DEVELOPMENT OF DROUGHT INDICES FOR MONITORING DROUGHTS IN THE CENTRAL REGION OF PENINSULAR MALAYSIA

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **“DEVELOPMENT OF DROUGHT INDICES FOR MONITORING DROUGHTS IN THE CENTRAL REGION OF PENINSULAR MALAYSIA”** was prepared by **NG WAI BIN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Drought can be described as a lacking of water in a certain location, which subsequently brings disastrous effects to the social, environment and economic sectors. The root causes for a drought to occur would be the weather conditions, the low volume of precipitation, the high potential evapotranspiration (PET) rate and the reduction of volume of groundwater storage. From the past 35 years, there were several droughts that occurred in the central region of Peninsular Malaysia. In order to reduce the effects of drought, a drought monitoring system should be established to monitor droughts in the central region of Peninsular Malaysia. Furthermore, the spatial and temporal analysis were conducted to understand the drought pattern from 1983 to 2017, which was completed by determining the drought characteristics and trend in monthly basis. The rainfall, streamflow and temperature data were acquired from the Department of Irrigation and Drainage (DID) and the Malaysian Meteorological Department (MMD). They were implemented to compute the drought indices such as the Standardized Precipitation Index (SPI), the Standardized Precipitation Evapotranspiration Index (SPEI) and the Streamflow Drought Index (SDI) with certain timescales (1-month, 3-month, 6-month and 12-month). The missing data for rainfall and temperature data were repaired using the Inverse Distance Weighting (IDW) method. The drought indices were developed and obtained using Microsoft Excel, and compared with historical observed drought events. In addition, the average moving range (AMR) was used to identify the sensitivity of drought indices over time. In order to obtain a better drought monitoring system, the accuracy of drought indices was evaluated using the Probability of Detection (POD), the Pearson correlation, the mean absolute percentage error (MAPE), the root mean square error (RMSE), the mean bias error (MBE) and the mean early or delayed prediction. In this research, the most suitable drought index for monitoring droughts in the central region of Peninsular Malaysia is the SPEI-1, as it is precise in terms of accuracy and is able to capture the historical drought events for the past 35 years. Thus, the 35 years of monthly trend for SPEI-1 was compared the Oceanic Nino Index (ONI) and the Dipole Mode Index (DMI) to investigate the linking between sea surface temperature (SST) anomalies and drought occurrence. In the comparison, it was shown that there is a relationship between the SST anomalies and the drought occurrence; suggesting that further studies are required in the future to formulate their relationship.

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LIST OF SYMBOLS / ABBREVIATIONS

α	scale parameter
β	shape parameter
γ	origin parameter
$\Gamma(\alpha)$	gamma function of α
$\Gamma(\beta)$	gamma function of β
$\overline{P}$	mean precipitation
$\overline{V}_k$	mean of cumulative streamflow volume
$\overline{X}$	mean of the rainfall
$\overline{X}_{\ln}$	log mean
c_0	coefficient for standard normal variable Z calculation
c_1	coefficient for standard normal variable Z calculation
c_2	coefficient for standard normal variable Z calculation
d_i	distance between x_0 and x_1
di	distance from station with data to station with missing data
d_1	coefficient for standard normal variable Z calculation
d_2	coefficient for standard normal variable Z calculation
d_3	coefficient for standard normal variable Z calculation
$f(x)$	probability density function
i	hydrological year
i	index value
i	range of observations in increasing sequence
j	month within the hydrological year
k	reference duration
m	coefficient that calculated based on I
n	number of sampled points used for the estimation
n	number of stations considered
p	power parameter
q	probability of zero

s	standard deviation of the rainfall
s_k	standard deviation of cumulative streamflow volume
t	t transform
w_s	PWMs of order s
w_1	PWMs of first order
w_2	PWMs of second order
y_i	detected drought duration
$y_{i,k}$	natural algorithms of cumulative streamflow volume
C_0	coefficient for standard normal variable Z calculation
C_1	coefficient for standard normal variable Z calculation
C_2	coefficient for standard normal variable Z calculation
D_i	water surplus or deficit
F_i	estimator of frequency
$G(X)$	cumulative probability of an observed rainfall event
$H(x)$	cumulative probability of an observed rainfall event
I	heat index
K	correction coefficient
N	maximum possible sunshine hours
N	number of data
N	number of rainfall stations
NDM	number of days
P	probability of exceeding a determined D value
P_i	Precipitation of station i
PET_i	potential evapotranspiration of station i
S	amount of available moisture in both layers of the soil at the beginning of the month
T	monthly mean temperature, °C
U	statistics U
$V_{i,k}$	cumulative streamflow volume
W_i	weightage of station
Z	standard normal variable

AMR	Average Moving Range
AWC	Available Water Content
CMI	Crop Moisture Index
DID	Department of Irrigation and Drainage
DMI	Dipole Mode Index
ENSO	El Nino-Southern Oscillation
GaWC	Globalization and World Cities Study Group
GIF	Graphic Interchange Format
GIS	Geographic Information System
IDW	Inverse Distance Weighting
IPCC	Intergovernmental Panel on Climate Change
KSWSI	Korean Surface Water Supply Index
MAPE	Mean Absolute Percentage Error
MBE	Mean Bias Error
MIDF	Malaysian Industrial Development Finance
MK	Mann Kendall
MMD	Malaysian Meteorological Department
NSE	Nash-Sutcliffe Efficiency
OK	Ordinary Kriging
ONI	Oceanic Nino Index
P	Period
PDHI	Palmer Hydrological Drought Index
PDSI	Palmer Drought Severity Index
PET	Potential Evapotranspiration
POD	Probability of Detection
RMSE	Root Mean Square Error
SatDroughtMon	Satellite Data and Ground Measurements for Drought Monitoring
SDI	Streamflow Drought Index
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SST	Sea Surface Temperature
SWSI	Surface Water Supply Index
US	United States

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Water is one of the fundamental elements to living organism. There are about 70% of earth is fill with water and also there are significant of number of waters inside human body. Besides, climate is a significant key to the drought. If there is a sudden disturbance to the system, there will be an unpredictable climate change and it may result in natural disaster across the globe and drought may just happen. Apart from that, the unpredictable climate change gives a gigantic impact to public and environment such as natural disaster. Thus, those evidences are obviously proof that the significance of water to the entire world.

Drought is a climacteric of water resource in expressed as the water storage and it has been classified in varies different terms according to the field of study which are further explained in socioeconomic, agricultural, meteorological and hydrological terms. Agricultural drought has been defined as the deficit of the volume of water in crop field. A meteorological drought explained in the term of a period of continuous low volume of precipitation received and caused the scarcity of water. In hydrological term, drought is defined as a relatively low water level and the supplement of water is not adequate in river, lake and groundwater. Furthermore, hydrological drought is mostly influence by human activities and physical factors such as climate.

Hydrological drought is a product from human activities which consists of changing the terrestrial properties and conveys the water from river, lake and groundwater as a supplementary to public around the world. Those human activities accelerate the rate of evaporation and cause a drought more likely to occur. For example, the runoff of a river accelerates and lower the groundwater level (water storage in underground) and this led to hydrological drought. Moreover, climate has played an important role to hydrological drought. As an analogy, global warning can result in increases the rate of evapotranspiration or transform the pattern of the precipitation which may cause lower streamflow (Van Loon, 2015).

Recently, the climate change has prompted serious consequences to the entire world such as extraordinary flood, drought, snowfall, heatwave, natural disaster and etc. For instance, El Nino event is arising from the increasing in temperature ofseawater surface and it has a cumulative effect with global warming. Global warming will further increase the temperature of seawater and thus a stronger El Nino event may take place. Usually, El Nino-Southern Oscillation (ENSO) arise from every 2-7 years and anomalies on sea surface temperature (SST) at Pacific Ocean may act as an indicator of the formation of El Nino or La Nina. El Nino created a disturbance to the climate around the world which gave a severely impact. El Nino event commonly rises up the global surface temperature and it will cause larger precipitation in South America, drought in those western Pacific countries and warmer winters in United States (Plumer, 2015).

In the record, El Nino event was occurred and brought critical damage across the globe in year 1997-1998. For example, Indonesia has experienced a drought event meanwhile excessive rainfall resulted in mudslide happened in United States which cause casualties. During El Nino event in year 1997, the temperature in Malaysia has reached the peak which was 40.1℃ (The El Nino of 1997-1998 | Weather Extremes, 2014). In addition, the forest fires took place in Malaysia and contributed to serious haze circumstance in 1997-1998. In 2016, El Nino has returned and led to hydrological drought in Malaysia. This caused water level of reserve water in seven dams have less than half of the storage which are in the area of: Timah Tasoh (Perlis), Beris Padang Saga, Muda (Kedah), Bukit Merak (Perak), Bukit Kwong (Kelantan) and Labong (Johor) (Anon., 2016). On the contrary, hydrological drought result in water crisis and therefore the production of crop reduced. This indicated that ENSO is one of the root causes and the drought monitoring system has to able to detect drought event regarding to the cause of the drought occur.

Since the drought issue has been a long-term issue across the globe, consequently a drought monitoring and analysing system should be implemented and to clarify the issue to forestall the drought happen. Moreover, there are also no general definition to define the term of drought currently and this is unclear to the drought study. Intergovernmental Panel on Climate Change (IPCC) has established that the occurrence of drought has become more frequent since 1970s (Pearce, 2015). In reality, it is a difficult task to response to a drought due to the unpredictable of the modal of the drought and it may become a false alert when the forecasting is incorrect. Thence, a more precise drought monitoring and analysing system required to comply in the future to have a quick response to drought with a more accurate prognostication.

1.2 Importance of the Study

Since the drought has a massive influence to the globe, thus the drought indices should be executed as an indicator to inspect the characteristic of an occurrence in a drought. Since Malaysia has monsoon seasons, thus drought may take place. Therefore, drought indices are important to make a strategic decision on water management during the drought happen. Basically, drought indices are constituted by six parameters to examine the characteristic of a drought which consists of magnitude, intensity, duration, severity, geographic extent and frequency of a drought. In some of the researches, there may only considered the duration, intensity and severity of drought to study the mode of drought.

The drought indices are playing an important role to hydrology, water engineering field and water management. Benjamin Franklin stated that "An ounce of prevention is worth a pound of cure". Thus, drought index can be a preventive measurement while monitoring the weather condition in Malaysia. Apart from that, drought index is applied to water management in water supply company. For instance, the water supply company uses drought index to anticipate the water storage on the few months later or up to years. If there is a drought occurs in the future, the water supply company can make a restriction policy or manipulate the water usage and storage in advance for incoming drought.

Furthermore, drought indices are important to water engineering field in term of dam design and operation of dam. The function of drought indices in water engineering are similar to the water management which is applied to predict the chance of an occurrence of a drought and take a precaution action. In agriculture field, the study of drought index is important as well as the drought may result in hot and dry weather and caused wildfire in forest area. The water engineer has to conduct a monitoring and analysing the long-term spell condition and respond to avoid the wildfire occur.

As aforesaid, the study of a drought is significant in retrospective and prospective study. The retrospective study of a drought is to imitate the previous drought event and prospective study of a drought is to predict the drought pattern occur in the future. Both of the study is considerable to drought indices which are applied in the risk evaluation of a drought. The retrospective and prospective study has provided a massive dedication in industry as a warning sign of a drought may happen in advance.

1.3 Problem Statement

Drought is described as a natural disaster that caused a tremendous negative impact to the globe. The occurrence of drought is corresponding to the shortage of precipitation, water storage or runoff. Those negative impacts have directly and indirectly impact. For example, a reduced in production of crop is a direct impact from the drought. An indirectly impact is a further affection to a situation and it also can be said as a chain reaction from the direct impact. For instance, farmers have a reduction of income and led to the food price increases dramatically due to decrease in production of crop. Obviously, this example has proved that a drought brings a significant impact. Thus, the occurrence of a drought will damage the economic, environmental and social of a country.

In economic, a drought can result in reduction on the yield of crops because of water shortage. In addition, farmers may spend more budget on irrigation to their farm to maintain the daily water consumption of the standard is achieve and the production of crops as expected. As the production of crops have been decrease, thus the processing factories have lesser number of products to sell in the market and result in profit loss. On the other hand, governments have to allocate some budget to buffer the farmers from the suffer of drought. There is higher energy cost to generate hydropower due to the lower water level in river or dam.

The drought can bring impact in environmental field can be foreseen based on the deficiency of the surface and groundwater supplies. First, the drought cause reduction on quantity and quality of the water and this may endanger aquatic life and those living organism that live with the rely on the water. This also may undermine the balance of the ecosystem. Second, the reduction of water also causes the soil quality decreases and result in unsuitable for plant and vegetation because of the soil organisms are reduce in a number. Third, the reduction of the water brings migration and mortality to wildlife. This evidence shows that the drought has sabotaged the nature of the ecosystem.

The social impacts of drought will result in outbreak of waterborne disease, illness, death and migration of people. The scarcity of water will increase the growth of the harmful bacterial because the availability of clean water is decrease. Thus, the waterborne disease is outbreak due to the people consumed a water that containing higher concentration of bacteria such as typhoid and cholera. Furthermore, there are people dead due to the insufficient of nutrition or suffer in hunger, anaemia and malnutrition. People also anxious to drought and decide to migrate to the place that is no drought happen.

1.4 Aims and Objectives

The aim of this study is to investigate the development of drought indices for monitoring droughts in central region of Peninsular Malaysia. The aim of the research is based on two objectives as shown in following:

(i) To develop drought indices for monitoring droughts in the central region of Peninsular Malaysia.

(ii) To analyse drought in central region of Peninsular Malaysia with the aid of spatial and temporal analysis.

1.5 Scope and Limitation of the Study

The scope and limitation of the study is listed as follow. First, there are concentrating in two research areas in Peninsular Malaysia which are Wilayah Persekutuan (Kuala Lumpur) and Selangor. Second, there are three data acquired from all the stations in precedented study areas which are rainfall data, temperature data and streamflow data. Last, the period of data used in research is limited from 1983 to 2017. The limitation of this drought study is the PDSI cannot be determined due to the lacking of information about soil moisture content.

1.6 Contribution of the Study

The drought brings an enormous influence to the entire world and thus the study of drought is significant. The study of drought will allow people to understand the nature of a drought and implemented in industry such as prediction of the duration, intensity and severity of drought. The modal used for drought prediction has contributed an early warning sign of a drought form and allow people to have precaution in advance. The precaution action take in advance can reduce drought impact to the economic, environmental and social. The study of drought is playing an important role in various fields, especially in water management. For instance, water supply company can implement water restriction policy or water rationing to manipulate water usage and water storage to handle drought impact during dry spell event. The research of the study will contribute in identify drought event and take a quick response to handle it.

1.7 Outline of the Report

There are total five main chapters presented in this report.

Chapter 1 is General Introduction of drought and also include the concise of the information of drought, importance, problem statement for this research, aim and objectives of the study, scopes and limitation in research region and contribution of the study.

Chapter 2 is Literature Review to review the previous researches' study or work.

Chapter 3 is Methodology and Work Plan which emphasizes the research strategy, method of data collection, research instrument and data analysis method.

Chapter 4 is Result and Discussion which are presented the data after obtained and analysed.

Chapter 5 is Conclusions and Recommendations are concluded the study of this research and provide recommendation to solve the limitations encountered in this research in future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the types of drought, drought index and spatial and temporal analysis method were reviewed to have a better understanding on droughts characteristics. Thereof, a better drought index to monitor drought in central region of Peninsular Malaysia can be determined. It is important to use better drought index to monitor and analyse the occurrence of drought in a more precise manner. Moreover, the relationship between drought and ENSO was investigated in order to understand the linking between them.

Drought is a general term to describe a situation of water scarcity on specific area. It can be classified in various fields according to previous researches. There are four types of drought, which are agricultural, hydrological, meteorological, socioeconomic droughts. The general sequence for various types of drought is shown in Figure 2.1.

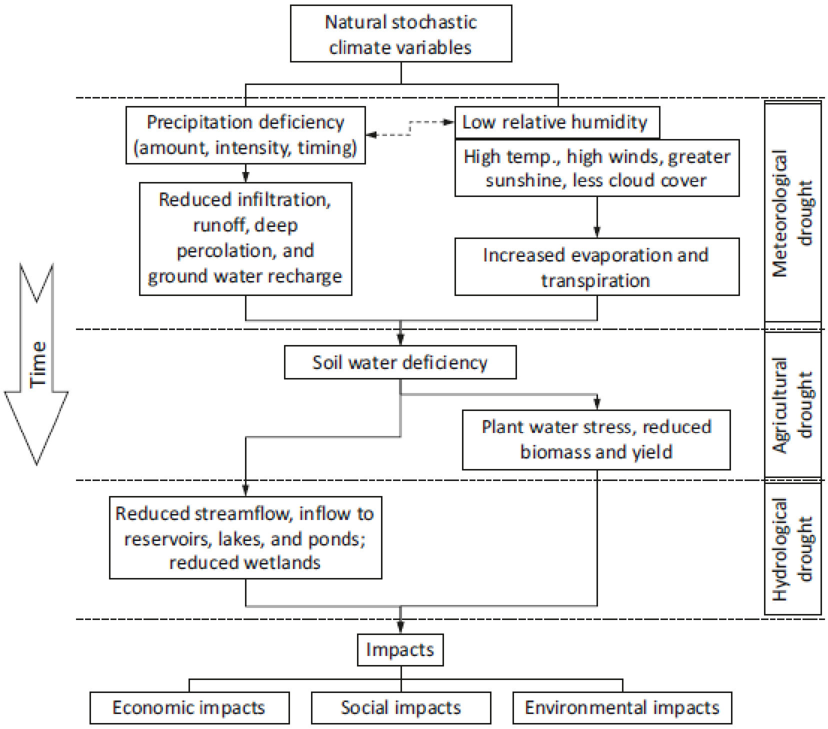

Figure 2.1: The Common Sequence for Various Drought Types to Occur (Zargar, et al., 2011)

Drought indices were reviewed and a comparison among all drought indices was presented. This study helps to define a suitable drought index that can adapt and perform well for monitoring droughts in central region of Peninsular Malaysia. The list of drought indices has been studied included Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Streamflow Drought Index (SDI), Palmer Drought Severity Index (PDSI), Surface Water Supply Index (SWSI) and etc.

In addition, drought is a process varies across space and time due to its spatio-temporal dynamic characteristic. Hence, spatial and temporal analysis is commonly executed to have a better understanding in drought with respect of the study area. There are six parameters of drought that commonly used in spatial and temporal analysis which are severity, duration, frequency, intensity, peak and areal extent. With the help of Geographic Information System (GIS), drought information can be visualized easily, e.g. animated graphics interchange for visualization of drought over time.

2.2 Types of Drought

2.2.1 Agricultural Drought

Agricultural drought is known as drought that causes influence directly or indirectly to agriculture sector. It has an inseparable connection to various behaviours of meteorological drought, which mainly due to water crisis. Moreover, agricultural drought happens when water demand of crop is not satisfied or the soil moisture is under minimum requirement for a crop (Zhao, et al., 2017). This is followed by damages to crop and subsequently reduction of crop yield.

2.2.2 Meteorological Drought

The definition of meteorological drought is described as a sustained deficiency on precipitation. Meteorological drought is the source that rise other types of drought and tend to influence huge region. The deficient of precipitation is related to the climate change and human activities such as global warming and deforestation (Pedro-Monzonís, et al., 2015). For instance, deforestation decreases the moisture of forest soil and the water vapor will release to atmosphere, which promotes greenhouse effect (National Geographic, 2017).

2.2.3 Hydrological Drought

Hydrological drought is a term used to describe a lower water level in river, lake and groundwater compared to regular reading in a timeframe (Pedro-Monzonís, et al., 2015). Generally, this is cause by climatic factors such as global warming that will result in higher rate of evaporation or deficient on precipitation. Those factors will lower the water level of river, lake and groundwater and the consequences include ripple effect to other aspect such as damage in crop production.

2.2.4 Socioeconomic Drought

The supply and demand of goods that are strongly influence by agricultural, hydrological and meteorological drought conditions are components in socioeconomic drought. When the demand is surpassing than the supply of economic goods, the socioeconomic drought takes place (National Weather Service, 2012). The complexity of this drought is higher because it is depending on the effects from other droughts. Socioeconomic drought is a consequence of other droughts. For example, deficient of precipitation leads to water scarcity in water supply and it also reduces the crop yield. Thus, the demand of economic goods will exceed the supply and subsequently increase the price of economic goods (Heim, 2002).

2.3 Drought Indices

Drought index is an indicator to determine the occurrence of drought, it is also a measurement of specific drought in term of magnitude, intensity, duration, severity, geographic extent and frequency. Recently, there is no general definition to describe drought explicitly. Thus, the degree of drought is determined by respective drought index. For example, Agricultural drought index is an index to identify integrated transpiration shortage in a timeframe by applying water balance equation and crop transpiration (Zargar, et al., 2011).

Moreover, drought index anticipates the chance of drought to occur. It is commonly used in monitoring and analysing system for advance planning. For instance, if drought index has determined there is a high possibility of drought occur in shortly, the water management implements water restriction policy in advance to overcome the hardship during dry spell event. This shows that the drought indices have play an important role in operation and management systems in water supply.

2.3.1 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a universal index used to identify meteorological drought occurrence through simple calculation using precipitation data. As a result of simplicity, SPI does not account other variables that can affect droughts such as temperature, rate of transpiration and potential evapotranspiration (PET), humidity and etc. There are two assumptions were made as a premise to implement SPI. First assumption states that the precipitation variable is more significant than other variables. Second assumption states other variables are stationary. Some researches have illustrated the diversity of SPI to soil moisture content, water activity, vegetation activity and crop production at different timescales (Vicente-Serrano, et al., 2010).

Furthermore, the timescales of SPI are normally pre-set and applied based on research objective. Generally, the timescale is categorized in 1, 3, 6, 9, 12 and 24 months for the study of past precipitation event to achieve the research objective (Zin, et al., 2012). The phenomena reflected by SPI and applications of SPI according to SPI duration are represented in Table 2.1.

Table 2.1: Phenomena Reflected by Specific-Duration Standardized Precipitation Indices (SPI) and Their Application (Zargar, et al., 2011)

SPI duration	Phenomena reflected	Application
SPI_1	Short-term water conditions	Soil moisture and crop stress for a short-term analysis
SPI_3	Short- and medium-term moisture conditions	Estimation of rainfall event in term of seasonal
SPI_6	Medium-term trends in rainfall	Estimation of rainfall amount that can provide information more than seasonal data
SPI_9	Rainfall modes over a medium timescale	SPI_9 is a good indicator in agriculture field
SPI_{12}	Long-term rainfall modes	Water management and operation are applied SPI_{12} to ensure the water supply is sufficient for current and future

SPI overcomes the discrepancies result of the collected precipitation data by constructing a normal distribution under specified duration (Zargar, et al., 2011), where positive SPI value reveals a greater median precipitation is observed and vice versa. Therefore, SPI creates a normal distribution measurement to sort the climate condition corresponding to the intensity of precipitation. The relationship between SPI value and climate condition is represented in Table 2.2.

Table 2.2: Standardized Precipitation Index (SPI) Classification Criteria (Agwata, 2014)

SPI Value	Climate Condition
≥ 2.0	Extremely wet
1.5 ~ 1.99	Very wet
1.0 ~ 1.49	Moderately wet
-0.99 ~ 0.99	Near normal
-1.0 ~ -1.49	Moderately dry
-1.5 ~ -1.99	Severely dry
≤ -2.0	Extremely dry

However, there is a main disadvantage of implementing SPI, which is sole consideration of precipitation variable rather than including other relevant variable such as PET, which has significant contribution in drought study. Next, the reliability of precipitation data is limited by the accuracy of measurement, number of rainfall station and record period. Lastly, SPI does not have the ability to determine research region with sufficient drought information, thereby it requires understanding the local climatology (Zargar, et al., 2011).

Ali Umran Komuscu (1999) performed a study on SPI with timescales of 3-, 6-, 12- and 24-month in Turkey. The study discovered that SPI-3 showed the highest drought frequency, but reduced with prolonged duration when the SPI timescales applied were greater (Ali Umran Komuscu, 1999). The classification of drought condition for SPI was done based on the research from McKee, et al. (1994), which consists of four classes to classify a drought. A SPI value between 0 and -0.99 is classified as mild drought; SPI value between -1.00 and -1.49 is classified as moderate drought; SPI value between -1.50 and -1.99 is classified as severe drought; and SPI value less than -2.00 is classified as extreme drought.

SPI has been a popular drought index since previous decades until now. For instance, Belayneh, et al. (2013) applied SPI at timescales of 6-, 12- and 24-month intervals for drought predictions in the Awash River Basin of Ethiopia. The results demonstrated that SPI-6, -12 and -24 performed well and precisely in predicting droughts in Awash River Basin. Furthermore, Tan, et al. (2018) adopted SPI to analyse the meteorological droughts in Johor River Basin for the period of 1975 - 2010. The authors found that the upper region of Johor River Basin has higher drought frequency than lower region, which indicated Linggiu Dam received lesser rainfall amount.

2.3.2 Standardized Precipitation Evapotranspiration Index (SPEI)

The Standardized Precipitation Evapotranspiration Index (SPEI) is one of the popular meteorological drought indices. SPEI is similar to SPI in term of mathematical expression. Both indices are presented in normal distribution curve and analysed to obtain outcome in drought assessment. The temperature effect is considered in SPEI to overcome the shortcoming of SPI. According to researches, evaporation and PET can deplete about 80% of precipitation in a general circulation model experiment. Therefore, the consideration of temperature variable in drought assessment is important as it is one of the major factors among drought variables in drought occurrence. Hence, SPEI assesses using precipitation and temperature data (Vicente-Serrano, et al., 2010).

