THE USE OF DROUGHT INDICES TO DESCRIBE MOISTURE CONDITIONS IN NORTHERN REGION OF 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 **"THE USE OF DROUGHT INDICES TO DESCRIBE MOISTURE CONDITIONS IN NORTHERN REGION OF MALAYSIA"** was prepared by **NG CHING WOON** 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

The moisture conditions in the northern region of Peninsular Malaysia including Perak, Penang, Kedah and Perlis states were studied using the Standardized Precipitation Index (SPI), the Standardized Precipitation Evapotranspiration Index (SPEI) and the Streamflow Drought Index (SDI). Retrieved input data for years from 1983 – 2017 was used to develop drought indices with timescale intervals of 1 month, 3 months, 6 months and 12 months to represent different types of drought. Similar to the SPI, the SDI is a single variable drought index, but each uses the deficiency in precipitation and streamflow, respectively, to represent drought. The SPEI that practically expressed the rainfall deficiency together with the consideration of the evapotranspiration phenomenon corresponded to changes in temperature performed best. The SPEI has wider applications because it can represent different types of drought with different timescales more accurately than SPI. A 1-month timescale represents the meteorological drought; 3-months timescale for a seasonal meteorological drought; 6-months timescale represents an agricultural drought; and 12-months timescale was used to represent a hydrological drought. Results of the SPEI also showed that in the years with higher Sea Surface Temperature (SST) caused by the El Nino Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), the drought conditions tend to be more severe. Next, drought frequency, mean drought duration, mean drought intensity, mean drought severity, mean drought peak and average moving range were estimated and analysed spatially. Results showed that the result of the SPEI is coherent to the results of both the SPI and the SDI. Temporal trend analysis was also carried out to study the pattern and predict the future trend of drought in the region. From the results, the SPEI-3 that represents the seasonal meteorological drought with precipitation and temperature input was shown to be the best index. It successfully detected the historical observed drought events and accurately measured the onset of drought events.

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LIST OF SYMBOLS / ABBREVIATIONS

$\bar{X}$	mean
s	standard deviation
U	statistics
β	shapeparameter
α	scaleparameter
γ	originparameter
τ	L-moment ratios
λ	L moments
i	hydrological year
j	hydrological month
k	reference period
AMR	Average Moving Range
CAFEC	Climatically Appropriate For Existing Conditions
DID	Department of Irrigation and Drainage
DMI	Dipole Mode Index
EDI	Effective Drought Index
EMI	El Nino Modoki Index
ENSO	El Nino Southern Oscillation
GIS	Geographic Information System
IDW	Inverse Distance Weighted
IOD	Indian Ocean Dipole
MAE	Mean Absolute Error
MBE	Mean Bias Error
MMD	Malaysian Meteorological Department
MR	Moving Range
NCER	Northern Corridor Economic Region
NCIA	Northern Corridor Implementation Authority
NOAA	National Oceanic Atmospheric Administration
ONI	Oceanic Nino Index

OK	Ordinary Kriging
PDSI	Palmer Drought Severity Indices
PET	Potential Evapotranspiration
POD	Probability of Detection
RMSE	Root Mean Square Error
SDI	Streamflow Drought Index
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SST	Sea Surface Temperature
UMFR	Ulu Muda Forest Reserve
Z	Moisture Anomaly Index

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Malaysia is a country with 2 rainy seasons. One of them is the southwest monsoon, which is also known as the summer monsoon that occurs from late May to September. The other is the northeast monsoon, the winter monsoon which occurs in between November to March. These two monsoon seasons come together with the inter-monsoon seasons, eventually lead to various raining and dry events. Therefore flood seasons, flash flood seasons, as well as the dry and hazy seasons will happen in Malaysia (Abdulah et al., 2014).

Malaysia is located in Southeast Asia within the latitudes of 1◦ to 7◦ north and longitudes of 99◦ to 105◦ east with a total area of 130,598 km^2 approximately. Since Malaysia is located at the equator, it is associated with abundant rainfall, high humidity, and uniform temperature in between 25 ◦C to 32 ◦C (Othman et al., 2016). The climate in Malaysia is suitable for plants to grow, therefore it is famous as a beautiful nature country which is surrounded with lots of rain forests and a good habitat for animals. The rainforests in Malaysia is the core of biodiversity, where numerous species of animals and plants are found within this biodiversity. It also constitutes to human daily basis supplements like vegetables, fruits, traditional medicines, clean water, oxygen, foods, meats, building materials and other products. A healthy ecosystem is also very important and beneficial to economy and developments of this country.

To maintain a healthy ecosystem, water is the most crucial element. Every human, animals and plants require water to survive. Without water, there will be no life on earth. However, the main water source is the precipitation. Rain falls into the streams, rivers, lakes, or seeps into underground, feeding the plants and animals. The study of precipitation is important in Malaysia, as the rainfall variability in Malaysia is large. The wet and dry seasons with extreme rainfall amount through a period of time together with episodes of extreme weather may lead to floods or droughts. Drought is a general term used to describe the natural phenomenon of water shortage primarily due to persistent deficiency in precipitation after a long period.

1.2 Importance of the Study

The importance of water and also the danger of water shortage is becoming more noticeable and most Malaysians are aware of the calamities that follow suit. Based on a series of historical drought events held in Malaysia, some of them are small scale drought which only happened in particular regions; and some are big scale that affect the whole nation. Malaysia usually experiences drought associated with severe haze episodes during June-July-August of the conventional El Nino Southern Oscillation year. In contrast to the conventional type, the El Nino Modoki exerts drier condition to both northern Borneo (Sabah and Sarawak) and Malaysia (especially northern region) during December through January and February of the following year (Low et al., 2016).

The strongest El Nino event that happened in 1997-1998 causes Malaysia to experience more than 50% of rainfall decrease, from a rainfall depth of 200mm in April 1997 to 58mm in February 1998. This is the most severe national water crisis case that had happened in the past 30 years. Many areas in Malaysia were affected during this event, included Perlis, Negeri Sembilan, Melaka, and the most severe area was in Selangor and Kuala Lumpur. Around 3.2 million users were affected due to mandatory water rationing which last for 5 months starting from April to September. Moreover, the whole country was experiencing severe haze disaster due to forest fires (including from neighbouring countries), hence affecting the health of people. Economy lost due to this drought episode is estimated to be USD9 billion (Abdulah et al., 2014). Malaysia also experienced a three-month-long drought in early of 2014. The effect of the El Nino phenomenon was still observable at the end of 2014 until the early of 2015 (Othman et al., 2016).

As water is the most essential element for our life, the lacking of it will subsequently cause damages to ecosystems, habitats and many economic and social sectors. All well-being of Malaysians will be affected, included the water supply, agricultural, industry, transportation and so on. Water is also a renewable energy source that is mainly used for power generation in Malaysia through hydroelectric power plants. Therefore, various researches have been conducted by hydrologists to find a way to ensure sufficiency of water supply.

In this study, three drought indices, which are the Standardized Precipitation Index (SPI), the Standardized Precipitation Evapotranspiration Index (SPEI), and the

Streamflow Drought Index (SDI) are used to describe moisture conditions in northern region of Malaysia. By using the drought indices, the severity, beginning and end of the drought at particular region in Malaysia can be evaluated. Drought indices can be used as a primary tool in drought detection and monitoring in Malaysia. It is the best way to help in forecasting the possibility of drought occurrences by evaluating the degree of dryness or wetness. It is a baseline study work which gives information for further operations like early warning, risk analysis, preparation and contingency planning for drought.

The problem of water supply deficiency in Malaysia is becoming more noticeable as the water pollution and water demand are increasing every year due to population growth. With the aids from drought indices, policy makers will be able to establish standards and guidelines for all public and private agencies. For instance, drought indices can be used to guide government's water saving management during drought.

The output of this study is also crucial to provide fundamental data input required for water engineer to do their research in water planning. Example of water resources planning are building dams, treatment plants and engineering structures that increase water supply to support the population growth. The hydrological data of this study is not only useful in proper planning and design of water resource projects, it can also be used to evaluate the management and development of water resources in Malaysia by measuring the drought in those water resources.

1.3 Problem Statement

The water crisis problem in Malaysia is mainly caused by a series of factors. Such as the changing of weather patterns, high wastage due to non-revenue water and low awareness of public, pollution and sedimentation due to construction, and a host of other problems which leads to water shortage. However, the main contributing factor of drought events in Malaysia is due to the great variation of rainfall amount over time and space. The rainfall variation causes uneven temporal and spatial distribution of precipitation. Together, these reasons may cause severe damage if the problems do not get a proper solution. In fact, some areas in Malaysia were always in danger to drought. On the other hand, Malaysia has high water demand compared to other countries. These values are anticipated to become even higher in the future due to population growth, subsequently causing more places to be under water stress. In this case, evaluation of current drought conditions and trends in Malaysia is important for mitigation planning to reduce the impacts of droughts as drought indices can effectively help to evaluate and forecast a drought's occurrence.

1.4 Aim and Objectives

The aim of the study is the investigation of drought conditions of Northern Region in Malaysia using Drought Indices. The objectives of the study are as below:

(i) To investigate the dryness of Northern Region in Malaysia using Drought Indices.

(ii) To carry out spatial analysis study on drought across the Northern Region in Malaysia

(iii) To carry out temporal trend analysis on drought for Northern Region in Malaysia.

(iv) To compare the theoretical drought events estimated by Drought Indices with the reported historical drought events.

1.5 Scope and Limitation of the Study

The scope of this study is to analyse the drought on northern region in Malaysia by measuring the moisture condition using the Standardized Precipitation Index (SPI), the Standardized Precipitation Evapotranspiration Index (SPEI), and the Streamflow Drought Index (SDI).

The northern region in Malaysia consists of 4 states, namely, Perlis, Kedah, Perak and Penang. Geographically, there are high and rough terrains surrounded the relatively flat northwest zone, and separated it from the rest of the Peninsular Malaysia. Majority of the paddies are grown at this northern region due to the present of flat terrains. Paddy's production is depending on soil moisture conditions therefore its cropping is affected by drought. However, previous studies had found that the northern region is one of the driest region during the northeast monsoon season (Tan, 2018). Therefore, drought condition in northern region will be assessed in this project.

Limitations of this study includes the availability of raw data. In Malaysia, measurement of meteorological and hydrological data is mostly done by ground-based (in situ) observations. Therefore, there are some uncertainties in the data which come from measurement errors, stochastic error due to the random nature of rainfall, and systematic errors. Although repairing procedure will be carried out, it is inevitable that the estimated value still differs from the exact real value. Furthermore, the variability data is also another limitation in describing droughts. For instance, soil moisture condition is not available in Malaysia for monitoring agricultural droughts. Hence, there is a need to identify a drought index that best describe drought conditions with the current status of data availability.

At the same time, the coverage area of whole northern region is wide, some remote areas did not have any meteorological stations to record the rainfall data in the past and some stations are not functioning well. The only solution is to apply spatial interpolation techniques to estimate the rainfall based on available data from surrounding stations. Hence, the discrete point measurements will be transformed into continuous measurements in this study by interpolating the data in between discrete points.

In short, there is a need to identify a drought index that best describe the exact moisture condition, from the various drought indices with different advantages and limitations. Furthermore, spatial interpolations are need to be done to show the moisture conditions in remote areas.

1.6 Contribution of the Study

Even though drought is a natural phenomenon, the data obtained in this study can help to forecast the happening of drought, giving out warning, so that the most effective early preparation can be done to reduce the impacts. Water resources planning based on the data can help to maintain a balanced supply-demand of water in Malaysia by reducing the demand or increasing the supply to make up for the rainfall deficiency. Example of water resources planning are providing adequate infrastructure, public awareness in water resources management, appropriate water policies and preventive measures. Therefore, the main contribution of the study is to help in reducing the various drought impacts by monitoring drought and providing warning in Malaysia. The impacts of drought can be economical, social and environmental, including forest fires, reduced crop, decreased in water level, decreased water quality, and increased death rates.

1.7 Outline of the Report

This report is divided into 5 chapters. Chapter 1 consists of general introduction of drought in Malaysia, background and significance of the research, objectives and their corresponding problem statements, scope and limitation of the study, contribution of the study as well as outline of the report.

Chapter 2 gives a review on drought definitions, drought indices, spatial and temporal analysis of drought, and sea surface temperature that may be related to drought.

Chapter 3 mainly discusses about the methodologies of different drought indices applied in this study.

Chapter 4 consists of the result and data obtained from computation of different indices. The results and data are then compared. Discussion is then made based on the outcome.

Chapter 5 makes a conclusion of the study conducted.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a literature review on the definition of drought. Different categories of drought were explained. Then, various studies on drought indices were reviewed, followed by spatial and temporal analysis method. Finally, sea surface temperature that may be related to drought were also discussed in this chapter.

2.2 Drought

Understanding of different concepts of drought, along with their characteristics is important in drought monitoring and warning. This can be done by studying the impacts caused by historical droughts as well as the contributing factors of the events. Thereof, assessment can be done and be useful for further water resources planning and management.

Drought is a temporary aberration in water availability, which occurs in every different climatic zone all over the world. It is mainly caused by the lack of rainfall over a long period, like a season or even a year. It is different with aridity and heat wave. Aridity is a permanent type of climate constantly happens at some low rainfall areas, while heat wave is an episode of excessive heat that often accompanied by excessive humidity. The typical time scale for drought is longer as compared to a heat wave. Drought may persist for months or even years, however heat wave only happens within period of a week (Mishra and Singh, 2010).

The definition of drought normally depends on its impacts on environment and society. Therefore, it is hard to define accurately the starting and ending dates of a drought, since the impacts of a drought only become observable after a long period and impacts may continue last for years even after the termination of a drought event (Zargar et al., 2004). Drought impacts are non-structural and may cause damage to large geographical areas. Thus, the quantification of its impacts and the corresponding mitigating measures are far more difficult, compared to other natural hazards (Mishra and Singh, 2010). At the same time, the sectors influenced by drought are broad. Firstly, the reduce in water quantity for both surface and groundwater resources may cause disturbance in hydro-power generation, riparian habitats, water recreation activities as well as other economic and social activities. Other than that, the absence of surface runoff may also cause deterioration of water quality when there is insufficient flow to transport the organic matter, nutrient, and sediment; affecting the water users.

Drought is a creeping phenomenon not only caused by rainfall deficits, other factors such as temperature, wind, humid and so on will also lead to drought. Therefore, drought is a complex phenomenon that is hard to be defined through universal method because the definitions differ when spatial and context conditions changes. The term of drought can be defined in two ways: conceptual and operational. Conceptual definitions are generally explaining the drought concept: drought is a natural hazard, which causes insufficient amount of water to meet the water requirement for ecosystems or human activities, due to deficiency of precipitation from expected or normal (Pedro-monzonís et al., 2015). Moreover, drought can be described as a significant event, which deviated from normal hydrologic conditions of that area (Wilhite and Glantz, 1985). Drought hazard is also defined as percentage of years when crops fail happens due to the lacking of moisture. In fact, there are more than 150 conceptual definitions were identified by different researchers, which are then classified into four main categories: meteorological, agricultural, hydrological, and socioeconomic drought (Quiring, 2009).

As for operational definition, it attempts to identify a drought's beginning, end and severity and explain how a drought operates (Wilhite and Glantz, 1985). These elements are the basis of an effective early warning system. It is arbitrarily derived by comparing the current situation to past 30 years historical average data or even longer period of time, to detect the threshold (the degree of departure of a variable from normal value) over a specific time period that might resulted in a beginning of drought (Wilhite and Glantz, 1985). One of the best ways to operationally define drought is by mathematical indices.

2.2.1 Meteorological Drought

Meteorological drought is defined as a natural phenomenon of continued lacking in precipitation, which is related global behaviour of the ocean-atmosphere system. Therefore, precipitation is commonly used to analyse the meteorological drought. Monthly precipitation data are usually studied to find the precipitation deficit with respect to average values in order to analyse the drought. However some approaches use cumulative precipitation shortages to analyse drought’s duration and intensity (Mishra and Singh, 2010).

2.2.2 Agricultural Drought

Agricultural drought is the phenomena when moisture in root zone is insufficient to meet the demands of a crop, thus affecting the crop yields. Precipitation, temperature and soil moisture are the three main components for agricultural drought study. A decline of soil moisture is caused by several factors, such as meteorological precipitation deficit and potential evapotranspiration which depends on temperature. The water demand of crop depends on its biological characteristics, stage of growth, prevailing weather conditions, and the soil’s physical and biological properties (Mishra and Singh, 2010).

2.2.3 Hydrological Drought

For hydrological drought, it represents the stage where the level of surface and subsurface water resources is too low to establish its water uses and functions. Flows in water resources like lakes, and groundwater will drop below normal level, and hence data required for hydrological drought monitoring is mainly the streamflow data. It is found that the geology properties will also affect the hydrological droughts, this is proved by result of a regression analyses which relate the streamflow to catchment properties in a drought analysis (Mishra and Singh, 2010).

2.2.4 Socioeconomic Drought

Socioeconomic drought is the only term that is not representing a nature hazard. It is associated with the water scarcity that has caused economic, social and environmental impacts. It is also associated with supply and demand for water, such as events of water resources systems fail to meet water demands. It occurs when the demand for water exceeds supply, due to happening of weather-related shortfall in water supply (Mishra and Singh, 2010).

2.2.5 Groundwater Drought

Groundwater drought is an addition type of drought which seldom included in classification of droughts. Drought will cause reduction of groundwater recharge followed with groundwater levels and groundwater discharge. Such phenomena are called groundwater drought and it generally occurs on a longer time scale. Usually the decrease of groundwater level is used to define the groundwater drought since the total amount of water that is under the ground is difficult to define (Mishra and Singh, 2010).

2.3 Drought Indices

Subjectivity in drought definition has made it very hard to establish a specific and universe drought index (Vicente-Serrano, Beguería and López-Moreno, 2010). Since there are too many conceptual drought definitions from different perspective, it is hard to define it precisely and monitor it in a single method. In other words, no single operational definition can be applied for all types of drought. Therefore, different drought index thresholds have to be applied by policy makers, resources planners and hence implement the most suitable preventive measure for different circumstances.

An association of variables that characterizes the drought, also known as the indicators, are investigated by researchers. Examples of indicators are: precipitation deficit, groundwater level, streamflow, reservoir storage and etc. Drought index is then developed from raw indicator data into a single numerical value that is readily usable for decision-makers or publics to define drought under different approaches. Drought index is “an index related to some of the cumulative effects of a prolonged and abnormal moisture deficiency” (Richard and Heim, 2002). Time and space processes of water supply and demand are important in defining drought and deriving its index (Richard and Heim, 2002). Based on Richard and Heim, there are some criteria used to choose a suitable drought index:

(i) The index should be able to account for problem statement.

(ii) It should have a long accurate past record for validation.

(iii) It should measure large-scale, long-continuing drought quantitatively.

(iv) The index should be practical based on situation (such as nature of indices, input data collecting process should be considered).

(v) The timescale of the index should be fitted to the problem.

Mostly drought indices are computed using precipitation data, which is the main indicator either individually or together with other meteorological elements (Richard and Heim, 2002). On the other hand, drought indices can be categorized based on the variables that they are related to or the use of disciplinary data, but more often they are categorized into three popular categories based on their impacts or definitions, which are meteorological, agricultural and hydrological drought indices (Zargar et al., 2004).

Examples of popular drought indices include Palmer Drought Indices (PDSI), Standard Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Streamflow Drought Indices (SDI) and etc. For example, SPI and PDSI were applied in examining past drought and assessing future drought scenarios in Oklahoma (Liu et al., 2013). The study showed that by considering the soil moisture contents, PDSI showed more severe future drought will occur in the western part of the basin. Other than that, SPI and PDSI have also been used to study their relationship with streamflow in 10 large regions of China (Zhai et al., 2010). The study found that these two indices were not limited to meteorological droughts but also presented a moderately high and statistically significant correlation with the percentage of runoff anomaly for six large rivers.

As for recent trend of researches, SPEI seems to be the popular choice among the indices. For example, it was used by Vicente-serrano et al. in year (2012) to assess its performance against SPI and PDSI in ecological, agricultural and hydrological drought. The authors found that SPEI and the SPI, which were calculated on different time scales, were better than PDSI in capturing the drought impacts. Although the difference between SPI and SPEI were small, the SPEI was shown to be the better index, especially during summer when temperature played an important role in affecting droughts. This is followed by the study from Liu et al. (2016), which conducted the SPEI on Loess Plateau of China to analyse multiscalar drought characteristics spatially and temporally. There was a comparison done between SPEI and SPI, results indicated that SPEI was a robust index to monitor and analyse regional drought, due to simplicity in calculation, its multi-scale nature, the consideration of temperature effects on drought conditions and low data requirement. Even in one of the latest studies, SPEI was applied together with SPI to characterize historical drought in Ethiopia by Bayissa et al. (2018).

Streamflow Drought Index (SDI) is another category of widely applied drought index, which the main purpose is to study hydrological drought. For example, Yeh et al. (2015) used SDI as input for Markov Chain model for hydrological drought forecasting of Yilan and Lanya River basins located in Taiwan. To compute SDI as input to the model, precipitation and streamflow data were used. The SDI analysis results in the study showed that significant drought characteristics were found in analysis periods of three months and six months. Borji et al. (2016) also explored the usage of SDI as inputs for the drought forecasting in Jajrood River, Iran. Runoff data was used to estimate SDI and thereafter the SDI were used as inputs for SVR and ANN to forecast hydrological droughts. Other than these studies, there are also other application of SDI in the study of hydrological droughts (Nalbantis, 2008; Tabari, Nikbakht and Talaee, 2012; Kermen and Onuşluel Gül, 2018).

2.3.1 Palmer Drought Severity Indices (PDSI)

Palmer drought severity index (PDSI) emphasises on abnormal deficiency of moisture supply (Zargar et al., 2004). It is mainly used to characterize and evaluate meteorological and agricultural droughts, by comparing the observed to the expected precipitation to find the anomaly moisture index, and also the drought index, which is severity of drought. It is the most popular landmark of drought indices developed by Palmer in year 1965 based on the concept of water balance equation in term of water demand and water supply. In order to compute the four important terms in water balance equation, which are evapotranspiration, runoff, soil recharge, and moisture loss from surface layer, data required to carry out PDSI calculation is a time series of antecedent data of precipitation, temperature, and also local available soil moisture content. PDSI is a measurement of both dryness and wetness, the negative index value represents the severity of dryness; the positive index value represents the severity of wetness.

