

Subsequently, there were 5 best predictors have been selected to be as influencers of the local climate formation. The major predictors need to undergo the screening process and predictors have been verified and passed after several repeating the simulated analysis. This analysis conducted by using statistical analysis in phases to identifying the desired decision. All 26 major predictors are observed thoroughly to make sure the decision is reliable. The analysis values have been identified and summarized in Table 4.2 below.

Table 4.2 Result of the selection for major predictors rainfall stations and correlation values

Predictand	R	Code	Predictor Variable
Kedah Peak	(R ≤1.0) = 0.997	ncepmslp.dat ncepp__z.dat	Mean sea level pressure Surface vorticity
Kg. Gajah Puteh	(R≤1.0) = 0.996	ncepp5th.dat ncepshum.dat	500 hPa wind direction Surface specific humidity
Kg. Jelutong	(R ≤1.0) = 0.993	nceptemp.dat	Mean temperature at 2m
Kota Sarang semut	(R ≤1.0) = 0.995		

4.2.3 Calibration perfomance for the rainfall analysis

The calibration is a stage of the predictand collaborated with a set of predictor variables and computes parameters of multiple regression equation through optimization algorithm. There were 30 years historical data was divided into two periods. The first half 15 years of daily data (1980 to 1994) was used for model calibration and the second half (1995 to 2009) was used for model validation. It was very important stage to determine the model parameters and allows the model to stimulate and develop the best correspondence between observed and model generated data at a given station. The calibration data obtained from the analysis then compared to historical rainfall data to ensure the accuracy of the climate pattern was consistent to the actual situation to fit the further analysis process.

Table 4.3 shows the comparison results between simulated and historical data. Based on the results, the percentage error was very small in range of below 20% which considered acceptable for this study. For Kedah Peak, the amount of annual rainfall generated by SDSM was 2881.40 mm. Compared to historical data, the annual rainfall for Kedah Peak was 2961.62 mm. Thus, the percentage of error produced was about 2.73% for Kedah Peak. The calibrate result for station 2, Kg. Gajah Puteh was 2257.51 mm which was differ about 9.24% of error compared to historical data. Meanwhile for Kg. Jelutong and Kota Sarang semut, the simulated annual rainfall were 1804.77 mm and 2347.40 mm respectively. The difference between the historical data and calibration with below 20% error for both stations which is 9.61% for Kg. Jelutong and 2.13% for Kota Sarang Semut.

Table 4.3 Statistical analyses for calibration process

Stations	**Calibrate (mm/year)**	**Historical (mm/year)**	**MAE (%)**	**NSE**
Kedah Peak	2881.40	2961.62	2.73	0.999
Kg. Gajah Puteh	2257.51	2488.12	9.24	0.998
Kg. Jelutong	1804.77	1996.55	9.61	0.997
Kota Sarang semut	2347.40	2297.54	2.13	0.998

Figure 4.0 shows the comparison of monthly rainfall between simulated and historical data during calibration process. Based on the result, the pattern of simulated result was successfully to produce consistent pattern with the historical. As a proved, the MAE of this location was only 2.73% with NSE closed to 1.0. The mean annual rainfall for Kedah Peak was 2962 mm and the calibrated result for Kedah Peak is not too differ with historical data which is 2881 mm.

Meanwhile for rainfall station of Kg. Gajah Puteh as shown in Figure 4.1, the simulated result was also produce consistent pattern with the historical pattern. The mean annual rainfall for Kg. Gajah Puteh was 2258 mm and the calibrated result for Kg. Gajah Puteh is not too differ with historical data which is 2488 mm. The MAE for the calibration and historical result is 9.24%. Since the NSE value close to 1.0 and average MAE is below 20%, thus the result obtained was acceptable.

Figure 4.2 and 4.3 show consistent pattern between simulated and historical results for Kg Jelutong and Kota Sarang Semut. Based on the result, the pattern of simulated result was successfully to produce consistent pattern with the historical. As a proved, the MAE of both location was 9.61% for Kg. Jelutong and 2.13% for Kota Sarang Semut with NSE closed to 1.0. The mean annual rainfall for Kg. Jelutong was 1997 mm and the calibrated result for Kedah Peak is not too differ with historical data which is 1805 mm. For Kota Sarang Semut, the mean annual rainfall was 2298 mm and the calibrated result was 2347 mm. In overall results show the high accuracy level which means the variables is reliable are appropriate to be used in carrying out to the next process.

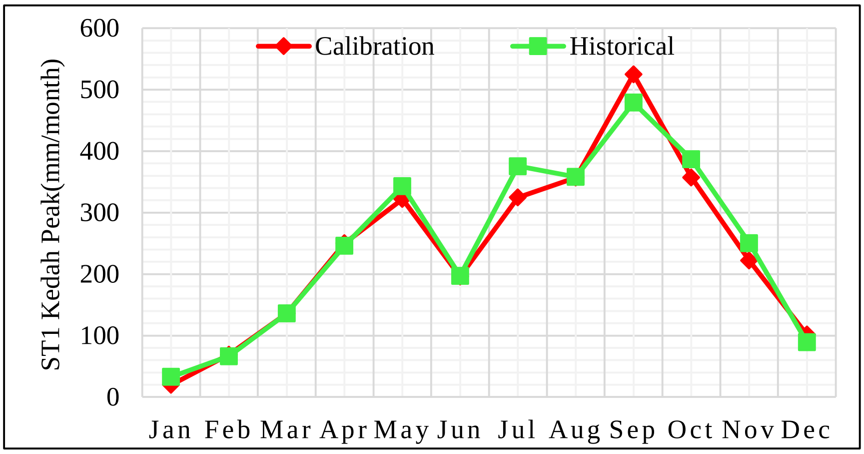

Figure 4.0 Results of comparison between calibration and historical for Kedah Peak

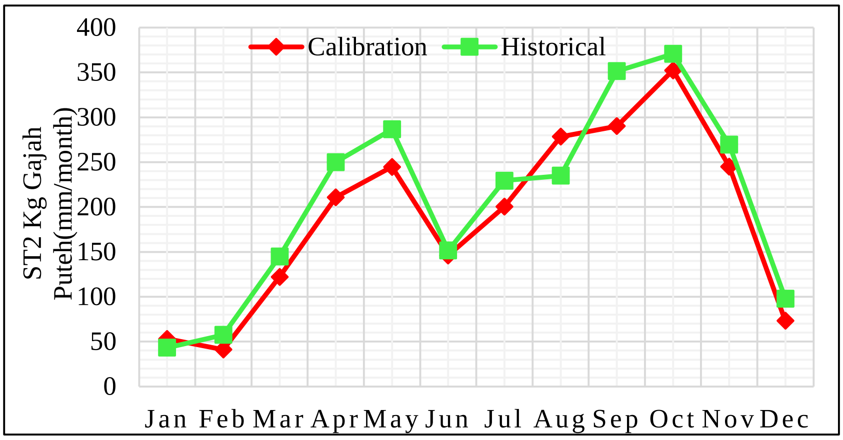

Figure 4.1 Results of comparison between calibration and historical for Kg. Gajah Puteh