Similarly, the SPEI is also able to describe droughts in different timescales. For example, Bayissa, et al., 2018 used a short-term timescale of SPEI such as 1-, 2- and 3-month interval in their study. However, the short-term timescale of SPEI can estimate droughts more accurately as compared to SPI. The water balance equation is required to be executed in calculation steps for the evaluation of PET (Vicente-Serrano, et al., 2010). A negative SPEI values indicates that drought condition is likely to occur due to the lacking of precipitation or higher rate of PET, or both happening simultaneously (Bayissa, et al., 2018).

Manatsa, Mushore and Lenouo (2015) also applied SPEI and ENSO to predict the droughts occurred in the southern of Africa. The SPEI was computed by using the equations developed by Vicente-Serrano, et al. (2010). In this research, ENSO was introduced as a prediction scheme as southern Africa can be affected by the event. The spatial variation of SPEI was conducted to identify the climate pattern across southern Africa. Besides, the connection between SPEI and ENSO is important because SPEI considers temperature variable, which is used to perform PET calculation, while ENSO has better prediction in precipitation for this study region. Thus, this combination was investigated and the results proved that it was an excellent way to identify the climate in the southern of Africa.

Li, et al. (2015) also used SPEI and conducted the spatial, temporal and trend analysis to study historical drought events that occurred in period of 1982 to 2012. The monthly SPEI value was determined with different timescales and the average values of the SPEI in each station were calculated. The SPEI value was compared with historical drought events to evaluate the accuracy of SPEI. In the study, the results showed that for 2010 onwards, there was an increasing trend of drought frequency and severity compared to the past.

In order to understand the spatial and temporal variation of droughts, Chen, et at. (2018) also used the variation of SPEI in Yangtze River basin of China, which is the third longest river in the world. The authors used four timescales of SPEI in the study and Penman-Monteith method was introduced to identify PET, which involved more parameters in PET considerations. In this research, there was 52 years data involved and the results showed that SPEI was capable to analyse the drought condition in Yangtze River basin (Chen, et al., 2018).

2.3.3 Streamflow Drought Index (SDI)

Streamflow Drought Index (SDI) defines the occurrence of hydrological drought. There are varieties of factor causing a hydrological drought to take place. Among the factors, streamflow is a key parameter to describe hydrological drought as the water scarcity of a streamflow is relatively simple to observe. Thereupon, the shortage of streamflow has a connection to hydrological drought. In hydrological drought, the parameters to define drought event are severity of drought, duration of drought, the coverage of area; and frequency of drought occurrence.

Nalbantis and Tsakiris (2008) proposed a methodology to determine hydrological drought. Instead of depending on four-dimensional relationship of drought, a simplified method that utilizes two-dimensional relationship of drought was introduced. It was constructed based on the severity and frequency to determine hydrological drought, and hence SDI is proposed. In water management, water manager is usually more concern on SDI instead of other indices due to the properties of SDI being able to be categorised in five states, as shown in Table 2.3 (Nalbantis, 2008).

Table 2.3: Classification of Hydrological Drought with the Aid of SDI (Nalbantis, 2008)

State	Description	Criterion	Probability (%)
0	Non-drought	SDI $\geq$ 0.0	50.0
1	Mild drought	-1.0 $\leq$ SDI < 0.0	34.1
2	Moderate drought	-1.5 $\leq$ SDI < -1.0	9.2
3	Severe drought	-2.0 $\leq$ SDI < -1.5	4.4
4	Extreme drought	SDI $\leq$ -2.0	2.3

In 2008, Nalbantis was applied SDI for Evinos and Boeoticos Kephisos river basin, which are the main water sources for Athens Metropolitan Area. Nalbantis has implemented SDI with 3-, 6-, 9- and 12-month intervals, which are October-December, October-March, October-June and October-September. The study showed that SDI was capable to detect the main historical droughts that occurred in the study region with high reliability (Nalbantis, 2008).

Tabari, Nikbakht and Talaee (2012) also executed SDI with the timescales of 3-, 6-, 9- and 12-month to determine hydrological droughts in the northwest of Iran from 1975 to 2009. The computation of SDI was carried out based on the equations developed by Nalbantis and Tsakiris (2008). Different probability distributions, namely, Log-normal, exponential and uniform probability distributions were tested in the study. Log-normal probability distribution outperformed other probability distributions to identify the hydrological droughts in the northwest of Iran. Moreover, SDI was able to capture the historical droughts events accurately. For instance, the water level in Lake Urmia dropped from 1277.80 m to 1273.35 m in 1999 was detected using SDI.

In order to determine hydrological drought at the upper Yangtze River basin, Hong, et al. (2014) adopted SDI as the drought index to monitor streamflow in the study. The daily streamflow data was collected from 1882 to 1992, which was recorded by Yichang hydrological station. SPI-12 was estimated to identify the droughts happened within the study region, using the equations developed by Nalbantis and Tsakiris (2008). Moreover, bootstrap method was introduced to resolve the sampling uncertainty, and temporal analysis of SDI-12 was done using Mann Kendall (MK) test. The results showed that the droughts occurred more frequent and with greater drought severity as compared to the past.

2.3.4 Palmer Drought Severity Index (PDSI)

The Palmer Drought Severity Index (PDSI) is a well-known meteorological drought index around the world, particularly in United States (US). The concept of drought in PDSI emphasizes in water supply-and-demand in water balance equation rather than irregularity in rainfall event. This suggests that PDSI emphasizes in irregularity of soil moisture deficiency as a manipulate variable compared to weather anomalies. The data inputs used to determine PDSI value are rainfall, temperature and available water content (AWC) in the soil. There are four main parameters in water balance equation, which include PET, runoff, soil recharge and moisture content. The computation of PDSI estimates these four parameters using the data inputs listed above (Zargar, et al., 2011), without considering the human impact in water balance equation such as irrigation (Agwata, 2014).

In PDSI, the comparison of moisture conditions is mainly based on the research location and the study timeframe. There are requirements to prepare a comparison for PDSI, i.e. requirement of standardized moisture condition measurement. Thus, data inputs were collected to obtain a standardized moisture condition distribution graph. This graph is a measurement of moisture condition and classify moisture condition according to PDSI values (Agwata, 2014).

Table 2.4: Palmer Index Classification Criteria (Agwata, 2014)

PDSI Value	Moisture Condition
≥ 4.0	Extremely wet
3.0 ~ 3.99	Very wet
2.0 ~ 2.49	Moderately wet
1.0 ~ 1.99	Slightly wet
0.5 ~ 0.99	Insipient wet spell
0.49 ~ -0.49	Near normal
-0.5 ~ -0.99	Insipient dry spell
-1.0 ~ -1.99	Mild drought
-2.0 ~ -2.99	Moderately drought
-3.0 ~ -3.99	Severely drought
≤ -4.0	Extremely drought

The PDSI is commonly computed in monthly basis and it is widely implemented in varieties applications after being modified such as Palmer Hydrological Drought Index (PHDI). Since the widespread of PDSI application, PDSI has offered a measurement of the irregularity of weather in certain region (Agwata, 2014). The behaviour of PDSI proved that it is able to applied in agricultural field as PDSI is sensitive to precipitation, temperature and soil moisture contain in soil (Pedro-Monzonís, et al., 2015).

Notwithstanding, PDSI provides an excellent result in drought assessment but it has several limitations when applying PDSI. First, the complex computation of PDSI prompted a low transparency due to the arbitrary selection of beginning and ending intensity value and algorithms. Second, PDSI has an exceptional sensitivity to AWC for soil and the expression of this information may be too ordinary to Climate Division. Third, PDSI does not consider other form of precipitation such as snowfall and cause the result of PDSI inaccurate in winter region. Next, PDSI may result in underestimation of runoff since PDSI has ignored the lag between rainfall and runoff. Then, Thornthwaite method is applied to estimate PET, and since it is an approximation result, hence causes inaccurate result (Agwata, 2014). The applicability of PDSI is limited. For instance, PDSI is not adopted in the location with climatic extreme, mountainous terrain and winter region unless a calibrated PDSI is conducted.

PDSI has a difficulty to be applied in water management since it does not consider water storage and human impact in water balance (Zargar, et al., 2011).

2.3.5 Surface Water Supply Index (SWSI)

One of the limitations in PDSI is ignorance of snow accumulation in drought index. Thus, Shafer and Dezman (1982) developed Surface Water Supply Index (SWSI) to overcome the weakness of PDSI. The condition of surface water acts as an indicator in SWSI, which the availability of water that is over the soil layer such as snow accumulation and runoff will be include in computation of SWSI. SWSI is suitable to implement in winter region country due to its consideration of snow accumulation. In SWSI, there are few components to define drought event: snow accumulation, streamflow, precipitation and reservoir storage.

There are specific procedures to execute the computation of SWSI. First, the monthly data from rainfall stations, reservoirs, snow accumulation and streamflow will be obtained and total-up according to the basin. After that, each component will be normalised based on the frequency analysis. Next, each component from frequency analysis will be computed as the probability of non-exceedance. The weightage of each component will then be computed and used to define SWSI value, which indicates the condition of study area.

Since SWSI is computed based on the normal probability distribution curve, this make SWSI one of the simple calculations among all drought indices. However, SWSI for each study region cannot be compared with other region due to the characteristics of SWSI. Due to the unique of SWSI, the redevelopment of SWSI required to implement once it failed to maintain homogeneous time series of SWSI. Besides, if the environment of study region changes such as new dam is constructed, and hence a new SWSI computation requires to execute (Agwata, 2014).

In order to determine hydrological droughts in South Korea, Kwon and Kim (2010) introduced a modified SWSI in semi-distributed mode. Two new parameters namely inflow of dam and groundwater level data were added, which originally were the volume of snow precipitation and water level in reservoir. The proposed two parameters were introduced due to the considerations of water resources in South Korea, which consists of surface and groundwater. Therefore, the multiple drainage basins were applied for the analyzing work. The outcomes certified if the segregation of watersheds increases, then more spatial detailed information could be obtained.

In 2018, a new drought index was proposed, namely Korean Surface Water Supply Index (KSWSI). There are two prerequisites to be completed for the computation of KSWSI. First, adequate hydrological and meteorological data for every sub-basin are required. Next, the most adequate probability of distribution needs to be selected for the computation of KSWSI (Jang, et al., 2018). This improvement enhanced the workability of SWSI by adopting the local conditions, which cause KSWSI more suitable to monitor weather condition in South Korea.

2.4 Spatial and Temporal Analysis

Drought is a spatio-temporal dynamic process, which has varying characteristic in its severity, duration, frequency and areal extent (Xu, et al., 2015). The spatial and temporal analysis of drought for a research study is usually conducted for the identification of drought. In spatial and temporal analysis, the main objective is to determine the drought period and the spatial extent of drought (Rossi, et al., 2007). The spatial and temporal analysis of drought and drought monitoring are common and significant issues to understand the structure of drought (Mao, et al., 2017).

In freshwater planning and management, a well understanding in spatial and temporal analysis is important. The behaviours of drought such as severity, duration, frequency and areal extent are the pre-requisites for spatial and temporal analysis to be performed. In some researches, simplified lower dimensional was used to define the drought variable, where the spatial and temporal analysis was carried out separately. This is not appropriate to describe the spatio-temporal structure of drought. To obtain a better understanding in spatio-temporal variation, a three-dimensional framework is crucial to be acquired from the identification of drought event (Xu, et al., 2015).

2.4.1 Inverse Distance Weighting (IDW)

Robinson and Metternicht (2003) applied inverse distance weighting (IDW) interpolation method to analyse soil properties in the Southwest of Western Australia, which the research area is 60 ha paddock. In this research, the authors applied IDW with power of two, and predicted soil pH accurately when it is compared with the actual soil pH using root mean square error (RMSE). As a result, it concluded that IDW are capable to be implemented in spatial analysis for soil properties in the Southwest of Western Australia.

Chen and Liu (2012) performed IDW method to identify the spatial distribution of rainfall in Taichung. The recorded rainfall data in daily scale was acquired from year 1981 to 2010. IDW was applied in the study to repair the unknown rainfall data from neighbour rainfall stations. The performance assessment of IDW method was assessed by RMSE. Based on the results, IDW method was concluded to be appropriate for repairing the missing rainfall data in Taichung.

2.4.2 Ordinary Kriging (OK)

Ordinary Kriging (OK) method interpolates by measuring the relationship in samples using weighted average technique. It uses data provided to build a mathematical function call semi-variogram, and then transform it into a prediction surface. Therefore, the input model can be validated by a cross-validation. Cao (2017) applied OK interpolation method for rainfall repairing in Ganjiang River of Jiangxi Province. The OK method was implemented using semi-variogram to measure the effective distance between two rainfall stations. Statistical metrics such as RMSE, coefficient of determination and Nash-Sutcliffe efficiency (NSE) were applied in the study to evaluate the accuracy of OK method. The author discovered that OK method has lower deviation than the other two spatial interpolation methods. Although it has the feature of strong prediction, the requirement on data to be normally distributed, stationary and no global trends has limited its applicable areas.

2.5 Summary

This chapter has briefly introduced the types of drought across the world such as agricultural, hydrological, meteorological and socioeconomic droughts, several drought indices have also been discussed based on their identifications in drought. Furthermore, the details and importance of spatial and temporal analysis were explained concisely in this chapter. Spatial and temporal analysis, which considers the drought period and spatial extent, helps to provide a better understanding on the influence of drought. In order to study the accuracy of drought indices, the measurements for accuracy evaluation of drought indices were also explained in this chapter.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

Chapter 3 explains about the procedures of determine if drought within the location of study. The location of study is the central region of Peninsular Malaysia, which consists of Wilayah Persekutuan (Kuala Lumpur) and Selangor. The rainfall, temperature and streamflow data of Kuala Lumpur and Selangor were collected and analysed by using drought indices, spatial and temporal analysis. After collection of data, the locations of rainfall, temperature and streamflow stations were pinned in Google Earth and saved in KML format which was implement in QGIS software. Before analysing, some of the rainfall and temperature data are missing and required to conduct data repairing. Then, those available data will be analysed in drought indices to determine the occurrence of drought in study area. In addition, those available data also analysed in spatial and temporal analysis to identify the spatial and temporal pattern of study area. Figure 3.1 illustrated the workflow in this methodology of study and the detail for each component of workflow is explained in the following sub-topic.

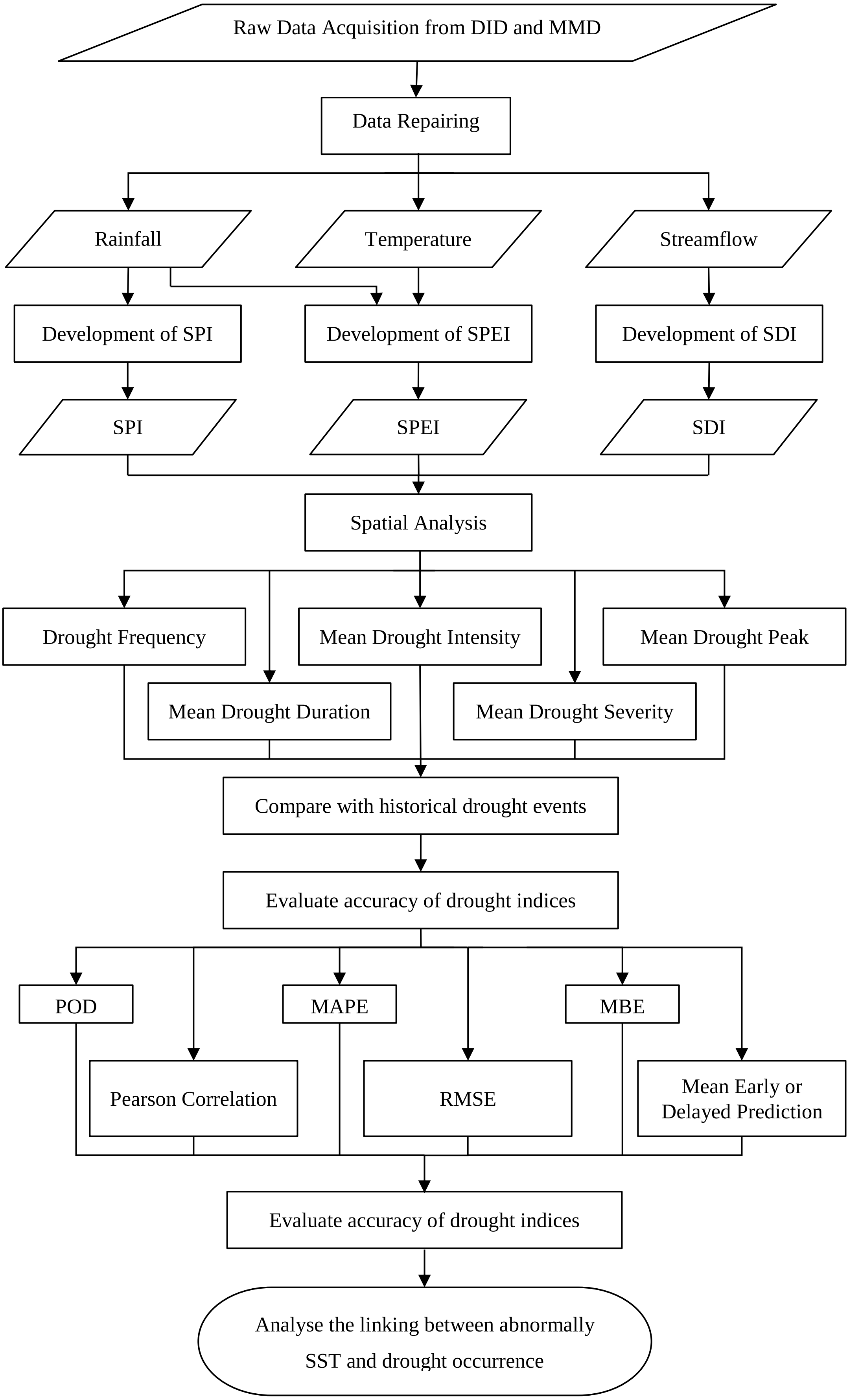

Figure 3.1: Workflow of Study

3.2 Location of Study and Data Acquisition

In this research, the drought study is in central region of Peninsular Malaysia which consists of Wilayah Persekutuan (Kuala Lumpur) and Selangor. The drought study is required some available data to identify the occurrence and characteristics of drought such as rainfall, temperature and streamflow data. Thereupon, the collection of data is a requirement in drought study. Rainfall, temperature and streamflow data were collected from Department of Irrigation and Drainage (DID) and Malaysian Meteorological Department (MMD). Nonetheless, the study in property of the research region is important in drought study because the parameters in water budget equation is highly dependent of the property of research region. The property of the research region consists of coverage area, the existing of river and water dam and major economic activities.

3.2.1 Wilayah Persekutuan (Kuala Lumpur)

According to Department of Statistics Malaysia, the coverage area for Kuala Lumpur is 243km^2 (Department of Statistics Malaysia, 2016). The existing rivers in Kuala Lumpur is shown in Figure 3.2.

Figure 3.2: Rivers in Kuala Lumpur (DBKL, n.d.)

Kuala Lumpur is the fastest growth region in Malaysia because of Malaysia has a good strategic in location (Angie, 2007). Globalization and World Cities Study Group (GaWC) has classified Kuala Lumpur city in alpha class (GaWC, 2010). The economics of Kuala Lumpur is mainly supported by service sector such as local and foreign banks in the city. Furthermore, education and health services are important as well as the contribution of service sector in economics of Kuala Lumpur. The urbanization process is developing Kuala Lumpur area towards a modern city due to its economic activities.

3.2.2 Selangor

The coverage area for Selangor is 7964km^2 based on the official portal from Department of Statistic Malaysia (Department of Statistics Malaysia, 2015). The rivers and water dams in Selangor are represented in Figure 3.3.

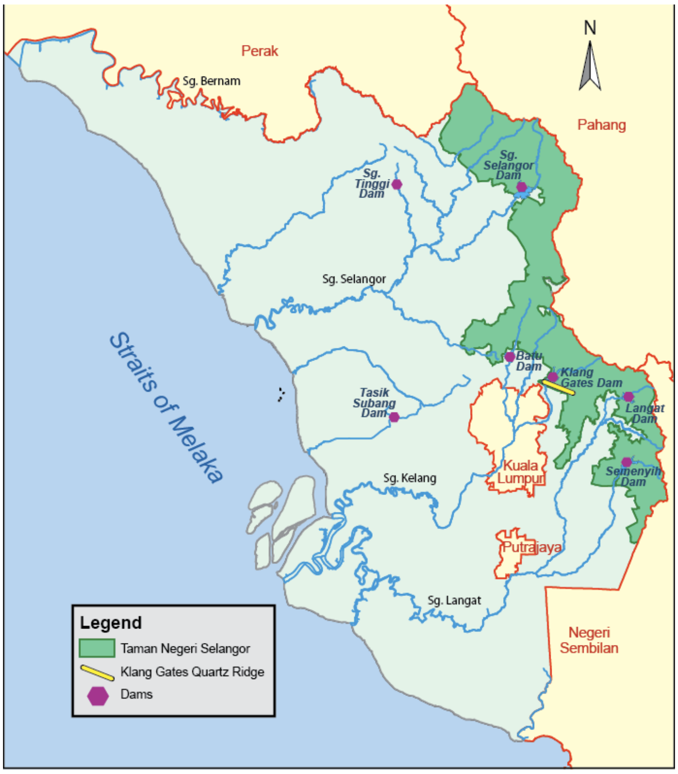

Figure 3.3: Rivers and Water Dams in Selangor (TrEES, n.d.)

Malaysian Industrial Development Finance (MIDF) Research established an economic report and said that Selangor has increased in heavy construction activity in 2017. This indicated that urbanization is expanded to Selangor due to the insufficient of undeveloped area in Kuala Lumpur. In addition, services sector in Kuala Lumpur and Selangor is held about half of entire services sector. The services sector is outspreaded to Selangor due to services sector in Kuala Lumpur area has been saturated (MIDF, 2018). The urbanization process is overspread in Selangor due to its economic activities and this led Selangor towards to modern city after Kuala Lumpur.

3.2.3 Data Acquisition

The data acquisition for this study is collected from DID and MMD for particular data, which are rainfall, streamflow and temperature data. In order to plot the rainfall, temperature and streamflow stations in QGIS, the details of rainfall, temperature and streamflow stations are included station number, state, latitude and longitude which demonstrated in Tables 3.1, 3.2 and 3.3 respectively. The rainfall, temperature and streamflow stations in Kuala Lumpur and Selangor were pinned in Google Earth Pro by their details and saved in KML format. Then, those KML saved files were opened in QGIS to visualize the distribution of those stations. QGIS also used in measurement of distance between two stations for data repairing purpose. The distribution map of those stations in QGIS is illustrated in Figure 3.4. In Figure 3.5, a procedure of data preparation based on study region is clearly displayed.