Palmer applied Thornthwaite's concept in estimating the potential evapotranspiration, which is an important parameter for hydrologic accounting. Certain assumptions were made for the hydrological accounting model such as how was the moisture transferring process at the soil layers. The model is assumed to be a two layers model, the top soil layer with 1 in. depth capacity, and the effective root zone bottom layer. Runoff is assumed to be generated only when both soil layers are saturated. Monthly precipitation is consumed during that month for evapotranspiration, soil moisture demand or lost as runoff (Richard and Heim, 2002).

Palmer also normalized his computations by Climatologically Appropriate for Existing Conditions (CAFEC) quantities. After normalizing, the index will be usable to make comparison across different across space and time. Normal rainfall and temperature that subsequently causing normal soil moisture condition will produce a zero index value, in different seasons and climates. However, the positive value denotes the extra wetness; and the negative value demotes the dryness, also known as the drought severity (Richard and Heim, 2002).

There are five main steps in PDSI computations. The first step is the hydrological accounting, next is to calculate the climate coefficients, followed by CAFEC value and the Z index, lastly is the PDSI time series, which shows the severity, beginning and ending of drought.

2.3.1.1 Advantages of PDSI

This index is the most effective in measuring agriculture drought, which is sensitive and high relevant to soil moisture conditions. It is the best drought monitoring tool in agriculture sector helps for planning of a drought contingency plan. Moreover, meteorological drought can be assessed by PDSI at the same time (Agwata, 2014). Therefore, the adoption of PDSI is beneficial to wide variety group of people, including the internal meteorologists, hydrologists, researchers and external policy decision makers, foresters and all the publics.

2.3.1.2 Limitations of PDSI

Based on the review by Richard and Heim (2002), there are severe limitations to take note when using the PDSI. The model was tested under different climate regimes in last 30 years, and the related concerns were divided into two categories: limitation based on general use of water balance models, and limitation in Palmer's model in particular. Firstly, Palmer Index was designed only accountable for drought problem happened in region with semiarid and dry sub-humid climates. It is designed to treat local precipitation as the main source of moisture. Extrapolation beyond these conditions will give an unrealistic result.

Secondly, the seasonal or annual changes of crops and their root development are neglected when forming the water balance models. It is assumed that all parameters are same for every month in the past few decades until today. Next, the neglect on natural delay between precipitation falls, and hence generating excess water and turning into runoff is not taken into consideration. At the same time, other types of precipitation such as snowfall, snow cover, snow melt, and frozen ground are not included. Therefore, PDSI computation is not accurate in regions with snow fall during the winter and spring seasons (Richard and Heim, 2002).

Two soil layers are assumed in the model, the water balance computations are simplified and it may not be an accurate representative for a specific location. In addition, it assumes no runoff is released in the model unless all soil layers were fully saturated, which leads to an underestimation of runoff (Richard and Heim, 2002).

Since the index is sensitive to the available soil moisture, therefore it is too general to apply a universe climate division only. Besides, Palmer’s index is not spatially comparable across the different countries nor directly comparable between months. Although this index was normalized and become applicable for different locations and seasons, it is not accurate enough for regions all over the world to apply it. The weighting factor in this model was derived from the study of only nine climatic divisions and based on annual data (Richard and Heim, 2002).

Furthermore, the drought severity classes and the transition index values, which indicates beginning and ending of drought or quantifying the intensity were arbitrarily selected and not proved by science theory. On the other hand, asymmetrical and bimodal statistical distributions of the PDSI may exist (Richard and Heim, 2002).

It is not suitable for hydrologic droughts impact analysis, which resulted from longer droughts since PDSI has an inherent time scale which focus on short-term agricultural impacts only. Moreover, its result may not be accurate in regions with extreme rainfall or runoff variability. The outcome result of PDSI computation will have more "extreme" and "severe" drought classifications in some parts than in others. PDSI is also not suitable to be used for drought intensity comparison of two regions and will increase the difficulty in drought planning responses. It is also slow responded to developing and diminishing droughts (Agwata, 2014).

Also, it is designed for agriculture and not for hydrological impacts from longer drought. Moreover, PDSI is not suitable to be applied at locations with extreme climate, mountainous terrain, or snow-pack. Lastly, the lag between rainfall and runoff is neglected in PDSI (Alley, 1984; Karl& Knight, 1985).

2.3.2 Standard Precipitation Index (SPI)

Since drought is dynamic in nature, its temporal characteristic must be considered. Therefore, another drought index, SPI has been introduced and is popular in hydrological studies until today. Based on Vicente-Serrano, Beguería and López-

Moreno (2010), SPI is an index developed by McKee in 1993, which is comparable in time and space. Therefore, it can effectively analyse the temporal changes and spatial changes of drought. Unlike some complex drought indices like PDSI, SPI is easier to be computed as it requires only precipitation as the data input. SPI derivation theory is based on the conversion of long-term precipitation data to probabilities; the probabilities are then standardized to the mean of '0' and standard deviation of '1' (Vicente-serrano et al., 2012). Result with negative value represents the lack of moisture condition, while positive value represents surplus of moisture condition.

2.3.2.1 Advantages of SPI

Based on the WMO and GWP (2016), SPI is popular since it has a strong theoretical development with high accuracy, the input data is easily obtained, and it has high versatility in drought analyses. Many research papers about SPI are available and can be referenced for assistance, which is very beneficial to SPI users. Other than that, SPI is suitable even when the precipitation record available is in short periods and contain missing data (WMO and GWP, 2016). SPI is also applicable for any climate regimes, and it is comparable between different climates (WMO and GWP, 2016) as it is measured based on the comparison of current conditions with historical standardized value of particular region. Therefore, its outcome will not be affected by geographical differences across the region. Another advantage of SPI is that it can be applied to measure different types of drought, with different time scales (Vicente-serrano et al., 2012).

2.3.2.2 Limitations of SPI

According to Vicente-Serrano, Beguería and López-Moreno (2010), temperature is having a slightly increase during the last 150 years due to the climate change. However, this slight change is expected to cause an increase in the evapotranspiration rate, and hence the resulting water demand will increase, causing dramatic consequences for drought conditions. Unfortunately, this global climate change, which will affect the drought events is unable to be detected using SPI. Since SPI is computed using only precipitation data, other variables such as temperature, evapotranspiration, and soil moisture are not considered. As temperature plays an important role in water balance and water use of a region, it will be less accurate to compare events with different temperature using SPI (WMO and GWP, 2016). Human impacts on the water balance, such as irrigation, are also neglected in SPI. On the other hand, although the SPI can proceed without a long-term, cohesive and complete datasets, it might still lead to misuse of the output, and reduce the reliability of SPI result (WMO and GWP, 2016).

2.3.3 Standard Precipitation Evapotranspiration Index (SPEI)

Vicente and Sergio (2015) has discussed a new index named standardized precipitation evapotranspiration index (SPEI), which is an extension of SPI index derived based on both precipitation and potential evapotranspiration (PET), making it being able to measure the impact of increased temperatures on water demand. PET can be estimated with the simple Thornthwaite method, if the data available is limited, so that wind speed, surface humidity and solar radiation variables are not required (Vicente and Sergio, 2015). However, a more detailed method to compute the PET can be applied if these variables are available, although these additional variables can have large uncertainties (Vicente and Sergio, 2015).

2.3.3.1 Advantages of SPEI

SPEI is the advancement of both PDSI and SPI, which combines the PET concept from PDSI and the precipitation computation concept of SPI. Hence, the SPEI can reflect the changes on evaporation demand resulted from temperature fluctuations and trends. At the same time, SPI’s function is included to simplify the precipitation calculation and consider the multitemporal nature of drought. SPEI is applicable and comparable for all climate regimes, because they are standardized. This is a new index that is suitable to be used for detection on consequences of climate change on drought conditions (Vicente-Serrano, Beguería and López-Moreno, 2010) and model output under various future scenarios.

2.3.3.2 Limitations of SPEI

Computation of SPEI requires more input data for PET modelling, this is because longer base period (30-50+ years) is required to sample the natural variability of drought (Vicente and Sergio, 2015). Therefore, SPEI is more difficult compared to SPI. Moreover, the accuracy of result is highly related to the model of PET (Vicente and Sergio, 2015). Although Thornthwaite method is widely accepted, it is still an approximation based on temperature data.

2.3.4 Streamflow Drought Index (SDI)

Computation method of SDI is relatively similar to SPI, it standardizes the historical monthly streamflow values and describes the current conditions based on the standardized value (WMO and GWP, 2016). Both wet and dry condition will be shown though the negativity of SDI values, and the duration of the drought is also observable from the time series.

2.3.4.1 Advantages of SDI

SDI is easy and flexible to apply. Various timescales can be applied, short and missing data are also allowed in the computation. However, long streamflow record is recommended for quality results (WMO and GWP, 2016).

2.3.4.2 Limitations of SDI

It does not consider the management decisions of water resources, as streamflow is the only input to the model (WMO and GWP, 2016). Therefore, the result might be hasty. Meanwhile, periods of no flow might skew the outcome (WMO and GWP, 2016).

2.4 Spatial and Temporal Analysis

Drought will bring uncountable damage to the economies, societies and also environment. Evaluation and prediction of drought's severity, intensity, frequency, and geographic extent is important for impacts control and mitigation, especially in hydrological cycle, water management and crop production sectors. An accurate quantitative measurement technique is required for monitoring of drought events. Therefore, spatial and temporal analysis to obtain accurate drought spatial and temporal information must be carried out.

Spatial analysis investigates the dependence of variables over space. For example, the drought pattern may be influenced by the rain shading or strong wind, which is related to irregular topography such as variability in altitude, slope and aspect. As for temporal analysis, it is about the analysis on the dependence of variables over time, e.g. monthly, seasonal and etc. In short, both spatial and temporal correlations are important to study the structure of droughts. Data with same period at each observation are required, and missing data must be taken into account (Matthias, 2005).

In order to obtain an accurate spatial distribution of rainfall, it would be better to increase the density of monitoring network. However, interpolation to estimate the data remains necessary even for dense networks, to transform point data into a raster map. Geographic Information System (GIS) is the common tool for the interpolation tasks. GIS provides visualisation, analysis, and modelling based on a raster representation (Mitas and Mitasova, 1999).

Many types of interpolation and approximation methods can be used to predict values at unsampled locations. In GIS applications, these interpolation and approximation methods are adopted to predict values at every single point so that different discrete can be transformed into a whole continuous representation of spatiotemporal fields. The selection of an appropriate interpolation method with adequate parameters is crucial since different methods will produce different spatial representation (Mitas and Mitasova, 1999).

A study on spatial and temporal analysis of meteorological drought with SPI and SPEI was carried out by Yuan, Quiring and Patil (2016). The authors found that drought was highly affected and varied over time and space, where seasonality was the major factor affecting the drought in the study compared to indices, interpolation method, density of stations and climate region. Between the two most popular interpolation methods, the results from the study by Ali et al. (2011) showed that Inverse Distance Weighted (IDW) with power of two was suitable for SPI and Ordinary Kriging (OK) was suitable for another index known as Effective Drought Index (EDI). This is followed by a few studies, which also claimed that IDW is more practical for the spatial interpolation at their study region (Rhee et al., 2008; Bagheri, 2016; Mondol, Ara and Das, 2017).

2.4.1 Inverse distance weighted (IDW)

IDW is the most common interpolation method since its computation is easy to understand and apply. This method enforces that the nearby known points will influence more than those farther away, suggesting that estimated value of a point is more dependent on the nearer points. The illustration of IDW is shown below as Figure 2.1. Despite of its popularity, it has some limitations compared to other interpolation methods, such as the limited extrema values. It will only produce local extrema based on the existing data points, where it cannot estimate any values out of the range used for known data points. Therefore, it is rather poor for prediction at peaks or mountainous areas (GIS Geography, 2018a). However, IDW is still applicable for meteorological estimation to estimate either the value of un-sampled points or points with missing data. This method is conformed to meteorological characteristic, where the estimation is more influence by nearby points.

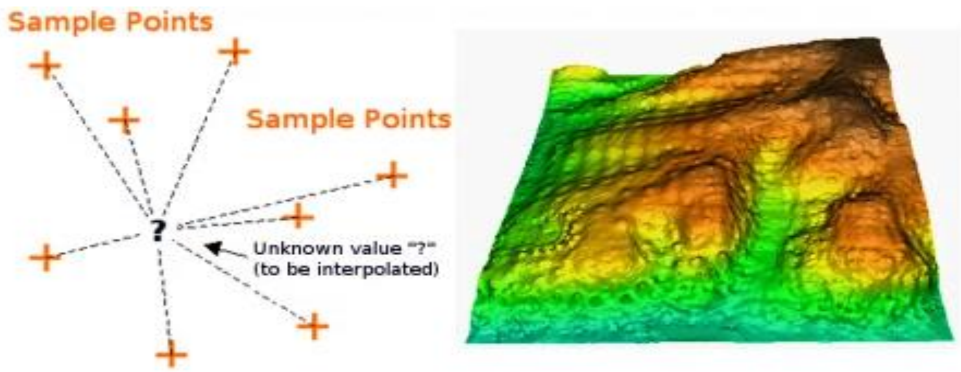


Figure 2.1: Inverse Distance Weighted (IDW) Interpolation Method (GIS Resources, 2014)

2.4.2 Ordinary Kriging (OK)

Ordinary Kriging (OK) is a geostatistical interpolation method. This interpolation technique does not only focus on the distance, it also considers the degree of variation between known data points. It measures the relationship in samples using weighted average technique and further estimate the value for other unknown points. The main feature of this method is strong prediction. It uses data provided, build a mathematical function with a semivariogram, then transform it into a prediction surface. Therefore, the input model can be validated by a cross-validation. At the same time, the validity of the prediction is measured. For OK, its estimated values can exceed value range of input data, and the estimated surface does not pass through the input samples. Its radius can be set to a fixed value depends on the data inter-related distance. There are three criteria that are needed to be fulfilled before applying the OK, which are data needs to be normally distributed, stationary and no global trends. Normally distributed denotes the plotting of data can be fitted into a bell-curve shape. Stationary denotes a fairly constant variance different region. No global trend denotes no systematic change in data across entire study area.

Autocorrelation helps in understanding the degree of similarity of one to others. It is quantified by semivariogram by graphing out the variance of all data pairs according to distance. Concept of semivariogram is simplified as closer things are highly related and have small semi-variance and vice versa. Up at a certain range, which is known as sill, there will be no more autocorrelation (GIS Geography, 2018b).

2.5 Climate Indices for Sea Surface Temperature (SST)

Malaysia is geographically located in between Pacific Ocean and Indian Ocean. Based on the report from Tan et al. in (2018), as one of the members of the Maritime Continent (MC), Malaysia's climate is highly affected by ocean-atmospheric interactions. For examples, El-Nino Southern Oscillation (ENSO), which is the study of ocean-atmosphere interactions in the Pacific Ocean; and Indian Ocean Dipole (IOD), which is the study of ocean-atmosphere interactions in the Indian Ocean (Islam et al., 2018). These climate phenomena are independent and can occur in conjunction with each other. All of them must be viewed together in order to study the precipitation pattern and also the drought pattern in Malaysia (Williams and Hanan, 2011).

2.5.1 Oceanic Nino Index (ONI)

Based on the National Oceanic Atmospheric Administration (NOAA), ENSO is a global atmospheric circulation which causes irregular periodic variation in the Sea Surface Temperature (SST) with the range of 1°C to 3°C, compared to the normal over the tropical eastern Pacific Ocean. Climate interaction that causes a periodic warming of SST at tropical eastern Pacific Ocean is the oscillating of warming pattern called as El Nino phase. In adverse, La Nina is an oscillating of cooling pattern at tropical eastern Pacific Ocean. The Oceanic Nino Index (ONI) is a measurement related to ENSO at eastern Pacific Ocean (NOAA, 2018). The index calculates monthly average SST in the Nino 3.4 region, averages it with values from the previous and following months to become a 3-months season, then comparing it to a 30-year average to observe the departure. ONI values of 0.5 and above represented a warm phase El Nino; and ONI values of -0.5 and below represented a cool phase La Nino. The evolution of an ENSO event takes about one year and occurs every 2 to 7 years (Jailan, 2015).

2.5.2 El Nino Modoki Index (EMI)

Furthermore, a variant of El Nino event known as El Nino Modoki, central Pacific El Nino, or warm pool El Nino is new evolved, where the maximum warming occurs at the central equatorial Pacific Ocean but cooling in the eastern and western tropical Pacific (Tangang et al., 2012), as shown in Figure 2.2. El Nino Modoki Index (EMI) is the index to measure it. Modoki event was found in the late of 1970s, it was probably caused by the increased of background temperature due to global warming (Salimun et al., 2014). The maximum warming location of El Nino Modoki shifted from east and reached the center equatorial Pacific Ocean, and thus affecting the area such as southern China, Indo-China Peninsula and Malaysia (Salimun et al., 2014). Due to westward shifting of warming of El Nino Modoki to the central equatorial of Pacific Ocean, the northern region of Malaysia was affected and experienced significant negative rainfall especially during the December, January and February (Dec.-Feb.) (Jailan, 2015), as shown in Figure 2.3.

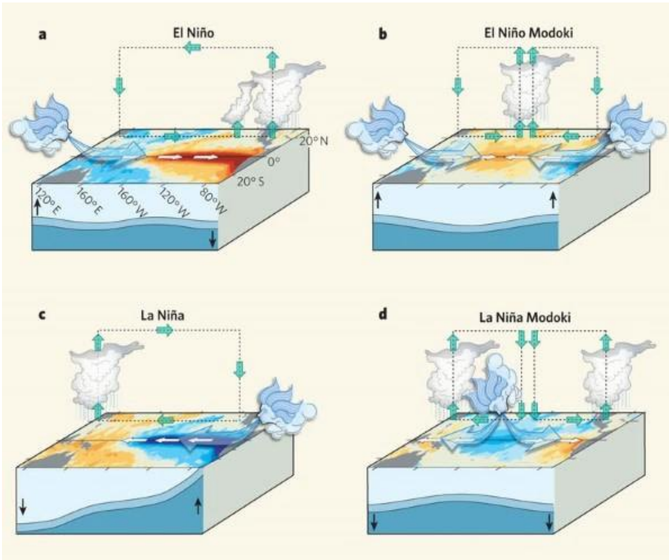


Figure 2.2: Diagram of El Nino, El Nino Modoki, La Nina, La Nina Modoki (PMF IAS, 2016)

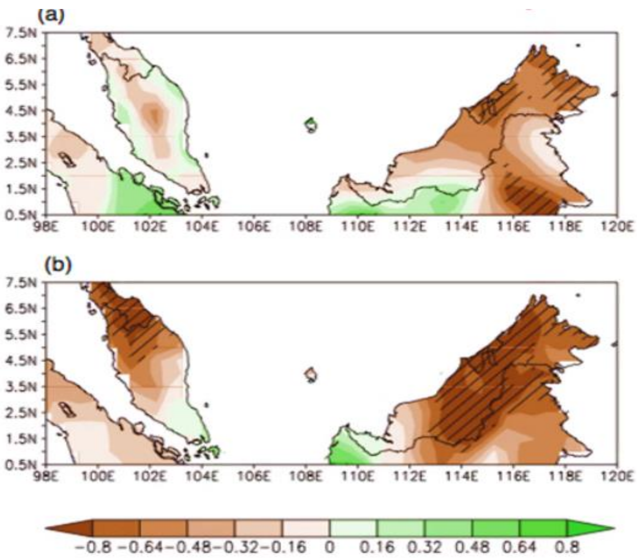


Figure 2.3: The Composite of Rainfall Anomalies in (Dec.-Feb.) for a) Conventional El Nino and b) El Nino Modoki (Salimun et al., 2014; Jailan, 2015)

2.5.3 Dipole Mode Index (DMI)

On the other hand, Indian Ocean Dipole (IOD) is the study of irregular oscillation of SST over the western Indian Ocean. Dipole Mode Index (DMI) is the index to measure the intensity of IDO by observing SST gradient between western equatorial and south eastern equatorial of Indian Ocean (Islam et al., 2018). Positive DMI indicates cooler than average SST in the southeast Indian Ocean and greater than average SST in the western Indian Ocean. Negative DMI indicates greater than average SST in the southeast Indian Ocean and cooler than average SST in the western Indian Ocean. IOD usually happens from July to November with 5 to 6 months duration (Tangang et al., 2012).

2.6 Summary

Drought can be defined as a temporary rainfall deficiency (meteorological drought), or creeping phenomenon caused by the lack of rainfall over a long period such as agricultural drought, hydrological drought, social-economical drought, ground water drought and so on. Drought is not only caused by rainfall deficits, other factors such as temperature, wind, humid and so on will also lead to drought. Other than that, drought may also be related to global behaviour of the ocean-atmosphere system, such as ENSO and IOD. One of the best ways to operationally define drought is through mathematical indices, which attempts to identify drought's beginning, end and severity and explain how drought operates. Mostly, drought indices are computed using precipitation data, either individually or together with other meteorological elements. Some examples of popular drought indices applied by researchers are PDSI, SPI, SPEI, SDI and so on due to their advantages. As for recent trend of researches, SPEI seems to be the popular choice among the indices due to it uses both precipitation and PET, making it being able to measure the impact of increased temperature with simple calculation. Spatial analysis investigates the dependence of variables over space, and previous studies showed that IDW with power of two is suitable to interpolate the spatial changes of drought condition in a region.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The overall work plan of this study is shown in Figure 3.1. After the reviews on previous studies, drought indices SPI, SPEI and SDI were chosen in this study to describe droughts in northern region of Peninsular Malaysia. These three indices require different combinations of input variables, which are rainfall for the SPI, rainfall and temperature for the SPEI and streamflow of the SDI. These three indices are used due to their computation simplicity, and the availability of input data. Historical daily data of these inputs in past few decades was recorded at meteorological stations distributed at whole region. However, the PDSI is not adopted as one of the input data, the soil moisture content is not available, and therefore the computation of the PDSI cannot be carried out.

Firstly, the baseline study was carried out to understand the characteristics of study area. The northern region of Malaysia is studied in this research to determine which type of drought commonly happen, and to double confirm the applied drought indices are suitable for the region.