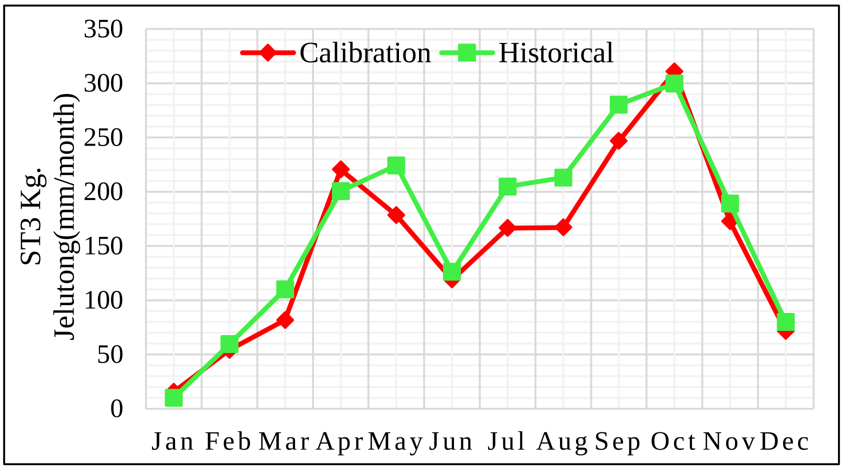

Figure 4.2 Results of comparison between calibration and historical for Kg.Jelutong

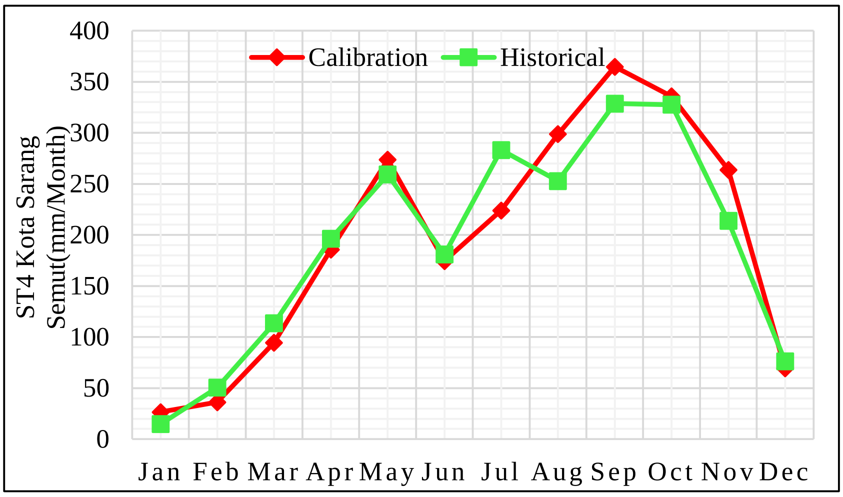

Figure 4.3 Results of comparison between calibration and historical for Kota Sarang Semut

4.2.4 Weather Generator

The weather generator process was used to produce the daily synthetic data for the historical time period by using calibration output and observed NCEP re-analysed atmospheric variables (Dawson, 2007). It enables verification of calibrated model (using independent data) and the synthesis of artificial time series for present climate condition, which means, it allows comparison of observed and simulated model outputs. During weather generator process, the data was stimulated twice for two different periods; first half 15 years of daily weather (1980 to 1994) used for calibration process and the second half 15 years of daily weather (1995 to 2009) used for validation process. The assemble size used was 100 times which presented in daily weather series. In this stage, it produced two type of data in *.OUT and *.SIM file. *.OUT file represent the data output after undergone the weather generator process while SIM file represent the value and variables used to generate the weather generator. The example of *.SIM file was explained for each part below.

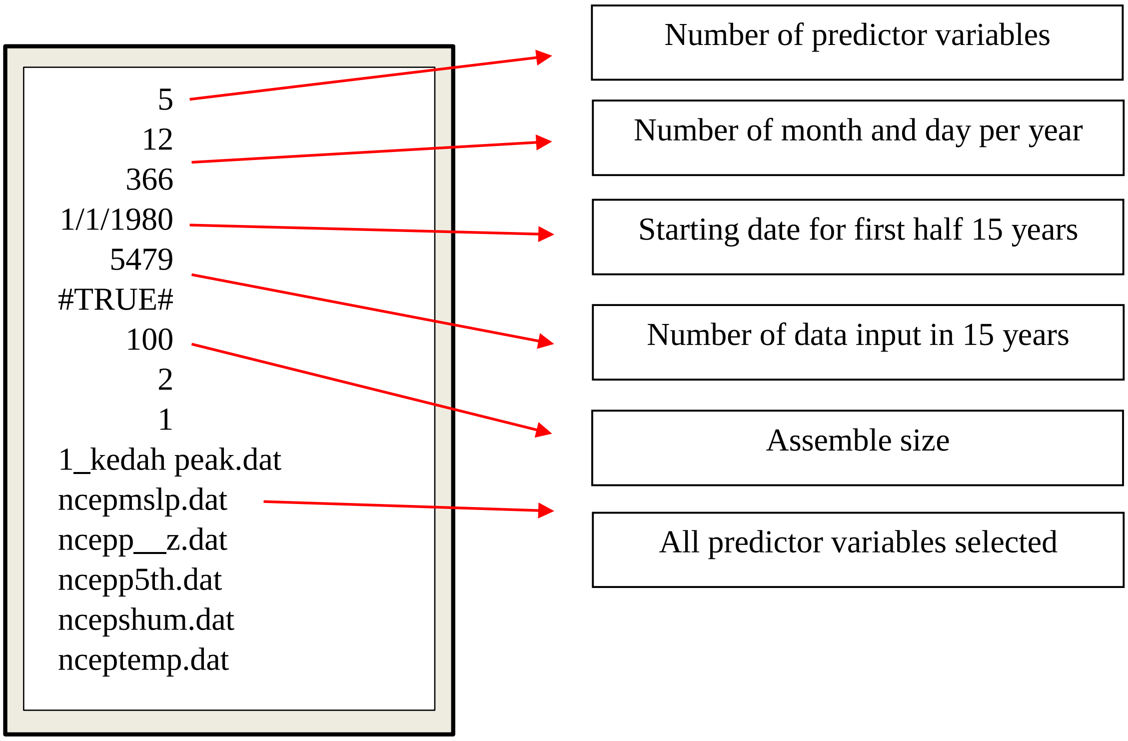

Figure 4.4 Example of *.SIM file produced after undergone weather generator process

4.2.5 Validation performance for rainfall analysis

The validation was carried out by comparing the generated of 100 ensembles of synthetic weather series using NCEP-reanalysis data used for calibration of the model with the withheld 15 years of observed data**.** Table 4.4 shows the comparison of statistical results in the validation process. In general, the pattern of simulated result was produce consistent pattern with the historical. The MAE of this location was 0.99% with NSE closed to 1.0. The mean annual rainfall for Kedah Peak was 3348 mm and the validated result for Kedah Peak was differ with historical data which is 3315 mm.

Meanwhile for rainfall station of Kg. Gajah Puteh as shown in Figure 4.6, the simulated result was also produce consistent pattern with the historical pattern. The mean annual rainfall for Kg. Gajah Puteh was 2524 mm and the validated result for Kg. Gajah Puteh was differ with historical data which is 2419 mm. The MAE for the validated and historical result is 4.16%. The NSE value was 0.98 which is close to 1.0.

Figure 4.7 and 4.8 show consistent pattern between simulated and historical results for Kg Jelutong and Kota Sarang Semut. Based on the result, the MAE of the location was 18.14% for Kg. Jelutong and 25.58% for Kota Sarang Semut with both NSE closed to 1.0. The mean annual rainfall for Kg. Jelutong was 2065 mm and the validated result was different with historical data which is 1685 mm. For Kota Sarang Semut, the mean annual rainfall was 2295 mm and the validated result was 2882 mm.