Table 3.1: Coordinates of Rainfall Stations in The Central Region of Peninsular Malaysia

Station No.	State	Latitude (Decimal Degree, ^{o}S)	Longitude (Decimal Degree, ^{o}E)
3116003	KL	3.15	101.68
3116006	KL	3.18	101.63
3117070	KL	3.15	101.75
3216001	KL	3.27	101.69
3217002	KL	3.24	101.75
3217003	KL	3.24	101.71
3217005	KL	3.25	101.72
3317004	KL	3.37	101.77
2815001	Selangor	2.83	101.54
2818110	Selangor	2.90	101.87
2913001	Selangor	2.93	101.39
2917001	Selangor	3.00	101.79
2917002	Selangor	2.95	101.75
3118102	Selangor	3.17	101.87
3314001	Selangor	3.37	101.41
3411017	Selangor	3.42	101.17
3416002	Selangor	3.44	101.66
3516022	Selangor	3.58	101.67
3613004	Selangor	3.70	101.35
3710006	Selangor	3.73	101.08

Table 3.2: Coordinates of Temperature Stations in The Central Region of Peninsular Malaysia

Station No.	State	Latitude (Decimal Degree, ^{o}S)	Longitude (Decimal Degree, ^{o}E)
48650	Selangor	2.73	101.70
48648	Selangor	3.10	101.65
48647	Selangor	3.13	101.55

Table 3.3: Coordinates of Streamflow Stations in The Central Region of Peninsular Malaysia

Station No.	State	Latitude (Decimal Degree, ^oS)	Longitude (Decimal Degree, ^oE)
3116430	KL	3.14	101.70
2816441	Selangor	2.99	101.79
2918401	Selangor	2.92	101.82
3414421	Selangor	3.40	101.44
3615412	Selangor	3.69	101.52
3813411	Selangor	3.81	101.37

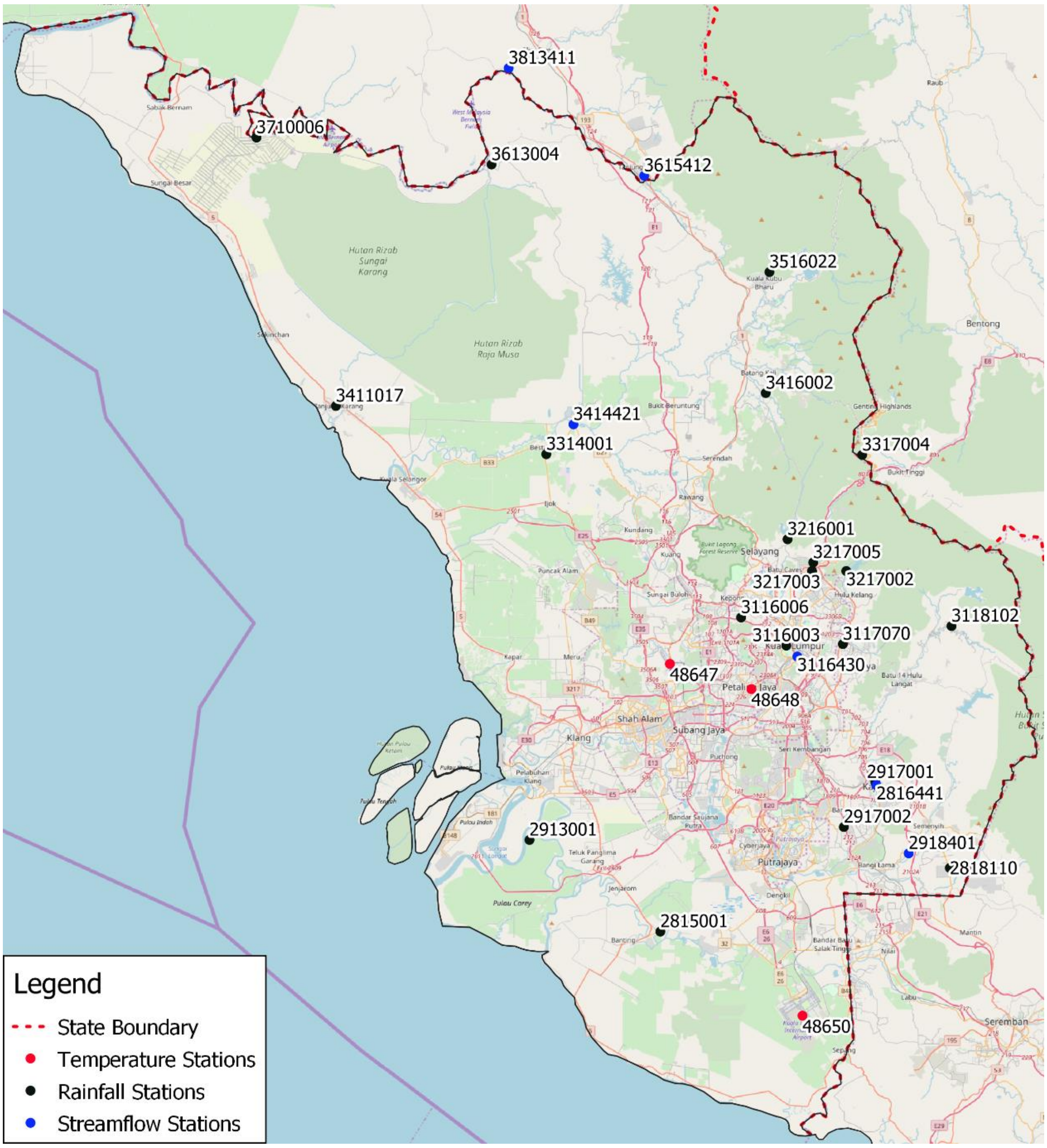

Figure 3.4: The Distribution of Stations in QGIS

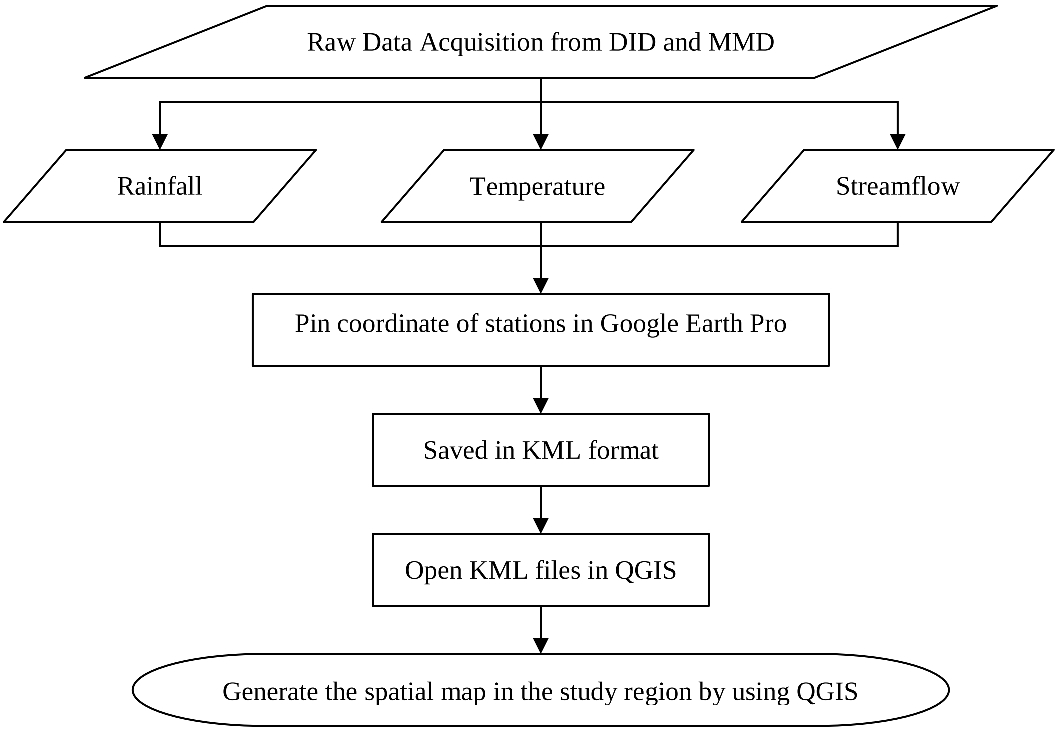

Figure 3.5: Procedure of Data Preparation Based on Study Region

3.3 Data Repairing

After data acquisition, there were some missing data in rainfall and temperature data. There are several factors to cause missing data such as station in maintenance, closure of station and apparatus spoiled. As a result of missing data among available data, the data repairing is an important step to conduct and it is repaired missing data to a valuable data for the development of drought indices, spatial and temporal analysis. There are various methods available to repair missing data such as normal ratio method and quadrant method. In this research, quadrant method was applied as data repairing for data and its equation is shown as following:

$$\overline{P} = \sum W_i P_i \tag{3.1}$$

where,

$$W_i = \frac{\left(\frac{1}{di^2}\right)}{\sum_{i=1}^{n}\left(\frac{1}{di^2}\right)} \tag{3.2}$$

where,

$\overline{P}$ = Mean precipitation

P_i = Precipitation of station *i*

W_i = Weightage of stations *i*

di = Distance between station with data and station without data

n = Number of stations considered

There are four quadrants in quadrant method and it was implemented to determine the data at particular station from the nearest possible neighbour station in each quadrant. The nearest possible neighbour station for each quadrant was chosen among three neighbour stations from each quadrant based on the availability of data. If there is none rainfall data provided in a quadrant, the formula of quadrant method was ignored the quadrant with no data consequently. The arrangement of quadrant is based on Figure 3.6.

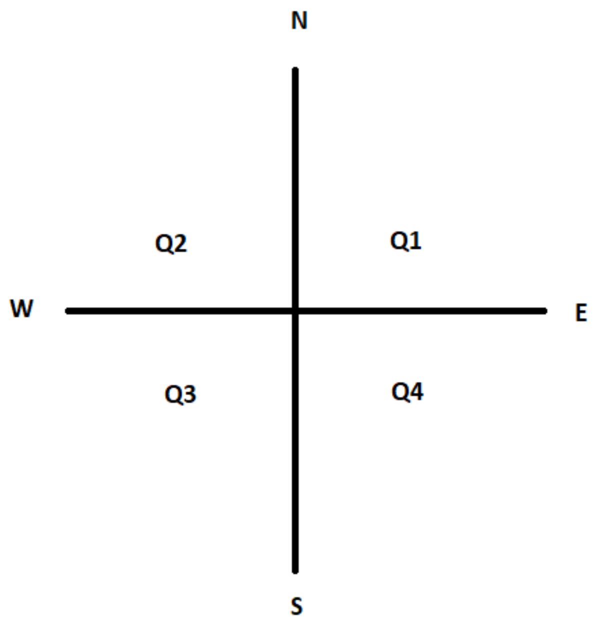

Figure 3.6: Arrangement of Quadrant in Quadrant Method

In data repairing spreadsheet, the formula of quadrant method is different due to the varies combination of missing data. There were 16 predicted outcomes from the combination of missing data, which “X” represents the data is missing and “0” represents the data is available. The description of combination of missing data in quadrant method is tabulated in Table 3.4. However, the missing data was not considered in quadrant method to prevent error in result such as divide by zero.

Table 3.4: Description of Combination of Missing Data in Quadrant Method

Combination of Missing Data	Description
0000	No missing data.
X000	Missing data in quadrant 1.
0X00	Missing data in quadrant 2.
00X0	Missing data in quadrant 3.
000X	Missing data in quadrant 4.
XX00	Missing data in quadrant 1 & 2.
X0X0	Missing data in quadrant 1 & 3.
00XX	Missing data in quadrant 3 & 4.
0X0X	Missing data in quadrant 2 & 4.
0XX0	Missing data in quadrant 2 & 3.
X00X	Missing data in quadrant 1 & 4.
XXX0	Available data in quadrant 4.
XX0X	Available data in quadrant 3.
X0XX	Available data in quadrant 2.
0XXX	Available data in quadrant 1.
XXXX	No available data.

3.4 Development of Drought Indices

In this section, the elements of development of drought indices were briefly explained and those equations were expressed in details. The application of drought index provides a better understanding in drought study by inspecting drought properties. The study of different types of droughts were required particular drought index such as SPI was applied when study meteorological drought. The most adequate drought index was selected among all drought indices by defining the sensitivity and accuracy of each drought index. Therefore, the most adequate drought index was utilized to determine drought properties in research region.

3.4.1 Standardized Precipitation Index (SPI)

SPI is one of the popular drought indices across the globe because of its simplicity to determine the occurrence of drought. In SPI, the actual rainfall represented as standard deviation from rainfall probability distribution function. Besides that, SPI is able to handle both spatial and temporal analysis, hence this offered SPI as a potential drought indicator around the world. In SPI, the drought conditions and its properties can be analysed by the probability distribution of long-term precipitation by implemented the gamma distribution function (Almedeij, 2014).

In *U* statistics, there are two parameters in gamma distribution is implemented in computation to identify the defective gamma cumulative probability of rainfall event which are shape and scale parameters (Naresh Kumar, et al., 2009). The transformation of gamma probabilities from imperfect gamma cumulative probability is applied and it is also included the occurrence of zero precipitation events. Then, the conversion of standardized normal distribution from gamma probabilities is accomplished by implement of equal-probability converting method. The purpose of conversion in rainfall data to SPI values are listed as following:

(i) To transform mean value of rainfall adjusted to zero.
(ii) To adjust standard deviation of the rainfall to 1.0.
(iii) To remodify the skewness of the existing data to zero.

Once the objectives are achieved, SPI can be represented as mean and standard deviation are equal to 0 and 1.0 respectively. The mean of the rainfall is denoted as Equation 3.3:

$$Mean = \overline{X} = \frac{\sum X}{N} \tag{3.3}$$

where,

$X =$ Precipitation in mm
$N =$ Number of rainfall stations

The standard deviation for the rainfall is computed as Equation 3.4:

$$s = \sqrt{\frac{\sum\left(X - \overline{X}\right)^2}{N}} \tag{3.4}$$

The skewness of the given rainfall is given as Equation 3.5:

$$Skew = \frac{N}{(N-1)(N-2)}\sum\left(\frac{X-\overline{X}}{s}\right)^3 \qquad (3.5)$$

The rainfall data is converted to log normal values (normalized numerical values) and the gamma distribution function for statistics U with shape and scale parameters are expressed in Equations 3.6, 3.7, 3.8 and 3.9 respectively:

$$\log mean = \overline{X}_{\ln} = \ln\left(\overline{X}\right) \qquad (3.6)$$

$$U = \overline{X}_{\ln} - \frac{\sum \ln(X)}{N} \qquad (3.7)$$

$$shape\ parameter = \beta = \frac{1+\sqrt{1+\frac{4U}{3}}}{4U} \qquad (3.8)$$

$$scale\ parameter = \alpha = \frac{\overline{X}}{\beta} \qquad (3.9)$$

After that, the resulting parameters above are applied to determine the cumulative probability of an observed rainfall event. The formula of the cumulative probability is donated by Equation 3.10:

$$G(X) = \frac{\int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}}\, dx}{\beta^{\alpha}\Gamma(\alpha)} \qquad (3.10)$$

As the gamma distribution function is undetermined for x = 0 and a rainfall distribution may contain zeros, the cumulative probability transforms to as given by Equation 3.11:

$$H(x) = q + (1-q)G(x) \qquad (3.11)$$

where,

$q =$ Probability of zero

The cumulative probability *H(x)* is converted to standard normal random variable *Z* with mean of zero and standard deviation of one, which the application of approximate conversion in SPI values by Abramowitz and Stegun as donated by Equation 3.12 or Equation 3.13:

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad for\ 0 < H(x) \leq 0.5 \qquad (3.12)$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad for\ 0.5 < H(x) \leq 1.0 \qquad (3.13)$$

where,

$$t = \sqrt{\ln\left(\frac{1}{H(x)^2}\right)} \quad for\ 0 < H(x) \leq 0.5 \qquad (3.14)$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \quad for\ 0 < H(x) \leq 1.0 \qquad (3.15)$$

where,

c_0	=	2.515517	c_1	=	0.802853	c_2	=	0.010328
d_1	=	1.432788	d_2	=	0.189269	d_3	=	0.001308

In this research, the various timescales in SPI was applied to study the occurrence, characteristics and pattern of drought in 35 years period which is from 1983 to 2017. Table 2.1 has briefly explained the usage of each timescale in SPI. The timescales in SPI were carried out by applying 1-, 3-, 6- and 12-month intervals respectively into two parameter gamma distribution functions. A long-term precipitation data was acquired to develop the probability distribution function and it was converted to log normal values or normalized numerical values with mean and standard deviation are equal to 0 and 1.0 respectively. SPI values were indicator for drought assessment by referring to its classification which was stated in Table 2.2.

3.4.2 Standardized Precipitation Evapotranspiration Index (SPEI)

Since temperature effect has a connection to drought, thence the application of SPEI is conducted to determine the occurrence of drought. SPEI is similar to SPI but SPEI has considered an additional variable than SPI, which is temperature data. The temperature data is applied in the water balance computation to identify PET. Recently, there are various computations to calculate PET such as Thornthwaite method, Pan Evaporation Model, Jensen-Haise Model, Penman Combination Equation and etc (Grace & Quick, 1988). In this research, Thornthwaite method was selected to compute and identify SPEI value. The sunshine hours were required in Thornthwaite method to execute the computation of PET. Sunshine hours are depends on the month and latitude and Table 3.5 is shown the average daily duration of maximum possible sunshine hours (N) regarding to various months and latitudes.

Table 3.5: Average Daily Duration of Maximum Possible Sunshine Hours (N) Regarding to Various Months and Latitudes (Doorenbos & Pruitt, 1977)

	Month											
Northern Lats (°)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Southern Lats (°)	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
50	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.0	11.1	12.0	12.9	13.6	14.0	13.9*	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

The computation of Thornthwaite method was represented as Equation 3.16.

$$PET = 16K\left(\frac{10T}{I}\right)^{m} \quad (3.16)$$

where,

$$i = \left(\frac{T}{5}\right)^{1.514} \quad (3.17)$$

$$K = \left(\frac{N}{12}\right)\left(\frac{NDM}{30}\right) \quad (3.18)$$

where,

PET =	Potential evapotranspiration
K =	Correction coefficient
T =	Monthly mean temperature, ^{o}C
I =	Sum of 12 months heat index
m =	Coefficient
=	$6.75 \times 10^{-7} I^{3} - 7.71 \times 10^{-5} I^{2} + 1.79 \times 10^{-2} I + 0.492$
i =	Monthly heat index
N =	Maximum sunshine hours
NDM =	Number of days of specific month

After obtained PET value, the water surplus or deficit of analysed month can be determined by compute subtraction of precipitation and PET, which the equation is displayed at below.

$$D_i = P_i - PET_i \quad (3.19)$$

where,

D_i =	Water surplus or deficit
P_i =	Precipitation of station i
PET_i =	Potential evapotranspiration of stations i

There are four statistical distributions available to model the D series which are Pearson III, Log-logistic, Lognormal and General Extreme Value. Among available statistical distributions, Log-logistic distribution is the most suitable to model the D series due to the curve for low value is decreased gradually and coherent probabilities were acquired in a relatively low value of D. Moreover, there is an absence of value below the origin parameter of the distribution.

The three parameters Log-logistic distributed variable in probability density function for D values are lesser than γ and ∞ and it is illustrated as Equation 3.20.

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2} \qquad (3.20)$$

where,

α = Scale parameter

β = Shape parameter

γ = Origin parameter

The parameters of Log-logistic distribution are acquired from L-moment procedure which Pearson III distribution is obtained as following:

$$\beta = \frac{2w_1 - w_0}{6w_1 - w_0 - 6w_2} \qquad (3.21)$$

$$\alpha = \frac{(w_0 - 2w_1)\beta}{\Gamma\,(1+1/\beta)\,\Gamma\,(1-1/\beta)} \qquad (3.22)$$

$$\gamma = w_0 - \alpha\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right) \qquad (3.23)$$

where, $\Gamma(\beta)$ is the gamma function of β.

The implementation of probability weighted moments (PWMs) with calculated parameters of log-logistic according to plotting-position approach has expressed the PWMs of order s as following:

$$w_s = \frac{1}{N}\sum_{i=1}^{N}(1-F_i)^s D_i \tag{3.24}$$

$$F_i = \frac{i-0.35}{N} \tag{3.25}$$

where,

N =	Numbers of data
F_i =	Frequency estimator
D_i =	Difference between Precipitation and PET for month i
i =	Range of observations in increasing order

The probability distribution function of D in the Log-logistic distribution is expressed as:

$$F(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{3.26}$$

Since the *F(x)* function is obtained, the standardized value of *F(x)* is easily determined by SPEI. In classical approximation, SPEI equation is expressed as Equations 3.27 and 3.28:

$$SPEI = W - \frac{C_0 + C_1W + C_2W^2}{1+d_1\,W + d_2\,W^2 + d_3\,W^3} \tag{3.27}$$

$$W = \sqrt{-2\ln(P)} \quad for\ P \le 0.5 \tag{3.28}$$

where,

C_0	=	2.515517	C_1	=	0.802853	C_2	=	0.010328
d_1	=	1.432788	d_2	=	0.189269	d_3	=	0.001308

The probability of exceeding a determined D value is computed as $P=1-F(x)$. However, P is substituted by $1-P$ and the sign of SPEI is reverse if P is more than 0.5. Based on Log-logistic distribution, the mean value of SPEI equals to 0 and standard deviation of SPEI equals 1. Since SPEI is a standardized value, thence the comparison of other SPEI with various time and space is available. If the value of SPEI is 0, the cumulative probability of D indicated 50% in Log-logistic distribution (Beguería, et al., 2018; Vicente-Serrano, et al., 2010).

In this research, the duration for drought study is from 1983 to 2017 which the drought study required 35 years rainfall data. Meanwhile, the timescales used in drought study is based on 1-, 3-, 6- and 12-month SPEI. The application of various timescales in SPEI are implemented to different field of study by its different concerning in term of duration.

3.4.3 Streamflow Drought Index (SDI)

Nalbantis and Tsakiris (2008) were exploited a simple and effective drought index to determine the properties of hydrological drought at various timescales which is SDI. The development of SDI is according to the SPI and the origin idea from Ben-Zvi work. The implement of various timescales in SDI provided a different drought study. For example, 3-month duration of SDI is employed to identify the water condition in soil which supply information in agriculture field. However, the study of impacts in climatic change in water resources are required to conduct a 12-months duration of SDI (Zeng, et al., 2015).

The hydrological year is beginning from 1st October and the ending of this hydrological year is on the next year 30th September (WATER UK, 2012). Generally, Malaysia is implementing this hydrological year to understanding in term of drought characteristics. Additionally, the timescales for analysing drought are setting with the starting of hydrological year to 31st December, 31st March, 30th June and 30th September respectively. Four overlapping timescales are established for every hydrological year which are October-December, October- March, October-June and October-September and these four overlapping timescales are applied to study the different types of drought occurred in the past or prediction for future. The reasons for 3-month intervals is selected in drought analysis are:

(i) To study drought as detail as possible.

(ii) Reduce carry-over effects between consecutive time intervals which are more significant for small timescales.

The assumptions in computation of the SDI are a time series of streamflow volumes, $Q_{i,j}$ on monthly basis is available where i is hydrological year while j donates the month within the hydrological year (j = 1 for October and j = 12 for September). From the time series, Equation 3.29 is applied to obtain the cumulative streamflow volume, $V_{i,k}$ for the i-th hydrological year and the k-th reference duration, where k =1 for October-December; k = 2 for October-March; k = 3 for October-June and k =4 for October-September.

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,} \qquad i = 1, 2, \ldots \qquad j = 1, 2, \ldots, 12 \qquad k = 1, 2, 3, 4 \qquad (3.29)$$

SDI is expressed by cumulative streamflow volume, $V_{i,k}$ and the duration k of the i-th hydrological year as following:

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V}_k}{s_k} \qquad i = 1, 2, \ldots, \qquad k = 1, 2, 3, 4 \qquad (3.30)$$

where,

$\overline{V}_k$ = Mean of cumulative streamflow volumes of reference duration k

s_k = Standard deviation of cumulative streamflow volumes of reference duration k

These values are estimated over a long duration. In this case, the truncation level is fixed to $\overline{V}_k$ even though other values can be used. Thus, SDI is considered equal to the standardized streamflow volume.

In this research, the two-parameter log-normal distribution is utilized because the normalization procedure is simple. Natural logarithms of streamflow data are considered in computation of suffices of the two-parameter log-normal distribution. The further calculation of the SDI is denoted as Equation 3.31:

$$SDI_{i,k} = \frac{y_{i,k} - \overline{y}_k}{s_{y,k}} \qquad i = 1, 2, \ldots, \qquad k = 1, 2, 3, 4 \tag{3.31}$$

where,

$$y_{i,k} = \ln\left(V_{i,k}\right) \qquad i = 1, 2, \ldots, \qquad k = 1, 2, 3, 4 \tag{3.32}$$

$\overline{y}_k$ = Mean of cumulative streamflow in natural algorithms

$s_{y,k}$ = Standard deviation of cumulative streamflow in natural algorithms

Positive SDI values represents wet conditions and vice versa for negative SDI values. The description of the states of hydrological drought corresponding to SDI values are displayed in Table 2.4.

3.5 Temporal Analysis

It is important to consider drought against timescale to be study, which is temporal analysis for drought. There are varies timescale in temporal analysis for drought and different timescales have their own study purpose. Temporal analysis was implemented with drought indices such as SPI, SPEI and SDI to identify the occurrence of drought and its properties within timescale provided. The timescales were implemented in this drought study are based on monthly, quarterly, semi-annual and annual. Moreover, there was a correlation between temporal analysis with drought properties such as drought duration, intensity and frequency.

In this research, trend analysis was executed in the basis of monthly for all drought indices. Hence, monthly drought study based on drought duration, intensity and frequency was applied by plotting a graph based on relevant data with specific month for a range of years. The plotted graph is compared with drought duration, intensity and frequency from month to month. Sometimes, the month against precipitation graph is plotted to investigate drought indirectly.

3.6 Spatial Analysis

Spatial analysis in drought study is related to topographic of the study region and this is significant to understanding an occurrence drought in spatial extent as well as temporal analysis. The properties of drought may vary due to different topographic in different regions. The different regions may offer a totally different topographic even in a short distance. Thereupon, spatial analysis was executed to have a comprehension of drought properties corresponding to spatial extent in research region.

3.6.1 Data Spatial Structure Analysis

The purpose of conducting data spatial structure analysis is to analyse the divergence of data while considered the influence of space. In this research, the prediction of extreme weather was based on modelling with available hydrological data. However, the network of hydrological stations was lacking and the hydrological data provided were insufficient to identify the diversity of drought properties in the basis of spatial distribution. The hydrological data can be estimated by applying spatial interpolation method. There are several spatial interpolation methods available. The most adequate method was selected according to the properties of the data (Keblouti, Ouerdachi, & Boutaghane, 2012).

Spatial interpolation method used the available data to estimate unknown data. In spatial interpolation, the application of GIS was utilized to determine the unknown data. The types of spatial interpolation were categorized according to its characteristics which are exact, inexact, global, local, deterministic and stochastic. Table 3.6 explained the global and local spatial interpolation method. In this research, a non-geo-statistical spatial interpolation method, Local Inverse Distance Weighted (IDW) was implemented to determine the relationship between spatial extent and drought.