Secondly, the coordinates of rainfall and streamflow stations were identified to retrieve the corresponding historical observed data (daily precipitation, streamflow) from the Department of Irrigation and Drainage (DID) in Malaysia. Meanwhile, the temperature data was obtained from the Malaysian Meteorological Department (MMD). In this study, all the historical data obtained span from year 1983 to 2017 (35 years).

After the raw daily data was obtained, they were formatted into an excel worksheet for further processing. Repairing works for the missing or error data were carried out using the four quadrant IDW in order to obtain a complete and valid input data set. Then, the daily data was converted to monthly for further computation usage. A series of computations were carried out for each drought indices using corresponding formula. Next, the indices obtained were analysed to estimate the drought frequency, mean drought duration, mean drought intensity, mean drought severity, mean drought peak, and average moving range. The comparison of results obtained using different drought indices is carried out, followed by a detail discussion to explain the results. The spatial and temporal analysis were then carried out to study the changes of drought indices over space and time. Lastly, a historical drought comparison between the estimated droughts and reported droughts is carried out evaluate the performance of each drought indices.

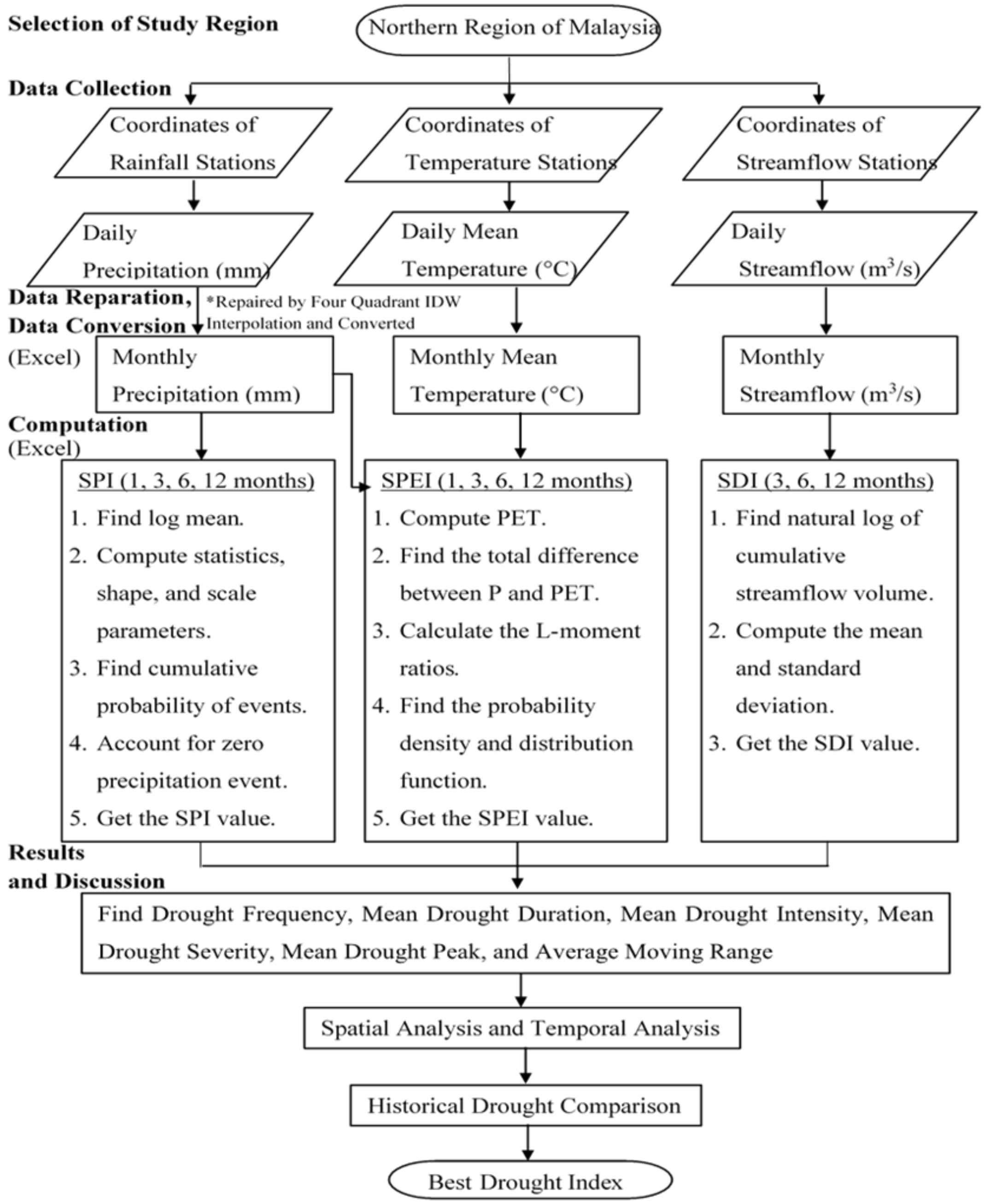


Figure 3.1: Flow Chart of Methodology

3.2 Location of Study and Data Acquisition

The rainfall, temperature and streamflow stations in the northern region that were investigated are shown in Figure 3.2. Coordinates of the stations was obtained from website of Bahagian Pengurusan Sumber Air & Hidrologi, JPS Malaysia, and plotted using Google Earth and QGIS software. There is a total of 35 rainfall stations which are well functioning in recording past historical rainfall data northern region of Malaysia, 19 of them located in Perak; 5 located in Penang; 9 located in Kedah; and 2 stations located in Perlis. Number of streamflow stations which able to provide us with streamflow input data is 6, 4 of them located in Perak; for Kedah and Perlis, each of them only has 1 station which recorded 35 years historical streamflow data.

Geographically, the relatively flat topography at the northwest zone makes it become a suitable place for agriculture expansion. However, the presence of the Titiwangsa Range in the northern parts of Peninsular Malaysia is an obstruction which makes the northern region separated with the rest of the region. At the same time it obstructs the whole northern region from receiving rainfall during the northeast monsoon raining season starting from December to March (NWRS, 2011).

The separated northwest zone of Malaysia consists of Penang, Perlis, Kedah, and Northern Perak. These few states make up the territory covered by the Northern Corridor Economic Region (NCER) which occupied about 7% area of the Malaysia. Meanwhile, 60% and above of the total agricultural area for paddy growing are located in this region, its contribution of tourism expenditures is around 30%, and contribution of exports is up to 45%. Together, The NCER contributes over 20% of GDP to the country as stated by CEO of the Northern Corridor Implementation Authority (NCIA) (Oxford, 2012). The agricultural sector is vulnerable to moisture condition, water sufficiency is extremely important in northern region, and hence, there are a variety of lakes and reservoirs for water supply and irrigation use, as shown in Table 3.1.

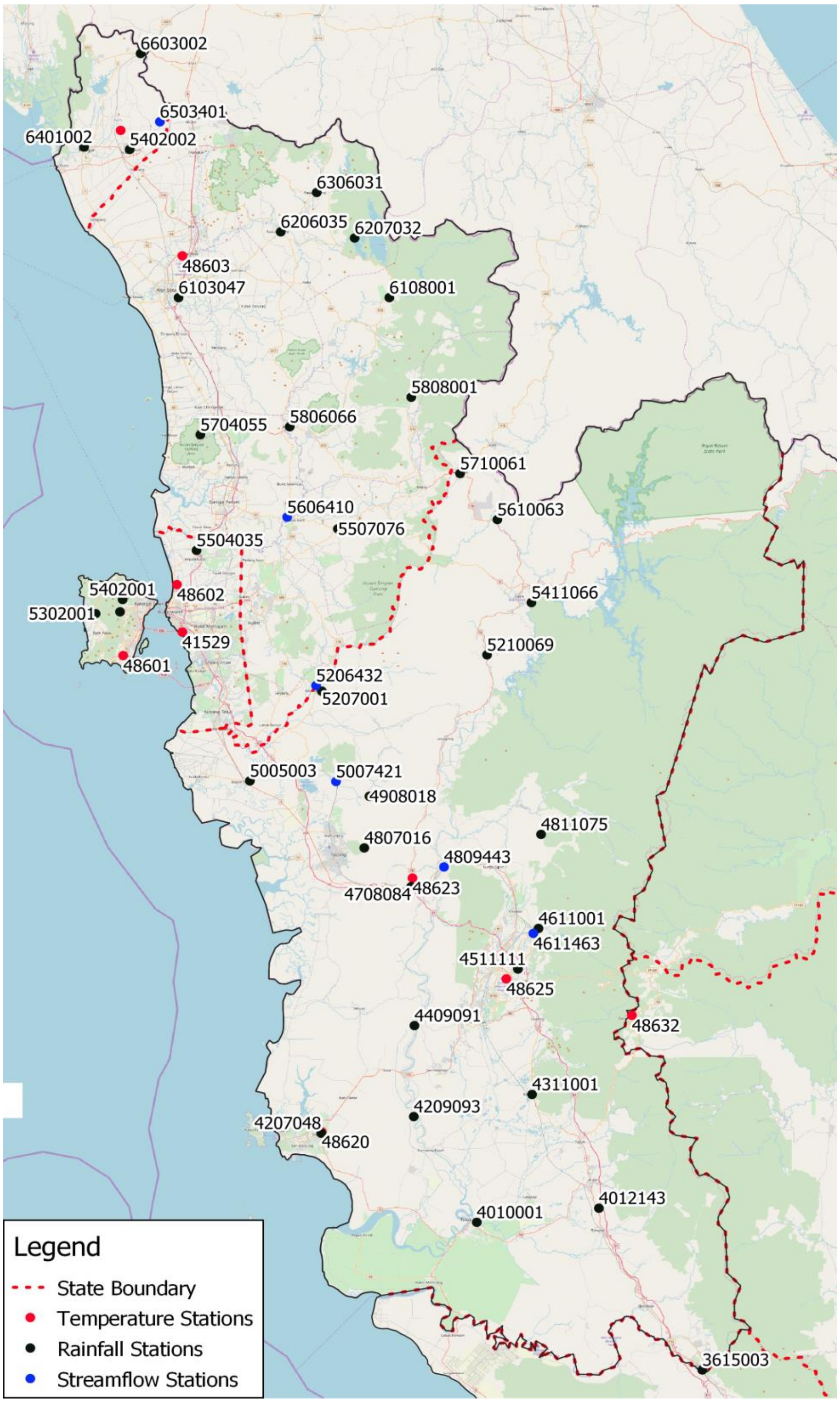


Figure 3.2: Rainfall and Streamflow Meteorological Stations in Northern Region Plotted by Google Earth and QGIS

Table 3.1: List of Lakes and Reservoirs in Northern Region (Huang et al., 2015)

State	Name of Lakes and Reservoirs	River	Purpose	Area (km^2)	Capacity (Mm^3)
Kedah	Ahning	Sg Kedah	Water Supply, Irrigation	-	275
	Malut	Sg. Malut	Water Supply	0.5	7.16
	Muda	Sg Muda	Irrigation	26	120
	Padang Saga	Sg. Ulu Melaka	Water Supply, Irrigation	0.05	0.2
	Pedu	Sg Kedah	Irrigation	65	860
	Dayung Bunting	Sg. Dayang Bunting	Natural	0.375	-
	Beris	Sg Muda	Water Supply	13.7	1224
Penang	Air Hitam	Sg Pinang	Water Supply	0.25	2.6
	Mengkuang	Sg. Mengkuang	Water Supply	0.625	23.6
	Teluk Bahang	Sg. TelukBahang	Water Supply	-	21
	Bukit Pancur	Sg. Kerian	Natural	0.061	-
Perak	Air Kuning	Sg Perak	Water Supply	-	1.8
	Bersia	Sg. Perak	Hydropower, Flood Control	5.7	70
	Bukit Merah	Sg Kurau	Water Supply, Irrigation	41	75
	Chenderoh	Sg. Perak	Hydropower, Flood Control	25	95.4
	Gopeng	Sg. Perak	Silt Retention	-	-
	Jor	Sg. Perak	Hydropower	0.5	3.9
	Kenering	Sg. Perak	Hydropower, Flood Control	60	352
	Mahang	Sg. Perak	Hydropower	0.1	0.4
	Temenggor	Sg. Perak	Hydropower, Flood Control	152	6168

Table 3.1 (Continued)

State	**Name of Lakes and Reservoirs**	**River**	**Purpose**	**Area (km^2)**	**Capacity (Mm^3)**
	Kinta	Sg. Perak	Ex-mining	-	-
	Tasik Raban	Sg. Perak	Reclaimation	0.375	-
Perlis	Timah Tasoh	Sg. Perlis	Water Supply, Irrigation, Flood Control	13.33	40
	Tasik Melanti	Sg. Perlis	Reclaimation	-	-

There are twelve districts in Kedah with a total geographical area of 9427 km^2. The total population size in Kedah is around 2,000,000. Two main river basins in Kedah are Sg Kedah and Sg Muda. Sg Kedah has a catchment area of 2972 km^2, and it consists of two dams, which are the Pedu Dam and the Ahning Dam. Pedu dams receives water from the Muda Dam and its own catchment, to suppy domestic water for Perlis and Kedah, and also for MADA scheme irrigation through Sg Padang. As for the Ahning Dam, it was mainly built to supply water to Alor Setar but it is then used to supply MADA.

On the other hand, Sg Muda is the largest river basin in Kedah with 4150km^2 of catchment area, with two main dams namely the Muda Dam and Beris Dam. The Muda dam conveys water to Pedu Dam for water supply to MADA scheme. It also functions as domestic supply dam to Sg Muda region and Pulau Pinang. On the other hand, the Beris Dam is mainly used for irrigation, domestic and industrial water supply. Furthermore, Padang Saga dam and Malut dam are another two dams in kedah state but located at Langkawi (NWRS, 2011).

Ulu Muda Forest Reserve (UMFR) in Kedah has a 163,103 km^2 expanse of rainforests, which is the largest and most important water catchment area to whole northern region. Its raw water fills the Muda, Ahning, and Pedu dams to sustain the daily water demands of few areas, which are 70% of Perlis’ daily water needs, 96% of Kedah’s daily water needs and more than 80% of Penang’s daily water needs (PBAHB, 2017).

Raw water from UMFR flows through Sg Muda and serves as Penang's main raw water resource. Penang has a total land area of 1048 km^2 but limited water catchment area of about 62.9 km^2. There are three dams in Penang, which are the Air Itam Dam, Teluk Bahang Dam, and Mengkuang Dam to provide domestic water supply. Over the long-term prospect, there are many projections that indicated that the Muda River can only provide water to Penang until 2020. After that, Penang should get its further additional sources of water supply from another additional water resource, such as the Perak River (PBAPP, 2014).

Perak has eleven major river basins, with the largest one being Sg Perak, which has an area of 14908 km^2. Other basins are: Sg Bernam (2836 km^2), Sg Kerian (1420 km^2), Sg Kurau (740 km^2), and etc. Most of the lakes and reservoirs in Perak are connected to Sg Perak.

In Perlis, the main river basin is Sg Perlis with the catchment size of 310 km^2. The total length of Sg Perlis is about 9.55 km, flowing from Kangar city to Kuala Perlis. The only dam in Perlis is the Timah Tasoh dam. It is located at Sungai Korok and is about 2.5 km below the confluence of Sungai Timah and Sungai Tasoh. The reservoirs regulate the flows of Sungai Korok and supply water for domestic and industrial usage. It also provides water for irrigation purpose in Perlis (DID, 2017).

3.3 Data Repairing

Data that are needed to be collected before the computation are: precipitation, temperature and streamflow over the past 35 years (1983-2017) in Malaysia. daily mean temperature data was obtained from the MMD while daily precipitation and streamflow data were collected from the DID. Thereon, data repairing was carried out to improve the quality of the data. In this study, the four quadrant Inverse Distance Weighting (IDW) method was used for the repairing tasks. Deriving the missing values using observations from neighbouring stations is recommended because precipitation is locally related, where nearby points have higher influences compared to further points. The closer the points to known values are, the greater the dependency they have.

The equation of the four quadrant IDW is shown as Equation 3.1 below:

$$z_p = \frac{\sum_{i=1}^{n}\left(\frac{z_i}{d_i^p}\right)}{\sum_{i=1}^{n}\left(\frac{1}{d_1^p}\right)} \tag{3.1}$$

where z_p is the estimated value at an unsampled point, n is the number of control point used for estimation, p is the power of which distance is raised, d is the distances from each control points to un-sampled points.

3.4 Development of Drought Indices

3.4.1 Standardized Precipitation Index (SPI)

The SPI was computed based on monthly precipitation data by two parameter gamma distribution function. Firstly, log normal values were found based on the rainfall data. Next, U statistics, shape and scale parameters of the gamma distribution were computed. This method adjusted the mean to 0, standard deviation to 1.0, and skewness of the existing data to 0.

Computation of the SPI:

(i) Calculate: the mean, $\bar{X}$ and standard deviation, s of precipitation.

(ii) Compute the skewness of data:

$$Skew = \frac{N}{(N-1)(N-2)}\sum\left(\frac{X-\bar{X}}{s}\right)^3 \tag{3.2}$$

(iii) Compute the following:

log mean:

$$\overline{X_{ln}} = \ln(\bar{X}) \tag{3.3}$$

statistics:

$$U = \overline{X_{ln}} - \frac{\sum \ln(X)}{N} \tag{3.4}$$

Shape parameter:

$$\beta = \frac{1 + \sqrt{1 + \frac{4U}{3}}}{4U} \tag{3.5}$$

Scale parameter:

$$\alpha = \frac{\bar{X}}{\beta} \tag{3.6}$$

(iv) Find the cumulative probability of events:

$$G(x) = \frac{\int_0^x x^{a-1} e^{\frac{-x}{\beta}} dx}{\beta \alpha \Gamma(\alpha)} \tag{3.7}$$

(v) Account for undefined x = 0, zero precipitation:

$$H(x) = q + (1 - q)G(x) \tag{3.8}$$

(vi) Transform to the standard normal random variable Z:

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), \ \ 0 < H(x) \le 0.5 \tag{3.9}$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), \ \ 0.5 < H(x) \le 1 \tag{3.10}$$

where

$$t = \sqrt{ln\left(\frac{1}{H(x)^2}\right)}, 0 < H(x) \le 0.5 \tag{3.11}$$

$$t = \sqrt{ln\left(\frac{1}{(1.0 - H(x))^2}\right)}, 0.5 < H(x) \le 1 \tag{3.12}$$

$c_0 = 2.515517, c_1 = 0.802583, c_2 = 0.010328$
$d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308$

Table 3.2: Drought Categories from the SPI

SPI	**Drought Category**
0 to -0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2.00 or less	Extreme drought

3.4.2 Standardized Precipitation Evapotranspiration Index (SPEI)

The SPEI is the modified SPI which added in the Potential Evapotranspiration (PET) for computation. The simplest PET approach invented by Thornwaite (1948) is applied in this methodology. Meanwhile, this temperature-based Thornthwaite method was chosen as it only requires monthly mean temperature data and the latitudinal coordinate of the location, which are easily accessible.

The computation of the SPEI:

(i) Compute monthly PET:

$$PET = 16K\left(\frac{10T}{I}\right)^m \tag{3.13}$$

where
$T = monthly - mean\ temperature(°C)$
$I = heat\ index = sum\ of\ 12\ monthly\ index\ value\ i$, and $i = \left(\frac{T}{5}\right)^{1.514}$
$m = 6.75 \times 10^{-7}I^3 - 7.71 \times 10^{-5}I^2 + 1.79 \times 10^{-2}I + 0.492$
$K = \left(\frac{N}{12}\right)\left(\frac{NDM}{30}\right)$
N = max. number of sun hours
NDM = number of days of the month

Table 3.3: Mean Daily Duration of Maximum Possible Sunshine Hours (N) (Doorenbos and Pruitt, 1977)

Northern Lats	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Southern Lats	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
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	10.4	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

(ii) Calculate the different between the precipitation and PET for the month:

$$D_i = P_i - PET_i \tag{3.14}$$

(iii) Sum up the D_i according to the time scale.

(iv) Calculate the L-moment ratios:

$$\tau_3 = \frac{\lambda_3}{\lambda_2}, \text{ and } \tau_4 = \frac{\lambda_4}{\lambda_2} \tag{3.15}$$

where L moments are:

$\lambda_1 = w_0$,

$\lambda_2 = w_0 - 2w_1$,

$\lambda_3 = w_0 - 6w_1 + 6w_2$,

$\lambda_4 = w_0 - 12w_1 + 30w_2 - 20w_3$.

(v) PWMs of order s are calculated by:

$$w_s = \frac{1}{N}\sum_{i=1}^{N}(1 - F_i)^s D_i \text{ , and } F_i = \frac{i - 0.35}{N}. \tag{3.16}$$

where

i = the range of observations in ascending order

N = the number of data points

(vi) Probability density function:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2} \tag{3.17}$$

where

$shapeparameter, \beta = \dfrac{2w_1 - w_0}{6w_1 - w_0 - 6w_2}$

$scaleparameter, \alpha = \dfrac{(w_0 - 2w_1)\beta}{\Gamma(1+1/\beta)\Gamma(1-1/\beta)}$

$originparameter, \gamma = w_0 - \alpha\Gamma(1+\dfrac{1}{\beta})\Gamma(1-\dfrac{1}{\beta})$

(vii) Probability distribution function:

$$F(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{3.18}$$

(viii) Lastly:

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3}\,, \tag{3.19}$$

where

$P = 1 - F(x)$

$for\ P \leq 0.5, W = \sqrt{-2\ln(P)}$

$for\ P > 0.5$, change P to *1-P*, and reverse the sign of resultant the SPEI

And constants:

$C_0 = 2.515517, C_1 = 0.802583, C_2 = 0.010328$

$d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308$

Table 3.4: Drought Categories from the SPEI

SPEI	Drought Category
0 to -0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2.00 or less	Extreme drought

3.4.3 Streamflow Drought Index (SDI)

The SDI is a rather simpler drought index computed based on the monthly stream flow volumes.