Table 4.4 Statistical analyses for validation process

Stations	Validate (mm/year)	Historical (mm/year)	MAE (%)	NSE
Kedah Peak	3314.86	3347.80	0.99	0.978
Kg. Gajah Puteh	2419.26	2524.35	4.16	0.980
Kg. Jelutong	1685.14	2065.48	18.40	0.988
Kota Sarang semut	2882.07	2295.03	25.58	0.974

The percentage of MAE for all stations were produced below allowable is below 20%. However from the validation result, the result obtained exceeding the percentage allowable which is more than 20% but below 40%. The less consistant rainfall historical data at Kedah state given from DID might be the reason for high percentage of error. The results of rainfall performance in term of Nash-Sutcliffe Efficiency (NSE) shows the great results since the value approaced close to 1.0. The graphical below shows the validation and historical output for second half 15 years of daily data (1995 to 2009) .

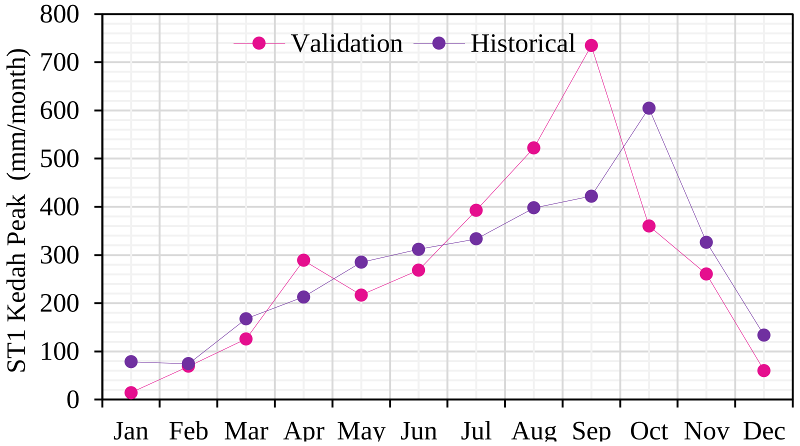

Figure 4.5 Results of comparison between validation and historical for Kedah Peak

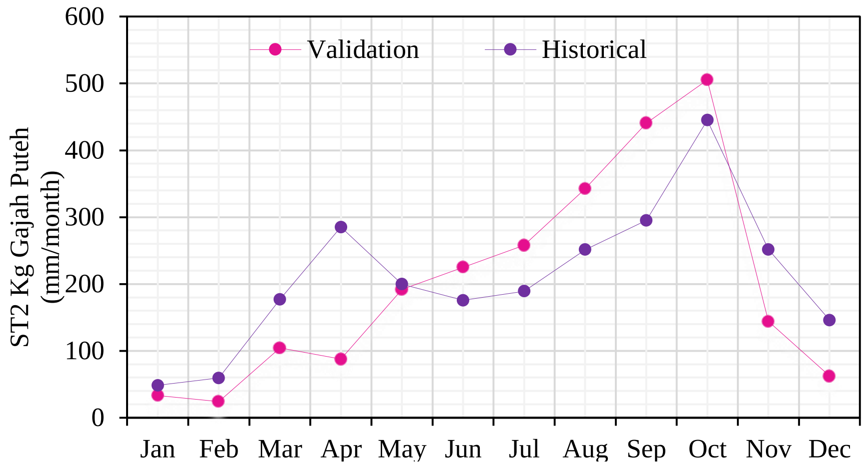

Figure 4.6 Results of comparison between validation and historical for Kg. Gajah Puteh

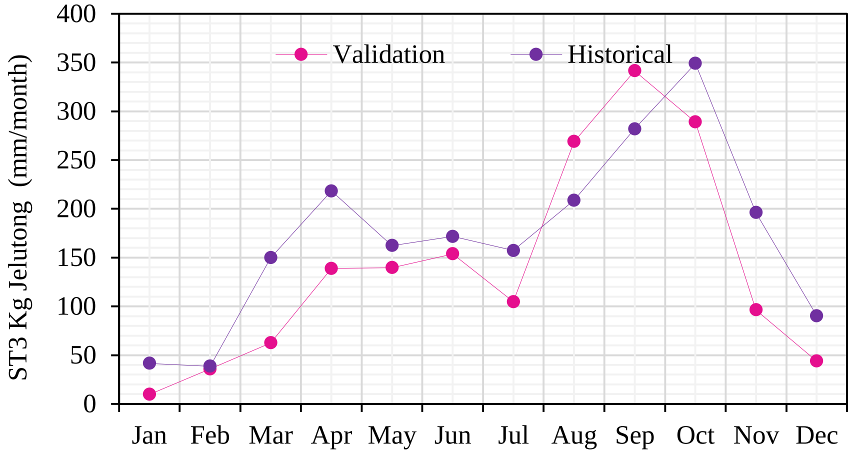

Figure 4.7 Results of comparison between validation and historical for Kg Jelutong

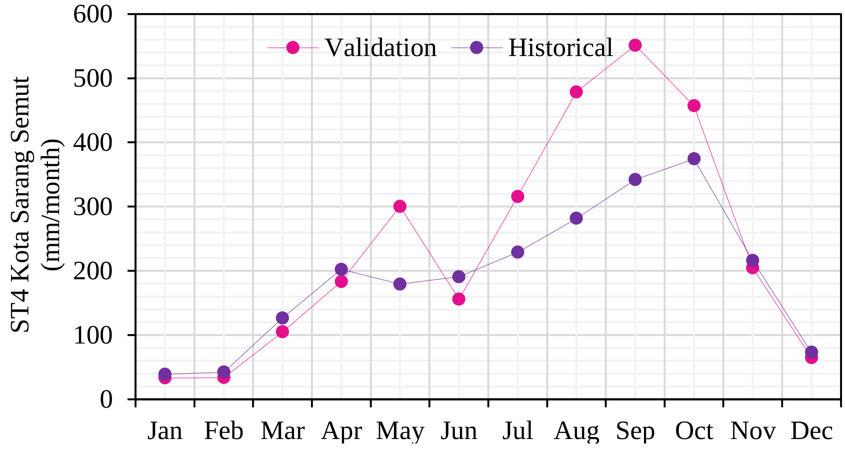

Figure 4.8 Results of comparison between calibration and historical for Kota Sarang Semut

4.3 Climate projection using RCPs

The prediction of climate trend for the historical years (1980 to 2009) and future years (2011 to 2040) were obtain using SDSM model. The synthetic daily rainfall for the upcoming years were generated using the RCPs variables. The RCPs were provided by the GCMs output for possible future values of local meteorological variables. The results of the rainfall prediction model then compared to historical rainfall to validate the accuracy of the GCMs as climate agent. The rainfall forecasting analysis conducted in a series of simulated climate pattern scenarios consisting of 3 simulations that have been adopted as RCP 2.6, RCP 4.5 and RCP 8.5.

The period of projected future climate trend for this study was 2011 to 2040 (30 years). Figure 4.9 shows the performance of RCPs for each station. Based on figure 4.9 for Kedah Peak station, the highest increment shown by Rcp 2.6 with about 66% increment in August. This prediction shows Kedah Peak expected to receive more rainfall in August where the monthly rainfall was 626 mm compared to historical data which indicate about 378mm. Meanwhile Rcp 8.5 shows the highest decrement with about 44% decrement during June. It shows that Kedah Peak expected to accept lesser rainfall where the predicted rainfall was 144mm compared to the historical data which is 255mm. Based on table 4.5, the annual rainfall projection by Rcp 2.6 indicate Kedah Peak will receive more rainfall which is 5.58% increment with the rainfall amount about 3331mm compared to historical data, 3155mm. However, Rcp 4.5 and Rcp 8.5 agreed Kedah Peak station will receive lesser annual rainfall with about 1.93% and 3.68% decrement respectively within 2011 to 2040.