Table 3.6: Classification of Spatial Interpolation Methods (Wackernagel, 1995)

Global		**Local**	
Deterministic	**Stochastic**	**Deterministic**	**Stochastic**
Trend Surface (inexact)*	Regression (inexact)	Thiessen (exact) Density estimation (inexact) IDW (exact) Splines (exact)	Kriging (exact)

3.6.2 Inverse Distance Weighting (IDW)

Inverse Distance Weighting (IDW) method is applied to determine specific values by considering the distance between two points. The number of sampled points is not limited so a greater number of sampled points provided a better result. Nonetheless, the distance between two sampled points is recommend to be as near as possible because the further the distance between two sampled points tend to reduce the accuracy of the result. The equation of IDW method is expressed in Equation 3.33.

$$\lambda_i = \frac{1/d_i^{\,p}}{\sum_{i=1}^{n} 1/d_i^{\,p}} \qquad (3.33)$$

where,

d_i = Distance between x_0 and x_1

p = Power parameter

n = Number of sampled points considered

3.6.3 Drought Characteristics

In order to identify a drought, drought characteristics were executed to identify a drought, which assessed by several parameters such as frequency, duration, intensity, severity and peak. However, some parameters were computed into average value over study period, which provided a perspective aspect by particular parameter such as mean drought duration, mean drought intensity, mean drought severity and mean drought peak. Hence, the equations to calculate drought characteristics are presented in Equations 3.34, 3.35, 3.36, 3.37, 3.38 and 3.39 respectively.

$$Drought\ frequency = \sum Drought\ index\ less\ than\ zero \qquad (3.34)$$

$$Mean\ drought\ duration = \frac{\sum Drought\ duration}{Drought\ frequency} \qquad (3.35)$$

$$Mean\ drought\ severity = \frac{\sum Drought\ index\ value\ less\ than\ zero}{\sum Drought\ duration} \qquad (3.36)$$

$$Drought\ intensity = \frac{\sum Drought\ index\ less\ than\ zero\ of\ a\ drought\ event}{Drought\ duration\ of\ a\ drought\ event} \qquad (3.37)$$

$$Mean\ drought\ intensity = \frac{\sum Drought\ intensity}{Drought\ frequency} \qquad (3.38)$$

$$Mean\ drought\ peak = \frac{\sum Drought\ peak\ of\ a\ drought\ event}{Drought\ frequency} \qquad (3.39)$$

3.7 Average Moving Range (AMR)

In this research, average moving range (AMR) is a measurement of sensitivity of drought indices over time. The greater AMR value of drought index at particular timescale indicated that drought index has greater sensitivity to conduct in order to monitoring the weather condition in central region of Peninsular Malaysia. The computation of AMR was calculated the mean of two consecutive moving range for all drought indices at different timescales. The computation of AMR is displayed in Equation 3.40.

$$Average\ moving\ range = \left. \frac{\sum Difference\ between\ two\ sucessive\ data\ points}{\sum number\ of\ moving\ range} \right._{i} \qquad (3.40)$$

3.8 Measurements for Accuracy of Drought Indices

In order to measure the accuracy of drought indices, the parameter used to measure the accuracy of drought indices are severity, frequency and duration. Thus, the severity of a drought can be defined with the historical drought events and comparing with the computed drought indices. In addition, the probability of detection (POD) is introduced to measure the accuracy of drought indices based on the frequency of drought. However, there are several measurements were measuring the accuracy of drought indices according to the duration of drought such as Pearson correlation, mean absolute percentage error (MAPE), root mean square error (RMSE), mean bias error (MBE) and early or delayed prediction.

3.8.1 Probability of Detection (POD)

Probability of detection (POD) was implemented to determine the accuracy of drought indices by drought frequency which means that it was based on the absence or presence of drought within the duration by comparing with the duration of historical drought events. The calculation of POD is illustrated in Equation 3.41.

$$POD = \frac{\sum number\ of\ \det ected\ event}{\sum number\ of\ recorded\ event} \tag{3.41}$$

3.8.2 Pearson Correlation Between Actual and Forecast Duration

Pearson correlation is a measurement of the degree of the linear relationship between two variables and it represented as *r*. Usually, the coefficient of Pearson correlation is between -1 to 1 and it can be classified by its value. The coefficient of Pearson correlation equals to ± 1 indicated that are perfect relationship between both variables. However, if the coefficient of Pearson correlation equals to 0 means no relationship between both variables. The classification of Pearson correlation is tabulated in Table 3.7. The formula for Pearson calculation is shown in Equation 3.42.

Table 3.7: Classification of Pearson Correlation

r	Description
≥ 0.70	Relatively strong positive relationship
0.40 ≤ r ≤ 0.69	Strong positive relationship
0.30 ≤ r ≤ 0.39	Intermediate positive relationship
0.20 ≤ r ≤ 0.29	Weak positive relationship
0.01 ≤ r ≤ 0.19	Relatively weak positive relationship
0	No relationship
-0.01 ≤ r ≤ -0.19	Relatively weak negative relationship
-0.20 ≤ r ≤ -0.29	Weak negative relationship
-0.30 ≤ r ≤ -0.39	Intermediate negative relationship
-0.40 ≤ r ≤ -0.69	Strong negative relationship
≤ -0.70	Relatively strong negative relationship

$$Pearson\,Correlation,\ r = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{\sqrt{\left(n\sum x^2 - \left(\sum x\right)^2\right) - \left(n\sum y^2 - \left(\sum y\right)^2\right)}} \tag{3.42}$$

where,

n = Number of samples

x = Forecast duration in months

y = Actual duration in months

3.8.3 Mean Absolute Percentage Error (MAPE)

The accuracy of drought indices can be assessed by mean absolute percentage error (MAPE), which detected the absolute error between actual and forecast duration in monthly term. MAPE is an average value of absolute error in percentage and this formula is illustrated in Equation 3.43.

$$MAPE = \frac{\frac{\sum Absolute\ error}{\sum Detected\ duration}}{\sum Number\ of\ detected\ event} x\, 100\% \qquad (3.43)$$

3.8.4 Root Mean Square Error (RMSE)

In order to visualize the difference of error among drought indices, the root mean square error (RMSE) was performed to compare the error difference between one drought index to other. RMSE will amplified the error if the error is significantly greater than other errors. Hence, the less accurate result of particular drought index will be removed from the selection as the most suitable drought index for monitoring the droughts in the central region of Peninsular Malaysia. The computation of RMSE is shown as the following equation.

$$RMSE = \sqrt{\frac{\sum x^2}{\sum Number\ of\ detected\ event}} \qquad (3.44)$$

where,

x = Forecast duration in months

3.8.5 Mean Bias Error (MBE)

Mean bias error (MBE) is a measurement about the over or under prediction. In this research, MBE was implemented to determine the accuracy of drought indices by checking the prediction, which is in term of month. A positive MBE value represents as over prediction; while a negative MBE value represents as under prediction. The calculation of MBE is illustrated in Equation 3.45.

$$MBE = \frac{\sum(Forecast\ duration - actual\ duration)}{\sum Number\ of\ detected\ event} \qquad (3.45)$$

3.8.6 Mean Early or Delayed Prediction

The mean early or delayed prediction is an average value of the difference of beginning of droughts between actual and forecast in term of months. A positive value of mean early or delayed prediction represents as delayed prediction; while a negative value of mean early or delayed prediction represented as early prediction. The calculation of mean early or delayed prediction is displayed as Equation 3.46.

$$Mean\ early\ or\ delayed\ prediction = \frac{\sum Early\ or\ delayed\ predicted\ duration}{\sum Number\ of\ detected\ event} \qquad (3.46)$$

3.9 Summary

In this chapter, the computations of each drought indices and the connection of between drought indices and spatial and temporal analysis are explained. The procedure to conduct the computations of each drought indices will be done by Microsoft Excel. Therefore, a comparison can be made in between computed drought indices and historical drought events in term of severity and accuracy from obtained result. Notwithstanding, the calculation of AMR conducts to identify the sensitivity of drought indices with respect of time variable. Among drought indices that applied in this research, the outcomes of each drought indices were compared to have a better understanding into the characteristics of drought indices. The accuracy of a drought index is one of the important essential elements for monitoring droughts in the central region of Peninsular Malaysia, thence certain measurements for accuracy of drought indices required to execute in order to evaluate the workability of drought indices. Moreover, the spatial and temporal analysis provided spatial extent and timescales of drought indices in drought study. Therefore, the achievement by spatial and temporal analysis with drought indices are discussed in the following chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the spatial and temporal analysis of drought indices in central region were discussed in term of the distribution of heat map and graphical method. In order to understand the details of drought indices computed, the average moving range (AMR) of each drought index was executed and the results of AMR were used to compare among drought indices. The results of computed drought indices were also used to compare with historical drought events to identify the accuracy of drought indices. Furthermore, there were several measurements used in evaluation of the accuracy of drought indices based on the drought frequency and drought duration. Lastly, the relationship between historical drought events and Oceanic Nino Index (ONI) and Dipole Mode Index (DMI) was also determined and discussed in this chapter.

4.2 Spatial Analysis of Drought in Central Region

In order to comprehend the states of drought appear in a region, a spatial analysis is required to comply. Drought characteristics, namely drought frequency, mean drought duration, mean drought severity, mean drought intensity and mean drought peak were estimated to identify the circumstances of central region. Then, analyses were done based on these five elements to study the spatial variation of droughts over central region.

4.2.1 Spatial Variation of Drought Frequency

The rate for a drought to occur or return is known as drought frequency. Spatial variation of drought frequency was investigated for different drought indices at timescales of 1-, 3-, 6- and 12-months. Figures 4.1, 4.2 and 4.3 illustrate the spatial variation of drought frequency for SPI, SPEI and SDI at different timescales, respectively. The red colour scheme in the spatial map of drought frequency represent high frequency; blue colour scheme represents low frequency drought; while yellow colour scheme represents intermediate frequency of drought.

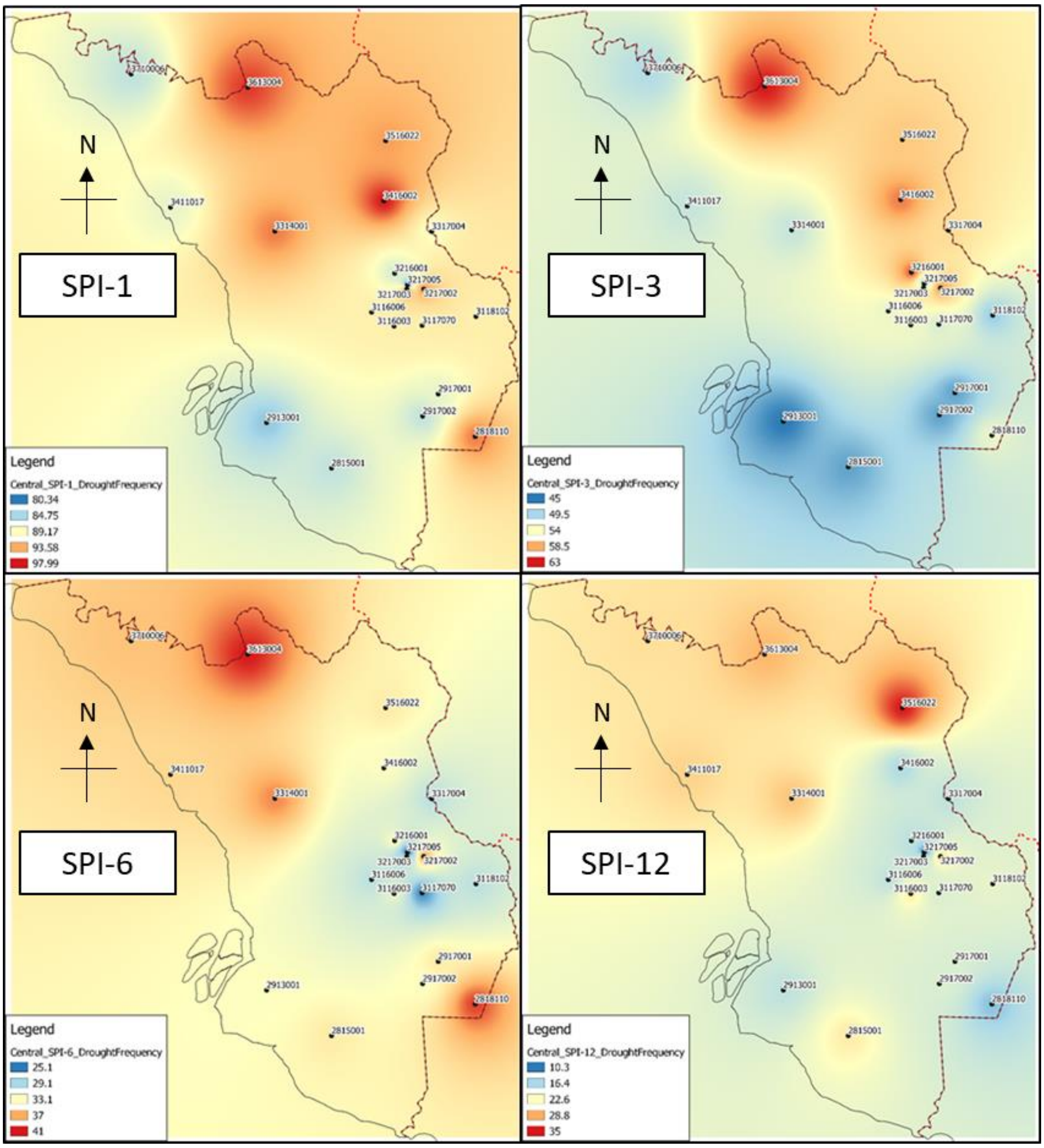

Figure 4.1: Spatial Map of Drought Frequency for SPI-1, -3, -6, -12

The spatial map of drought frequency for SPI-1 shows that high drought frequency occurred at the north and northeast of central region, while low drought frequency occurred in the south. However, the drought frequency of SPI-3 demonstrated the north of central region has high drought frequency and the south of central region has relatively low drought frequency. The most frequent drought for SPI-6 is located at north of central region followed by the southeast of central region. As for SPI-12, the drought events happened most at northeast of central region.

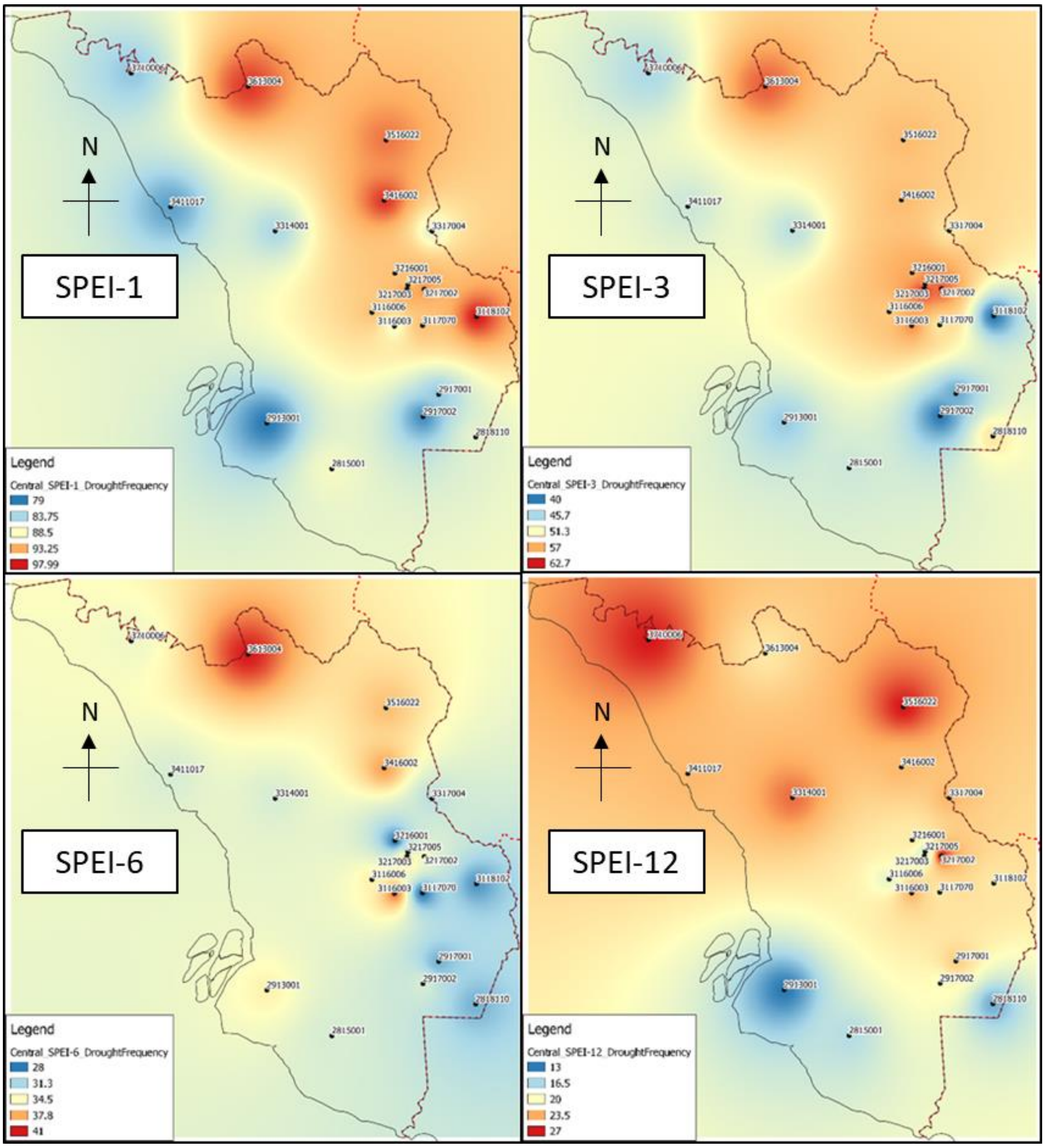

Figure 4.2: Spatial Map of Drought Frequency for SPEI-1, -3, -6, -12

Basically, the drought frequency for SPEI-1 and -3 have a similar spatial variation, except the southwest of central region. SPEI-1 has greater overall drought frequency than SPEI-3. The spatial variation of drought frequency for SPEI-6 has an average distribution in central region except for the north, which has the highest drought frequency. For SPEI-12, the drought frequency that is higher than the average value, was observed from the centre to the north of central region, while the drought frequency that is lower than the average value, was observed from the centre to the south of central region. The highest drought frequency appeared at the northwest of central region.

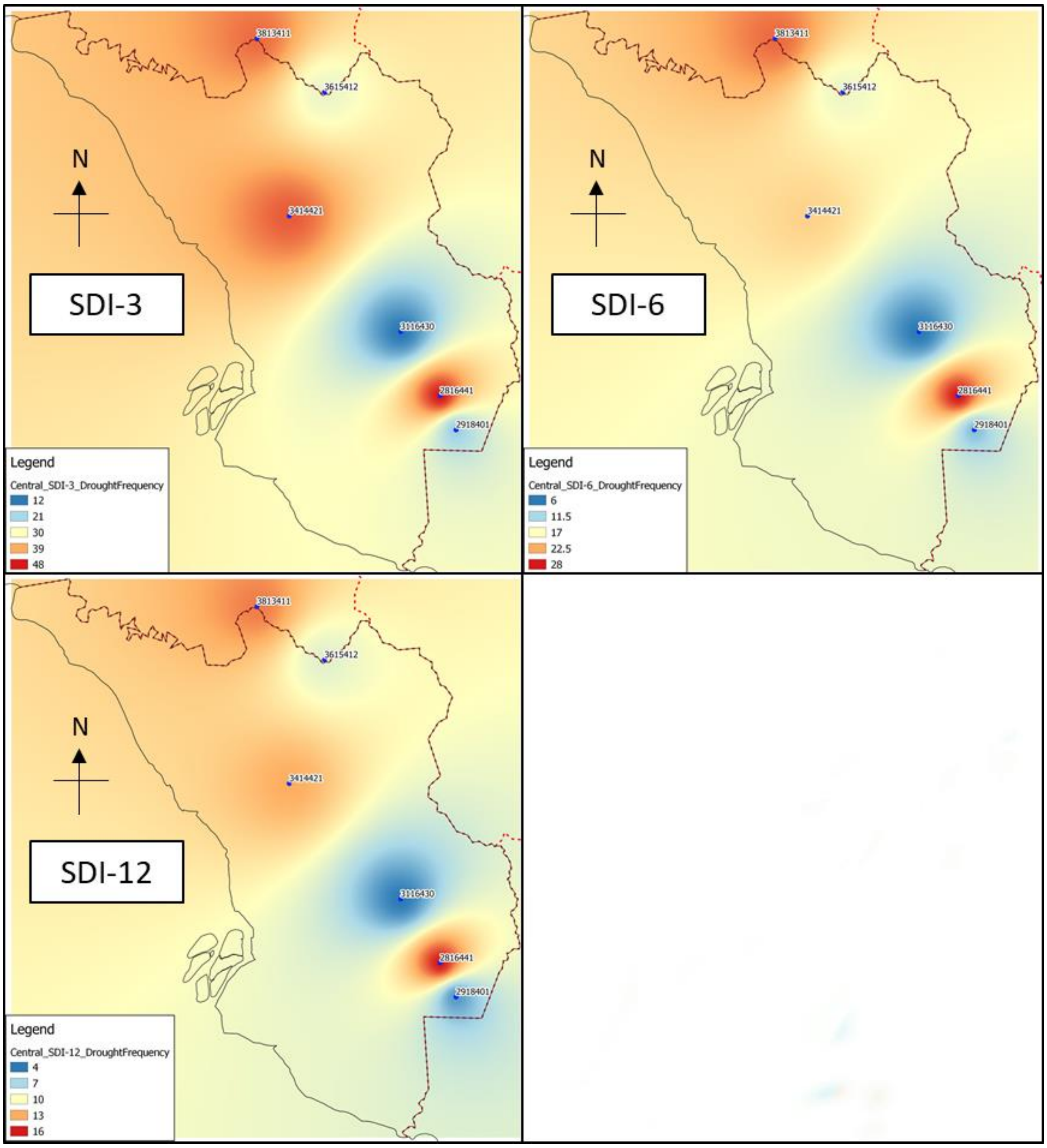

Figure 4.3: Spatial Map of Drought Frequency for SDI-3, -6, -12

The spatial map of drought frequency for SDI at different timescales have similar pattern but different in frequency. The southeast of central region showed the highest drought frequency, while the north of central region showed decrement in drought frequency, when the SDI timescales increased as shown in Figure 4.3.

Drought indices with 1-month timescale indicates north and northeast of central region high frequency of drought returned or happened for both SPI and SPEI. However, SPEI-1 also showed a drought more likely to return or happen in east of central region. Furthermore, the all drought indices with 3-months timescale illustrate the north of central region has relatively high chance of drought to return or happen except SPI-3 and SPEI-3 extend to the east of central region of Peninsular Malaysia. In SDI-3, the highest drought frequency locates at the southwest of central region. Besides that, SPI-12 and SPEI-12 display a high drought frequency at the northwest of central region extend to the northeast of central region; and the high drought frequency only located at north of central region for SDI-12.

4.2.2 Spatial Variation of Mean Drought Duration

In order to understand the distributions of spatial variation of mean drought duration of drought indices, the spatial map of mean drought duration of drought indices presented in this subtopic to visualize the pattern of mean drought duration in central region. The results of spatial variation of mean drought duration in central region illustrate as Figures 4.4, 4.5 and 4.6. The red colour scheme means that area has higher mean drought duration; the blue colour scheme represents has low mean drought duration; while yellow colour scheme indicates that region has intermediate mean drought duration.

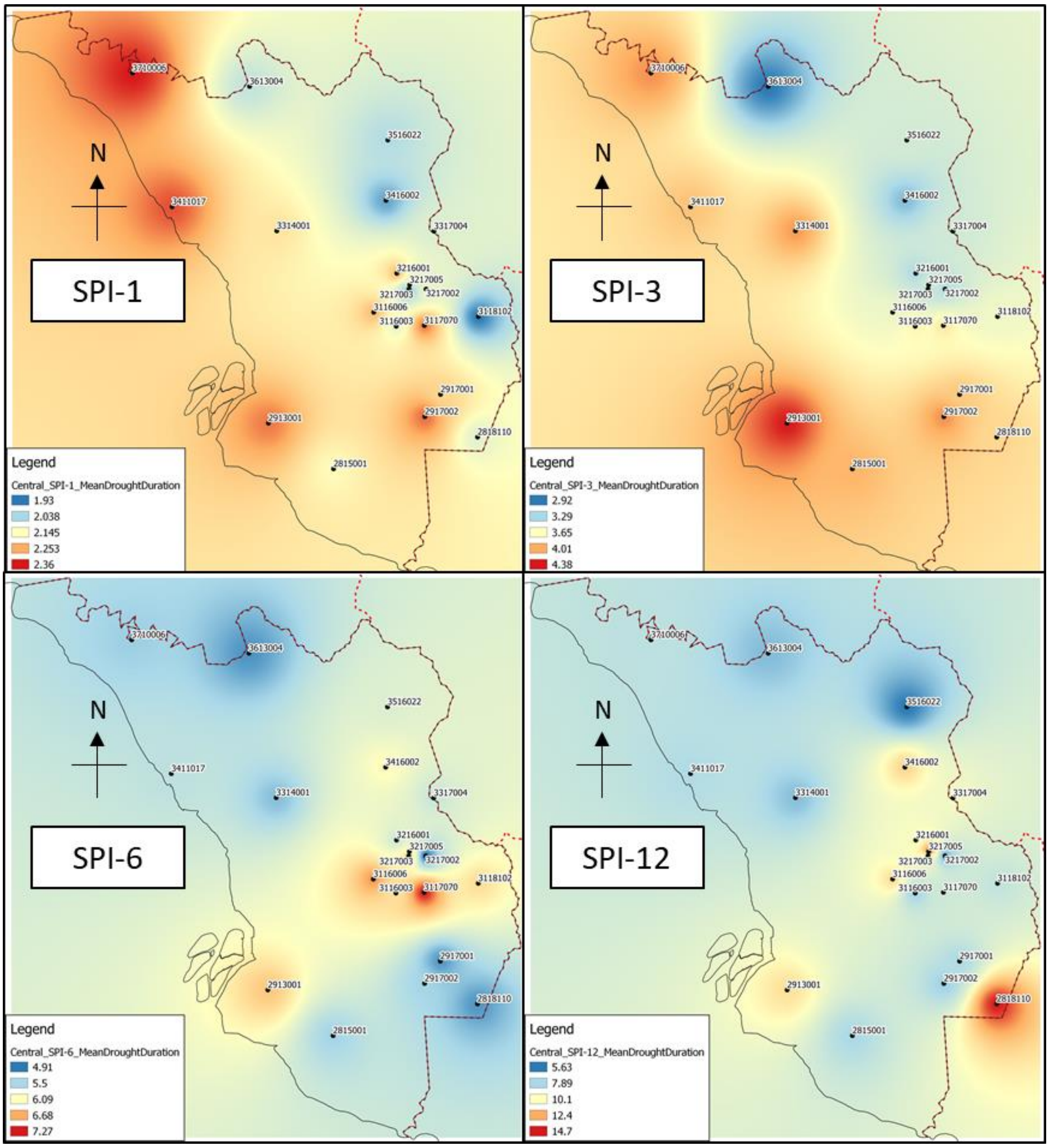

Figure 4.4: Spatial Map of Mean Drought Duration for SPI-1, -3, -6, -12

SPI-1 and -3 have similar pattern for spatial map that related with mean drought duration except the centre of central region. The centre of central region of SPI-1 has greater mean drought duration contrasted with SPI-3. In addition, the highest mean drought duration for SPI-1 located at the northwest of central region but the highest mean drought duration for SPI-3 located at the southwest of central region. For SPI-6, the mean drought duration more than average was discovered at the centre and the southwest of central region. However, the greatest mean drought duration of SPI-12 was located at the southeast of central region and there was some mean drought duration greater than average value which located at the centre and southwest of central region.