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \tag{3.20}$$

where

$V_{i,k}$= cumulative stream flow volume for i years

$Q_{i,j}$= monthly streamflow volumes

i = hydrological year

j = month corresponding to the hydrological year, start from j=1 for October

k = reference period

Reference period for hydrological year also begins with October with 3 months time intervals. In this assignment, the four overlapping time period instead of classical non-overlapping time intervals will be applied to increase the coherency and accuracy.

k = 1 for October–December

k = 2 for October–March

k = 3 for October–June

k = 4 for October–September

$$SDI_{i,k} = \frac{V_{i,k} - \bar{V}_k}{s_k} \tag{3.21}$$

where

$\bar{V}_k$= mean

s_k= standard deviation

Truncation level of this method is the standard deviation. In other words, water shortage occurs when the streamflow volume is lower than the mean by more than one standard deviation. The method can be modified to tackle with the problem of non-stationarity, as the SDI computation for small streamflow always possess a skewed probability distribution. Therefore, it is better to normalise it using two-parameter log-normal distribution as shown below to account the natural logarithms of streamflow.

$$SDI_{i,k} = \frac{y_{i,k} - \bar{V}_k}{s_k} \tag{3.22}$$

where

$y_{i,k} = \ln(V_{i,k})$

For the watercourse with complete streamflow data throughout the hydrological year, the formulas can be directly applied. It is also applicable for watercourse with temporary flow but without completely dried out throughout a whole hydrological year as cumulative streamflow will still give positive value for computation. However, for the watercourse with totally no flow in a hydrological year, it will directly be classified as an extreme drought without computation.

Table 3.5: Drought Categories from the SDI

SDI	**Drought Category**
0 to -0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2.00 or less	Extreme drought

3.4.4 Time Scales of Drought Indices

The time scales of drought indices were the temporal interval used in this study. It defined the specific interval (number of months) used to compare the current situation to historical situation of the same interval time over the 35 years. For example, in this assignment a 3-month SPI, which known as the SPI-3, is used to measure the condition over past 35 years. The result of the SPI-3 on March 1983 is generated by comparison of January-March of year 1983 over January-March in the past 35 years.

Time scales of 1 month, 3 months, 6 months, and 12 months were applied for the SPI and the SPEI to measure drought condition over the past 35 years. The computation with 1-month timescale such as the SPI-1 and the SPEI-1 were started in January 1983. But for 3-months timescale, the SPI-3 and the SPEI-3 started in March and so on for 6-months and 12-months. However, the SDI only has 3 months, 6 months and 12 months' timescale. Nevertheless, all computations ended on Dec 2017.

After that, the results of different drought indices with different temporal scales values were plotted for comparison. However, the SDI graphs were not compared together with the SPI and the SPEI graphs, as the sources of input data for the SDI were totally different with the SPI and the SPEI. The SDI was computed based on the streamflow data which were collected from the streamflow stations; the SPI and the SPEI were computed based the rainfall data which were collected from the rainfall and temperature stations. The locations of the streamflow stations were very different with the locations of rainfall stations. The drought indices' result only represented drought condition of that particular location thus the SDI was not plotted with the SPI and the SPEI in a same graph.

3.5 Drought Frequency, Mean Drought Duration, Mean Drought Intensity, Mean Drought Severity, Mean Drought Peak, and Average Moving Range (AMR)

Frequency, mean duration, mean intensity, mean severity, and mean peak of drought were observed. The frequency of drought presents how often the negative results were shown; and the duration of drought presents how long the result remains negative. Intensity is total sum of negativity per unit time of each event; and severity is how negative is the result. On the other hand, the peak of the drought is the lowest value in a negative event. Moving range is the difference between consecutive index values, and it was used to measure the variation changes of index values over time. Absolute values of moving ranges were averaged to represents the sensitivity of the indices to the changes in input variables. The average moving range can be calculated from the formula:

$$MR_j = \left|x_j - x_{j-1}\right| \tag{3.23}$$

$$\overline{MR} = \frac{1}{m-1}\sum_{j=1}^{m} MR_j \tag{3.24}$$

where

MR_j = moving range of event j

$\overline{MR}$ = average moving range

m = total number of events

3.6 Spatial Analysis

The spatial analysis was carried out to examine the location dependency of droughts. A spatial structure means that the data is locational dependent and a non-spatial structure means that the data is locational independent. Drought should be locational dependent, where the stations are inter-related up to a certain finite distance. Through spatial analysis, the indices were analysed to study the relation and pattern of drought across the region.

The first step in data spatial structure analysis was to identify the characteristics of drought. Based on the identified characteristics, the IDW interpolation method was selected to be applied in this study due to its reliable accuracy and simplicity. With the help of GIS tools, the irregular discrete data (drought indices) from different points were transformed into a raster surface to represent the values over the whole region.

3.7 Temporal Analysis

The temporal analysis was carried out to examine changes in pattern of drought over the past 35 years, which can be detected by different indices and different timescales.

In this analysis, the average value for each month in the past 35 years was found by using excel spreadsheet to observe the temporal variation of drought over 12 months. The negative mean monthly drought indices value indicates that drought was likely to have happened in that month over the past 35 years. Therefore, the ‘negative’ months resulted from different indices with time scales of 1 month, 3 months, 6 months and 12 months were estimated to investigate the monthly temporal pattern of drought over the past 35 years.

3.8 Trend Analysis

The trend analysis was carried out using the “trend” function in excel spreadsheet, which calculated a linear trend line based on the monthly drought indices values (known arrays) over the past 35 years in order to describe the trend of projected monthly moisture condition in northern region of Malaysia, and thereof forecast the occurrence of drought in northern region of Malaysia. A negative value indicates a decreased trend of moisture condition (drier) of that particular month while a positive value indicates an increased trend (wetter) of moisture condition of that month.

3.9 Historical Drought Comparison

Reports of drought events that had occurred over the northern region in Malaysia in the past 35 years were gathered for evaluation purpose, where most of the drought events found for the northern region happened in the last 3 decades (1990-2017). The data for older events is rare; this could due to the study of drought events in Malaysia being very limited in the past, before researchers found out that Malaysia might even face severe droughts and the impacts of drought could be highly disruptive.

The information of significant historical drought events that were retrieved from reports are the location, onset and offset of drought as the news reported only the overview about the entire event in a descriptive way without any detailed exact digitalised information about the severity of drought of the affected area. Fortunately, the onset and offset data retrieved from news is sufficient to validate the occurrence of drought event calculated by indices in this project, and hence evaluate the performance of drought indices in drought detection, drought duration estimation, and their accuracy in detecting drought onset. At the same time, based on the description in news, the types of drought were identified.

3.9.1 Probability of Detection (POD) Analysis

For drought detection, the accuracy of the indices were evaluated based on the calculated drought event that occurred within the onset and offset period of historical drought event. For this purpose, the probability of detection (POD) of the drought indices was used for evaluation based on all the 16 cases.

$$POD = \frac{Detected\ Cases}{Total\ Cases} \tag{3.25}$$

3.9.2 Over/Under-estimated Duration Error Analysis

The duration of each historical drought was found by estimating the difference between onset and end of the historical event. The duration of detected drought event computed by drought indices was compared with the duration of historical drought to evaluate the performance of drought indices in estimating the duration. When the detected duration was longer than the duration of the historical events, the differences between the detected duration to historical duration was positive, and it was an overestimation and vice versa. The estimation is accurate when the difference equals 0. The average of error in over/under estimated duration was summarized by finding the Mean Absolute Error (MAE), Mean Bias Error (MBE), and Root Mean Square Error (RMSE). So, the formula applied in this section are:

$$e_i = estimated\ duration - historical\ actual\ duration \tag{3.26}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|e_i| \tag{3.27}$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n} e_i \tag{3.28}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} e_i^2} \tag{3.29}$$

where n= total number of cases

3.9.3 Average Early/Delay Detection Magnitude

The early/delay detection was estimated by computing the difference between the detected onset with the historical onset. A positive result represented delay detection, negative result represented early detection and zero represented exact detection of onset. Again, the averaged magnitude of early/delay detection was calculated to summarize the findings.

$$e_i = estimated\ onset - historical\ actual\ onset \tag{3.30}$$

$$\text{Average Magnitude of Early/Delay Detection} = \frac{1}{n}\sum_{i=1}^{n} e_i \tag{3.31}$$

where n= total number of cases for early and delay detection

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

By following the methodology in Chapter 3, all the SPI, the SPEI and the SDI values that represented the moisture condition of Perak, Penang, Kedah and Perlis states in northern region of Malaysia were computed. This chapter begin with graphs presentation of the SPI and the SPEI indices' values at all the meteorological stations and the SDI index's values at streamflow stations from the year 1983 to 2017. Furthermore, drought frequency, mean drought duration, mean drought intensity, mean drought severity, mean drought peak, and average moving range of these stations in this past 35 years were shown. After that, spatial analysis and temporal analysis were carried out to study and the pattern of drought over the past 35 years and over the northern region discussed. Meanwhile, trend analysis was carried out to discuss the future trend of drought. Next, it was continued with the validation of indices, by matching the drought events found through computation of drought indices to the historical drought events. It is crucial to check the validity of these indices in drought detection, in order to find out the most suitable index to describe the moisture condition in northern region in Malaysia. Last but not least, a comparison of the three indices with different timescales was discussed throughout the study in order to understand the differences between them.

For a recap on previous chapters, the four main types of drought are the meteorological, agricultural, hydrological, and socioeconomic drought. Each of them referred to different impacts and appearances which are the indicators of that particular type of drought event. The SPI is the index which measures drought based on the phenomena of deficit in precipitation only, therefore this precipitation-based SPI index is a meteorological drought index. In the sense of other drought impacts such as reduced soil moisture and reduced water level, these may become observable after a long period of rainfall deficit, and some impacts may linger for years even after the termination of a rainfall deficit, therefore different timescales can be applied to reflect these drought impacts.

However, the SPEI is the advancement of the SPI which included both precipitation and temperature component in the computation. Together with the ability of the SPEI to be calculated at various timescales makes it become even more suitable for measuring different types of drought. The temperature component is the key which make the SPEI become more practical than the SPI in measuring longer timescales agricultural, hydrological drought. Since temperature account for the potential evapotranspiration (PET) which reflect the water demand in water balance calculation. Temperature component is also important when there is a climate change that cause higher temperature and hence higher water demand.

In brief, 1 month and 3 months are suitable for basic meteorological drought monitoring, which focus on the short-term precipitation deficit. The benefit of using shorter timescale is the ability to identify short-term dry spells within long-term wet periods. Single rainfall deficit event during a wet season is visible on short time scales, even though the deficit did not cause drought or end the overall wet season. 6 months is a medium-term monitoring which addressed agricultural drought because agricultural drought may only happen after a medium-term precipitation deficit which cause the soil moisture level to drop and insufficient to meet the plant needs for water. 12 months or longer is applied for hydrological drought study as low water level in water resources only appear after long period of precipitation deficit.

For the SDI, the only input is streamflow. It is used to measure the reduced water level in a stream which indicated a hydrological drought event. With reference to reading of a particular streamflow station, the result of the SDI may not represent the whole basin. Its computation is similar to the SPI, but using streamflow data instead of precipitation, therefore various timescales can be applied also. However, the minimum timescale is 3-months, this may attribute to the reason of the SDI is measuring a hydrological drought which require a minimum of 3 months to appear.

On the other hand, climate indices which measured a high SST that might related to happening of extreme in northern region were plotted in Figure 4.1 below. The years with high SST are framed.

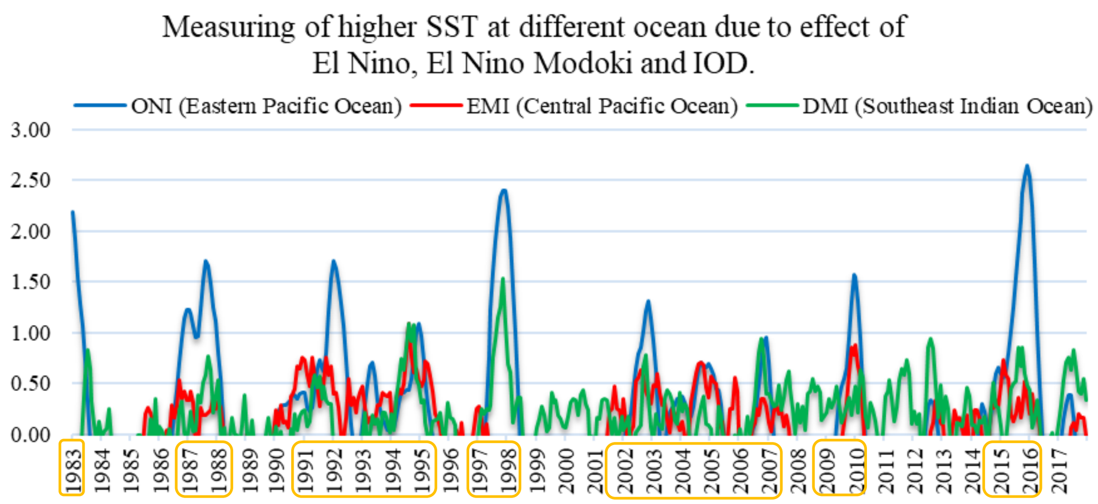


Figure 4.1: ONI, EMI and DMI Indices With High Measured SST

4.2 Results

The results were mainly divided into two parts. The first part was the SPI, the SPEI and the SDI values that used to observe each drought event held in past 35 years. The second part was the drought frequency, mean drought duration, mean drought intensity, mean drought severity, mean drought peak, and average moving range which make a summary for all the drought events at each station.

4.2.1 The SPI, the SPEI and the SDI

Overall, the results of drought indices with different timescales were totally different. For example, the graphs of the SPI-1, the SPI-3, and the SPI-6 and the SPI-12 were not same to each other. Therefore, it was proved that the timescale used in computation is also an important manipulating parameter which affects the of results. As discussed in literature review, different timescales were actually referring to different types of drought. When the timescale increased, the fluctuation of graphs decreased. This shown that 1-months meteorological drought had the greatest monthly variation, followed with agricultural and hydrological drought.

At the same time, different indices which were different models to measure drought with different inputs shown different results. Therefore, both the drought indices and the number of months for computation must be selected properly during the investigation of a particular type of drought.

By referring to graphs below, the index value on y-axis represented the moisture condition, while its negativity was equal to the severity of a drought event.

For the duration of the drought event, it was read from the time series on the x-axis. Furthermore, the frequency, intensity and peak can be analysed from the graphs. Frequency is the total number of counts of events with negative index values. Intensity is magnitude per unit time of each event. And peak is the most negative value of each drought event.

4.2.1.1 Perak

Figure 4.2 and Figure 4.3 below show a sample plotting of the SPI, the SPEI, the SDI index graphs which described the moisture condition of a station in Perak in past 35 years. the SPI and the SPEI were computed by precipitation data collected from rainfall station 5207001; the SDI were computed by streamflow data collected from streamflow station 5206432 in Perak.

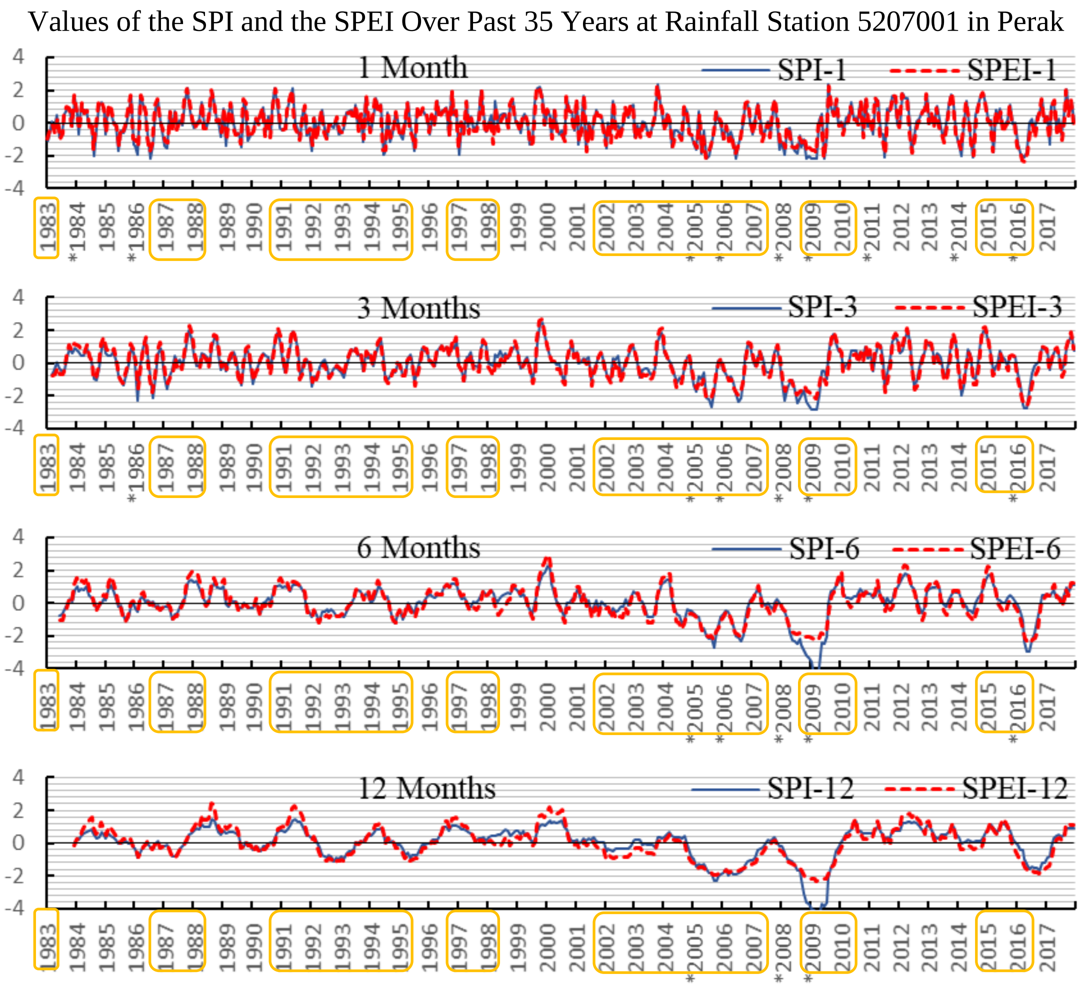


Figure 4.2: The SPI and the SPEI Graphs of Rainfall Station 5207001 (Perak)

In Figure 4.2 above, years with value less and equal to -2 were labelled with a '*' symbol. The value of -2 indicated an extreme drought according to drought categorization tables of the SPI and the SPEI listed in chapter 3 methodology above. Based on the figure above, Perak was experienced an extreme meteorological drought in year 1984, 1986, 2005, 2006, 2009, 2011, 2014 and 2016 for the SPI-1 and the SPEI-1. For the SPI-3 and the SPEI-3, the years with extreme index value were 1986, 2005, 2006, 2008, 2009, 2016. For 6-months timescale, it was obviously shown that extreme agricultural drought events were happened in year 2005, 2006, 2008, 2009 and 2016. The extreme negative values also observed in year 2005, 2008, and 2009 for graphs of 12 months computation which indicated an extreme hydrological drought. It was observed that the number of years with extreme drought values was reduced for longer timescales, which mean the happening of extreme hydrological and agricultural drought were lesser than the happening of extreme meteorological drought.

Meanwhile, years which are suspected to experience high SST value were framed. Those framed years are 1983, 1987-1988, 1991-1995, 1997-1998, 2002-2007, 2009-2010 and 2015-2016. By inspection on the symbols and frames, it was observed that they are related, except during period of 1991-1995 and 1997-1998. By the way, Perak station was observed to experienced more extreme drought events after 2000s'decade.

Other than that, it was observed that the result of the SPI and the SPEI are similar except in year 2009. The SPI-6 and the SPI-12 value had dropped to an extreme value of -4 but the SPEI-6 and the SPEI-12 remained at -2. Year 2009 was having a higher SST, but the computation of the SPI did not include the temperature factor and the SPEI did include the temperature factor, therefore the outcomes were different.

Values of the SDI Over Past 35 Years at Streamflow Station 5206432 in

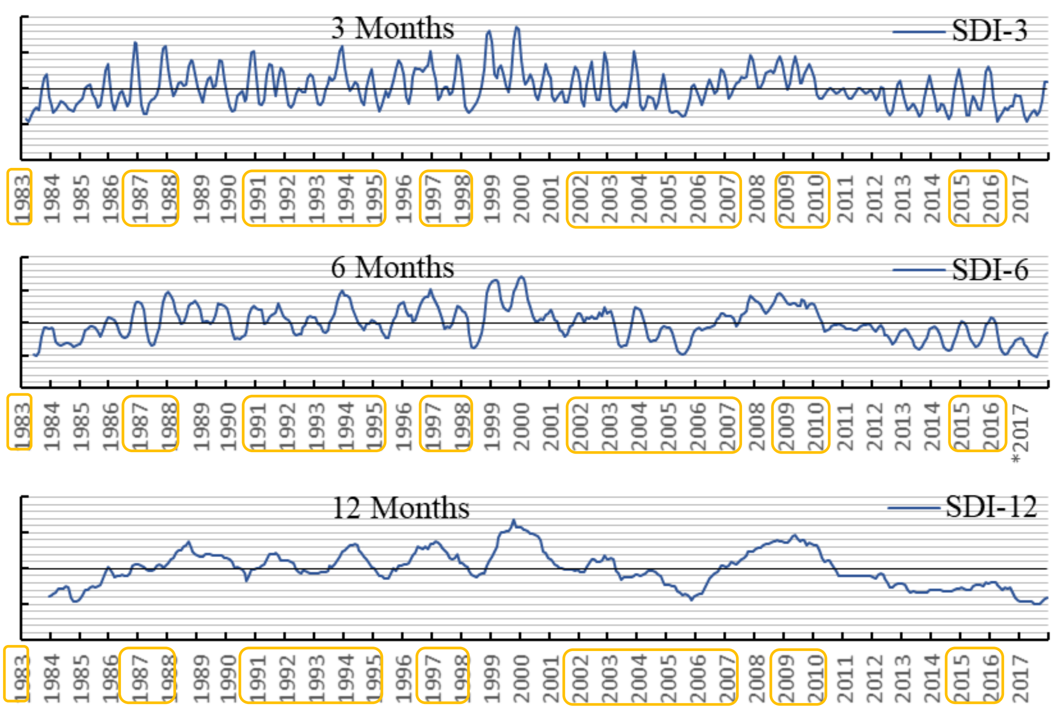


Figure 4.3: The SDI Graphs of Streamflow Station 5206432 (Perak)

Based on all the three graphs of the SDI in Figure 4.3 above, value of -2 which represented an extreme hydrological drought only happened in year 2017 by the SDI-6 computation. Although there are many events detected with value in the range of -1.5 to -2 which represented a severe drought. These extreme and severe hydrological drought events were also related to the framed year with high SST as observed from graphs above. It was more observable especially in the SDI-12, there were only three significant events with negative result, the period for the first one was 1983-1986, second was 2004-2007, and last one was 2013-2017. These years were the framed years which have high SST.