In addition, the projection of Kg Gajah Puteh as shown in figure 4.9 also shows the same trend as Kedah Peak. But, the highest increment shown by Rcp 4.5 with about 59% increment in February. This prediction shows Kg Gajah Puteh expected to receive more rainfall in February where the monthly rainfall was 93mm compared to historical data which indicate about 58mm. Meanwhile Rcp 2.6 shows the highest decrement with about 32% decrement during December. It shows that Kg Gajah Puteh expected to accept lesser rainfall where the predicted rainfall was 83mm compared to the historical data which is 122mm. As shown in table 4.5, the annual rainfall projection by Rcp 2.6 indicate Kg Gajah Puteh will receive more annual rainfall which is 32.92% increment with the annual rainfall amount about 3331mm compared to historical data, 2506mm. Rcp 4.5 and Rcp 8.5 also agreed Kg Gajah Puteh station will receive more annual rainfall with about 23.46% and 7.78% increment respectively in future.

For Kg Jelutong station, the highest increment shown by Rcp 8.5 with about 74% increment in February. This prediction shows Kg Jelutong expected to receive more rainfall in February where the monthly rainfall was 85mm compared to historical data which indicate about 49mm. Meanwhile Rcp 8.5 also shows the highest decrement with about 50% decrement during January. It shows that Kg Jelutong expected to accept lesser rainfall where the predicted rainfall was 13mm compared to the historical data which is 26mm. Refer to table 4.5, the annual rainfall projection by Rcp 4.5 indicate Kg Jelutong will receive lesser rainfall which is 6.94% decrement with the annual rainfall amount about 1890mm compared to historical data, 2031mm. Rcp 4.5 also agreed that Kg Jelutong will receive lesser rainfall with 6.80% decrement compared to the historical. Rcp 8.5 also claim that Kg Jelutong station will receive lesser annual rainfall about 0.39% decrement within 2011 to 2040.

Last but not least, the projection of Kota Sarang Semut as shown in figure 4.9 also shows the same trend as other stations. But, the highest increment shown by Rcp 4.5 with about 60% increment in December. This prediction shows Kota Sarang Semut expected to receive more rainfall in December where the monthly rainfall was 119mm compared to historical data which indicate about 75mm. Meanwhile Rcp 4.5 also shows the highest decrement with about 42% decrement during January. It shows that Kota Sarang Semut expected to accept lesser rainfall where the predicted rainfall was 16mm compared to the historical data which is 27mm. Based on table 4.5, the annual rainfall projection by Rcp 8.5 indicate Kota Sarang Semut will receive more rainfall which is 7.49% increment with the annual rainfall amount about 2468mm compared to historical data, 2296mm. Rcp 2.6 and Rcp 4.5 also agreed Kota Sarang Semut station will receive more annual rainfall with about 0.52% increment respectively in future projection.

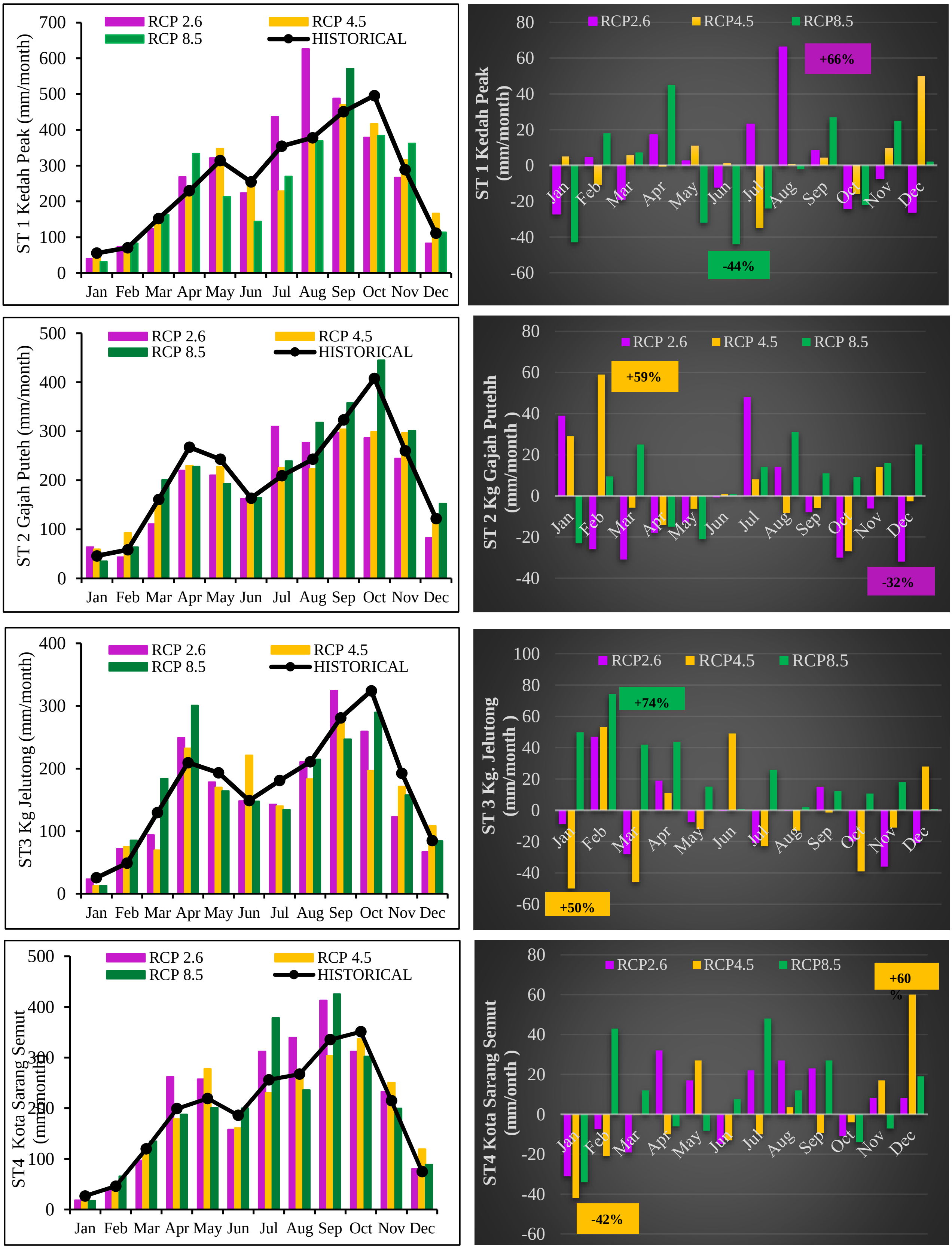

Figure 4.9 RCPs performance for selected stations at Kedah state

Table 4.5 Comparison result between historical rainfall data and future emission scenario

Annual Rainfall (mm/yr)							
Stations	**RCP 2.6**	*Performance*	**RCP 4.5**	*Performance*	**RCP 8.5**	*Performance*	**Historical**
Kedah Peak	3331	+5.58	3094	-1.93	3039	-3.68	3155
Kg. Gajah Puteh	3331	+32.92	3094	+23.46	2701	+7.78	2506
Kg. Jelutong	1893	-6.80	1890	-6.94	2023	-0.39	2031
Kota Sarang Semut	2527	+0.52	2308	+0.52	2468	+7.49	2296

4.4 Estimation of long term Dryness Index using SPI

The process of dry period pattern analysis conducted by using prediction rainfall pattern. This study was done on the monthly basis for a 30-year time period, starting from 2011 to 2040. All of this analysis uses SPI method to monitor the potential dry period pattern. The method was preferred due to its simple calculation method which only require precipitation data. Basically, the cumulative month period depends on the suitability of the study situation. Therefore, this study has conducted in varies cumulative time period of 5 quartiles consisting of 1-month SPI, 3-month SPI, 6-month SPI, 9-month SPI and 12-month SPI. But in this study, the only quartiles used for analysed the SPI output is 3-month SPI and 12-month SPI. Each cumulative period was analysed for all 4 stations in the study area. 3-stage of long-term simulation scenario analysis of Rcp 2.6, Rcp 4.5 and Rcp 8.5 has been conducted at each station. The calculation and analysis will be covers the long run scenario simulation with 30 years period with 3 scenarios. In general, the dry period pattern has categorised by several levels such as a. tabulated below.