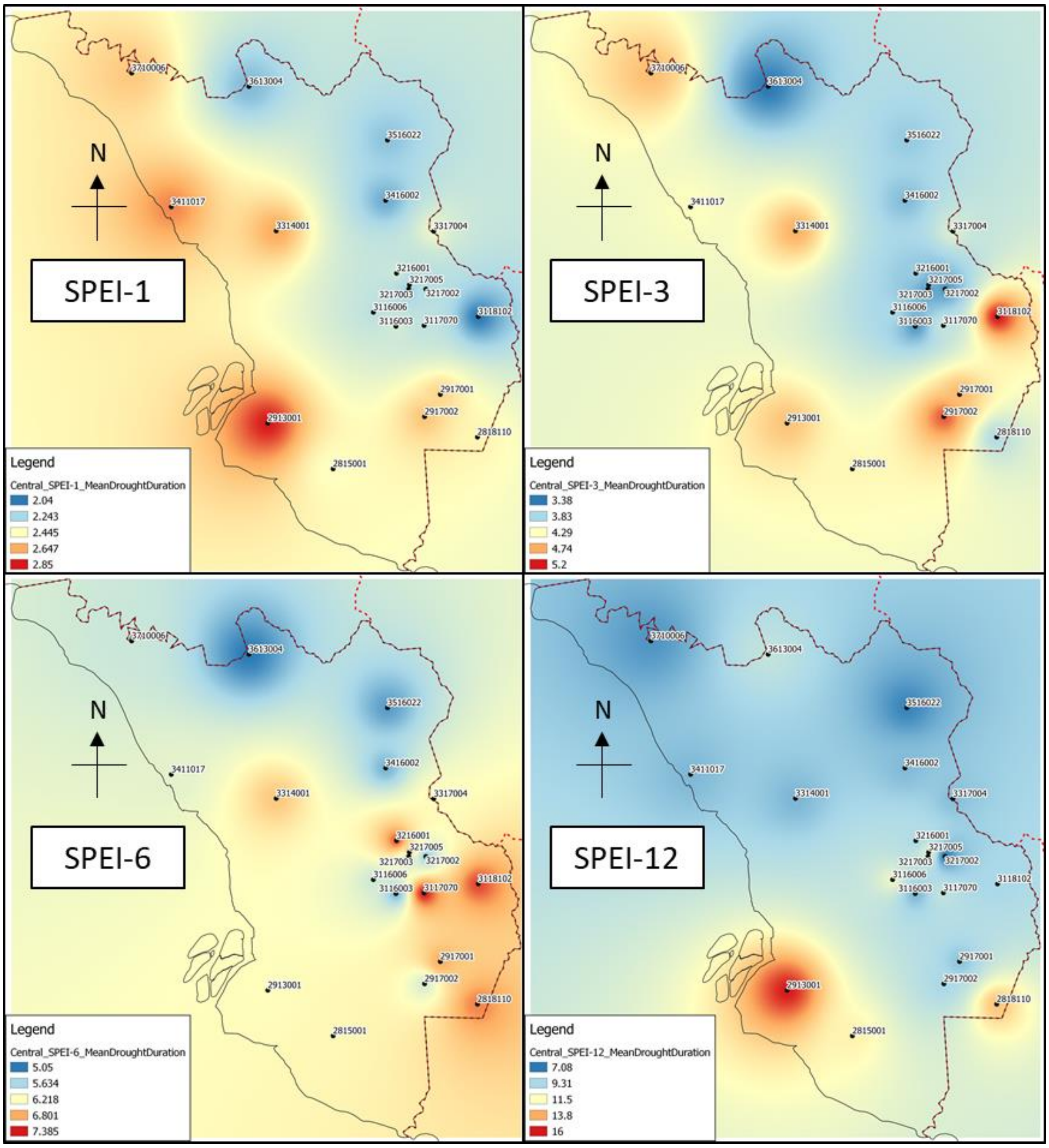

Figure 4.5: Spatial Map of Mean Drought Duration for SPEI-1, -3, -6, -12

In Figure 4.5, the mean drought duration that are below average value throughout all SPEI which discovered at the centre, north and northeast of central region except the centre of central region in SPEI-6 which it was a mixed of various mean drought duration. SPEI-1 and -12 has the highest mean drought duration at the southwest of central region but there is a difference in the northwest of central region. At the northwest of central region, SPEI-1 has greater average value of mean drought duration but a lower average value of mean drought duration of SPEI-12 was discovered at the same location. The highest mean drought duration of SPEI-3 and -6 were spotted at the east of central region.

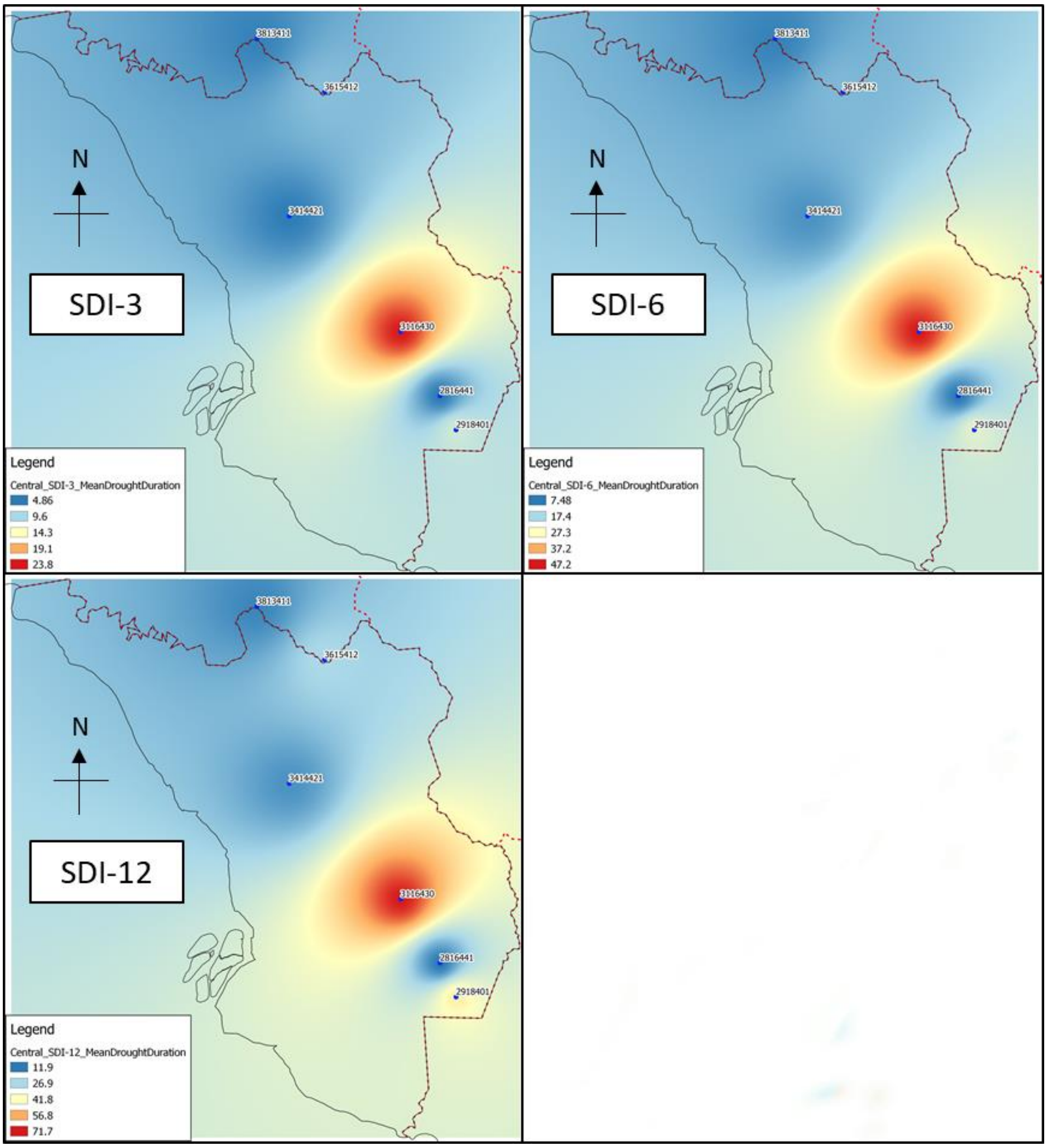

Figure 4.6: Spatial Map of Mean Drought Duration for SDI-3, -6, -12

The mean drought duration for all SDI have similar distribution pattern except SDI-12 has lower mean drought duration in north of central region when comparing to different timescales of SDI. The greatest mean drought duration was appeared at the centre of central region for all SDI.

Both SPI-1 and SPEI-1 indicate as blue colour scheme from the northwest of central region extended along the west side to the southeast of central region. For drought indices with 3-months timescale, the pattern of spatial map is similar to SPI-1 and SPEI-1 but SDI-3 has different pattern of spatial map of mean drought duration.

4.2.3 Spatial Variation of Mean Drought Severity

The spatial variation mean drought severity can be defined as the average of severity of a drought to appear at particular location. This provides a better understanding to study a region about the severity of a drought with a timeframe included. The red colour scheme means it has higher than average of mean drought severity value; the blue colour scheme represents a lower than average of mean drought severity value while yellow colour scheme indicates that region has intermediate mean drought severity. In Figures 4.7, 4.8 and 4.9 illustrate the spatial map of mean drought severity of SPI, SPEI and SDI respectively.

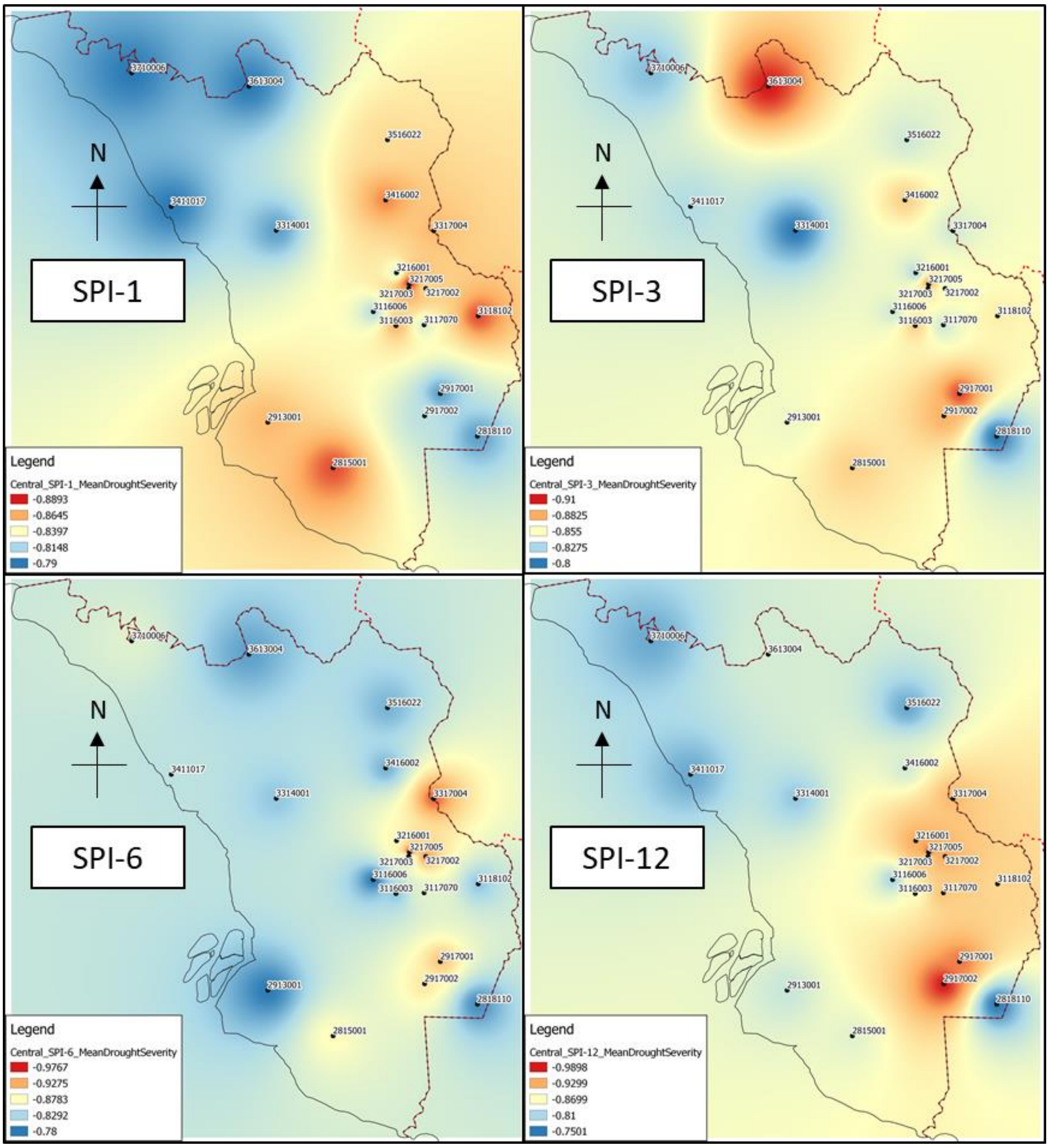

Figure 4.7: Spatial Map of Mean Drought Severities for SPI-1, -3, -6, -12

In Figure 4.7, the spatial map of mean drought severity for SPI indicated that east and southwest of central region have greater than average of mean drought severity. In SPI-3, the place that has higher mean drought severity were spotted at the north and southeast of central region. For SPI-6, the mean drought severity that observed yellow colour scheme was found at the east and some were located at the south of central region. At the east of central region, the mean drought severity for SPI-12 shown more than average value and the highest mean drought severity was spotted near to the south of central region.

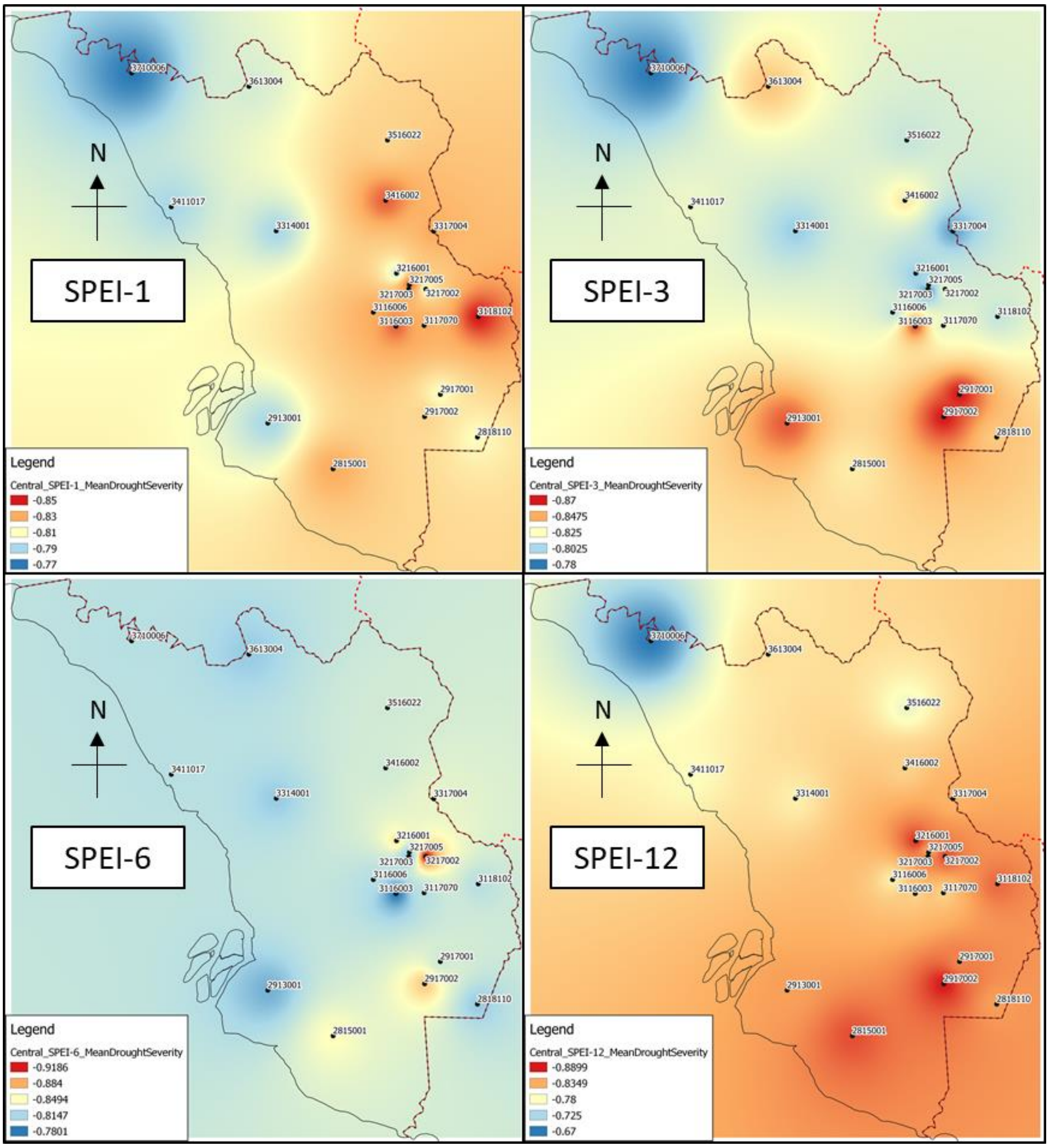

Figure 4.8: Spatial Map of Mean Drought Severities for SPEI-1, -3, -6, -12

In Figure 4.8, the spatial distribution about mean drought severity for SPEI-1 demonstrated the north and south extended to east of central region has higher value of mean drought severity especially at the east of central region has highest value. For SPEI-3, the south of central region shown a significant of higher mean drought severity especially at the southeast and north of central region has marked as red colour scheme. However, the spatial map of mean drought severity for SPEI-6 has minor area that were slightly higher value than mean drought severity which spotted at centre and south of central region. In SPEI-12, the spatial distribution of mean drought severity mapping shown that the northwest of central region has lowest mean drought severity and the north and west of the central region has an intermediate value of mean drought severity and the east and south of central region has relatively greater value of mean drought severity.

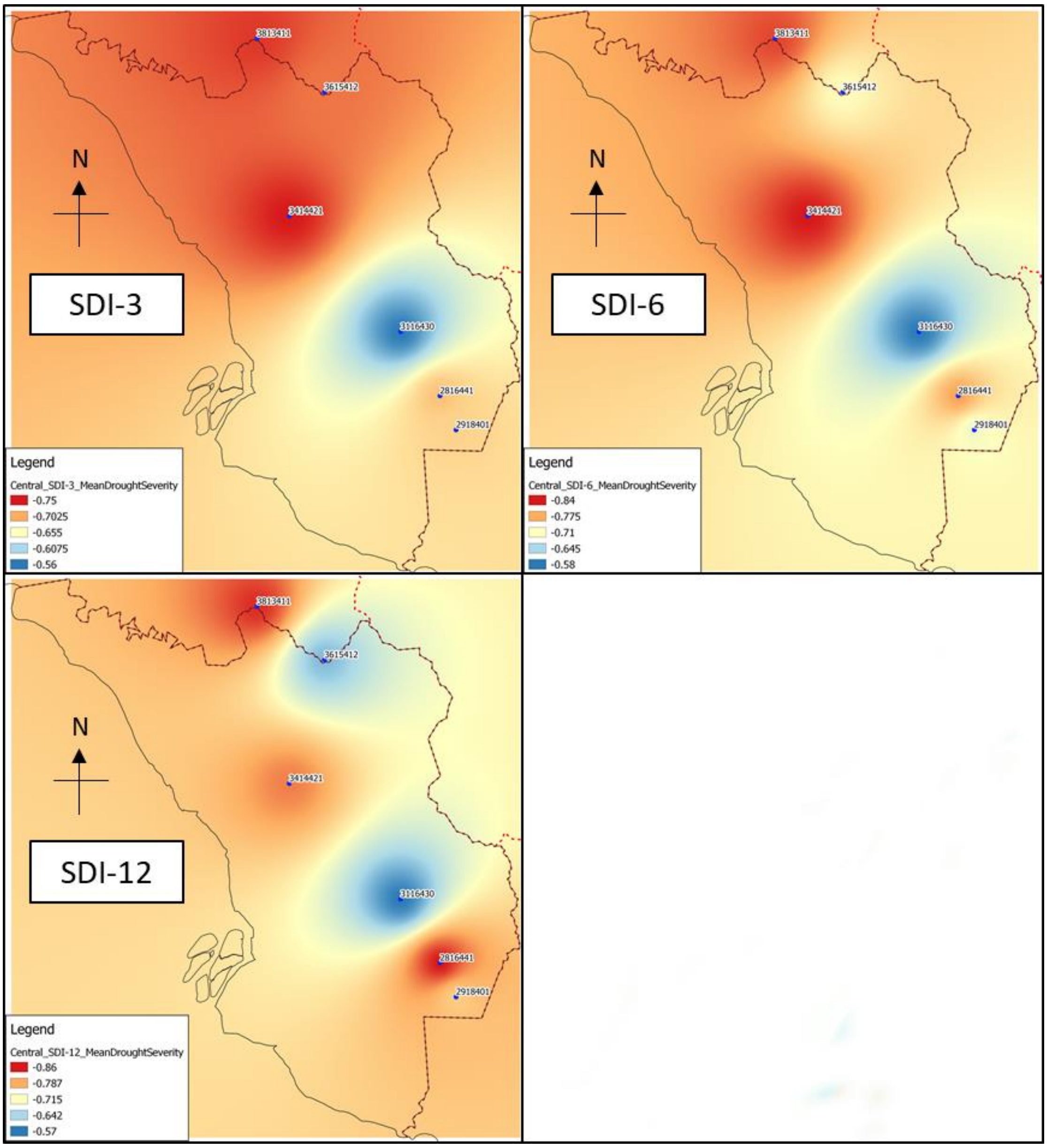

Figure 4.9: Spatial Map of Mean Drought Severities for SDI-3, -6, -12

From Figure 4.9, the spatial distribution of mean drought severity for all SDI were similar except SDI-12 which the northeast of central region has a below average value of mean drought severity. The greatest mean drought severity of SDI-3 and -6 were found near to the centre of central region. However, the greatest mean drought severity for SDI-12 was spotted at the north and southeast of central region.

Furthermore, the SPI-1 and SPEI-1 has similar spatial map pattern in term of mean drought severity which the half of the right-hand side map illustrates a greater mean drought severity. In addition, both SPI-3 and SPEI-3 represented the north and south of central region has relatively high value of mean drought severity except SDI-3 showed the centre of central region has lowest value of mean drought severity and the rest of the map represented in a value that from yellow colour scheme to red colour scheme. Both SPI-6 and SPEI-6 are similar in distribution of spatial map of mean drought severity as the most of area in central region marked as blue colour scheme.

4.2.4 Spatial Variation of Mean Drought Intensity

The spatial variation of mean drought intensity is a measurement of drought characteristics to understand the condition of a drought severity over duration in average. The results of spatial distribution map concerned about the mean drought intensity were shown in Figures 4.10, 4.11 and 4.12. In those figures, the red colour scheme defined as greater value than average in term of mean drought intensity; the blue colour scheme represented a lower value than average in term of mean drought intensity; while yellow colour scheme indicates that region has intermediate mean drought intensity.