4.2.1.2 Penang

Graphs in Figure 4.4 below indicated the moisture condition in the area near to Air Itam Dam located in Penang over past 35 years. the SPI and the SPEI was computed based on rainfall data retrieved from rainfall station 5302003. However, there was no the SDI computation based on the streamflow data in Penang. The streamflow input data that received were not completed and cannot be repaired. Without the input data required, the computation was not able to be carried out.

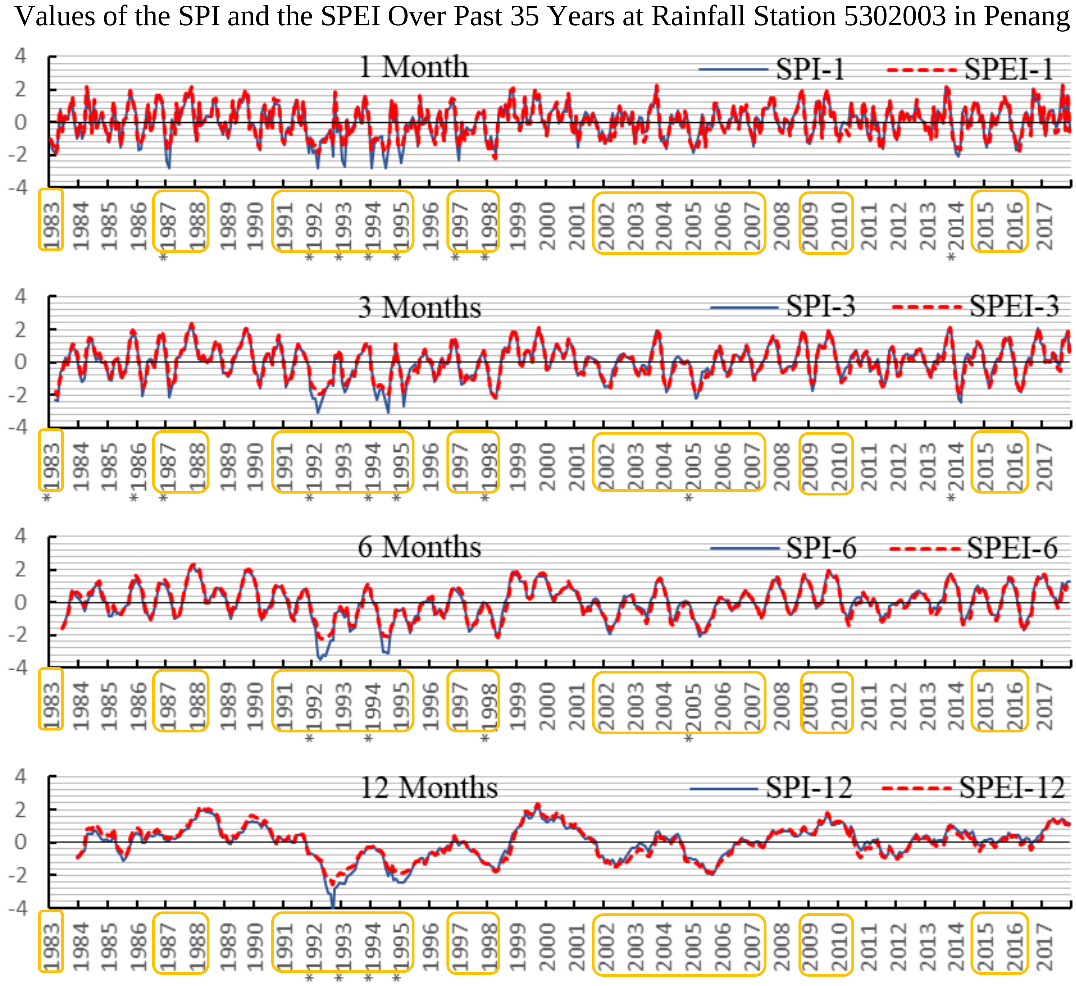


Figure 4.4: The SPI and the SPEI Graphs of Rainfall Station 5302003 (Penang)

The detected extreme drought events were in conformity to year with high SST as framed in Figure 4.4 above. By the way, the value of the SPI-1 plunged to -3 in year 1987, 1992-1995 but the SPEI-1 fluctuated above -2 over the past 35 years. Besides, the SPI-3 also reached the lowest value of -3 in years 1992, 1994 and 1995, however the reading for these points by the SPEI-3 computation were -2. The index value of the SPI-6 and the SPEI-6 were similar except in 1992 and 1994. Last but not least, the SPI-12 also shown a more negative reading than the SPEI-12 in year 1992 and 1994. These might attribute to the high SST factor which cause the disagreed result of the SPI and the SPEI. Furthermore, most of the extreme drought events were happened in 1990s' decade for this station in Penang.

4.2.1.3 Kedah

The moisture condition in Kedah were shown by the SPI, the SPEI graphs at rainfall station 5808001 in Figure 4.5 below and the SDI graphs at streamflow station 5606410 were shown in Figure 4.6 below.

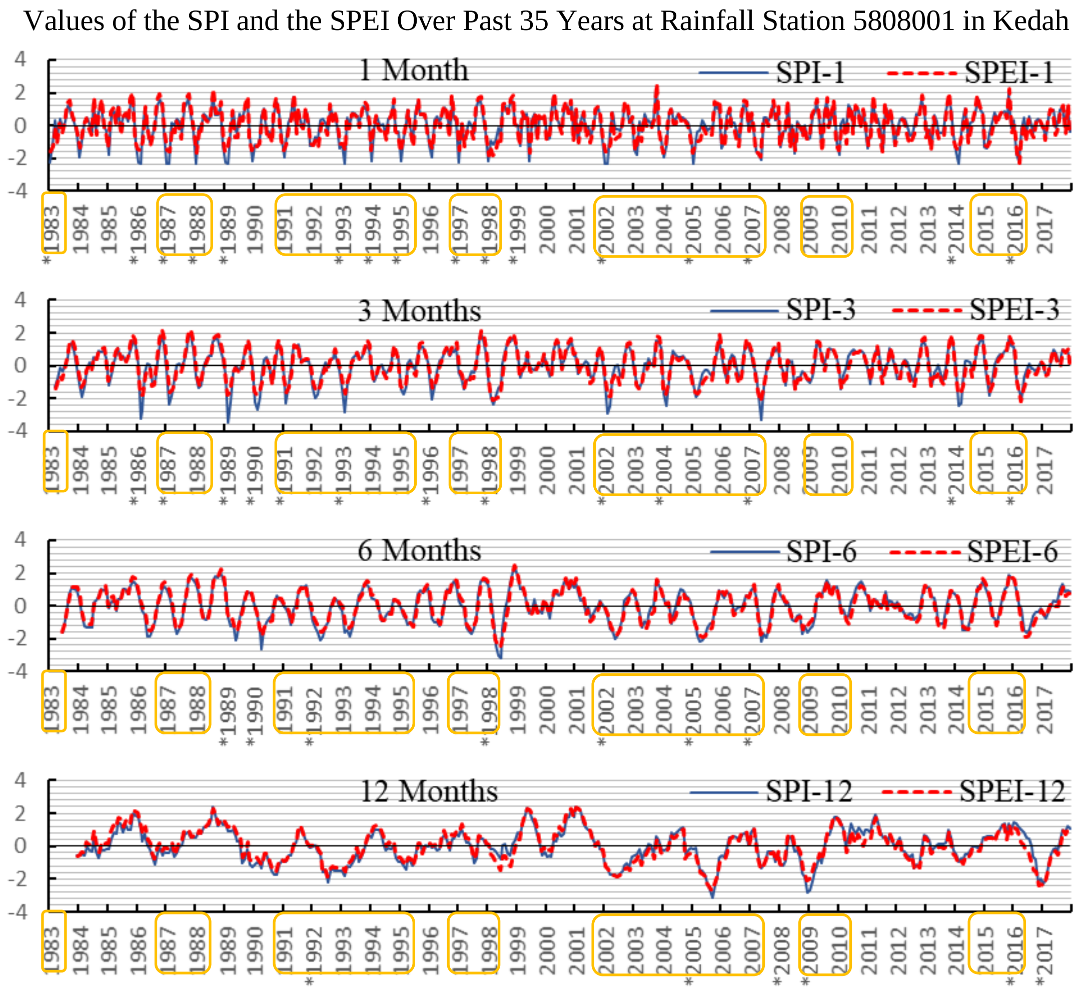


Figure 4.5: The SPI and the SPEI Graphs of Rainfall Station 5808001 (Kedah)

It was clearly shown that the SPI-1 and the SPEI-1 had low values at the beginning of every year over the past 35 years in this station. Therefore, meteorological drought seemed to happen more often at the beginning of the year. On the other hand, the abnormal low points by the SPI-3 computation which disagree with the SPEI-3 computation were happened around years 1986, 1989, 1990, 1993, 1998,2002, 2004, 2007, 2014, and 2017, these all were the years with high SST. Besides, the extreme drought events happened evenly in every decade. These extreme drought events were also in conformity with high SST.

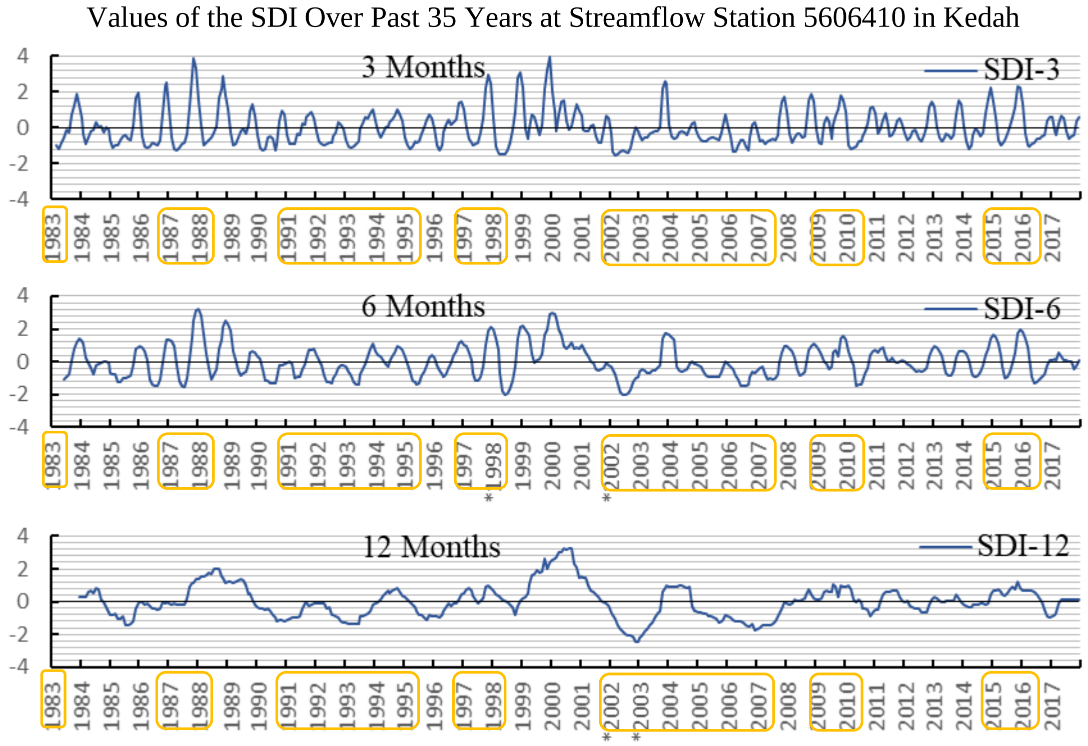


Figure 4.6: The SDI Graphs of Streamflow Station 5606410 (Kedah)

There was no extreme drought observed from the SDI-3 graph, the only observable thing was the temporal pattern. Generally, there will be a huge increment in year end until the beginning of the next year, then plunged to a negative value at the middle of the year, and increase back repetitively. From the SDI-6 graph, the years with extreme index values were 1998 and 2002. However, for the SDI-12 computation, the years of extreme droughts were 2002 and 2003. These measured extreme hydrological drought events were related to high SST.

4.2.1.4 Perlis

SPI and the SPEI graphs in Figure 4.7 were computed based on rainfall data retrieved from rainfall station 6401002, however the SDI graphs in Figure 4.8 were computed based on streamflow data retrieved from streamflow station 5606410.

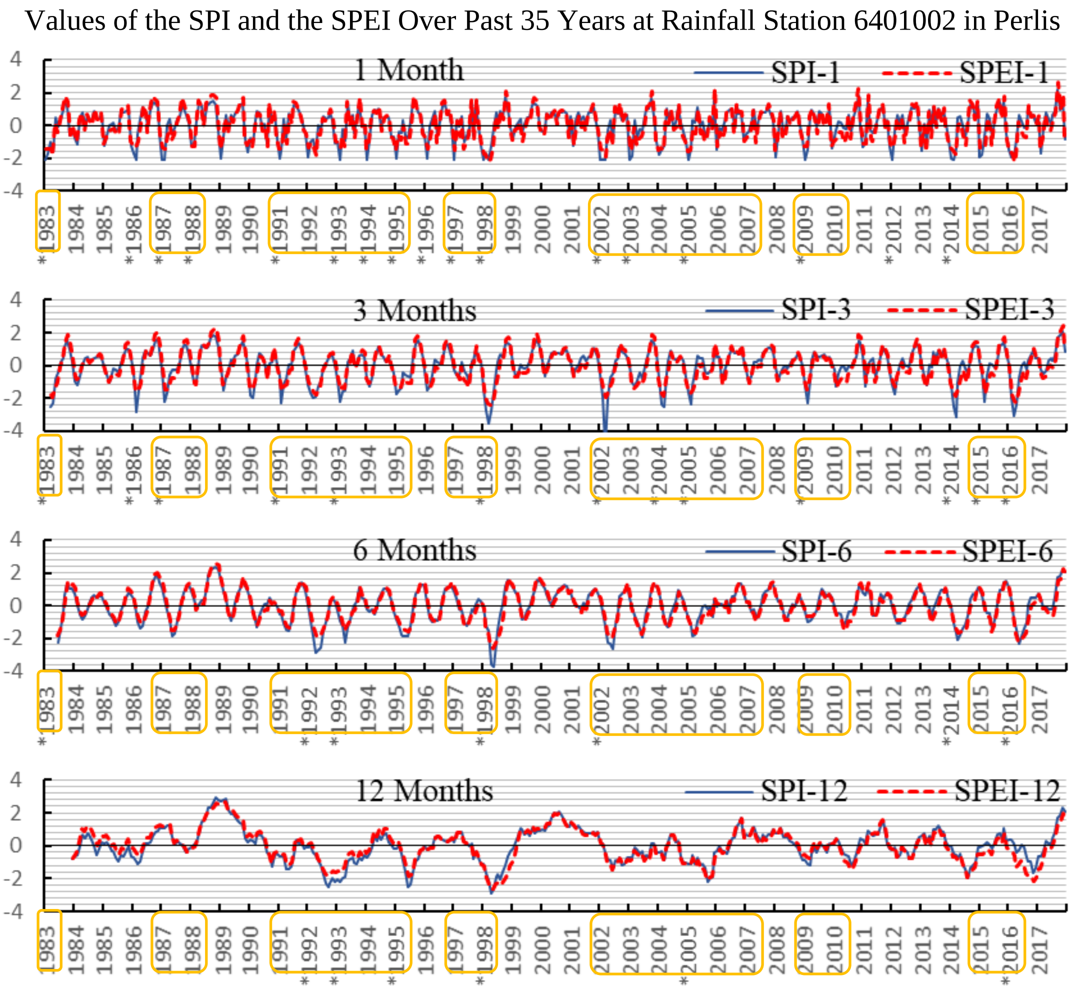


Figure 4.7: The SPI and the SPEI Graphs of Rainfall Station 6401002 (Perlis)

SPI-1 and the SPEI-1 in Perlis also shown a low precipitation for beginning of every year in this station. This pattern continued consistently over the past 35 years without any abrupt change. For year with high SST such as year 1998, 2002, 2014 and 2016, the values of the SPI were different with the SPEI. At the same time, extreme drought events were found in every decade and most detected extreme drought events were happened in years with high SST.

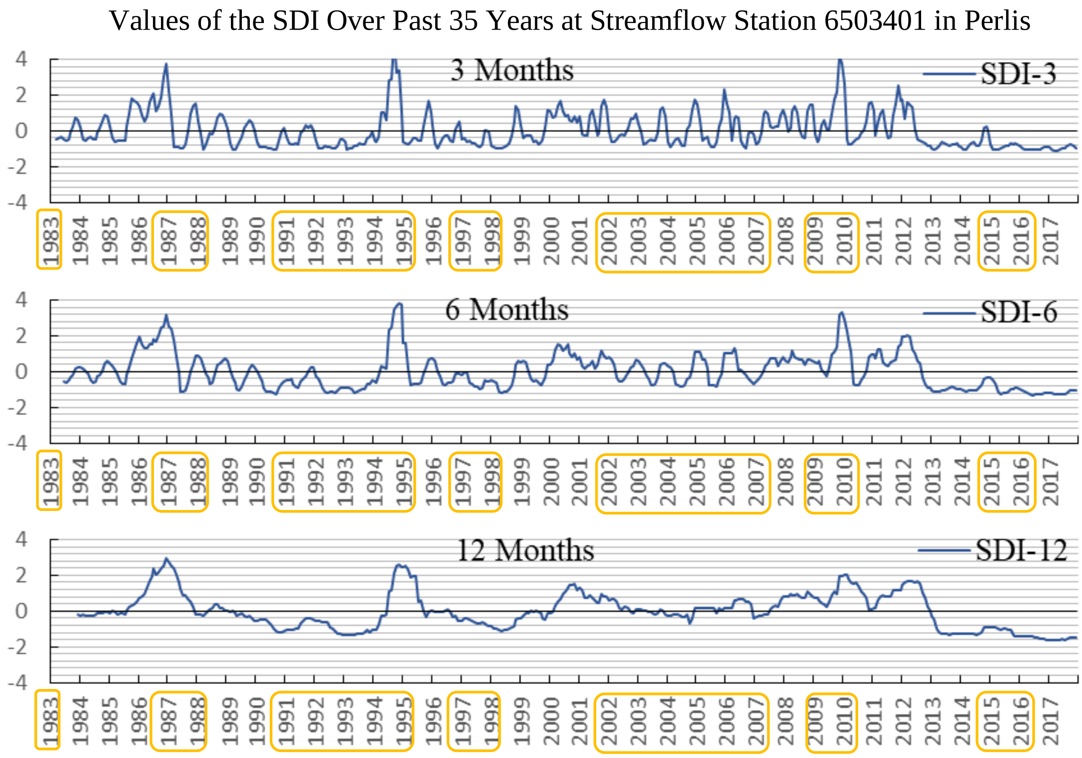


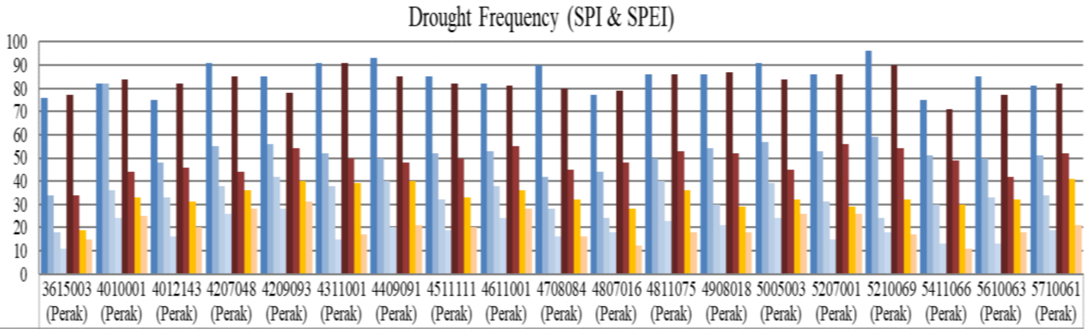
Figure 4.8: The SDI Graphs of Streamflow Station 6503401 (Perlis)

There was no extreme drought event detected by the SDI, however there was observable long-term severe drought started in 2012 and lasted until 2017 based on all the three the SDI graphs above. Meanwhile, the temporal pattern in the SDI-1 was same with the SDI-1 Kedah, where the drought generally happened in middle of the year.

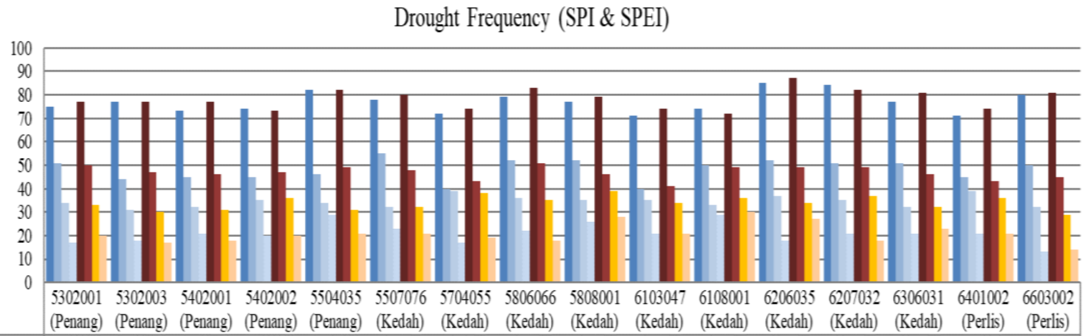
4.2.2 Drought Frequency, Mean Drought Duration, Mean Drought Intensity, Mean Drought Severity, Mean Drought Peak, and Average Moving Range

To summarize all the drought events in past 35 years, the drought frequency, mean drought duration, mean drought intensity, mean drought severity, mean drought peak, and average moving range for all events over the past 35 years were determined and recorded.