Table 4.6 SPI classification

Moderate dry	–1.0 to –1.49
Severe dry	–1.5 to –1.99
Extreme dry	-2.0 to below
Normal	-0.99 to 0.99
Moderately wet	1.0 to 1.49
Very wet	1.5 to 1.99
Extreme wet	2.0 above

However, this study only covers and discussed the dry period pattern analysis. The rainfall data is compiled on the monthly basis according to the divided phase in order to run the SPI analysis in continuous monthly cumulative. The analysis is repeated for each phase so that the comparison graph can be generated. All long-term SPI pattern projection results are presented and analysed to obtain the projected level and intensity of the dry period.

4.4.1 The Future SPI Pattern using RCP 2.6,4.5,8.5

Based on SPI analysis, Results from 3-month SPI and 12-month SPI analysis are shown in figure below using scenario 2.6, 4.5 and 8.5. The analysis results obtained shows the different SPI level for each area and the climate trend for each station was differ to each other obviously. The results of dry month projection listed based on monthly observations at each station involved. The period used to estimate the dryness index at Kedah state is should be within 2011 to 2040. However, because the current year is 2018, so the projection was conduct from 2019 until 2040. The highest dryness level at a number of the station also analysed for each month from the observation of the projection results. The figure below shows the monthly projection results for each of station with combination of three scenarios.

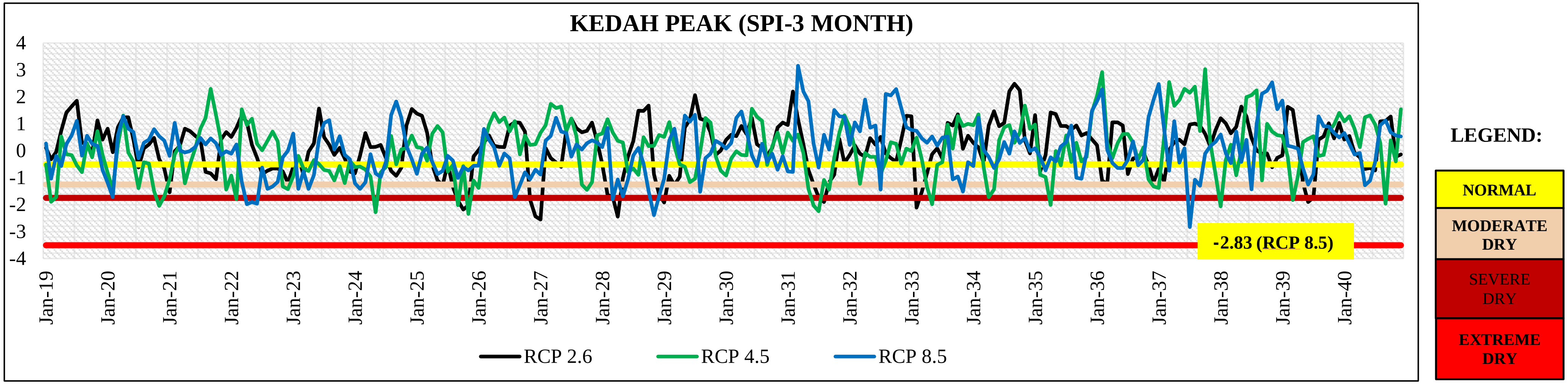

Figure 4.10 SPI-3 month for Kedah Peak using RCP 2.6, 4.5 and 8.5

Figure 4.10 above shows SPI 3-month at Kedah Peak station. Kedah Peak expected to experience extreme dry within 2019 to 2040. The critical years that have to be caution at Kedah Peak were predicted on year 2019, 2020, 2022, 2025, 2027, 2031,2033, 2035, 2037 and 2038 which the SPI value drop to -2.00. For the RCPs perfomances, the RCP4.5 potentially to produce frequent drought event compared to other RCPs. RCP4.5 claimed Kedah Peak predicted to experience extreme dry for 7 times which on 2020 (November), 2024 (May), 2025 (September and November), 2031 (July), 2035 (April) and 2038 (January). RCP2.6 agreed Kedah Peak will experience drought events for 4 times which on 2025(October and November), 2027 (January) and 2033 (February) in future. Meanwhile, the RCP8.5 shows Kedah Peak predicted to experience twice drought event which on 2028 (November) and 2037 (July). The highest SPI value shown by RCP8.5 which is -2.83 (-below 2.0) that indicate Kedah Peak expected to experience extreme dry in July 2037.

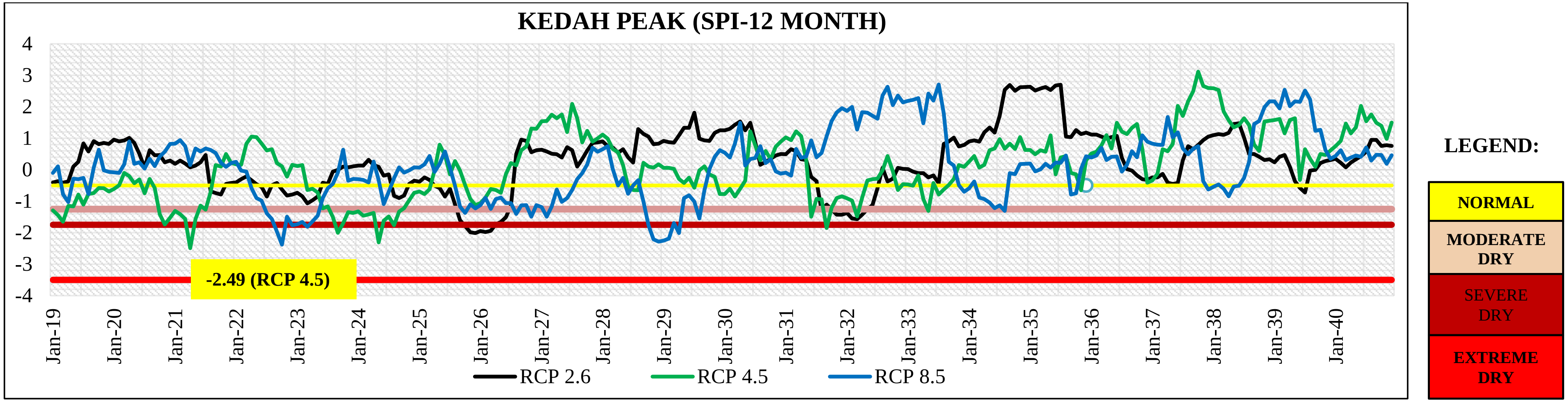

Figure 4.11 SPI-12 month for Kedah Peak using RCP 2.6, 4.5 and 8.5

Figure 4.11 above shows SPI 12-month at Kedah Peak station. Kedah Peak expected to experience extreme dry within 2019 to 2040. The critical years that have to be caution at Kedah Peak were predicted on year 2021, 2022, 2023, 2024 and 2029 which the SPI value drop to -2.00. For the RCPs perfomances, the RCP4.5 potentially to produce frequent drought event compared to other RCPs. RCP4.5 claimed Kedah Peak predicted to experience extreme dry for 3 times which on 2021 (April), 2023 (September), and 2024 (May). RCP2.6 agreed Kedah Peak will not experience drought events within 2019 until 2040. Meanwhile, the RCP8.5 shows Kedah Peak predicted to experience four times of drought event which on 2022 (October) and 2029 (January, February and April). The highest SPI value shown by RCP4.5 which is -2.49 (-below 2.0) that indicate Kedah Peak expected to experience extreme dry in April 2021.