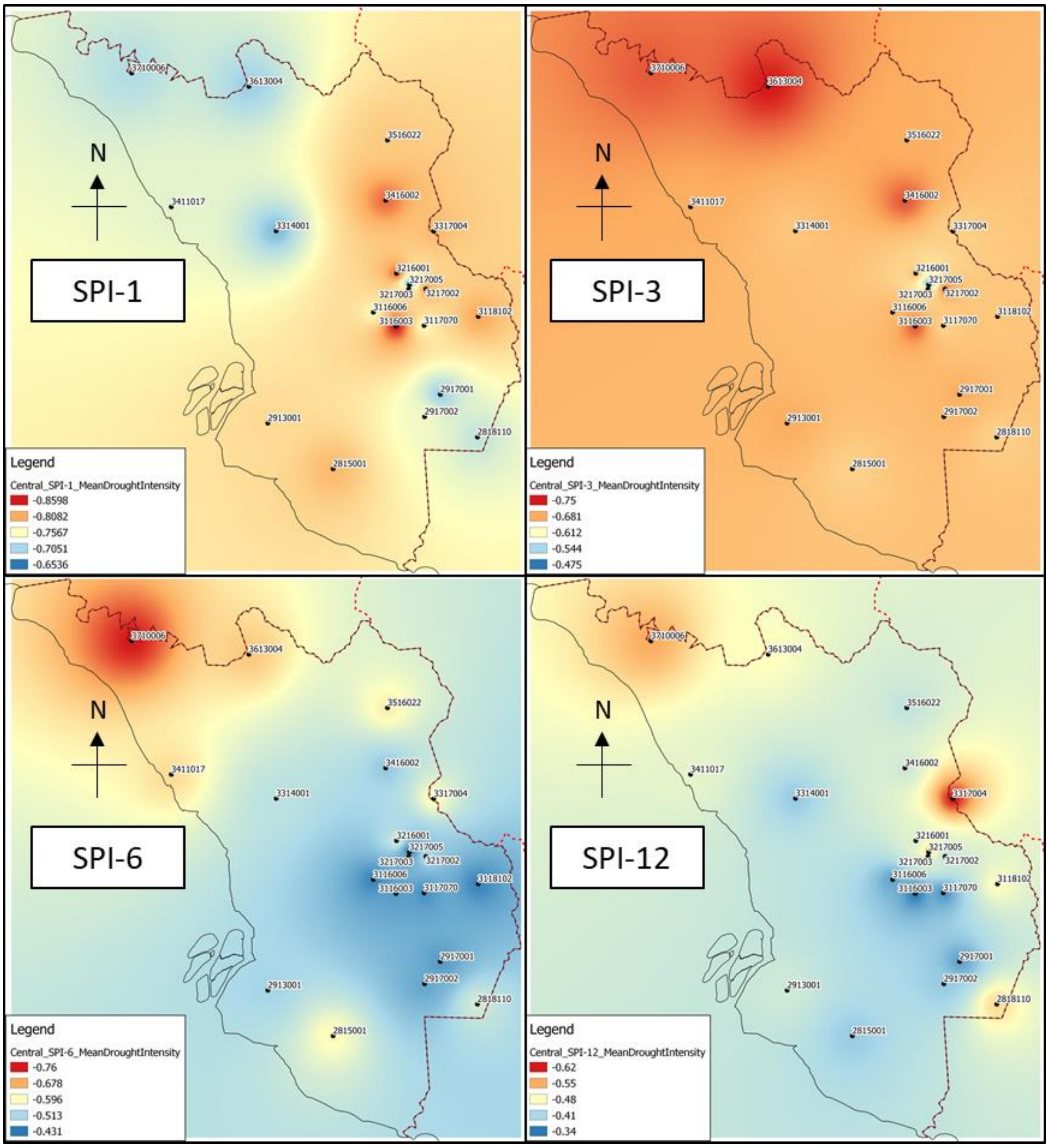

Figure 4.10: Spatial Map of Mean Drought Intensities for SPI-1, -3, -6, -12

In Figure 4.10, there were certain places have slightly higher value of mean drought intensity for SPI-1 which located at the centre, east and southwest of the central region. For SPI-3, most of the study region has slightly greater value of mean drought intensity except the north of central region has a significant greater value of mean drought intensity and the centre of central region indicated as blue colour scheme. The highest mean drought intensity was found at the northwest of central region for SPI-6. The red colour scheme marked in the spatial map of mean drought intensity for SPI-12 is spotted at the northwest and east of central region and the east of central region shown as highest value of mean drought intensity in the central region.

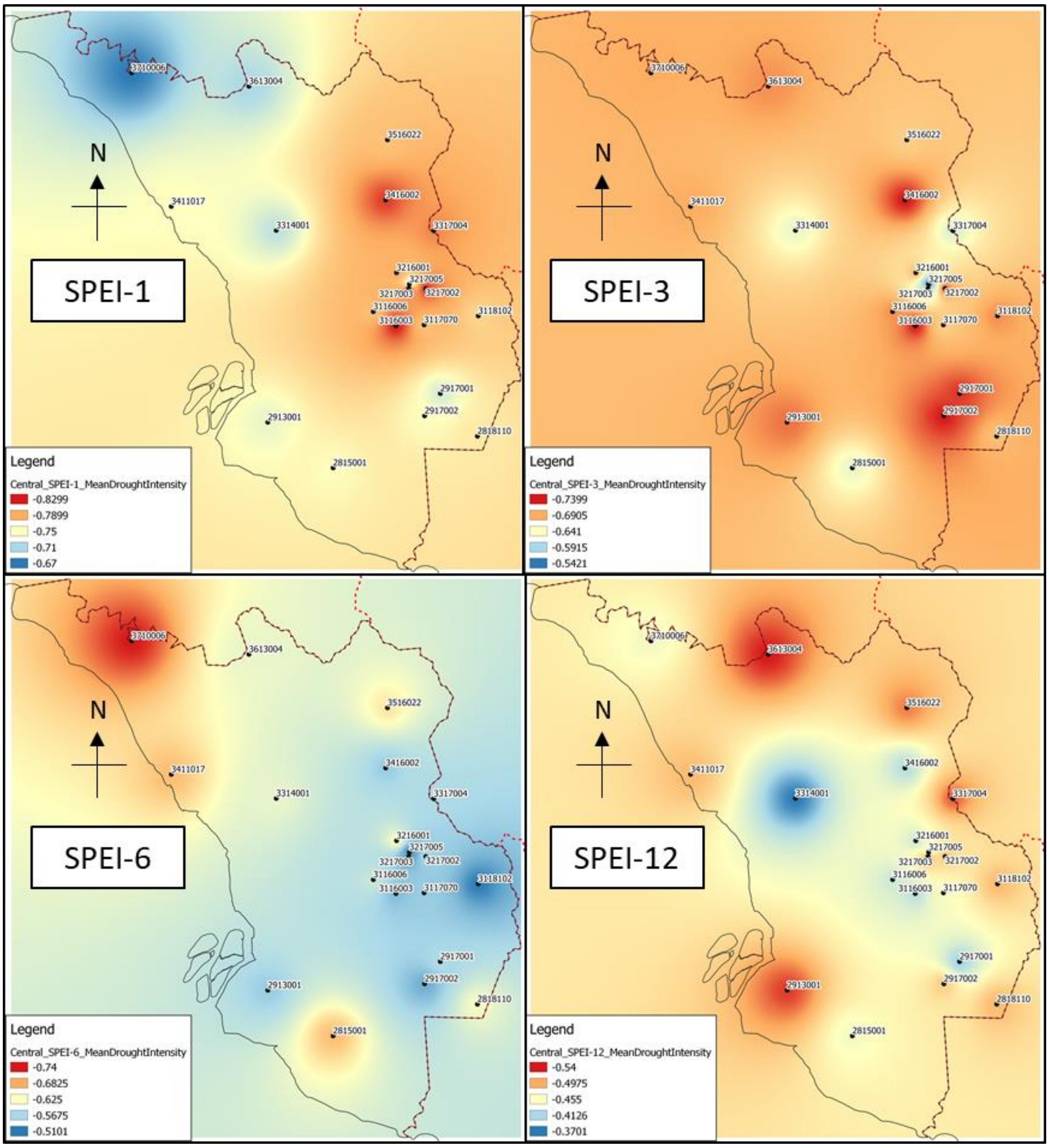

Figure 4.11: Spatial Map of Mean Drought Intensities for SPEI-1, -3, -6, -12

Figure 4.11 illustrated that the northwest of central region has lowest mean drought intensity value in study region for SPEI-1. However, the mean drought intensity for SPEI-1 at the west of central region extended to south of central region indicated as red colour scheme. The greatest mean drought intensity for SPEI-1 has found at the area near to the northeast of central region. In SPEI-3, the study region mostly filled with red colour scheme which represented most of the central region has a slightly greater value of mean drought intensity but there were few places covered in blue colour and it represented a lower value of mean drought intensity. The east and southeast of central region indicated the relatively great value of mean drought intensity in the study area. For SPEI-6, the northwest of central region indicated the highest mean drought intensity compered to entire study area. The north and southwest of central region has relatively high mean drought intensity value and yellow colour scheme covered along the east of central region which both situations were shown in the spatial map of mean drought intensity for SPEI-12.

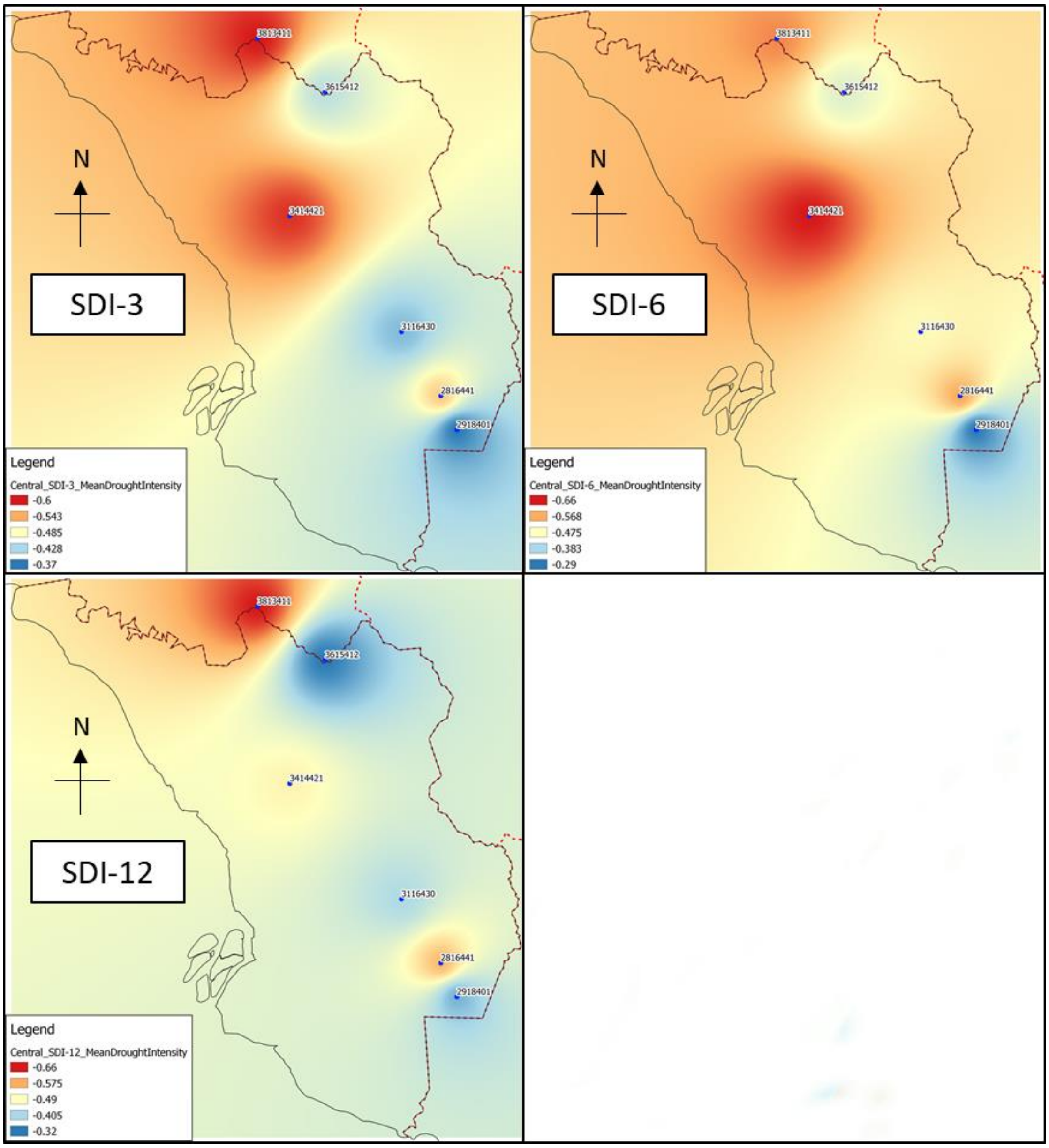

Figure 4.12: Spatial Map of Mean Drought Intensities for SDI-3, -6, -12

Figure 4.12, the spatial map for SDI-3 illustrated the greater mean drought intensity at the centre and north of central region and minor part happened at the southeast of central region. For SDI-6, the centre of central region has highest mean drought intensity when looking into entire study area but the rest of the study area has a slightly greater of mean drought intensity value except the southeast of central region shown a lower value of mean drought intensity. The spatial distribution for SDI-12 has demonstrated the north of central region observed the greatest value of mean drought intensity and the lowest value of mean drought intensity was located next to it. The centre and southeast of central region have a minor area covered with red colour scheme for SDI-12 which indicated in Figure 4.12.

From the spatial map of mean drought intensity, there is similarity between SPI and SPEI at 1-month, 3-months and 6-months timescale. At 1-month timescale, both SPI and SPEI have indicated a greater value of mean drought intensity in the east of central region. Moreover, the most of the central region obtained red colour scheme for SPI and SPEI at 3-months timescale. The mean drought intensity for SPI and SPEI at 6-months timescale displayed the northwest of central region has significant great value compared to the rest of the central region.

4.2.5 Spatial Variation of Mean Drought Peak

In order to understand the characteristics of a drought in study region, the computation of spatial variation of mean drought peak can be one of the parameters. The mean drought peak is an average value of the peak of drought in specify location and timeframe. Figures 4.13, 4.14 and 4.15 shown the results of the spatial variation map of mean drought peak in central region respect to SPI, SPEI and SDI at different timescales. There is a colour scheme in those figures, red colour scheme represented that study area has higher mean drought peak value; blue colour scheme means that study area has lower mean drought peak value; while yellow colour scheme indicates that region has intermediate mean drought peak.

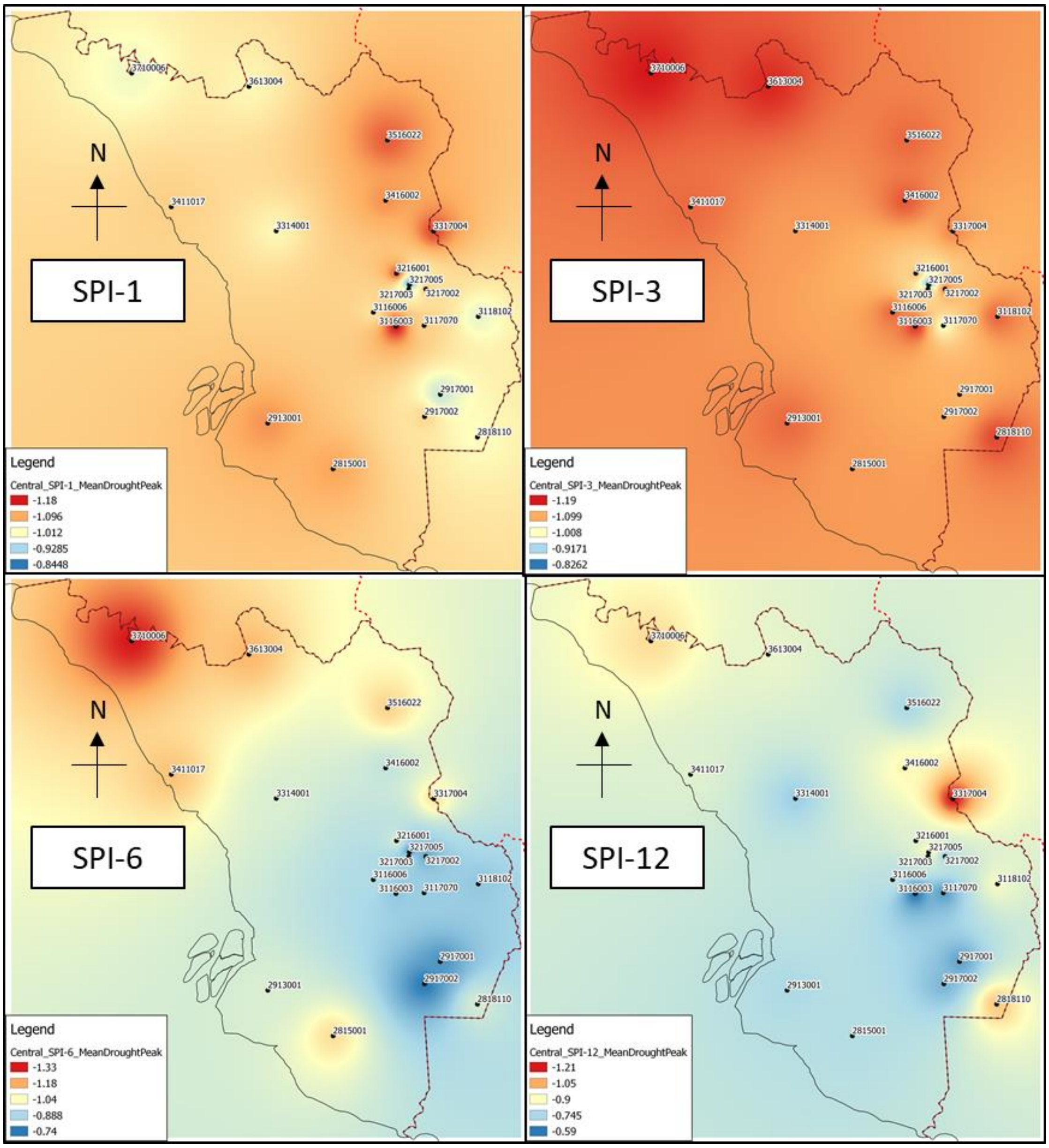

Figure 4.13: Spatial Map of Mean Drought Peak for SPI-1, -3, -6, -12

In Figure 4.13, the spatial distribution of mean drought peak for SPI-1 was covered by red colour scheme in most of the study area. The significant mean drought peak was represented in the northeast and centre of central region. For SPI-3, the mean drought peak of central region is higher than SPI-1 especially at the north and northwest of central region. The highest mean drought peak in spatial map of mean drought peak for SPI-6 was located at northwest of central region and the lowest mean drought peak at southeast of central region. In the spatial map of mean drought peak for SPI-12, the greatest mean drought peak in central region is placed at the east of central region but there is some area of central region have low mean drought peak especially those at the south of central region have a relatively low value of mean drought peak.

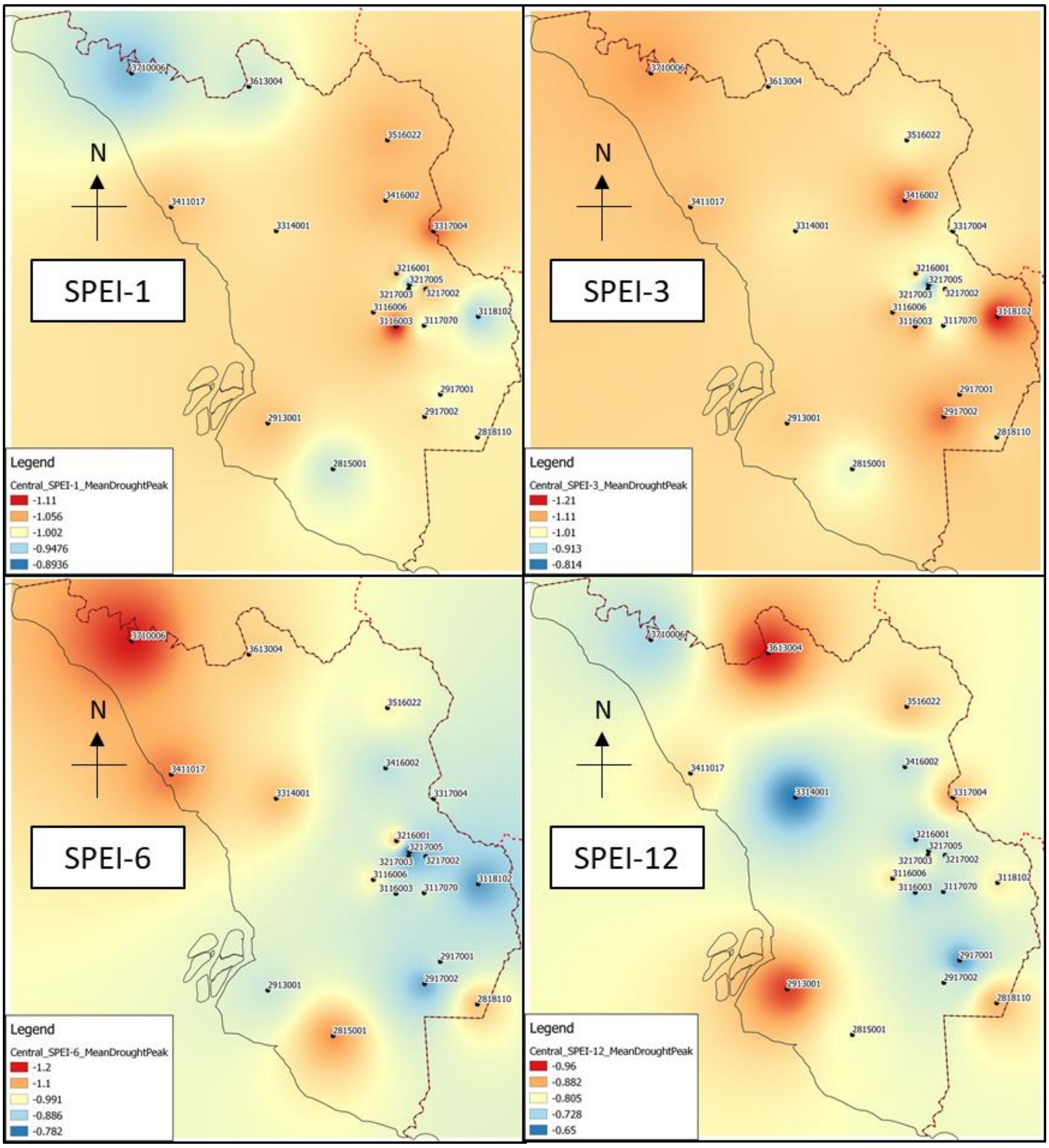

Figure 4.14: Spatial Map of Mean Drought Peak for SPEI-1, -3, -6, -12

The spatial distribution map of mean drought peak for SPEI-1 illustrated the significant great value of mean drought peak at the centre and east of central region. For SPEI-3, the relatively high value in mean drought peak was obtained and it was located along the east of central region and the highest value of mean drought peak was obtained which located at the east of central region. The highest value of mean drought peak for SPEI-6 was illustrated at the northwest of central region. There is some area of central region represented has a above intermediate value of mean drought peak which placed at the north, west, south and southeast of central region. However, the east and centre of central region indicated as blue colour scheme. The spatial distribution map of mean drought peak for SPEI-12 demonstrated significant high value of mean drought peak at the north and southwest of central region and the northeast and southeast of central region were also marked as red colour scheme. The centre of central region represented as a relatively low value of mean drought peak when comparing with other part of central region.

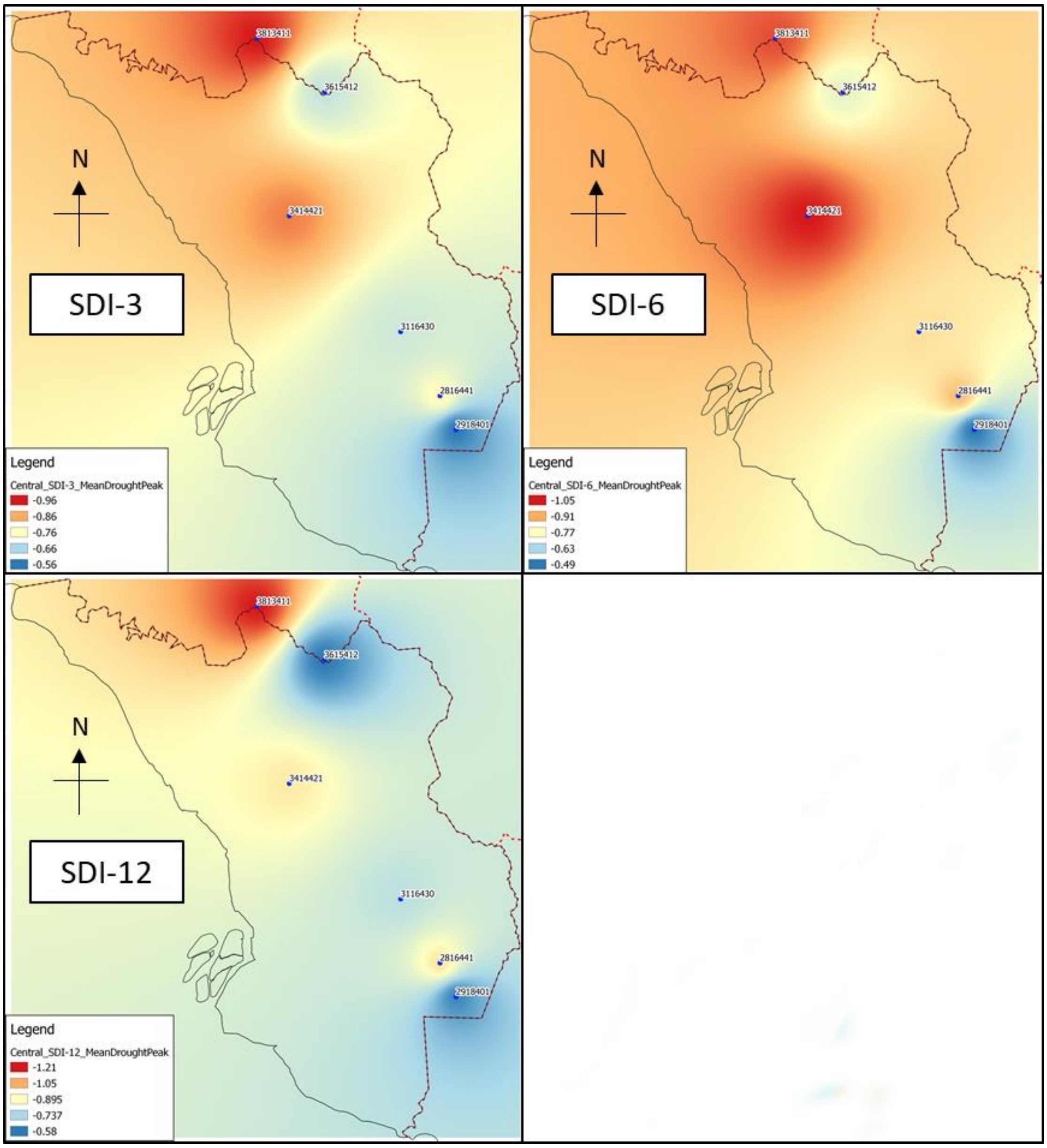

Figure 4.15: Spatial Map of Mean Drought Peak for SDI-3, -6, -12

The spatial map of mean drought peak for SDI-3, -6 and -12 demonstrated the north of central region has a significant high value of mean drought peak and the centre of central region was also covered with red colour scheme except SDI-6 has significant great value of mean drought peak. However, the southeast of central region has relatively low value of mean drought peak for all SDI. In addition, there is a blue colour scheme marked for all SDI located at the north of central region except SDI-12 has relatively great value of mean drought peak.