4.2.2.1 Drought Frequency

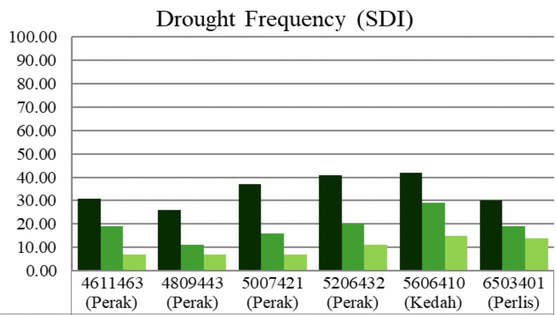


	3615003 (Perak)	4010001 (Perak)	4012143 (Perak)	4207048 (Perak)	4209093 (Perak)	4311001 (Perak)	4409091 (Perak)	4511111 (Perak)	4611001 (Perak)	4708084 (Perak)	4807016 (Perak)	4811075 (Perak)	4908018 (Perak)	5005003 (Perak)	5207001 (Perak)	5210069 (Perak)	5411066 (Perak)	5610063 (Perak)	5710061 (Perak)
SPI-1	76	82	75	91	85	91	93	85	82	90	77	86	86	91	86	96	75	85	81
SPI-3	34	82	48	55	56	52	50	52	53	42	44	50	54	57	53	59	51	50	51
SPI-6	18	36	33	38	42	38	40	32	38	28	24	40	30	39	31	24	30	33	34
SPI-12	11	24	16	26	28	15	20	19	24	16	18	23	21	24	15	18	13	13	19
SPEI-1	77	84	82	85	78	91	85	82	81	80	79	86	87	84	86	90	71	77	82
SPEI-3	34	44	46	44	54	50	48	50	55	45	48	53	52	45	56	54	49	42	52
SPEI-6	19	33	31	36	40	39	40	33	36	32	28	36	29	32	29	32	30	32	41
SPEI-12	15	25	20	28	31	17	21	20	28	16	12	18	18	26	26	17	11	18	21



	5302001 (Penang)	5302003 (Penang)	5402001 (Penang)	5402002 (Penang)	5504035 (Penang)	5507076 (Kedah)	5704055 (Kedah)	5806066 (Kedah)	5808001 (Kedah)	6103047 (Kedah)	6108001 (Kedah)	6206035 (Kedah)	6207032 (Kedah)	6306031 (Kedah)	6401002 (Perlis)	6603002 (Perlis)
SPI-1	75	77	73	74	82	78	72	79	77	71	74	85	84	77	71	80
SPI-3	51	44	45	45	46	55	40	52	52	40	50	52	51	51	45	50
SPI-6	34	31	32	35	34	32	39	36	35	35	33	37	35	32	39	32
SPI-12	17	18	21	20	29	23	17	22	26	21	29	18	21	21	21	13
SPEI-1	77	77	77	73	82	80	74	83	79	74	72	87	82	81	74	81
SPEI-3	50	47	46	47	49	48	43	51	46	41	49	49	49	46	43	45
SPEI-6	33	30	31	36	31	32	38	35	39	34	36	34	37	32	36	29
SPEI-12	20	17	18	20	21	21	19	18	28	21	30	27	18	23	21	14

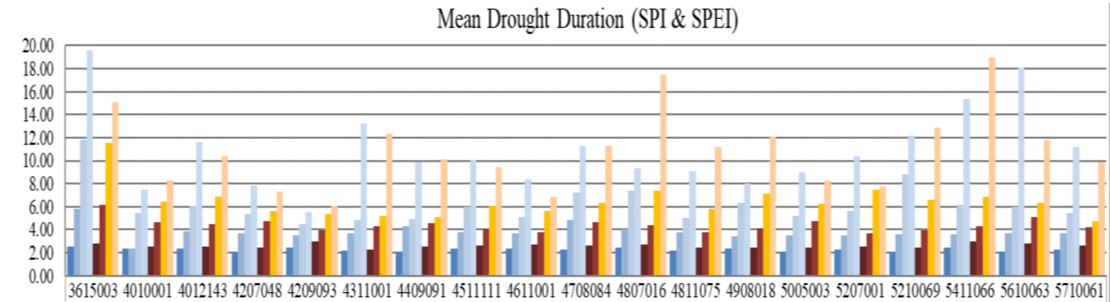
Figure 4.9: Graph and Table of Drought Frequency Computed by the SPI and the SPEI



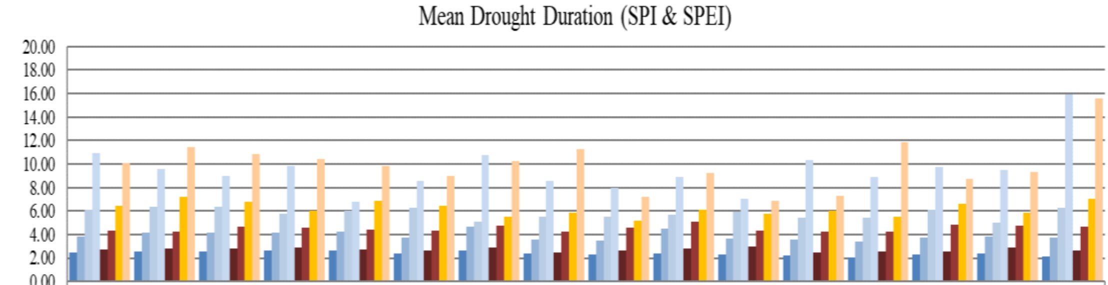
	4611463 (Perak)	4809443 (Perak)	5007421 (Perak)	5206432 (Perak)	5606410 (Kedah)	6503401 (Perlis)
SDI-3	31.00	26	37	41	42	30
SDI-6	19.00	11	16	20	29	19
SDI-12	7.00	7	7	11	15	14

Figure 4.10: Graph and Table of Drought Frequency Computed by the SDI

4.2.2.2 Mean Drought Duration

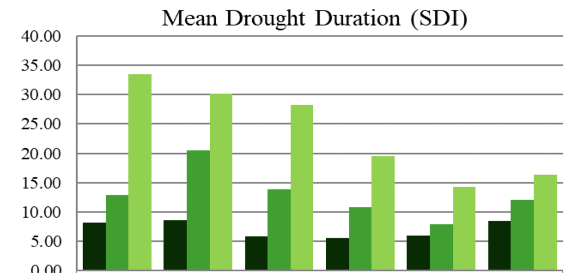


	3615003 (Perak)	4010001 (Perak)	4012143 (Perak)	4207048 (Perak)	4209093 (Perak)	4311001 (Perak)	4409091 (Perak)	4511111 (Perak)	4611001 (Perak)	4708084 (Perak)	4807016 (Perak)	4811075 (Perak)	4908018 (Perak)	5005003 (Perak)	5207001 (Perak)	5210069 (Perak)	5411066 (Perak)	5610063 (Perak)	5710061 (Perak)
SPI-1	2.53	2.37	2.36	2.13	2.40	2.14	2.08	2.35	2.37	2.27	2.45	2.21	2.33	2.07	2.28	2.06	2.47	2.09	2.30
SPI-3	5.76	2.34	3.83	3.65	3.48	3.71	4.28	3.75	3.64	4.81	4.02	3.76	3.41	3.51	3.47	3.59	3.59	3.72	3.65
SPI-6	11.78	5.44	6.03	5.37	4.48	4.87	4.90	5.97	5.11	7.21	7.42	5.00	6.33	5.21	5.61	8.83	6.17	6.00	5.41
SPI-12	19.64	7.50	11.63	7.81	5.54	13.27	9.85	10.05	8.33	11.25	9.33	9.09	8.00	9.00	10.40	12.17	15.38	18.08	11.21
SPEI-1	2.77	2.55	2.52	2.41	2.94	2.30	2.54	2.59	2.67	2.61	2.72	2.45	2.47	2.45	2.57	2.40	3.00	2.77	2.65
SPEI-3	6.12	4.66	4.48	4.77	3.93	4.26	4.58	4.00	3.75	4.62	4.35	3.81	4.12	4.71	3.71	3.94	4.29	5.07	4.25
SPEI-6	11.58	6.45	6.87	5.67	5.40	5.21	5.08	6.03	5.61	6.38	7.36	5.78	7.10	6.25	7.48	6.56	6.87	6.38	4.76
SPEI-12	15.07	8.28	10.40	7.29	6.06	12.35	10.14	9.40	6.89	11.31	17.50	11.22	12.06	8.27	7.77	12.88	19.00	11.83	9.86



	5302001 (Penang)	5302003 (Penang)	5402001 (Penang)	5402002 (Penang)	5504035 (Penang)	5507076 (Kedah)	5704055 (Kedah)	5806066 (Kedah)	5808001 (Kedah)	6103047 (Kedah)	6108001 (Kedah)	6206035 (Kedah)	6207032 (Kedah)	6306031 (Kedah)	6401002 (Perlis)	6603002 (Perlis)
SPI-1	2.47	2.56	2.59	2.61	2.61	2.42	2.63	2.42	2.29	2.42	2.31	2.19	2.04	2.27	2.39	2.14
SPI-3	3.84	4.18	4.16	4.18	4.22	3.71	4.68	3.54	3.50	4.48	3.68	3.56	3.43	3.75	3.82	3.74
SPI-6	6.12	6.32	6.38	5.80	6.00	6.28	5.13	5.47	5.51	5.69	5.91	5.46	5.43	6.13	5.03	6.25
SPI-12	10.94	9.61	9.00	9.80	6.76	8.57	10.76	8.55	7.92	8.86	7.07	10.33	8.90	9.76	9.52	15.92
SPEI-1	2.73	2.77	2.77	2.93	2.72	2.68	2.89	2.49	2.66	2.80	2.97	2.46	2.54	2.54	2.91	2.60
SPEI-3	4.30	4.28	4.63	4.57	4.43	4.31	4.74	4.22	4.61	5.07	4.31	4.24	4.20	4.85	4.77	4.67
SPEI-6	6.45	7.20	6.77	6.03	6.90	6.44	5.50	5.86	5.18	6.12	5.78	6.00	5.54	6.59	5.86	7.03
SPEI-12	10.05	11.41	10.83	10.45	9.81	9.00	10.26	11.22	7.18	9.24	6.83	7.26	11.83	8.70	9.33	15.57

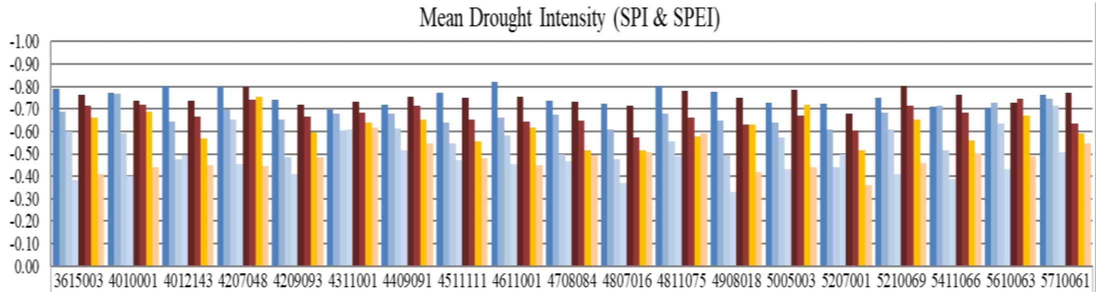
Figure 4.11: Graph and Table of Mean Drought Duration Computed by the SPI and the SPEI



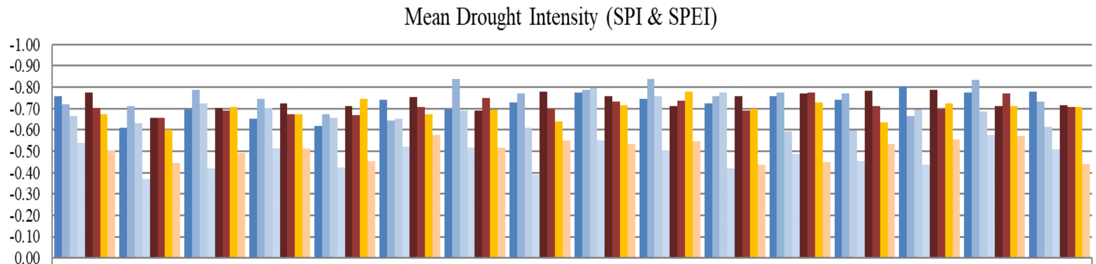
	4611463 (Perak)	4809443 (Perak)	5007421 (Perak)	5206432 (Perak)	5606410 (Kedah)	6503401 (Perlis)
SDI-3	8.19	8.54	5.86	5.54	5.93	8.43
SDI-6	12.84	20.45	13.88	10.80	7.97	12.05
SDI-12	33.57	30.14	28.29	19.55	14.20	16.36

Figure 4.12: Graph and Table of Mean Drought Duration Computed by the SDI

4.2.2.3 Mean Drought Intensity

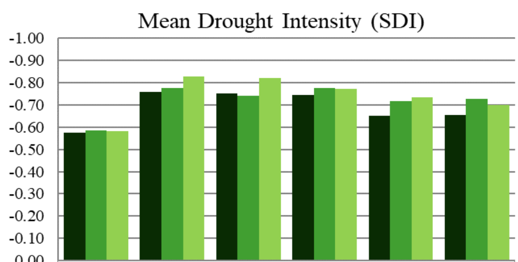


	3615003 (Perak)	4010001 (Perak)	4012143 (Perak)	4207048 (Perak)	4209093 (Perak)	4311001 (Perak)	4409091 (Perak)	4511111 (Perak)	4611001 (Perak)	4708084 (Perak)	4807016 (Perak)	4811075 (Perak)	4908018 (Perak)	5005003 (Perak)	5207001 (Perak)	5210069 (Perak)	5411066 (Perak)	5610063 (Perak)	5710061 (Perak)
SPI-1	-0.79	-0.77	-0.80	-0.80	-0.74	-0.70	-0.72	-0.77	-0.82	-0.73	-0.72	-0.80	-0.78	-0.73	-0.72	-0.75	-0.71	-0.70	-0.76
SPI-3	-0.69	-0.77	-0.65	-0.70	-0.65	-0.68	-0.68	-0.64	-0.66	-0.67	-0.61	-0.68	-0.65	-0.64	-0.61	-0.68	-0.71	-0.73	-0.74
SPI-6	-0.60	-0.59	-0.47	-0.65	-0.48	-0.60	-0.61	-0.55	-0.58	-0.50	-0.47	-0.56	-0.49	-0.58	-0.44	-0.61	-0.52	-0.63	-0.71
SPI-12	-0.38	-0.40	-0.50	-0.45	-0.41	-0.61	-0.51	-0.47	-0.46	-0.47	-0.37	-0.49	-0.33	-0.43	-0.50	-0.41	-0.39	-0.43	-0.51
SPEI-1	-0.76	-0.73	-0.74	-0.80	-0.72	-0.73	-0.75	-0.75	-0.75	-0.73	-0.72	-0.78	-0.75	-0.79	-0.68	-0.80	-0.76	-0.73	-0.77
SPEI-3	-0.71	-0.72	-0.67	-0.74	-0.67	-0.68	-0.72	-0.65	-0.64	-0.65	-0.57	-0.66	-0.63	-0.67	-0.60	-0.71	-0.68	-0.74	-0.64
SPEI-6	-0.66	-0.69	-0.57	-0.75	-0.60	-0.64	-0.65	-0.55	-0.62	-0.52	-0.52	-0.58	-0.63	-0.72	-0.51	-0.65	-0.56	-0.67	-0.59
SPEI-12	-0.41	-0.44	-0.45	-0.45	-0.49	-0.62	-0.55	-0.48	-0.45	-0.49	-0.51	-0.59	-0.42	-0.44	-0.36	-0.46	-0.50	-0.49	-0.55



	5302001 (Penang)	5302003 (Penang)	5402001 (Penang)	5402002 (Penang)	5504035 (Penang)	5507076 (Kedah)	5704055 (Kedah)	5806066 (Kedah)	5808001 (Kedah)	6103047 (Kedah)	6108001 (Kedah)	6206035 (Kedah)	6207032 (Kedah)	6306031 (Kedah)	6401002 (Perlis)	6603002 (Perlis)
SPI-1	-0.76	-0.61	-0.70	-0.65	-0.62	-0.74	-0.69	-0.73	-0.77	-0.75	-0.72	-0.76	-0.74	-0.80	-0.78	-0.78
SPI-3	-0.72	-0.71	-0.79	-0.74	-0.67	-0.65	-0.84	-0.77	-0.79	-0.84	-0.76	-0.77	-0.77	-0.67	-0.83	-0.73
SPI-6	-0.66	-0.63	-0.72	-0.70	-0.66	-0.65	-0.69	-0.61	-0.79	-0.76	-0.78	-0.59	-0.59	-0.69	-0.69	-0.61
SPI-12	-0.54	-0.37	-0.42	-0.51	-0.42	-0.52	-0.51	-0.39	-0.55	-0.50	-0.42	-0.49	-0.45	-0.43	-0.58	-0.51
SPEI-1	-0.78	-0.66	-0.70	-0.72	-0.71	-0.75	-0.69	-0.78	-0.76	-0.71	-0.76	-0.77	-0.78	-0.79	-0.71	-0.71
SPEI-3	-0.70	-0.65	-0.69	-0.67	-0.67	-0.71	-0.75	-0.70	-0.73	-0.74	-0.69	-0.77	-0.71	-0.70	-0.77	-0.71
SPEI-6	-0.67	-0.60	-0.71	-0.67	-0.74	-0.67	-0.69	-0.64	-0.72	-0.78	-0.70	-0.73	-0.64	-0.72	-0.71	-0.70
SPEI-12	-0.51	-0.45	-0.49	-0.51	-0.45	-0.57	-0.52	-0.55	-0.53	-0.55	-0.44	-0.45	-0.53	-0.56	-0.57	-0.44

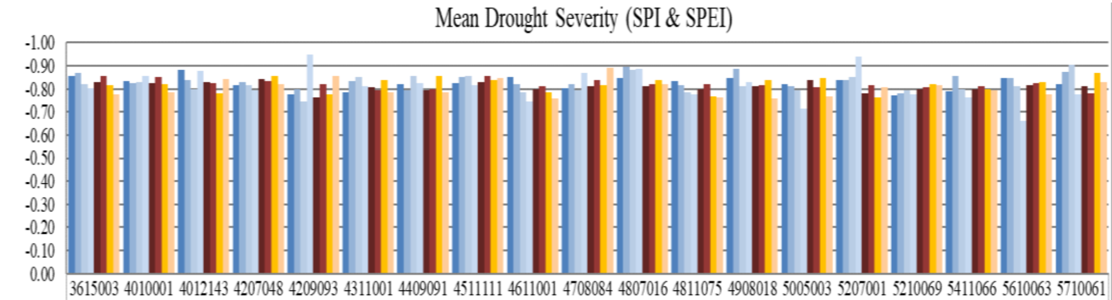
Figure 4.13: Graph and Table of Mean Drought Intensity Computed by the SPI and the SPEI



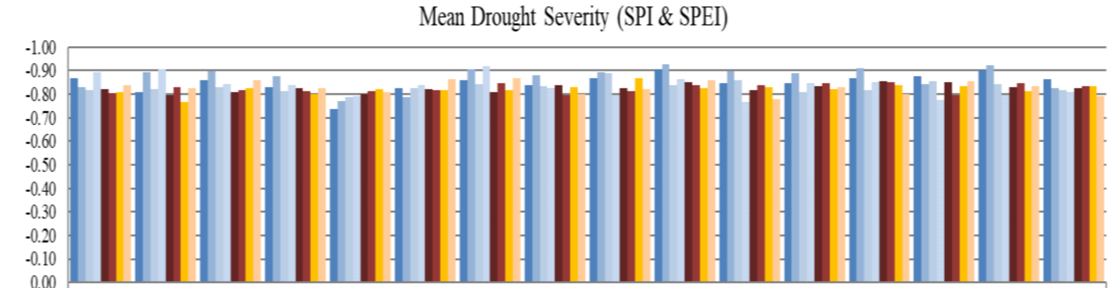
	4611463 (Perak)	4809443 (Perak)	5007421 (Perak)	5206432 (Perak)	5606410 (Kedah)	6503401 (Perlis)
SDI-3	-0.58	-0.76	-0.75	-0.74	-0.65	-0.65
SDI-6	-0.59	-0.77	-0.74	-0.78	-0.72	-0.73
SDI-12	-0.58	-0.83	-0.82	-0.77	-0.74	-0.70

Figure 4.14: Graph and Table of Mean Drought Intensity Computed by the SDI (Perak)

4.2.2.4 Mean Drought Severity

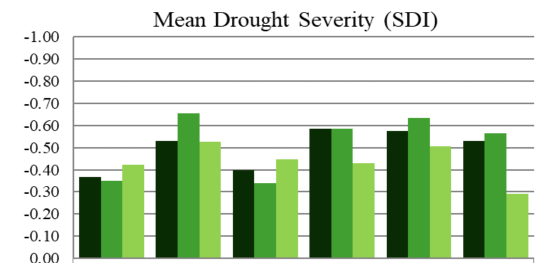


	3615003 (Perak)	4010001 (Perak)	4012143 (Perak)	4207048 (Perak)	4209093 (Perak)	4311001 (Perak)	4409091 (Perak)	4511111 (Perak)	4611001 (Perak)	4708084 (Perak)	4807016 (Perak)	4811075 (Perak)	4908018 (Perak)	5005003 (Perak)	5207001 (Perak)	5210069 (Perak)	5411066 (Perak)	5610063 (Perak)	5710061 (Perak)
SPI-1	-0.86	-0.83	-0.88	-0.82	-0.78	-0.78	-0.82	-0.83	-0.85	-0.80	-0.85	-0.84	-0.84	-0.82	-0.84	-0.77	-0.79	-0.85	-0.82
SPI-3	-0.87	-0.82	-0.84	-0.83	-0.80	-0.83	-0.80	-0.85	-0.82	-0.82	-0.90	-0.82	-0.89	-0.81	-0.84	-0.78	-0.85	-0.85	-0.87
SPI-6	-0.82	-0.83	-0.80	-0.82	-0.74	-0.85	-0.85	-0.86	-0.78	-0.79	-0.88	-0.79	-0.81	-0.79	-0.85	-0.79	-0.80	-0.81	-0.91
SPI-12	-0.80	-0.86	-0.88	-0.79	-0.95	-0.81	-0.82	-0.82	-0.74	-0.87	-0.89	-0.77	-0.83	-0.72	-0.94	-0.78	-0.76	-0.66	-0.78
SPEI-1	-0.83	-0.82	-0.83	-0.84	-0.76	-0.81	-0.80	-0.83	-0.80	-0.81	-0.81	-0.80	-0.81	-0.84	-0.78	-0.80	-0.80	-0.82	-0.81
SPEI-3	-0.85	-0.85	-0.82	-0.84	-0.82	-0.79	-0.80	-0.85	-0.81	-0.84	-0.82	-0.82	-0.82	-0.81	-0.82	-0.81	-0.81	-0.82	-0.78
SPEI-6	-0.82	-0.82	-0.78	-0.86	-0.78	-0.84	-0.86	-0.84	-0.79	-0.82	-0.84	-0.77	-0.84	-0.85	-0.76	-0.82	-0.80	-0.83	-0.87
SPEI-12	-0.78	-0.79	-0.84	-0.82	-0.86	-0.79	-0.79	-0.85	-0.76	-0.89	-0.82	-0.76	-0.76	-0.77	-0.81	-0.81	-0.79	-0.77	-0.83