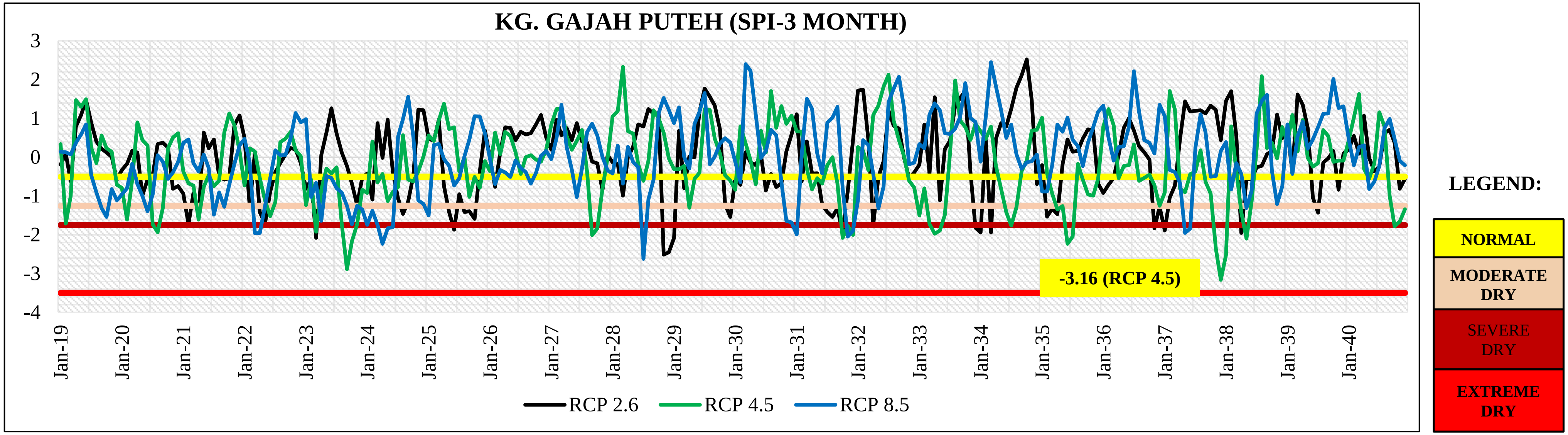

Figure 4.12 SPI-3 month for Kg. Gajah Puteh using RCP 2.6, 4.5 and 8.5

Figure 4.12 above shows SPI 3-month at Kg Gajah Puteh station. Kg Gajah Puteh expected to experience extreme dry within 2019 to 2040. The critical years that have to be caution at Kg Gajah Puteh were predicted on year 2023, 2024, 2027, 2028, 2031, 2035, 2037, and 2038 which the SPI value drop to -2.00. For the RCPs perfomances, the RCP4.5 potentially to produce frequent drought event compared to other RCPs. RCP4.5 claimed Kg Gajah Puteh predicted to experience extreme dry for 6 times which on 2023 (September), 2027 (September), 2035 (June and July), 2037 (December) and 2038 (May). RCP2.6 agreed Kg Gajah Puteh will experience once drought events which on 2028(November). Meanwhile, the RCP8.5 shows Kg Gajah Puteh predicted to experience 3 times of drought event which on 2024 (April), 2028 (July) and 2031 (November). The highest SPI value shown by RCP4.5 which is -3.16 (-below 2.0) that indicate Kg Gajah Puteh expected to experience extreme dry in December 2037.

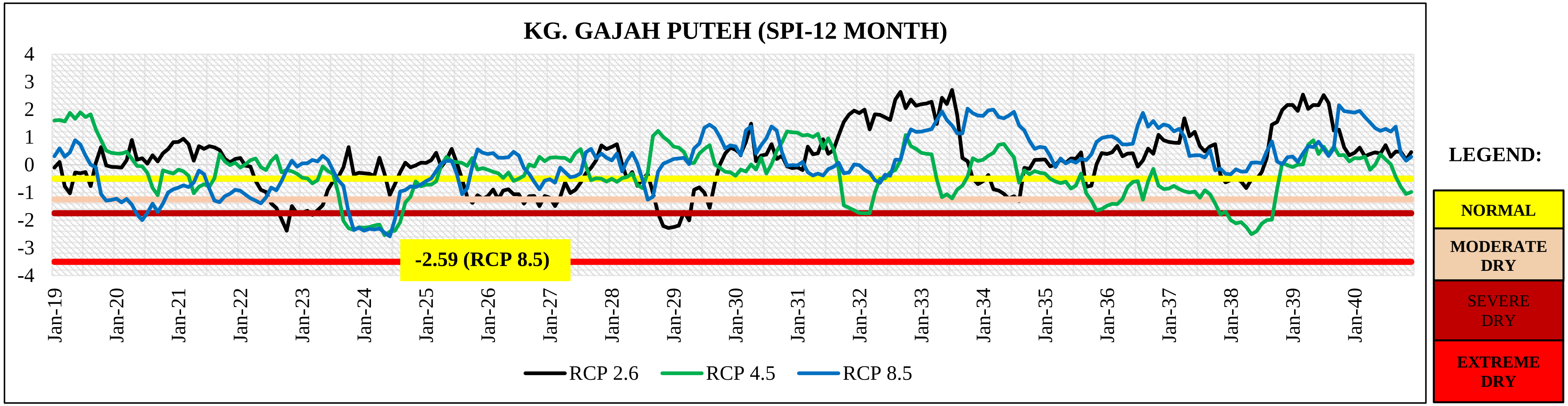

Figure 4.13 SPI-12 month for Kg. Gajah Puteh using RCP 2.6, 4.5 and 8.5

Figure 4.13 above shows SPI 12-month at Kg Gajah Puteh station. Kg Gajah Puteh expected to experience extreme dry within 2019 to 2040. The critical years that have to be caution at Kg Gajah Puteh were predicted on year 2022, 2023, 2024, 2029 and 2038 which the SPI value drop to -2.00. For the RCPs perfomances, the RCP4.5 potentially to produce frequent drought event compared to other RCPs. RCP4.5 claimed Kg Gajah Puteh predicted to experience extreme dry for 18 times which on 2023 (November and December), 2024 (January until August) and 2038 (January until August). RCP2.6 agreed Kg Gajah Puteh will experience twice drought events which on 2022 (October) and 2029 (February). Meanwhile, the RCP8.5 shows Kg Gajah Puteh predicted to experience 8 times of drought event which on 2023 (November and December) and 2024 (January until June). The highest SPI value shown by RCP8.5 which is -2.59 (-below 2.0) that indicate Kg Gajah Puteh expected to experience extreme dry in June 2024.