Besides that, there is a similarity between SPI and SPEI at 1-month, 3-months and 6-months timescales in spatial map of mean drought peak. For 1-month timescale, most of the central region represented in red colour scheme for both SPI and SPEI except there was a blue colour scheme at the northwest of central region for SPEI-1. There is higher mean drought peak value covered most of the central region for both SPI-3 and SPEI-3. Furthermore, the northwest of central region for both SPI-6 and SPEI-6 have relatively great value of mean drought peak compared to the rest of the central region.

4.3 Average Moving Range (AMR)

Average moving range (AMR) of a drought index can be identified as a mean value of two moving ranges of monthly drought index values. AMR is a measurement about sensitivity to the changes of drought pattern in the study region. In order to know the sensitivity of drought indices in central region of Peninsular Malaysia, thence AMR analysis was carried out for each drought index with different timescales. The sensitivity of drought indices was evaluated by evaluating the greatest value of AMR. For instance, SPI-1 is not suitable to implement in desert region due to the precipitation in desert region has low volume in a month. Hence, the greater SPI timescale introduces to monitoring the drought condition in desert region. In central region of Peninsular Malaysia, AMR analysis of drought indices with different timescales were evaluated by 20 rainfall stations and 6 streamflow stations. The outcome of AMR analysis for 20 rainfall stations and streamflow stations is tabulated in Tables 4.1 and 4.2 respectively and those results are plotted according to drought indices and SPI, SPEI and SDI graphs are presented as Figures 4.16, 4.17 and 4.18 respectively.

Table 4.1: Average Moving Range (AMR) of Rainfall Stations with Respect to SPI-1, -3, -6, -12 and SPEI-1, -3, -6, -12

Station No.	State	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12
3116003	**KL**	1.03	0.65	0.38	0.24	1.04	0.64	0.40	0.26
3116006	**KL**	1.00	0.61	0.36	0.22	1.01	0.62	0.40	0.25
3117070	**KL**	0.96	0.59	0.34	0.20	0.97	0.59	0.36	0.22
3216001	**KL**	1.02	0.67	0.40	0.26	1.04	0.65	0.41	0.27
3217002	**KL**	0.99	0.67	0.39	0.25	1.01	0.67	0.42	0.29
3217003	**KL**	1.01	0.65	0.38	0.24	1.02	0.65	0.40	0.26
3217005	**KL**	0.80	0.47	0.25	0.13	0.92	0.55	0.34	0.20
3317004	**KL**	0.97	0.63	0.37	0.25	0.98	0.61	0.37	0.24
2815001	**Selangor**	0.96	0.57	0.41	0.26	0.96	0.55	0.41	0.26
2818110	**Selangor**	0.94	0.62	0.38	0.22	0.96	0.60	0.37	0.21
2913001	**Selangor**	0.94	0.54	0.38	0.21	0.93	0.52	0.38	0.21
2917001	**Selangor**	0.89	0.56	0.33	0.19	0.94	0.57	0.36	0.22
2917002	**Selangor**	0.97	0.58	0.35	0.19	0.97	0.57	0.38	0.24
3118102	**Selangor**	0.95	0.55	0.34	0.22	1.01	0.58	0.36	0.24
3314001	**Selangor**	1.00	0.60	0.42	0.25	0.97	0.56	0.40	0.24
3411017	**Selangor**	0.96	0.58	0.42	0.29	0.95	0.55	0.41	0.26
3416002	**Selangor**	1.02	0.67	0.39	0.24	1.03	0.66	0.42	0.26
3516022	**Selangor**	1.04	0.66	0.42	0.31	1.06	0.65	0.43	0.30
3613004	**Selangor**	1.03	0.68	0.50	0.35	1.02	0.66	0.48	0.33
3710006	**Selangor**	0.95	0.57	0.43	0.30	0.91	0.54	0.41	0.26

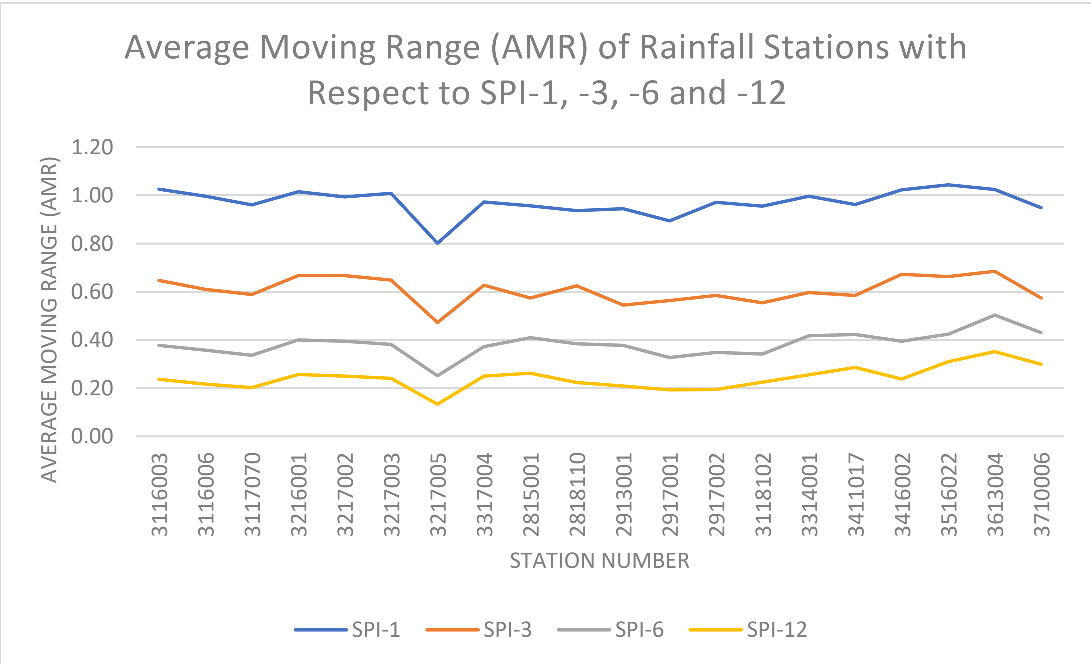

Figure 4.16: Average Moving Range (AMR) of Rainfall Stations with Respect to SPI-1, -3, -6 and -12

Figure 4.16 is showing the AMR value of 20 rainfall stations for SPI at different timescales in the central region of Peninsular Malaysia. From Table 4.1, the AMR value of 20 rainfall stations for SPI-1 is within a range from 0.80 to 1.04; while AMR value for SPI-3 is within a range from 0.47 to 0.67; while AMR value for SPI-6 is within a range from 0.25 to 0.50; while AMR value for SPI-12 is within a range from 0.13 to 0.35. Therefore, the sensitivity to the changes of drought pattern is decreasing across the SPI timescales as shown in Figure 4.16, which illustrated a decreasing trend of AMR value when across SPI timescales for 20 rainfall stations.

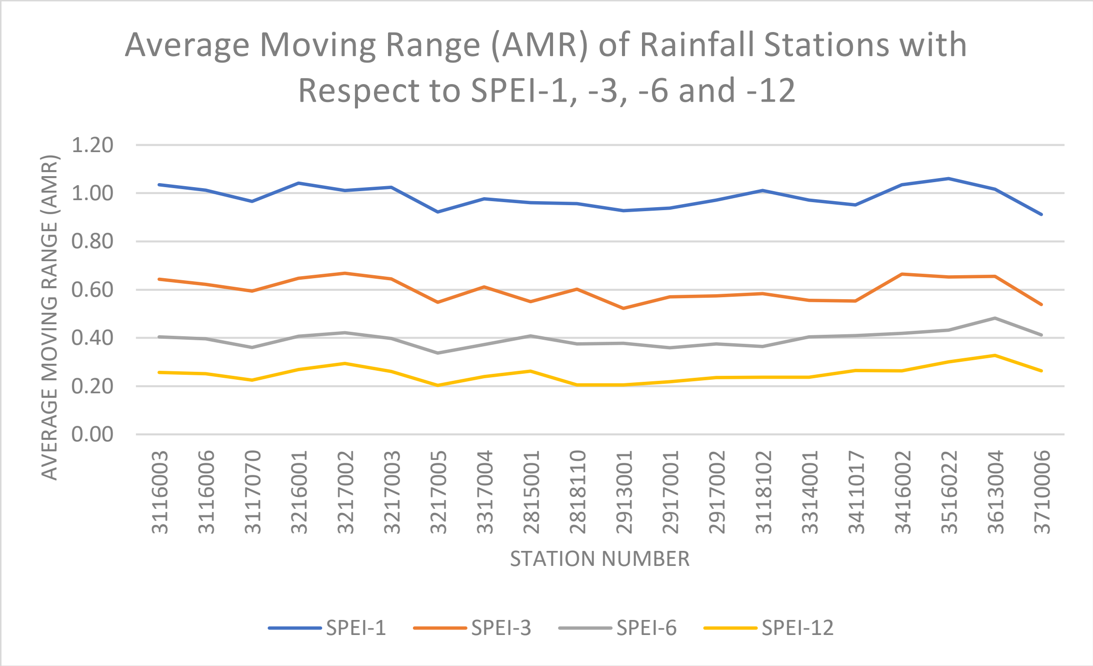

Figure 4.17: Average Moving Range (AMR) of Rainfall Stations with Respect to SPEI-1, -3, -6 and -12

From Table 4.1, the AMR value of 20 rainfall stations for SPEI-1 is within a range from 0.91 to 1.04; while AMR value for SPEI-3 is within a range from 0.52 to 0.67; while AMR value for SPEI-6 is within a range from 0.34 to 0.48; while AMR value for SPEI-12 is within a range from 0.21 to 0.33. Figure 4.17 has shown a decreasing trend of AMR value of 20 rainfall stations with respect to SPEI-1, -3, -6 and -12, thence the sensitivity to the changes of drought pattern is decreasing trend.

Table 4.2: Average Moving Range (AMR) of Streamflow Stations with Respect to SDI -3, -6, -12

Station No.	State	SDI-3	SDI-6	SDI-12
3116430	**KL**	0.24	0.12	0.06
2816441	**Selangor**	0.50	0.31	0.18
2918401	**Selangor**	0.26	0.14	0.07
3414421	**Selangor**	0.51	0.27	0.14
3615412	**Selangor**	0.30	0.15	0.07
3813411	**Selangor**	0.53	0.30	0.18

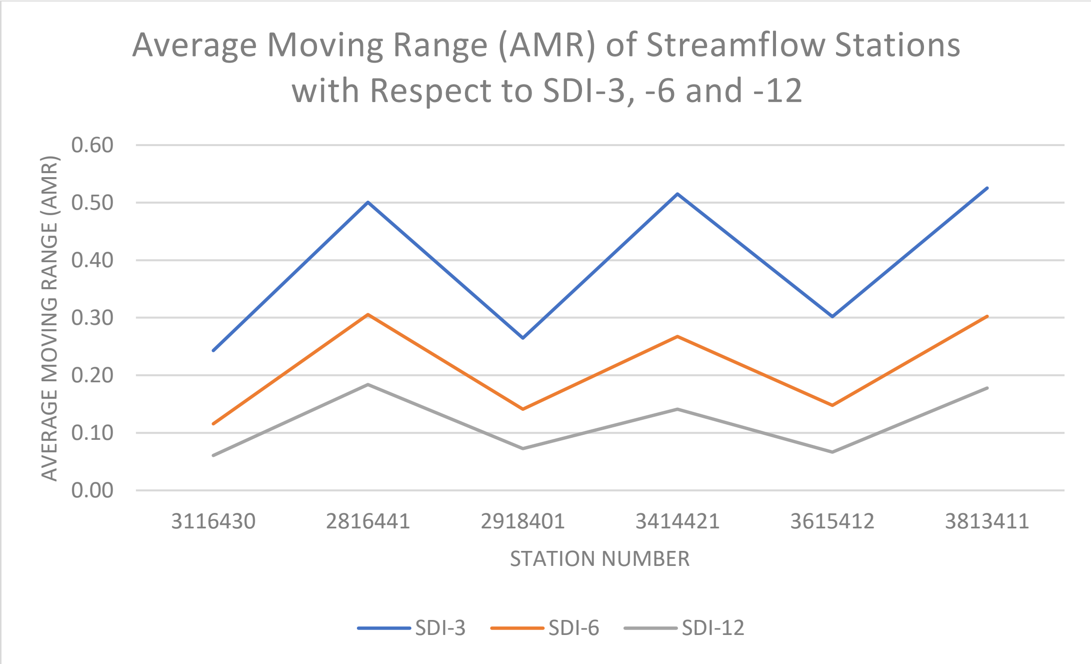

Figure 4.18: Average Moving Range (AMR) of Streamflow Stations with Respect to SDI -3, -6 and -12

From Table 4.2, the AMR value of 6 streamflow stations for SDI-3 is within a range from 0.24 to 0.53; while AMR value for SDI-6 is within a range from 0.12 to 0.31; while AMR value for SDI-12 is within a range from 0.06 to 0.18. Figure 4.18 has demonstrated a decreasing trend of AMR value of 6 streamflow stations with respect to SDI-3, -6 and -12, thence this represented the sensitivity to the changes of drought pattern is decreasing trend.

The sensitivity to the change of drought pattern can be measured by the AMR value for all drought indices. An excellent drought index has the ability to capture the changes in detail. Thus, the results of AMR value with respect to SPI, SPEI and SDI demonstrated drought indices has a smaller timescale were able to capture the sensitivity of changes of drought pattern more detail, which means that drought index obtained higher AMR value.

4.4 Comparison of Historical Drought Events with Drought Indices (SPI, SPEI and SDI)

In order to reveal the accuracy of computed drought indices, those computed drought indices will be compared with historical drought events. The pattern of drought in term of frequency, duration, severity, magnitude, intensity and peak can be understand by the comparison between computed drought indices and actual drought events. The aim of performing comparison between computed drought indices and historical drought events is to monitoring the drought model in central region of Peninsular Malaysia. In the past 35 years, there were 11 historical drought events occurred in central region of Peninsular Malaysia and it can be separated into timeline. In order to understand the root cause of historical drought events, timeline of historical drought events was introduced. In the timeline diagram, there were four periods denoted as P1, P2, P3 and P4 and the period of drought is tabulated as Table 4.3. Moreover, those historical drought events were separated into a timeline as illustrated in Figure 4.19.

Table 4.3: Notation of Period of Drought

Notation	Period of Drought
P1	03/1998 – 09/1998
P2	04/2012 – 09/2012
P3	02/2014 – 04/2014
P4	02/2014 – 09/2014

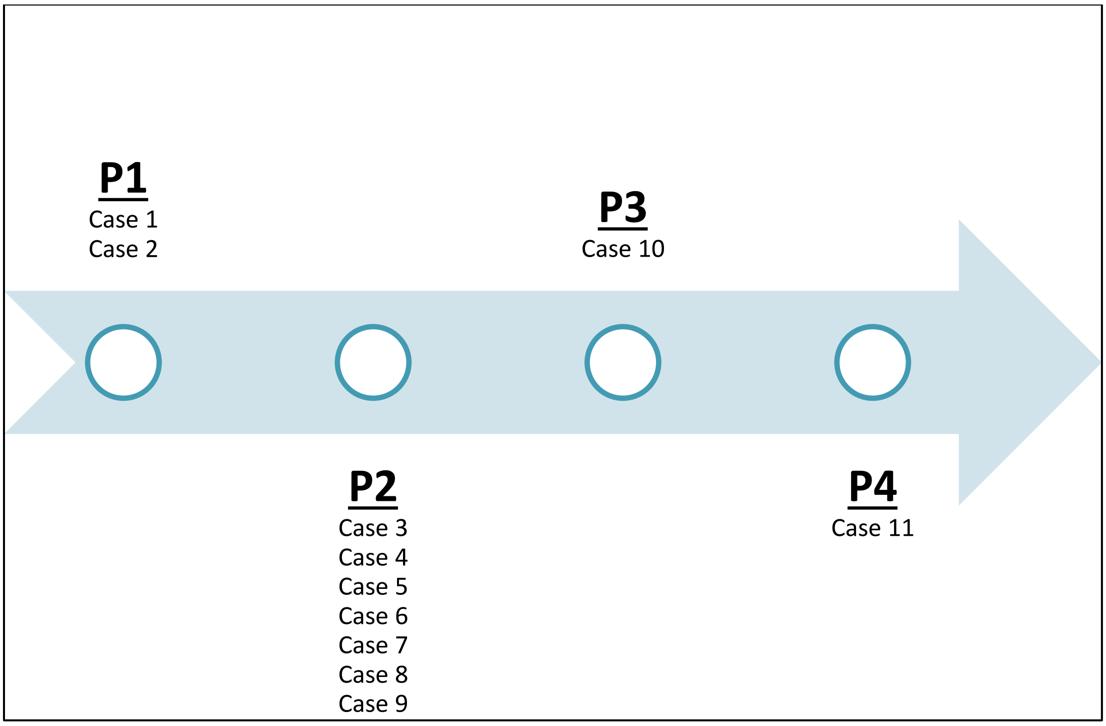

Figure 4.19: Timeline of Historical Drought Events in The Central Region of Peninsular Malaysia

There were four important periods for drought occurrence in central region of Peninsular Malaysia which in the year of 1998, 2012 and 2014, which displayed in Table 4.3 and Figure 4.19. However, droughts in P3 and P4 are appeared in same year but it is separated into two different periods due to the different in term of drought duration, which P3 represented a drought happened from February 2014 till April 2014; while P4 represented a drought happened from February 2014 till September 2014. In Table 4.4, The comparison of historical drought events with computed drought indices is tabulated and there were 11 historical drought events happened in the past in central region of Peninsular Malaysia.

Table 4.4: Comparison of Historical Drought Events with Computed Drought Indices

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Case 1: Historical Drought Event (Location: Kajang, Onset: 03/1998, End: 09/1998) (Task Force on El Nino, 2016)											
Nearest Station	2917001				2917001				2816441		
Distance (km)	1.082				1.082				0.097		
1st Onset	05/1998	02/1998	05/1998	05/1998	01/1998	02/1998	04/1998	02/1998	03/1998	06/1998	-
1st End	05/1998	03/1998	02/1999	05/1998	03/1998	11/1998	02/1999	03/2000	04/1998	06/1998	-
2nd Onset	07/1998	07/1998	-	08/1998	05/1998	-	-	-	09/1998	-	-
2nd End	09/1998	11/1998	-	01/2000	05/1998	-	-	-	09/1998	-	-
3rd Onset	-	-	-	-	07/1998	-	-	-	-	-	-
3rd End	-	-	-	-	09/1998	-	-	-	-	-	-
Duration (Months)	1, 3	2, 5	10	1, 18	3, 1, 3	10	11	26	2, 1	1	-
Maximum Severity	-2.59	-2.59	-1.74	-1.59	-1.8	-1.82	-1.7	-1.49	-0.36	-0.05	-
Case 2: Historical Drought Event (Location: Bangi, Onset: 03/1998, End: 09/1998) (Task Force on El Nino, 2016)											
Nearest Station	2917002				2917002				2918401		
Distance (km)	3.554				3.554				5.108		
1st Onset	05/1998	03/1998	06/1998	09/1998	01/1998	02/1998	05/1998	05/1998	02/1997	06/1994	11/1994
1st End	05/1998	03/1998	02/1999	10/1999	03/1998	11/1998	02/1999	10/1999	11/2000	04/2007	08/2007
2nd Onset	07/1998	05/1998	-	-	05/1998	-	-	-	-	-	-
2nd End	09/1998	11/1998	-	-	09/1998	-	-	-	-	-	-
Duration (Months)	1, 3	1, 7	9	14	3, 5	10	10	18	46	155	154
Maximum Severity	-3.27	-2.56	-1.8	-1.06	-1.88	-1.86	-1.72	-1.47	-1.49	-1.59	-1.51

Table 4.4 (Continued)

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Case 3: Historical Drought Event (Location: Hulu Langat, Onset: 04/2012, End: 09/2012) (Lee, 2012; Nik Anis and Ahmad, 2012)											
Nearest Station	2917001				2917001				2816441		
Distance (km)	1.013				1.013				0.269		
1st Onset	06/2012	07/2012	06/2012	-	06/2012	03/2012	06/2012	01/2012	07/2012	09/2012	-
1st End	07/2012	08/2012	08/2012	-	07/2012	04/2012	08/2012	04/2012	09/2012	09/2012	-
2nd Onset	-	-	-	-	-	07/2012	-	06/2012	-	-	-
2nd End	-	-	-	-	-	08/2012	-	06/2012	-	-	-
Duration (Months)	2	2	3	-	2	2, 2	3	4, 1	3	1	-
Maximum Severity	-1.43	-0.7	-0.21	-	-1.67	-1.05	-0.6	-0.34	-0.8	-0.15	-
Case 4: Historical Drought Event (Location: Petaling, Onset: 04/2012, End: 09/2012) (Lee, 2012; Nik Anis and Ahmad, 2012)											
Nearest Station	3116006				3116006				3116430		
Distance (km)	11.31				11.31				18.454		
1st Onset	06/2012	07/2012	-	04/2012	06/2012	06/2012	06/2012	07/2011	-	-	-
1st End	06/2012	08/2012	-	04/2012	07/2012	09/2012	10/2012	09/2012	-	-	-
2nd Onset	09/2012	-	-	06/2012	09/2012	-	-	-	-	-	-
2nd End	09/2012	-	-	06/2012	09/2012	-	-	-	-	-	-
Duration (Months)	1, 1	2	-	1, 1	2, 1	4	5	15	-	-	-
Maximum Severity	-1.81	-0.31	-	-0.11	-1.89	-0.84	-0.57	-0.69	-	-	-

Table 4.4 (Continued)

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Case 5: Historical Drought Event (Location: Semenyih, Onset: 04/2012, End: 09/2012) (Lee, 2012; Nik Anis and Ahmad, 2012)											
Nearest Station	2818110				2818110				2918401		
Distance (km)	5.924				5.924				4.329		
1st Onset	04/2012	06/2012	06/2012	-	04/2012	06/2012	06/2012	-	08/2012	-	-
1st End	04/2012	08/2012	09/2012	-	04/2012	08/2012	09/2012	-	08/2012	-	-
2nd Onset	06/2012	-	-	-	06/2012	-	-	-	-	-	-
2nd End	08/2012	-	-	-	08/2012	-	-	-	-	-	-
Duration (Months)	1, 3	3	4	-	1, 3	3	4	-	1	-	-
Maximum Severity	-1.24	-1.36	-0.74	-	-1.48	-1.41	-0.93	-	-0.01	-	-
Case 6: Historical Drought Event (Location: Sepang, Onset: 04/2012, End: 09/2012) (Lee, 2012; Nik Anis and Ahmad, 2012)											
Nearest Station	2719001				2719001				2519421		
Distance (km)	24.012				24.012				19.67		
Onset	03/2012	05/2012	06/2012	-	03/2012	05/2012	06/2012	-	08/2012	-	-
End	09/2012	10/2012	10/2012	-	09/2012	10/2012	10/2012	-	08/2012	-	-
Duration (Months)	7	6	5	-	7	6	5	-	1	-	-
Maximum Severity	-1.53	-0.92	-1.35	-	-1.33	-0.94	-1.31	-	-0.07	-	-

Table 4.4 (Continued)

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Case 7: Historical Drought Event (Location: Taman Maluri, Onset: 04/2012, End: 09/2012) (Lee, 2012; Nik Anis and Ahmad, 2012)											
Nearest Station	3117070				3117070				3116430		
Distance (km)	4.173				4.173				3.452		
1st Onset	06/2012	08/2012	-	03/2012	06/2012	01/2012	09/2011	02/2012	-	-	-
1st End	06/2012	08/2012	-	06/2012	06/2012	04/2012	04/2012	10/2012	-	-	-
2nd Onset	08/2012	-	-	-	08/2012	08/2012	06/2012	-	-	-	-
2nd End	08/2012	-	-	-	08/2012	08/2012	06/2012	-	-	-	-
Duration (Months)	1, 1	1	-	4	1, 1	4, 1	8, 1	9	-	-	-
Maximum Severity	-1.28	-0.04	-	-0.3	-1.64	-0.65	-1.33	-0.83	-	-	-
Case 8: Historical Drought Event (Location: Kuala Selangor, Onset: 04/2012, End: 09/2012) (Hassan, 2012; Nik Anis and Ahmad, 2012)											
Nearest Station	3411017				3411017				3414421		
Distance (km)	13.269				13.269				22.249		
1st Onset	04/2012	02/2012	04/2012	04/2012	02/2012	02/2012	04/2012	04/2012	07/2012	09/2012	-
1st End	04/2012	10/2012	11/2012	02/2015	09/2012	10/2012	11/2012	03/2015	10/2012	10/2012	-
2nd Onset	06/2012	-	-	-	-	-	-	-	-	-	-
2nd End	09/2012	-	-	-	-	-	-	-	-	-	-
Duration (Months)	1, 4	9	8	35	8	9	8	36	4	2	-
Maximum Severity	-1.73	-1.78	-1.88	-2.16	-1.87	-1.81	-1.95	-2.03	-0.67	-0.3	-