	5302001 (Penang)	5302003 (Penang)	5402001 (Penang)	5402002 (Penang)	5504035 (Penang)	5507076 (Kedah)	5704055 (Kedah)	5806066 (Kedah)	5808001 (Kedah)	6103047 (Kedah)	6108001 (Kedah)	6206035 (Kedah)	6207032 (Kedah)	6306031 (Kedah)	6401002 (Perlis)	6603002 (Perlis)
SPI-1	-0.87	-0.81	-0.86	-0.83	-0.74	-0.83	-0.86	-0.84	-0.87	-0.91	-0.85	-0.85	-0.87	-0.88	-0.90	-0.86
SPI-3	-0.83	-0.89	-0.90	-0.87	-0.77	-0.79	-0.91	-0.88	-0.89	-0.93	-0.90	-0.89	-0.91	-0.84	-0.92	-0.83
SPI-6	-0.82	-0.82	-0.83	-0.81	-0.79	-0.83	-0.84	-0.83	-0.89	-0.84	-0.86	-0.81	-0.82	-0.85	-0.84	-0.81
SPI-12	-0.89	-0.91	-0.84	-0.84	-0.79	-0.84	-0.92	-0.82	-0.80	-0.86	-0.77	-0.85	-0.85	-0.77	-0.79	-0.81
SPEI-1	-0.82	-0.79	-0.81	-0.82	-0.80	-0.82	-0.81	-0.84	-0.83	-0.85	-0.82	-0.83	-0.85	-0.85	-0.83	-0.82
SPEI-3	-0.81	-0.83	-0.82	-0.81	-0.81	-0.82	-0.85	-0.79	-0.81	-0.84	-0.84	-0.85	-0.85	-0.80	-0.85	-0.83
SPEI-6	-0.81	-0.77	-0.82	-0.80	-0.82	-0.82	-0.82	-0.83	-0.87	-0.82	-0.83	-0.82	-0.84	-0.83	-0.81	-0.83
SPEI-12	-0.84	-0.83	-0.86	-0.82	-0.81	-0.86	-0.87	-0.80	-0.82	-0.86	-0.78	-0.83	-0.80	-0.86	-0.83	-0.79

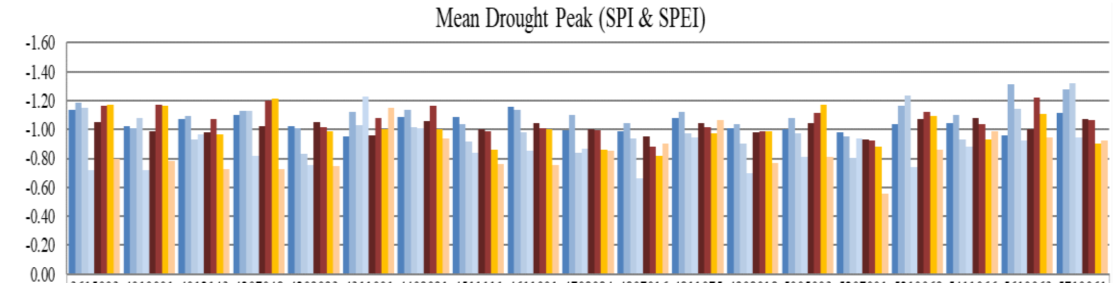
Figure 4.15: Graph and Table of Mean Drought Severity Computed by the SPI and the SPEI



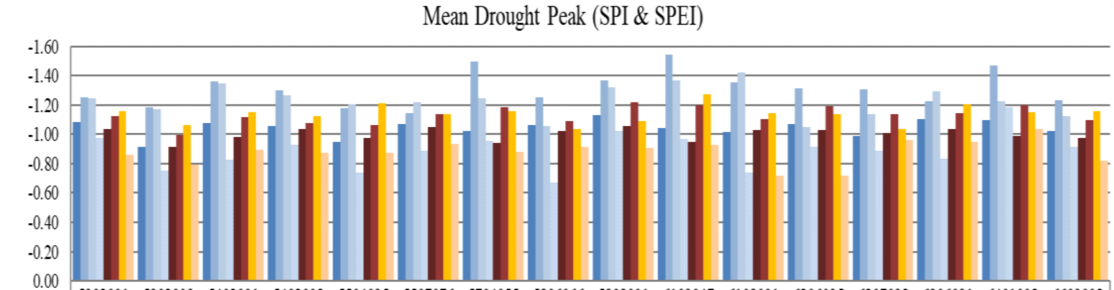
	4611463 (Perak)	4809443 (Perak)	5007421 (Perak)	5206432 (Perak)	5606410 (Kedah)	6503401 (Perlis)
SDI-3	-0.37	-0.53	-0.40	-0.59	-0.57	-0.53
SDI-6	-0.35	-0.66	-0.34	-0.59	-0.64	-0.57
SDI-12	-0.42	-0.53	-0.45	-0.43	-0.50	-0.29

Figure 4.16: Graph and Table of Mean Drought Severity Computed by the SDI

4.2.2.5 Mean Drought Peak

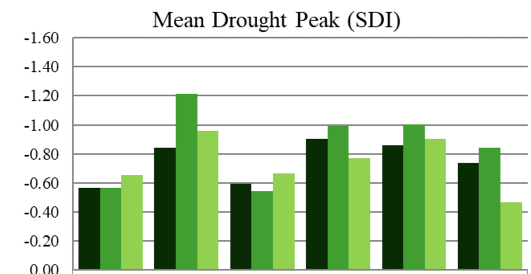


	3615003 (Perak)	4010001 (Perak)	4012143 (Perak)	4207048 (Perak)	4209093 (Perak)	4311001 (Perak)	4409091 (Perak)	4511111 (Perak)	4611001 (Perak)	4708084 (Perak)	4807016 (Perak)	4811075 (Perak)	4908018 (Perak)	5005003 (Perak)	5207001 (Perak)	5210069 (Perak)	5411066 (Perak)	5610063 (Perak)	5710061 (Perak)
SPI-1	-1.14	-1.02	-1.07	-1.10	-1.02	-0.95	-1.09	-1.08	-1.16	-1.00	-0.98	-1.08	-1.01	-1.00	-0.98	-1.03	-1.04	-0.96	-1.12
SPI-3	-1.19	-1.01	-1.09	-1.13	-1.01	-1.12	-1.13	-1.04	-1.14	-1.10	-1.04	-1.13	-1.04	-1.08	-0.95	-1.17	-1.10	-1.31	-1.28
SPI-6	-1.15	-1.08	-0.93	-1.13	-0.83	-1.03	-1.02	-0.92	-0.98	-0.84	-0.94	-0.97	-0.90	-0.97	-0.80	-1.23	-0.93	-1.15	-1.32
SPI-12	-0.72	-0.72	-0.97	-0.82	-0.75	-1.23	-1.01	-0.84	-0.85	-0.87	-0.66	-0.94	-0.70	-0.81	-0.94	-0.74	-0.88	-0.92	-0.95
SPEI-1	-1.05	-0.98	-0.98	-1.02	-1.05	-0.96	-1.06	-1.00	-1.05	-1.00	-0.95	-1.04	-0.98	-1.04	-0.93	-1.07	-1.08	-1.00	-1.07
SPEI-3	-1.16	-1.17	-1.07	-1.20	-1.02	-1.08	-1.16	-0.99	-1.01	-1.00	-0.88	-1.02	-0.99	-1.12	-0.92	-1.12	-1.04	-1.22	-1.06
SPEI-6	-1.17	-1.16	-0.96	-1.21	-0.99	-1.00	-1.00	-0.86	-1.00	-0.86	-0.82	-0.98	-0.99	-1.17	-0.88	-1.09	-0.93	-1.10	-0.90
SPEI-12	-0.80	-0.78	-0.73	-0.73	-0.74	-1.15	-0.94	-0.76	-0.76	-0.85	-0.90	-1.07	-0.77	-0.81	-0.56	-0.86	-0.99	-0.95	-0.93



	5302001 (Penang)	5302003 (Penang)	5402001 (Penang)	5402002 (Penang)	5504035 (Penang)	5507076 (Kedah)	5704055 (Kedah)	5806066 (Kedah)	5808001 (Kedah)	6103047 (Kedah)	6108001 (Kedah)	6206035 (Kedah)	6207032 (Kedah)	6306031 (Kedah)	6401002 (Perlis)	6603002 (Perlis)
SPI-1	-1.08	-0.92	-1.08	-1.05	-0.95	-1.07	-1.03	-1.07	-1.13	-1.05	-1.01	-1.07	-0.99	-1.10	-1.10	-1.02
SPI-3	-1.25	-1.19	-1.36	-1.30	-1.18	-1.15	-1.49	-1.25	-1.37	-1.54	-1.35	-1.31	-1.31	-1.23	-1.47	-1.23
SPI-6	-1.25	-1.17	-1.34	-1.27	-1.20	-1.22	-1.25	-1.05	-1.32	-1.37	-1.42	-1.05	-1.14	-1.30	-1.23	-1.12
SPI-12	-0.98	-0.75	-0.82	-0.93	-0.74	-0.89	-0.96	-0.67	-1.03	-0.97	-0.74	-0.91	-0.89	-0.84	-1.18	-0.92
SPEI-1	-1.03	-0.92	-0.98	-1.04	-0.98	-1.05	-0.94	-1.02	-1.06	-0.95	-1.03	-1.03	-1.01	-1.03	-0.99	-0.97
SPEI-3	-1.13	-0.99	-1.12	-1.08	-1.06	-1.14	-1.18	-1.09	-1.22	-1.20	-1.10	-1.19	-1.13	-1.14	-1.20	-1.10
SPEI-6	-1.16	-1.07	-1.15	-1.12	-1.21	-1.14	-1.15	-1.04	-1.09	-1.28	-1.15	-1.14	-1.04	-1.20	-1.15	-1.16
SPEI-12	-0.86	-0.79	-0.89	-0.88	-0.87	-0.93	-0.88	-0.92	-0.90	-0.93	-0.72	-0.72	-0.96	-0.95	-1.04	-0.82

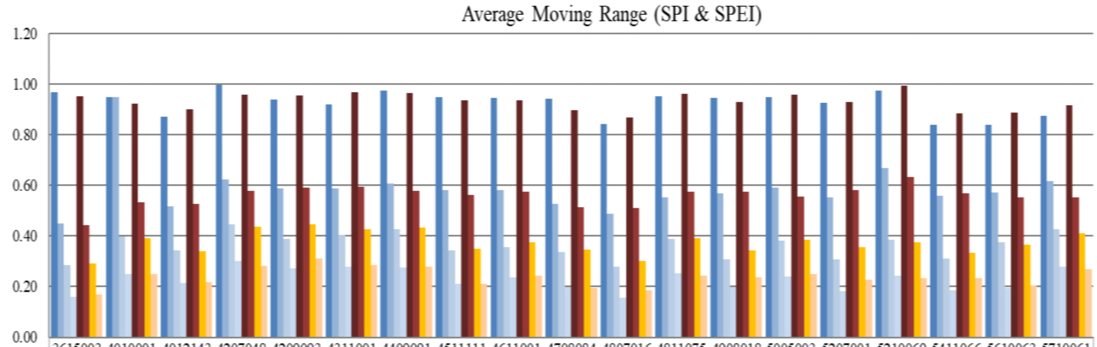
Figure 4.17: Graph and Table of Mean Drought Peak Computed by the SPI and the SPEI



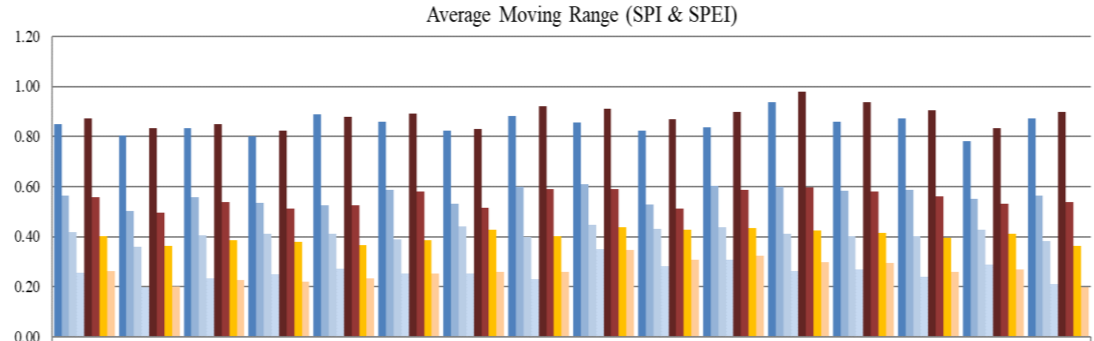
	4611463 (Perak)	4809443 (Perak)	5007421 (Perak)	5206432 (Perak)	5606410 (Kedah)	6503401 (Perlis)
SDI-3	-0.56	-0.84	-0.59	-0.90	-0.86	-0.74
SDI-6	-0.57	-1.21	-0.54	-0.99	-1.00	-0.84
SDI-12	-0.65	-0.96	-0.67	-0.77	-0.90	-0.47

Figure 4.18: Graph and Table of Mean Drought Peak Computed by the SDI

4.2.2.6 Average Moving Range

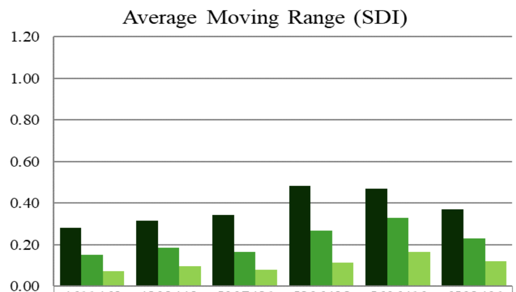


	3615003 (Perak)	4010001 (Perak)	4012143 (Perak)	4207048 (Perak)	4209093 (Perak)	4311001 (Perak)	4409091 (Perak)	4511111 (Perak)	4611001 (Perak)	4708084 (Perak)	4807016 (Perak)	4811075 (Perak)	4908018 (Perak)	5005003 (Perak)	5207001 (Perak)	5210069 (Perak)	5411066 (Perak)	5610063 (Perak)	5710061 (Perak)
SPI-1	0.97	0.95	0.87	1.00	0.94	0.92	0.97	0.95	0.94	0.94	0.84	0.95	0.95	0.95	0.93	0.97	0.84	0.84	0.87
SPI-3	0.45	0.95	0.52	0.62	0.59	0.59	0.61	0.58	0.58	0.53	0.49	0.55	0.57	0.59	0.55	0.67	0.56	0.57	0.62
SPI-6	0.28	0.40	0.34	0.45	0.39	0.40	0.43	0.34	0.36	0.34	0.28	0.39	0.31	0.38	0.31	0.39	0.31	0.38	0.43
SPI-12	0.16	0.25	0.21	0.30	0.27	0.28	0.28	0.21	0.24	0.20	0.16	0.25	0.20	0.24	0.18	0.24	0.18	0.19	0.28
SPEI-1	0.95	0.92	0.90	0.96	0.95	0.97	0.97	0.94	0.93	0.90	0.87	0.96	0.93	0.96	0.93	0.99	0.89	0.89	0.92
SPEI-3	0.44	0.53	0.53	0.58	0.59	0.59	0.58	0.56	0.58	0.51	0.51	0.57	0.57	0.55	0.58	0.63	0.57	0.55	0.55
SPEI-6	0.29	0.39	0.34	0.44	0.45	0.43	0.43	0.35	0.37	0.35	0.30	0.39	0.34	0.39	0.36	0.38	0.33	0.36	0.41
SPEI-12	0.17	0.25	0.22	0.28	0.31	0.28	0.28	0.21	0.24	0.19	0.18	0.24	0.24	0.25	0.23	0.23	0.23	0.20	0.27



	5302001 (Penang)	5302003 (Penang)	5402001 (Penang)	5402002 (Penang)	5504035 (Penang)	5507076 (Kedah)	5704055 (Kedah)	5806066 (Kedah)	5808001 (Kedah)	6103047 (Kedah)	6108001 (Kedah)	6206035 (Kedah)	6207032 (Kedah)	6306031 (Kedah)	6401002 (Perlis)	6603002 (Perlis)
SPI-1	0.85	0.80	0.83	0.80	0.89	0.86	0.82	0.88	0.85	0.82	0.84	0.94	0.86	0.87	0.78	0.87
SPI-3	0.56	0.50	0.56	0.53	0.53	0.59	0.53	0.60	0.61	0.53	0.60	0.60	0.58	0.59	0.55	0.56
SPI-6	0.42	0.36	0.40	0.41	0.41	0.39	0.44	0.40	0.45	0.43	0.44	0.41	0.40	0.40	0.43	0.38
SPI-12	0.26	0.20	0.23	0.25	0.27	0.25	0.25	0.23	0.35	0.28	0.31	0.26	0.27	0.24	0.29	0.21
SPEI-1	0.87	0.83	0.85	0.82	0.88	0.89	0.83	0.92	0.91	0.87	0.90	0.98	0.94	0.90	0.83	0.90
SPEI-3	0.56	0.50	0.54	0.51	0.53	0.58	0.51	0.59	0.59	0.51	0.59	0.60	0.58	0.56	0.53	0.54
SPEI-6	0.40	0.36	0.38	0.38	0.37	0.39	0.43	0.40	0.44	0.43	0.44	0.43	0.41	0.39	0.41	0.36
SPEI-12	0.26	0.20	0.23	0.22	0.23	0.25	0.26	0.26	0.35	0.31	0.33	0.30	0.29	0.26	0.27	0.20

Figure 4.19: Graph and Table of Average Moving Range Computed by the SPI and the SPEI



	4611463 (Perak)	4809443 (Perak)	5007421 (Perak)	5206432 (Perak)	5606410 (Kedah)	6503401 (Perlis)
SDI-3	0.28	0.32	0.34	0.48	0.47	0.37
SDI-6	0.15	0.19	0.17	0.27	0.33	0.23
SDI-12	0.07	0.10	0.08	0.11	0.16	0.12

Figure 4.20: Graph and Table of Average Moving Range Computed by the SDI

4.2.2.7 Data Range, Median, Mean

Table 4.1: Range, Median, Mean of Drought Frequency, Mean Drought Duration, Mean Drought Intensity, Mean Drought Severity, Mean Drought Peak, Average Moving Range

Drought Frequency												
States	**Indices**	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SDI-3**	**SDI-6**	**SDI-12**
Perak	Range	21	48	24	17	20	22	22	20	15	9	4
	Median	85	52	33	19	82	49	32	20	34	17.5	7
	Mean	84.89	52.26	33.05	19.11	82.47	48.47	33.05	20.42	33.75	16.5	8
Penang	Range	9	7	4	12	9	4	6	4			
	Median	75	45	34	20	77	47	31	20			
	Mean	76.2	46.2	33.2	21	77.2	47.8	32.2	19.2			
Kedah	Range	14	15	7	12	15	10	7	12			
	Median	77	51	35	21	80	48	35	21			
	Mean	77.44	49.22	34.89	22	79.11	46.89	35.22	22.78			
Perlis	Range	9	5	7	8	7	2	7	7			
	Median	75.5	47.5	35.5	17	77.5	44	32.5	17.5			
	Mean	75.5	47.5	35.5	17	77.5	44	32.5	17.5			

Mean Drought Duration												
States	**Indices**	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SDI-3**	**SDI-6**	**SDI-12**
Perak	Range	0.46	3.42	7.3	14.1	0.7	2.4	6.82	12.94	3	9.65	14.03
	Median	2.3	3.65	5.61	10.05	2.57	4.29	6.38	10.4	7.03	13.36	29.21
	Mean	2.28	3.79	6.16	10.92	2.6	4.39	6.46	10.93	7.03	14.49	27.89

Table 4.1 (Continued)

States	Indices	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Penang	Range	0.14	0.37	0.58	4.18	0.21	0.35	1.17	1.6			
	Median	2.59	4.18	6.12	9.61	2.77	4.43	6.77	10.45			
	Mean	2.57	4.12	6.12	9.22	2.78	4.44	6.67	10.51			
Kedah	Range	0.59	1.24	1.15	3.7	0.51	0.87	1.41	5			
	Median	2.31	3.68	5.51	8.86	2.66	4.31	5.86	9			
	Mean	2.33	3.81	5.67	8.97	2.67	4.51	5.89	9.06			
Perlis	Range	0.26	0.08	1.22	6.4	0.3	0.1	1.17	6.24			
	Median	2.27	3.78	5.64	12.72	2.76	4.72	6.45	12.45			
	Mean	2.27	3.78	5.64	12.72	2.76	4.72	6.45	12.45			

Mean Drought Intensity

States	Indices	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Perak	Range	0.12	0.16	0.28	0.28	0.12	0.17	0.24	0.26	0.18	0.19	0.24
	Median	-0.75	-0.68	-0.58	-0.45	-0.75	-0.67	-0.62	-0.48	-0.75	-0.76	-0.8
	Mean	-0.75	-0.67	-0.56	-0.45	-0.75	-0.67	-0.61	-0.48	-0.71	-0.72	-0.75
Penang	Range	0.15	0.12	0.09	0.17	0.12	0.05	0.15	0.07			
	Median	-0.65	-0.72	-0.66	-0.42	-0.71	-0.67	-0.67	-0.49			
	Mean	-0.67	-0.73	-0.68	-0.45	-0.71	-0.68	-0.68	-0.48			
Kedah	Range	0.11	0.19	0.2	0.16	0.1	0.08	0.14	0.14			
	Median	-0.74	-0.77	-0.69	-0.49	-0.76	-0.71	-0.7	-0.53			
	Mean	-0.74	-0.76	-0.68	-0.48	-0.75	-0.72	-0.7	-0.52			
Perlis	Range	0	0.1	0.07	0.07	0	0.06	0.01	0.13			
	Median	-0.78	-0.78	-0.65	-0.54	-0.71	-0.74	-0.71	-0.51			
	Mean	-0.78	-0.78	-0.65	-0.54	-0.71	-0.74	-0.71	-0.51			