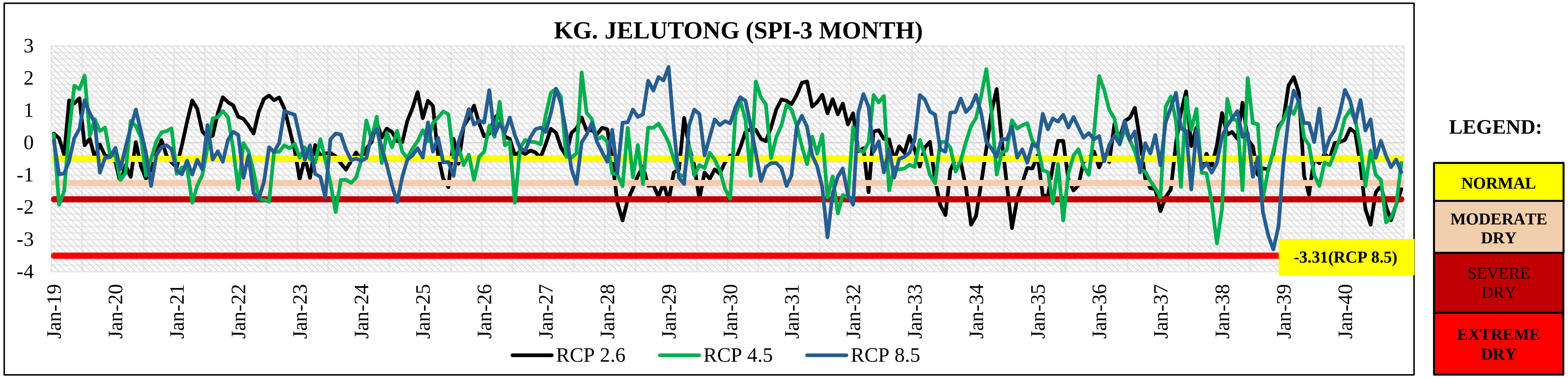

Figure 4.14 SPI-3 month for Kg. Jelutong using RCP 2.6, 4.5 and 8.5

Figure 4.14 above shows SPI 3-month at Kg Jelutong station. Kg Jelutong expected to experience extreme dry within 2019 to 2040. The critical years that have to be caution at Kg Jelutong were predicted on year 2031, 2033, 2034, 2037, 2038 and 2040 which the SPI value drop to -2.00. For the RCPs perfomances, the RCP2.6 potentially to produce frequent drought event compared to other RCPs. RCP2.6 claimed Kg Jelutong predicted to experience extreme dry for 7 times which on 2033 (July and December), 2034 (January and August), 2037 (January) and 2040 (May and June). RCP4.5 agreed Kg Jelutong will experience drought events for 4 times which on 2037 (January) and 2040 (September and October) in future. Meanwhile, the RCP8.5 shows Kg Jelutong predicted to experience 5 times of drought event which on 2031 (July) and 2038 (September until December). The highest SPI value shown by RCP8.5 which is -3.31 (-below 2.0) that indicate Kg Jelutong expected to experience extreme dry in November 2038.

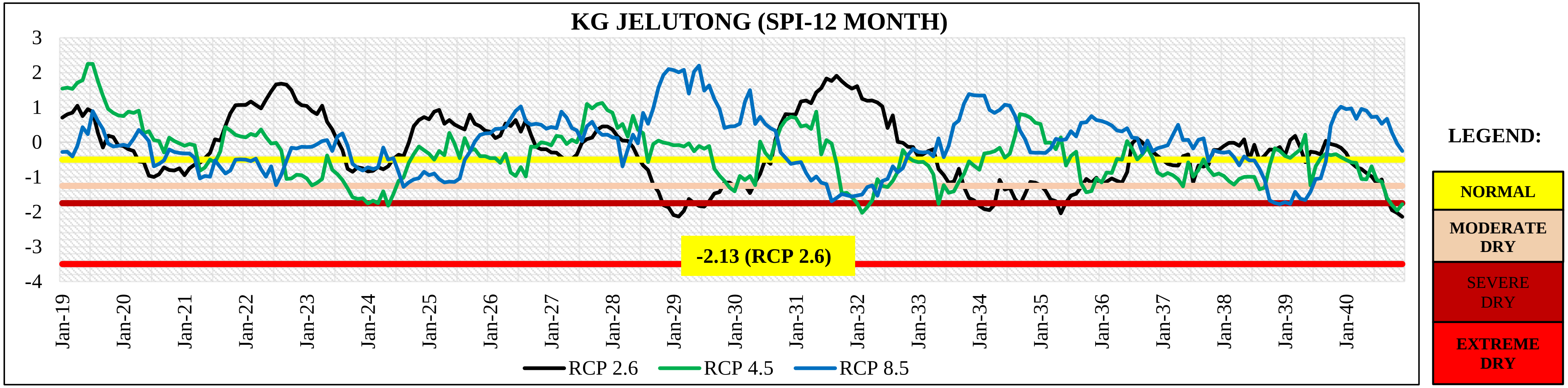

Figure 4.15 SPI-12 month for Kg. Jelutong Puteh using RCP 2.6, 4.5 and 8.5

Figure 4.15 above shows SPI 12-month at Kg Jelutong station. Kg Jelutong expected to experience extreme dry within 2019 to 2040. The critical years that have to be caution at Kg Jelutong were predicted on year 2029, 2032, 2035 and 2040 which the SPI value drop to -2.00. For the RCPs perfomances, the RCP2.6 potentially to produce frequent drought event compared to other RCPs. RCP2.5 claimed Kg Jelutong predicted to experience extreme dry for 4 times which on 2029 (January and February), 2035 (May) and 2040 (December. RCP4.5 agreed Kg Jelutong will experience once drought events which on February 2032. Meanwhile, the RCP8.5 claimed Kg Jelutong will not experience drought events within 2019 until 2040. The highest SPI value shown by RCP2.6which is -2.13 (-below 2.0) that indicate Kg Jelutong expected to experience extreme dry in February 2029.