Table 4.4 (Continued)

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Case 9: Historical Drought Event (Location: Sabak Bernam, Onset: 04/2012, End: 09/2012) (Hassan, 2012)											
Nearest Station	3710006				3710006				3813411		
Distance (km)	12.94				12.94				44.589		
1st Onset	04/2012	06/2012	06/2012	-	04/2012	06/2012	06/2012	-	07/2012	09/2012	-
1st End	04/2012	09/2012	11/2012	-	04/2012	10/2012	11/2012	-	10/2012	10/2012	-
2nd Onset	06/2012	-	-	-	06/2012	-	-	-	-	-	-
2nd End	09/2012	-	-	-	09/2012	-	-	-	-	-	-
Duration (Months)	1, 4	4	6	-	1, 4	5	6	-	4	2	-
Maximum Severity	-2	-2.36	-2.11	-	-1.82	-1.87	-1.75	-	-0.91	-0.44	-
Case 10: Historical Drought Event (Location: Sungai Selangor Dam, Onset: 02/2014, End: 04/2014) (The Rakyat Post, 2014)											
Nearest Station	3516022				3516022				3615412		
Distance (km)	3.908				3.908				23.944		
Onset	01/2014	01/2014	02/2014	11/2013	01/2014	01/2014	02/2014	11/2013	02/2010	02/2010	03/2010
End	03/2014	08/2014	09/2014	01/2015	03/2014	08/2014	09/2014	04/2015	12/2017	12/2017	12/2017
Duration (Months)	3	8	8	15	3	8	8	18	95	95	94
Maximum Severity	-1.88	-2.26	-2.59	-1.02	-1.56	-1.97	-2.14	-1.23	-1.69	-1.78	-1.7

Table 4.4 (Continued)

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Case 11: Historical Drought Event (Location: Sungai Selangor Dam, Onset: 02/2014, End: 09/2014) (The Star Online, 2014)											
Nearest Station	3516022				3516022				3615412		
Distance (km)	3.908				3.908				23.944		
1st Onset	01/2014	01/2014	02/2014	11/2013	01/2014	01/2014	02/2014	11/2013	02/2010	02/2010	03/2010
1st End	03/2014	08/2014	09/2014	01/2015	03/2014	08/2014	09/2014	04/2015	12/2017	12/2017	12/2017
2nd Onset	05/2014	-	-	-	05/2014	-	-	-	-	-	-
2nd End	07/2014	-	-	-	07/2014	-	-	-	-	-	-
Duration (Months)	3, 3	8	8	15	3, 3	8	8	18	95	95	94
Maximum Severity	-1.88	-2.26	-2.59	-1.02	-1.82	-1.97	-2.14	-1.23	-1.69	-1.78	-1.7

From Figure 4.19, Case 1 and 2 showed the drought occurred in Kajang and Bangi from March 1998 till September 1998 which caused by the El Nino (Task Force on El Nino, 2016). In Case 1, both SPI-1 and -3 has most maximum severity of drought was computed as -2.59, but SPEI-3 displayed the maximum severity as -1.82. Nevertheless, the computed maximum severity for SDI were relatively lower than SPI and SPEI in Case 1. In Case 2, SPI-1 computed the most maximum severity of drought which is -3.27. However, SPEI-1, -3, -6 and -12 calculated the maximum severity as -1.88, -1.86, -1.72 and -1.47 respectively. Besides that, the most maximum severity for SDI-3, -6 and -12 are -1.49, -1.59 and -1.51 respectively for Case 2. From Case 2, it illustrated that might be an occurrence of ecological drought due to the water disruption in Klang Valley area. Notwithstanding, there might be a meteorological drought happened and led to the intake volume of water dam decreased and further led to water disruption in Klang Valley and interpreted as an occurrence of ecological drought. Furthermore, Malaysia heavily relied on surface water which can be explained as the water dam mainly based on the precipitation.

There were 7 historical drought events happened in central region of Peninsular Malaysia in 2012 which recorded in Table 4.3 as Case 3, 4, 5, 6, 7, 8 and 9. The location of Case 3 to Case 9 were located at Hulu Langat, Petaling, Semenyih, Sepang, Taman Maluri, Kuala Selangor and Sabak Bernam respectively. In order to identify the occurrence of drought during P2, the maximum severity of each drought index was computed. During P2, the maximum severity of SPI and SPEI are relatively greater than SDI in term of magnitude which obtained from Table 4.4, thus it can be said there was a meteorological drought happened in central region of Peninsular Malaysia. However, The Star Online reported that the water level of reservoir in Semenyih and Hulu Langat used to serve in Hulu Langat, Petaling, Semenyih, Sepang and Taman Maluri which indicated that would be an occurrence of a hydrological drought during that period. Abdul Halem has announced that there were hot and dry weather happened in 2012 and it will last long to September 2012 (Lee, 2012). Meanwhile, the dry weather was produced by southwest monsoon season and it also caused a relatively low precipitation (Nik Anis and Ahmad, 2012). In Kuala Selangor and Sabak Bernam, farmers were suffered due to the water level in rice field dropped about 1 m depth measured from normal water level which indicated there was a drought occurred due to hot and dry weather (Hassan, 2012). Based on the computed maximum severity of drought indices and news reported, it indicated that central region of Peninsular Malaysia faced a meteorological drought during P2.

Case 10 represented the drought occurred in Sungai Selangor Dam from February 2014 and it was ended at April 2014. SPI-6 has the highest maximum severity in Case 10 which is -2.59. The Rakyat Post reported the dropped of water level in Sungai Selangor Dam due to El Nino phenomena (The Rakyat Post, 2014). At the same time, Case 11 was based on The Star Online reported that Sungai Selangor Dam had been observed that low water level due to extreme hot weather and the duration of drought was obtained which started from February 2014 until September 2014 (The Star Online, 2014). In Table 4.4, the maximum severity for all drought indices have a magnitude below -1.0 in both Case 10 and 11, which might be indicated the central region of Peninsular Malaysia was facing meteorological and hydrological drought simultaneously.

4.5 Measurements for Determine the Accuracy of Drought Indices

4.5.1 Probability of Detection (POD)

In order to determine the accuracy of computed drought indices, the method of probability of detection (POD) was introduced to evaluate the accuracy of drought indices based on the drought frequency. The result of POD is tabulated in Table 4.5 which "1" with orange colour background represented as presence of drought and "0" represented as absence of drought.

Table 4.5: Probability of Detection (POD)

Drought Index	**SPI 1**	**SPI 3**	**SPI 6**	**SPI 12**	**SPEI 1**	**SPEI 3**	**SPEI 6**	**SPEI 12**	**SDI 3**	**SDI 6**	**SDI 12**
Case 1	1	1	1	1	1	1	1	1	1	1	0
Case 2	1	1	1	1	1	1	1	1	1	1	1
Case 3	1	1	1	0	1	1	1	1	1	1	0
Case 4	1	1	0	1	1	1	1	1	0	0	0
Case 5	1	1	1	0	1	1	1	0	1	0	0
Case 6	1	1	1	0	1	1	1	0	1	0	0
Case 7	1	1	0	1	1	1	1	1	0	0	0
Case 8	1	1	1	1	1	1	1	1	1	1	0
Case 9	1	1	1	0	1	1	1	0	1	1	0
Case 10	1	1	1	1	1	1	1	1	1	1	1

Table 4.5 (Continued)

Case 11	1	1	1	1	1	1	1	1	1	1	1
Total Detected Drought Events	11	11	9	7	11	11	11	8	9	7	3
POD	100%	100%	82%	64%	100%	100%	100%	73%	82%	64%	27%

4.5.2 Pearson Correlation Between Actual and Forecast Duration, Mean Absolute Percentage Error and Root Mean Square Error (RMSE)

The measurements of the accuracy of drought indices can be assessed by the drought duration. Hence, the actual duration and forecast duration by all drought indices at different timescales was tabulated in Table 4.6.

Table 4.6: Actual and Forecast Durations of All Drought Indices at Different Timescales for Each Case

Drought Index				**SPI 1**	**SPI 3**	**SPI 6**	**SPI 12**	**SPEI 1**	**SPEI 3**	**SPEI 6**	**SPEI 12**	**SDI 3**	**SDI 6**	**SDI 12**
Case	**Onset**	**End**	**Actual Duration**	**Forecast Duration**										
1	03/1998	09/1998	**7**	4	7	10	19	7	10	11	26	3	1	-
2	03/1998	09/1998	**7**	4	8	9	14	8	10	10	18	16	155	154
3	04/2012	09/2012	**6**	2	2	3	-	2	4	3	5	3	1	-
4	04/2012	09/2012	**6**	2	2	-	2	3	4	5	15	-	-	-
5	04/2012	09/2012	**6**	4	3	4	-	4	3	4	-	1	-	-
6	04/2012	09/2012	**6**	7	6	5	-	7	6	5	-	1	-	-
7	04/2012	09/2012	**6**	2	1	-	4	2	5	9	9	-	-	-
8	04/2012	09/2012	**6**	5	9	8	35	8	9	8	36	4	2	-
9	04/2012	09/2012	**6**	5	4	6	-	5	5	6	-	4	2	-
10	02/2014	04/2014	**3**	3	8	8	15	3	8	8	18	95	95	94
11	02/2014	09/2014	**8**	6	8	8	15	6	8	8	18	95	95	94

From Table 4.6, it was difficult to determine the accuracy of drought indices by assessing between actual and forecast duration for all historical drought events. In order to visualize the actual and forecast duration for each drought index, the correlation of drought indices between actual and forecast duration was presented. The Pearson correlation of drought indices between actual and forecast duration is tabulated in Table 4.7.

Table 4.7: Pearson Correlation of Drought Indices Between Actual and Forecast Duration

Drought Index	**SPI 1**	**SPI 3**	**SPI 6**	**SPI 12**	**SPEI 1**	**SPEI 3**	**SPEI 6**	**SPEI 12**	**SDI 3**	**SDI 6**	**SDI 12**
Correlation	0.34	0.05	0.16	0.03	0.46	0.18	0.19	0.08	-0.23	0.02	0.33

From Table 4.7, SPEI-1 obtained the largest positive correlation between actual and forecast duration which represented SPEI-1 is a strong positive relationship between actual and forecast duration. Moreover, SPI-1 and SDI-12 also revealed both drought indices have moderate positive relationship between actual and forecast duration. Nonetheless, the mean absolute percentage error (MAPE) and root mean square error (RMSE) were introduced to further evaluate the accuracy of all drought indices which was tabulated in Table 4.8. The blank cell in absolute error indicated as absence of drought.

Table 4.8: Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) of Drought Indices

Drought Index	**SPI 1**	**SPI 3**	**SPI 6**	**SPI 12**	**SPEI 1**	**SPEI 3**	**SPEI 6**	**SPEI 12**	**SDI 3**	**SDI 6**	**SDI 12**
Case	**Absolute Error**										
1	3	0	3	12	0	3	4	19	4	6	
2	3	1	2	7	1	3	3	11	9	148	147
3	4	4	3		4	2	3	1	3	5	
4	4	4		4	3	2	1	9			
5	2	3	2		2	3	2		5		
6	1	0	1		1	0	1		5		
7	4	5		2	4	1	3	3			
8	1	3	2	29	2	3	2	30	2	4	
9	1	2	0		1	1	0		2	4	
10	0	5	5	12	0	5	5	15	92	92	91
11	2	0	0	7	2	0	0	10	87	87	86
Mean Absolute Percentage Error (%)	3.3	4.4	4.6	27.4	2.7	3.7	3.9	27.7	57.1	134.1	689.8
RMSE (month)	0.038	0.061	0.070	0.361	0.034	0.054	0.055	0.353	1.207	2.097	7.395

Table 4.8 have indicated that both SPI-1 and SPEI-1 are capable to implement in monitoring drought condition in central region of Peninsular Malaysia due to the relatively low MAPE and RMSE. The values of MAPE for SPI-1 and SPEI-1 are 3.3% and 2.7% respectively. Moreover, the values of RMSE for SPI-1 and SPEI-1 are 0.038 month and 0.034 month respectively.

4.5.3 Mean Bias Error (MBE)

In term of duration, the forecast of the beginning of drought can be one of the measurements to identify the accuracy of drought indices. Therefore, mean bias error (MBE) is executed to determine the accuracy of drought indices. MBE of drought indices is tabulated in Table 4.9. The sign conventions are denoted as negative sign means under prediction; positive sign means over prediction; "0" means neutral; while blank cells mean no drought occurred.

Table 4.9: Mean Bias Error (MBE) of Drought Indices

Drought Index	**SPI 1**	**SPI 3**	**SPI 6**	**SPI 12**	**SPEI 1**	**SPEI 3**	**SPEI 6**	**SPEI 12**	**SDI 3**	**SDI 6**	**SDI 12**
Case	**Bias Error**										
1	-0.27	0.00	0.33	1.71	0.00	0.27	0.36	2.38	-0.44	-0.86	
2	-0.27	0.09	0.22	1.00	0.09	0.27	0.27	1.38	1.00	21.14	49.00
3	-0.36	-0.36	-0.33		-0.36	-0.18	-0.27	-0.13	-0.33	-0.71	
4	-0.36	-0.36		-0.57	-0.27	-0.18	-0.09	1.13			
5	-0.18	-0.27	-0.22		-0.18	-0.27	-0.18		-0.56		
6	0.09	0.00	-0.11		0.09	0.00	-0.09		-0.56		
7	-0.36	-0.45		-0.29	-0.36	-0.09	0.27	0.38			
8	-0.09	0.27	0.22	4.14	0.18	0.27	0.18	3.75	-0.22	-0.57	
9	-0.09	-0.18	0.00		-0.09	-0.09	0.00		-0.22	-0.57	
10	0.00	0.45	0.56	1.71	0.00	0.45	0.45	1.88	10.22	13.14	30.33
11	-0.18	0.00	0.00	1.00	-0.18	0.00	0.00	1.25	9.67	12.43	28.67
Mean Bias Error (month)	-0.19	-0.07	0.07	1.24	-0.10	0.04	0.08	1.50	2.06	6.29	36.00

The obtained result of RMSE has narrowed down the selection of the most suitable drought index to monitoring the drought condition in central region of Peninsular Malaysia which are SPI-1 and SPEI-1. From Table 4.9, MBE for both SPI-1 and SPEI-1 are under prediction which are -0.19 month and -0.10 month respectively. Thus, this shown that both SPI-1 and SPEI-1 are relatively low MBE values and both of the drought indices can be considered well drought index used to monitoring drought condition in central region of Peninsular Malaysia.

4.5.4 Mean Early or Delayed Prediction

The mean early or delayed prediction is an average of the difference between actual and forecast of the beginning of drought and it can be one of the measurements to identify the accuracy of drought indices. This measurement provides a measure to determine the reliability of the forecast of the beginning of drought towards the historical drought events that were happened in the past. The result of mean early or delayed prediction is tabulated in Table 4.10. There are several indicators in Table 4.10 which are negative value denoted as early prediction; positive value denoted as delayed prediction; “0” denoted as the forecast of the beginning of drought is accurate; while the blank cells denoted as absence of drought occurrence.

Table 4.10: Mean Early or Delay Prediction of Drought Indices

Drought Index	**SPI 1**	**SPI 3**	**SPI 6**	**SPI 12**	**SPEI 1**	**SPEI 3**	**SPEI 6**	**SPEI 12**	**SDI 3**	**SDI 6**	**SDI 12**
Case	**Early/ Delayed Prediction**										
1	2	-1	2	2	-2	-1	1	-1	0	3	
2	2	0	3	6	-2	-1	2	2	-13	-45	-47
3	2	3	2		2	-1	2	-3	3	5	
4	2	3		0	2	2	2	3			
5	0	2	2		0	2	2		4		
6	-1	1	2		-1	1	2		4		
7	2	4		-1	2	-3	5	-2			
8	0	-2	0	0	-2	-2	0	0	3	5	
9	0	2	2		0	2	2		3	5	
10	-1	-1	0	-3	-1	-1	0	-3	-48	-48	-47
11	-1	-1	0	-3	-1	-1	0	-3	-48	-48	-47
Mean Early/ Delayed Prediction (month)	0.6	0.9	1.4	0.1	-0.3	-0.3	1.6	-0.9	-10.2	-17.6	-47.0

Based on the result obtained, the mean early or delayed prediction for SPI-1 and SPEI-1 are expressed as delayed by 0.6 month and early by 0.3 month respectively. Theoretically, an early prediction is better than a delayed prediction. Thereby, SPEI-1 is the most suitable drought index to monitoring the drought condition in central region of Peninsular Malaysia.

4.6 Analysis Between 35 Years Monthly Trend and Oceanic Nino Index (ONI) and Dipole Mode Index (DMI)

In order to analyse the weather condition in central region of Peninsular Malaysia, Oceanic Nino Index (ONI) and Dipole Mode Index (DMI) were introduced to determine the relationship between abnormal SST to the weather condition in central region of Peninsular Malaysia. Since the SPEI-1 is the most reliable drought index to monitor in central region of Peninsular Malaysia, thence 35 years monthly trend of SPEI-1 was used in this analysis to identify the relationship between ONI and DMI towards the 35 years monthly trend in central region of Peninsular Malaysia. The 35 years monthly trend of rainfall stations for SPEI-1 was tabulated in Table 4.11; the monthly trend for 3-months running mean of ONI and monthly trend for DMI were tabulated in Table 4.12. In Tables 4.11 and 4.12, the up arrow represented increasing trend; down arrow represented decreasing trend. The comparison between ONI, DMI and 35 years monthly trend of rainfall stations for SPEI-1 in term of monthly are shown in Figures 4.20, 4.21 and 4.22.

Table 4.11: 35 Years Monthly Trend of Rainfall Stations for SPEI-1

Station no.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2815001	↓	↓	↓	↓	↓	↓	↓	↓	↑	↑	↑	↑
2818110	↓	↓	↑	↑	↓	↓	↓	↓	↑	↑	↑	↑
2913001	↓	↓	↓	↓	↓	↓	↓	↓	↑	↑	↑	↑
2917001	↓	↓	↑	↑	↓	↓	↓	↓	↓	↑	↑	↑
2917002	↓	↓	↑	↑	↓	↓	↓	↓	↑	↑	↑	↑
3116003	↓	↑	↓	↑	↓	↓	↓	↓	↑	↑	↑	↓
3116006	↓	↓	↑	↑	↓	↓	↓	↓	↓	↑	↑	↑
3117070	↓	↑	↑	↑	↓	↓	↓	↓	↑	↑	↑	↓
3118102	↓	↓	↑	↓	↓	↓	↓	↓	↑	↑	↑	↓
3216001	↓	↓	↑	↓	↑	↓	↓	↑	↑	↑	↑	↑
3217002	↓	↓	↑	↓	↓	↓	↓	↑	↑	↑	↑	↓
3217003	↓	↓	↑	↑	↓	↓	↓	↓	↑	↑	↑	↓
3217005	↓	↓	↓	↓	↓	↓	↓	↓	↑	↑	↑	↓
3314001	↑	↑	↑	↑	↑	↓	↓	↓	↑	↑	↑	↑
3317004	↓	↓	↓	↑	↑	↓	↓	↓	↑	↑	↑	↓
3411017	↑	↓	↓	↓	↓	↓	↓	↓	↑	↑	↑	↑
3416002	↓	↓	↓	↑	↑	↓	↓	↓	↑	↑	↑	↓
3516022	↓	↓	↓	↑	↑	↓	↓	↓	↑	↑	↑	↑

Table 4.11 (Continued)

3613004	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	↑	↑
3710006	↓	↓	↑	↑	↓	↓	↓	↓	↑	↑	↑	↑

Table 4.12: Monthly Trend for 3-Months Running Mean of ONI and Monthly Trend for DMI

Month	ONI Trend	DMI Trend
Jan	↓	↓
Feb	↓	↓
Mar	↓	↓
Apr	↓	↓
May	↓	↑
Jun	↓	↓
Jul	↓	↑
Aug	↓	↑
Sep	↓	↑
Oct	↑	↑
Nov	↑	↑
Dec	↑	↑

By comparing Tables 4.11 and 4.12, most of the months of the 35 years monthly trend of rainfall stations are affected by ONI except March, April and September. During March and April, there is no relationship between 35 years monthly trend of rainfall stations and ONI and DMI. However, the 35 years monthly trend of rainfall stations in September is affected by DMI, which DMI indicated an increasing trend in September. From the comparison, although there is no relationship between 35 years monthly trend of rainfall stations and ONI and DMI in March and April, but there is a linking between ONI, DMI and 35 years monthly trend of rainfall stations for the rest of the months. Thence, a further research requires to execute and clarify the relationship between abnormal SST and drought occurrence.

Figure 4.20: Comparison of ONI, DMI and 35 Years Monthly Trend of Rainfall Stations for SPEI-1 From January to April.

Figure 4.21: Comparison of ONI, DMI and 35 Years Monthly Trend of Rainfall Stations for SPEI-1 From May to August.

Figure 4.22: Comparison of ONI, DMI and 35 Years Monthly Trend of Rainfall Stations for SPEI-1 From September to December.

4.7 Summary

The spatial analysis of drought in central region of Peninsular Malaysia provides a better vision to understanding the circumstances of drought in term of drought frequency, mean drought duration, mean drought severity, mean drought intensity and mean drought peak. Moreover, AMR also provides a better understanding about the sensitivity of a drought index over time factor in order to monitoring in central region of Peninsular Malaysia. After that, the type of drought happened in the past 35 years is identified by the comparison of historical drought events with computed drought indices. The accuracy for each drought index is evaluated and it shows that SPEI-1 is the most suitable drought index to monitoring drought condition in central region of Peninsular Malaysia. Lastly, there is a linking between abnormal SST and drought occurrence in central region of Peninsular Malaysia and it requires a further research to clarify the relationship between them.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The assessment for this research is to identify the most suitable drought index for monitoring droughts in the central region of Peninsular Malaysia. Hence, there are few drought indices were computed and compared with historical drought events in order to identify the capability of drought indices in the central region of Peninsular Malaysia. First, AMR of drought indices at different timescales were introduced to determine the sensitivity of drought indices over time in the study region. The result of AMR analysis shows that all drought indices at 1-month timescale are good for monitoring droughts in the study region, which indicated that smallest timescale of drought indices are more sensitive to detect the fluctuation of precipitation over time. In order to evaluate a drought, there are several parameters were adopted, which evaluated the drought in term of frequency, duration, severity, intensity and magnitude. The drought occurrence can be identified by the reading of drought indices are below zero. The first negative value in drought indices indicated as the beginning of drought; while the first positive value in drought indices observed after the continuous negative values, which can be considered the last continuous negative value is the end of drought.

In the central region of Peninsular Malaysia, the recorded droughts in between of the year 1983 and 2017 were related to meteorological drought, which usually caused by the weather condition or lack of precipitation. In 1998, El Nino has brought hot and dry weather to Kajang and Bangi area, which also led to drought happened in these two areas. This situation shows that temperature variable act as an important role in order to determine drought in the study region. Furthermore, the drought characteristics are important in determining the drought conditions such as duration and severity, which these two parameters were implemented and compared with historical drought events in order to monitoring droughts in the central region of Peninsular Malaysia. Furthermore, the accuracy of drought indices is one of the essential elements for monitoring droughts in the study region, which evaluated by drought frequency and duration. POD was implemented to determine the accuracy of drought indices, which assessed by drought frequency; while Pearson correlation between actual and forecast duration, MAPE, RMSE, MBE and mean early or delay prediction were executed to determine the accuracy of drought indices by drought duration. Among all drought indices, SPEI-1 represents an outstanding drought index that is capable for monitoring droughts in the study region. The reason of SPEI-1 is an outstanding drought index is due to its computation includes temperature as a variable and this indicated PET is important variable in accounting for drought evaluation.

In spatial analysis, there are five drought characteristics implemented in order to understand the spatial relationship for five drought characteristics in the study region, which these five drought characteristics consists of drought frequency, mean drought duration, mean drought severity, mean drought intensity and mean drought peak. This spatial analysis is presented in colour contour and it was done by using QGIS software. In temporal analysis, the monthly trend analysis for SPEI-1 was computed and the results of 35 years monthly trend of rainfall stations for SPEI-1 is presented. Moreover, 35 years monthly trend of rainfall stations for SPEI-1 was comparing with ONI and DMI trends in order to clarify the relationship between abnormal SST and drought occurrence. From the result, most of the 35 years monthly trend of rainfall stations for SPEI-1 were matched with ONI and DMI trends, which indicated there is a linking between abnormal SST and drought occurrence. Therefore, it can be concluded there are several factors that affect the weather condition in the central region of Peninsular Malaysia have not been discover yet.

5.2 Recommendations for future work

There are several recommendations for future work after this research, which listed as followings:

(i) Complementary drought indices can be executed for monitoring droughts in the central region of Peninsular Malaysia such as Crop Moisture Index (CMI), which can detect a drought in different perspective.

(ii) The different timescales of SPI, SPEI and SDI can be implemented to determine drought events with different aspects such as drought index with 9-months timescale act as an indication of inter-seasonal precipitation patterns.

(iii) The relationship between the abnormal SST and droughts occurrence in the central region of Peninsular Malaysia can be further studied to clarify the relationship between them.

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