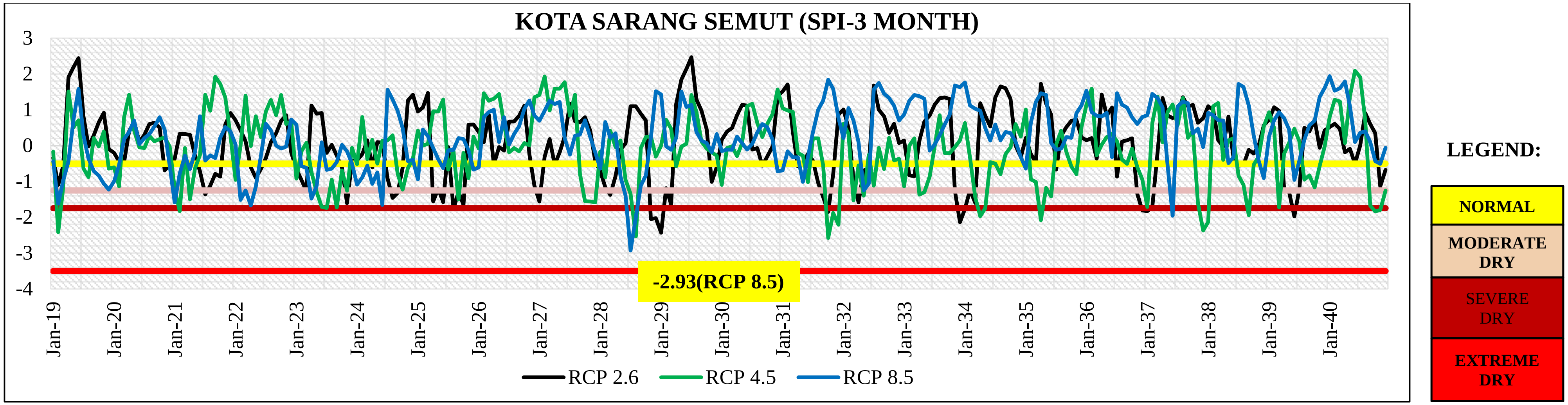

Figure 4.16 SPI-3 month for Kota Sarang Semut using RCP 2.6, 4.5 and 8.5

Figure 4.16 above shows SPI 3-month at Kota Sarang Semut station. Kota Sarang Semut expected to experience extreme dry within 2019 to 2040. The critical years that have to be caution at Kota Sarang Semut were predicted on year 2028, 2029, 2031, 2033, 2035, 2037 and 2038 which the SPI value drop to -2.00. For the RCPs perfomances, the RCP4.5 potentially to produce frequent drought event compared to other RCPs. RCP4.5 claimed Kota Sarang Semut predicted to experience extreme dry for 5 times which on 2028 (August), 2031 (December), 2035 (April), 2037 (December) and 2038 (January). RCP2.6 agreed Kota Sarang Semut will experience drought events for 4 times which on 2028 (November and December), 2029 (January) and 2033 (December) in future. Meanwhile, the RCP8.5 shows Kota Sarang Semut predicted to experience once drought event which on July 2028. The highest SPI value shown by RCP8.5 which is -2.93 (-below 2.0) that indicate Kota Sarang Semut expected to experience extreme dry in July 2028.

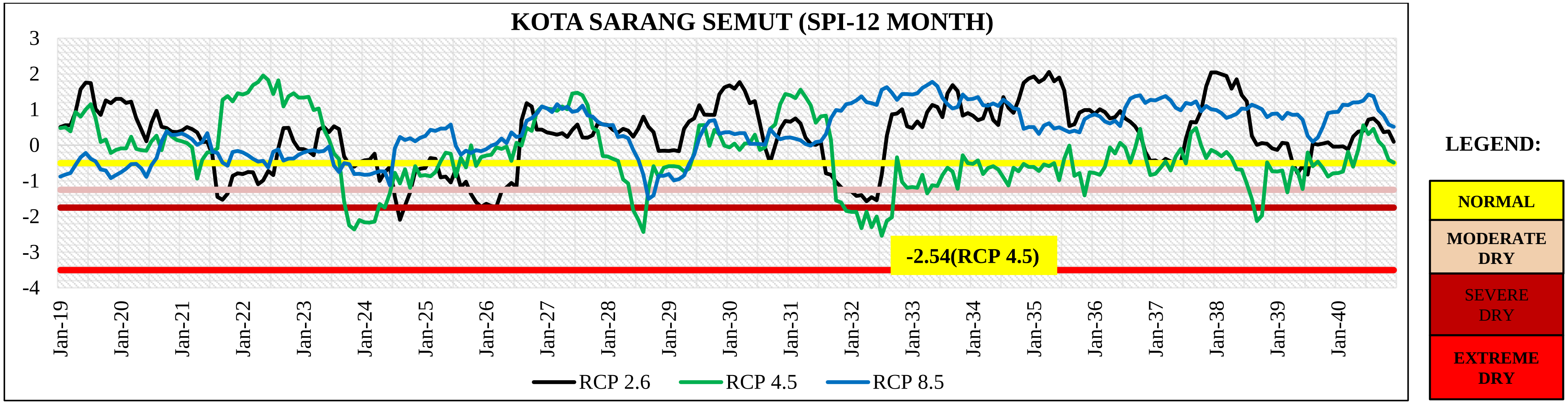

Figure 4.17 SPI-12 month for Kota Sarang Semut using RCP 2.6, 4.5 and 8.5

Figure 4.17 above shows SPI 12-month at Kota Sarang Semut station. Kota Sarang Semut expected to experience extreme dry within 2019 to 2040. The critical years that have to be caution at Kota Sarang Semut were predicted on year 2023, 2024, 2028, 2032 and 2038 which the SPI value drop to -2.00. For the RCPs perfomances, the RCP4.5 potentially to produce frequent drought event compared to other RCPs. RCP4.5 claimed Kota Sarang Semut predicted to experience extreme dry for 14 times which on 2023 (October until December), 2024 (January to March), 2028 (July and August), 2032 (March, May until September) and 2038 (September). RCP2.6 agreed Kota Sarang Semut will experience once drought events only f which on August 2024. Meanwhile, the RCP8.5 claimed Kota Sarang Semut will not experience drought events within 2019 until 2040. The highest SPI value shown by RCP4.5 which is -2.54 (-below 2.0) that indicate Kota Sarang Semut expected to experience extreme dry in July 2032.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In projecting future climates using statistical tools, SDSM is the best model. As a result, SDSM tends to analysis of future climate with small value of MAE for calibration and validation. Both shows the acceptable error for this simulation. As a result, SDSM tends to analysis of future climate with small value of MAE for calibration and validation.

1) For calibration, the highest MAE obtained was 9.24% at Kg Gajah Puteh while the smallest MAE obtained was 2.13% at Kota Sarang Semut.

2) For validation, the highest MAE obtained was 25.58% at Kota Sarang Semut while the smallest MAE obtained was 0.99% at Kedah Peak.

The percentage of MAE for all stations were produced below allowable is below 20%. However, from the validation result, the result obtained exceeding the percentage allowable which is more than 20% but below 40%. The less consistent rainfall historical data at Kedah state given from DID might be the reason for high percentage of error

The projection also shows the good performance in predict the long term climate change of rainfall at Kedah since all scenarios not produce too largest increment/decrement. For rainfall projection using RCPs, the increment and decrement for each stations were summarized as below

1) RCP2.6 shows the highest increment with (+66%) in August and (-44%) in June shown by RCP 8.5 at Kedah Peak. The highest increment shown by RCP4.5 with

59% in February and RCP2.6 shows about (-32%) in December at Kg. Gajah Puteh. Meanwhile for Kg Jelutong, the highest increment shown by RCP4.5 with 53% in February and the highest decrement presented by RCP8.5 with (-50%) in January. RCP2.6 shows the highest increment with (+60%) and (-42%) claimed by RCP4.5 at Kota Sarang Semut.

2) RCP2.6 agreed that Kedah Peak and Kg Gajah Puteh expected to receive lesser annual rainfall compared to historical with (-5.58%) and (-32.92%) respectively. All RCPs claim Kg Jelutong expected to receive more rainfall because all RCPs shows increment in predict the annual rainfall. Meanwhile, RCP8.5 claim Kota Sarang Semut will receive lesser annual rainfall with 7.49% decrement

The SPI value obtained at all selected stations in Kedah shows that the area will receive small amount of rainfall at a certain time.

1) The highest SPI value recorded at Kg Jelutong which is -3.31 claimed by RCP 8.5 for SPI-3-month. The critical years that have to be caution at Kg Jelutong were predicted on year 2031, 2033, 2034, 2037, 2038 and 2040 which the SPI value drop to -2.00.
2) The highest SPI value recorded by RCP8.5 which is -2.59 at Kg Gajah Puteh for SPI-12-month. The critical years that have to be caution at Kg Gajah Puteh were predicted on year 2022, 2023, 2024, 2029 and 2038 which the SPI value drop to -2.00.

Based on overall SPI result, all selected stations expected to experience at least once extreme dry within period 2019 until 2040. All RCPs projection shows all selected stations at Kedah will experience a dry period pattern in future. Thus, the dryness index at Kedah state has been proved by using Standard Precipitation Index (SPI).

5.2 Recommendation

Several recommendations were provided in enhancing for study purpose:

1) The prediction of rainfall trend is very sensitive to the atmospheric circulation changes. Because of that, it would be better if focus at the place where facing a lot of damage after the calamity happen. This is to understand the climatic trend generally and obtain the average intensity for the study area.

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

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