Table 4.1 (Continued)

		Mean Drought Severity										
States	**Indices**	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SDI-3**	**SDI-6**	**SDI-12**
Perak	Range	0.11	0.12	0.16	0.29	0.08	0.08	0.11	0.14	0.22	0.32	0.11
	Median	-0.83	-0.83	-0.81	-0.81	-0.81	-0.82	-0.82	-0.79	-0.46	-0.47	-0.44
	Mean	-0.82	-0.84	-0.82	-0.81	-0.81	-0.82	-0.82	-0.8	-0.47	-0.48	-0.46
Penang	Range	0.13	0.12	0.04	0.11	0.03	0.02	0.06	0.05			
	Median	-0.83	-0.87	-0.82	-0.84	-0.81	-0.81	-0.81	-0.83			
	Mean	-0.82	-0.85	-0.81	-0.85	-0.81	-0.81	-0.8	-0.83			
Kedah	Range	0.08	0.14	0.08	0.15	0.05	0.06	0.05	0.09			
	Median	-0.86	-0.89	-0.84	-0.84	-0.83	-0.84	-0.83	-0.83			
	Mean	-0.86	-0.88	-0.84	-0.83	-0.83	-0.83	-0.83	-0.83			
Perlis	Range	0.04	0.1	0.03	0.02	0.01	0.01	0.02	0.04			
	Median	-0.88	-0.87	-0.83	-0.8	-0.83	-0.84	-0.82	-0.81			
	Mean	-0.88	-0.87	-0.83	-0.8	-0.83	-0.84	-0.82	-0.81			

		Mean Drought Peak										
States	**Indices**	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SDI-3**	**SDI-6**	**SDI-12**
Perak	Range	0.21	0.36	0.51	0.57	0.15	0.34	0.39	0.59	0.34	0.67	0.31
	Median	-1.03	-1.1	-0.97	-0.85	-1.02	-1.06	-0.99	-0.81	-0.72	-0.78	-0.72
	Mean	-1.04	-1.11	-1.01	-0.86	-1.02	-1.06	-1	-0.85	-0.73	-0.83	-0.76
Penang	Range	0.17	0.18	0.17	0.24	0.12	0.13	0.15	0.1			
	Median	-1.05	-1.25	-1.25	-0.82	-0.98	-1.08	-1.15	-0.87			
	Mean	-1.02	-1.26	-1.25	-0.84	-0.99	-1.08	-1.14	-0.86			

Table 4.1 (Continued)

States	Indices	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Kedah	Range	0.15	0.4	0.37	0.35	0.11	0.12	0.24	0.24			
	Median	-1.07	-1.31	-1.25	-0.89	-1.03	-1.14	-1.14	-0.92			
	Mean	-1.06	-1.33	-1.23	-0.88	-1.01	-1.16	-1.14	-0.88			
Perlis	Range	0.07	0.24	0.1	0.27	0.01	0.1	0	0.22			
	Median	-1.06	-1.35	-1.17	-1.05	-0.98	-1.15	-1.16	-0.93			
	Mean	-1.06	-1.35	-1.17	-1.05	-0.98	-1.15	-1.16	-0.93			
Average Moving Range												
States	**Indices**	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SDI-3**	**SDI-6**	**SDI-12**
Perak	Range	0.16	0.5	0.17	0.14	0.13	0.19	0.16	0.14	0.2	0.11	0.04
	Median	0.94	0.58	0.38	0.24	0.93	0.57	0.37	0.24	0.33	0.18	0.09
	Mean	0.93	0.59	0.36	0.23	0.93	0.56	0.37	0.24	0.36	0.19	0.09
Penang	Range	0.09	0.06	0.06	0.08	0.06	0.06	0.04	0.06			
	Median	0.83	0.53	0.41	0.25	0.85	0.53	0.38	0.23			
	Mean	0.84	0.54	0.4	0.24	0.85	0.53	0.38	0.23			
Kedah	Range	0.11	0.08	0.06	0.12	0.15	0.08	0.05	0.09			
	Median	0.86	0.59	0.41	0.26	0.9	0.58	0.43	0.29			
	Mean	0.86	0.58	0.42	0.27	0.9	0.57	0.42	0.29			
Perlis	Range	0.09	0.01	0.05	0.08	0.06	0.01	0.05	0.07			
	Median	0.83	0.56	0.41	0.25	0.87	0.53	0.39	0.23			
	Mean	0.83	0.56	0.41	0.25	0.87	0.53	0.39	0.23			

Data from Figure 4.9 to Figure 4.20 was analyzed, and then data range, median and mean for each states were recorded in Table 4.1 above for better interpretation. The range represented the consistency of data of all stations in the state. It was calculated by the difference between the highest value and the lowest value of data. The range for drought frequency of the SPI-3 in Perak was high due to the abnormal high the SPI-3 result at station 4010001 as shown in Figure 4.9. At the same time, median and mean for all data were found. It was discovered that their results were close to each other. This shown that all the values of stations within a state were consecutive.

By inspection on mean value of Table 4.1 for a comprehensive review, the drought frequency computed by the SPI was near to the SPEI, however the results of the SDI were much more lesser as compared to the SPI and the SPEI. At the same time, when the timescale increased, the frequency results were decreased. Therefore, the frequency of meteorological drought was highest, followed with agricultural drought, and the frequency of hydrological drought was very low. On the other hand, Perak had highest drought frequency, followed with other states.

Next, the mean drought duration of the SPI and the SPEI was shorter than the SDI. Generally, the mean drought duration was increased with the timescale of computation. So, the hydrological drought had longest duration, followed with agricultural drought and meteorological drought. As well as the range of results, it also increased with the timescales. In other words, the mean drought duration of meteorological drought for each station was similar, and the mean drought duration for agricultural or hydrological drought was very different for each station.

Mean drought intensity computed by the SPI and the SPEI was decreased when the timescale increased which shown that the intensity of meteorological drought was highest as compared to other droughts. At the same time, the range of results was increased when the timescale increased. So, the intensity of meteorological drought also similar for all stations. Meanwhile, based on data of the SDI, it was observed that the SDI-3, the SDI-6 and the SDI-12 shown a close result in measuring mean drought intensity. This shown that mean drought intensity of hydrological drought is not affect much by the number of months interval used for the SDI computation. At the same time, only the data from station 4611463 was different with the other three stations in Perak as shown in Figure 4.14 above. It is reasonable for stream to have different drought intensity, since the stream will have upstream and downstream, and their drought intensity will definitely different. Water flow from upstream to downstream, therefore upstream was suspected to have higher drought intensity compare to downstream.

The mean drought severity computed by the SPI and the SPEI was near to -0.85 for all timescales, however the mean drought severity computed by the SDI was near to -0.45 only. This proved that models with different input will have very different outcome in term of the severity. Even the SPI-12 and the SPEI-12 which are theoretically explained to measure a hydrologically drought, but their outcome values were largely different with the values of the SDI which measure hydrological drought based on streamflow data. Furthermore, index which had smallest range is the SPEI-3 generally, which mean the result of the SPEI-3 was relatively more consistent in computing mean drought severity.

The mean drought peak was low for the SPI-12, the SPEI-12 and also the SDI with any timescale which referred to hydrological drought as expected; it was high in seasonal and agricultural drought for the SPI and the SPEI of 3 months and 6 months. Furthermore, for mean drought peak of the SPI and the SPEI, the range was increased with the timescale except the range of the SDI-6 which was abnormal high. Therefore, it was assumed that peak of meteorological drought will be more similar for all stations as compared to agricultural and hydrological drought.

The moving range monitored the variation between consecutive data over time. By averaging them, the complicated variation of data over 35 years was displayed in a value, where higher average moving range means greater variation between consecutive data and vice versa. Moreover, the greater the average moving range, the greater the fluctuation of data, which means the amplitude was not even out and more detail the data was. Based on Table 4.1 above, the average moving range was highest for 1-month computation of every indices, and it decreased as the number of months used for computation increased. The highest average moving range in timescale of 1 month means that meteorological drought had highest variation. Meanwhile, it also shown that the drought level or moisture condition in Malaysia was very different from month to month throughout the past 35 years without long-term aridity.

4.3 Spatial Analysis

Results of multiple point data of drought frequency, mean drought duration, mean drought intensity, mean drought severity and mean drought peak at different stations and locations in previous section were transformed into a raster surface spatial map. Furthermore, by carry out a spatial analysis of different indices, it provides us a visual interpretation and comparison of result of different indices. It is especially helpful for comparison of the SPI, the SPEI to the SDI. Since the location of the SDI point data was different with the SPI and the SPEI, the data cannot be directly compared without a spatial analysis. Spatial analysis is important as the precipitation has spatial variations due to the complex distribution of land, sea and terrain in the region and hence may affect the drought frequency, duration intensity, severity and peak of the drought to have spatial distributions over the region.

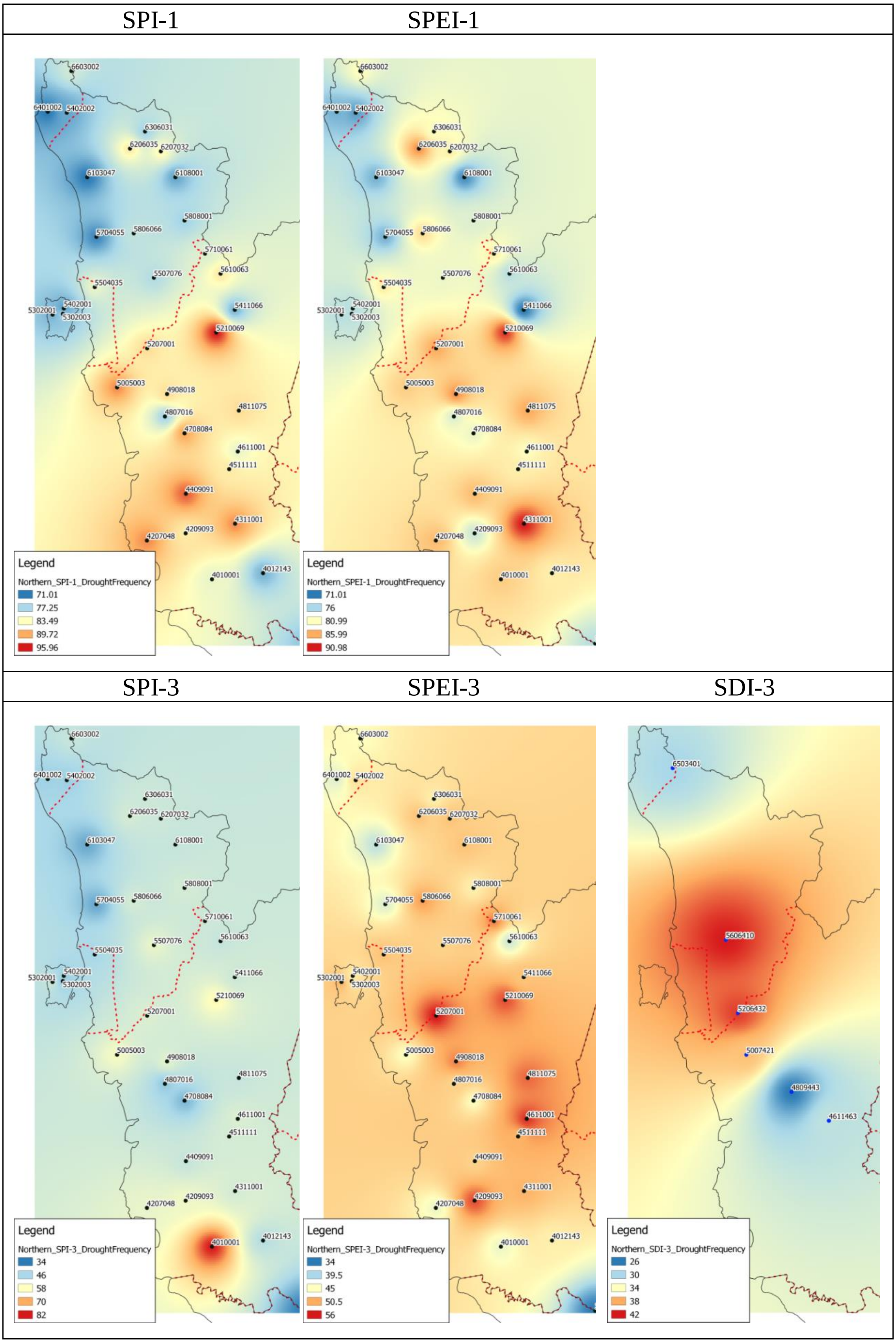


Figure 4.21: Spatial Map of Drought Frequency

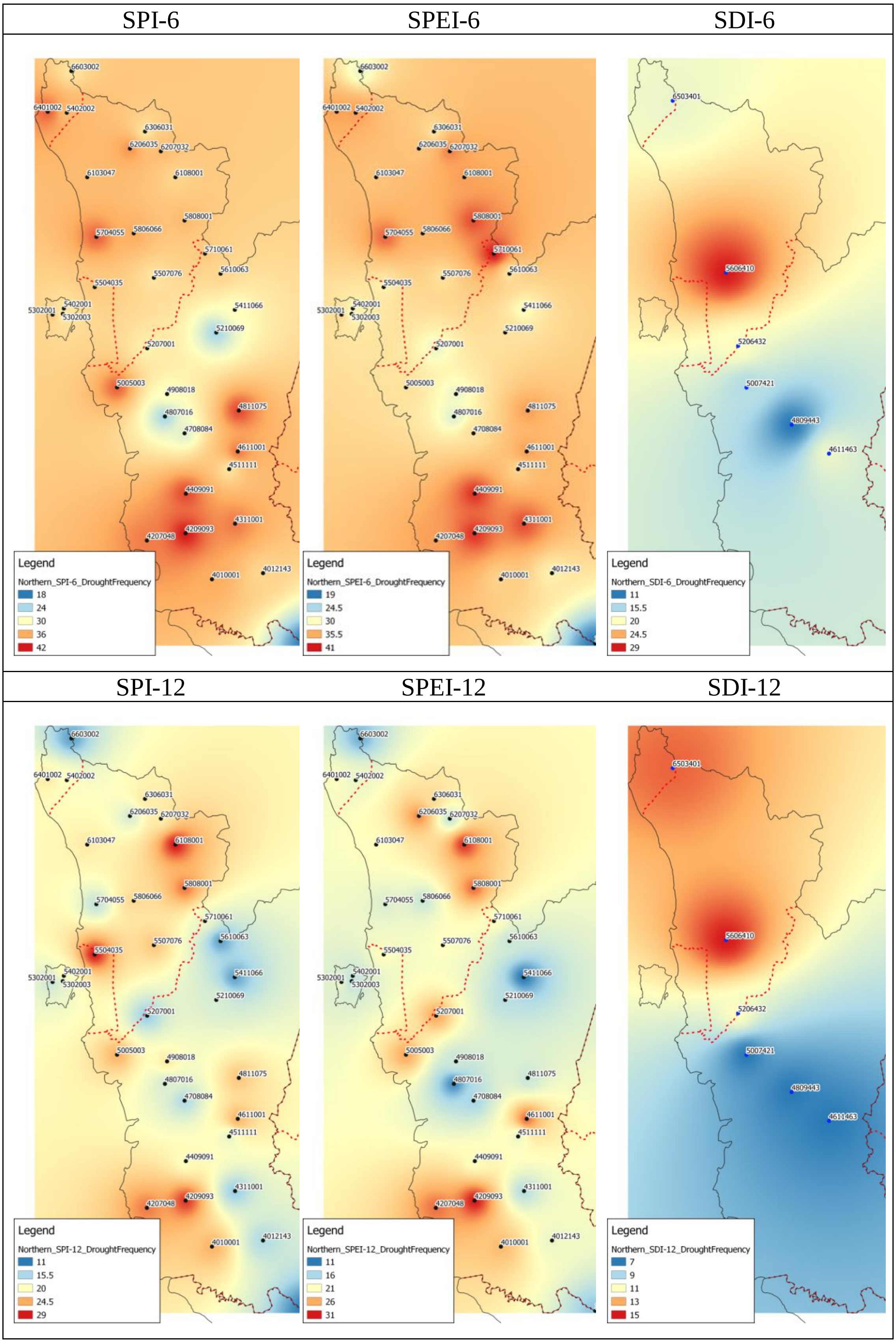


Figure 4.21 (Continued)

Plotting of the SPI-1 and the SPEI-1 in Figure 4.21 shown the frequency of short-term meteorological drought happened at all stations in northern region. Both maps similarly shown that short-term meteorological drought happened more frequent in Perak state, as it was observed that most of the brown colour was accumulated in Perak state as compared to Perlis, Penang and Kedah.

For 3 months timescale which represented a seasonal meteorological drought, the SPI and the SPEI shown different results. Drought frequency of the SPI-3 was low for all stations except the station 4010001 at south Perak with extreme high frequency. However, drought frequency of the SPEI-3 was evenly high across the whole region. The maximum frequency of the SPEI-3 was located at station 5207001 at the border of Kedah-Perak. Besides that, the SDI-3 also shown the frequency of hydrological drought computed by streamflow input was higher in Kedah, the maximum frequency was located at station 5606410 in Kedah and 5206432 at the border of Kedah. Therefore, the results of the SPEI-3 and the SDI-3 are more reliable.

The maps of the SPI-6 and the SPEI-6 indicated the frequency of medium-term agricultural drought that happened in past 35 years. the SPI-6 shown that the stations located at the south of Perak had the highest frequency. However, the SPEI-6 shown that there were two parts with high frequency. The first part was the south part of Perak which matched to the SPI-6. And the second part was the border between Kedah-Perak, this part was matched to the SDI-6 which measured a maximum frequency at station 5606410 near to the border.

Frequency of longer-term hydrological drought were shown by maps of the SPI-12 and the SPEI-12. Both maps shown that station 4209093 in Perak, and 6108001 in Kedah had high frequency of hydrological drought. Other than that, 5504035 in Penang also detected to be high frequent by the SPI-12. Coherently, the maximum frequency of long-term hydrological drought resulted by the SDI-12 was located at station 5606410 in Kedah near to Penang.

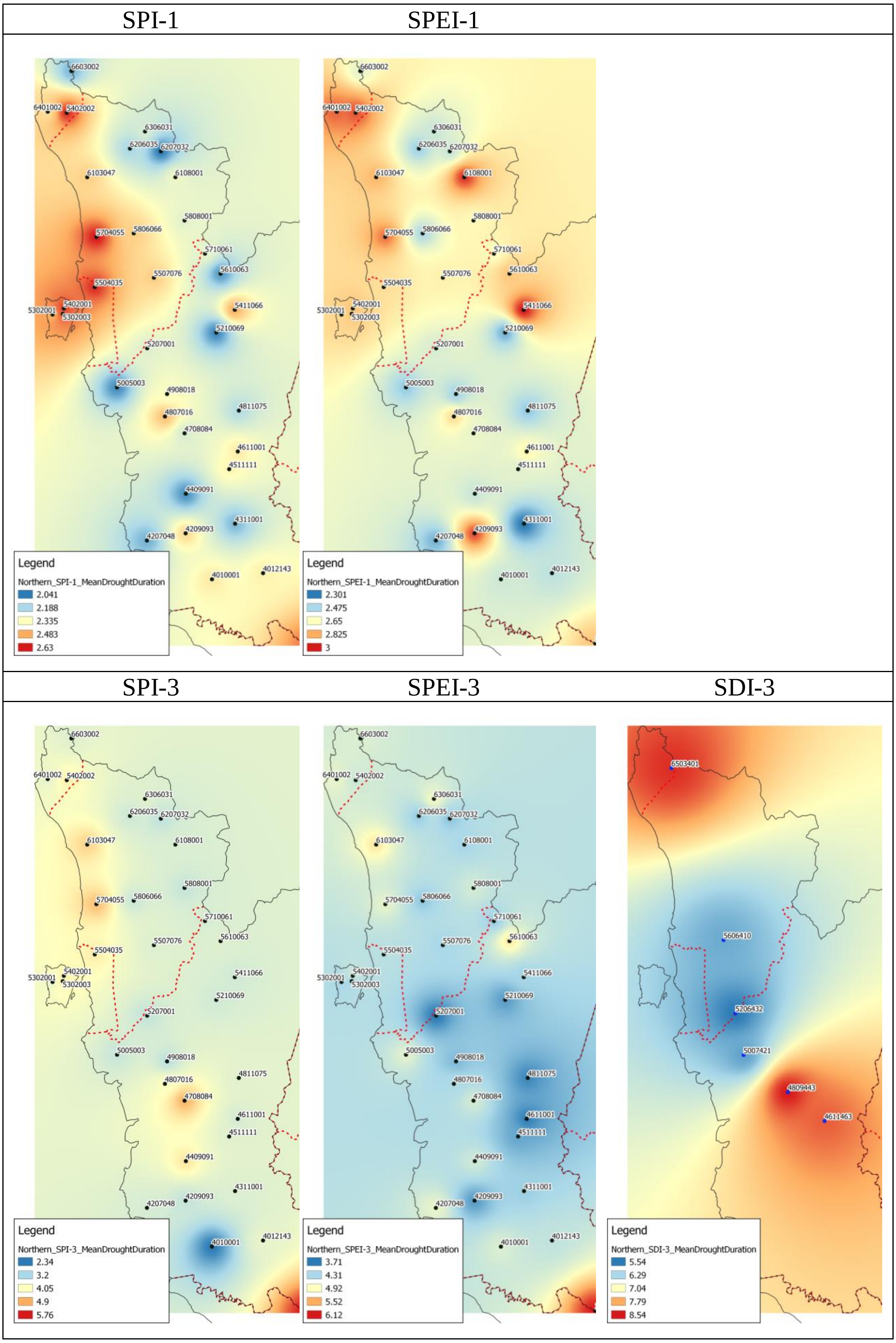
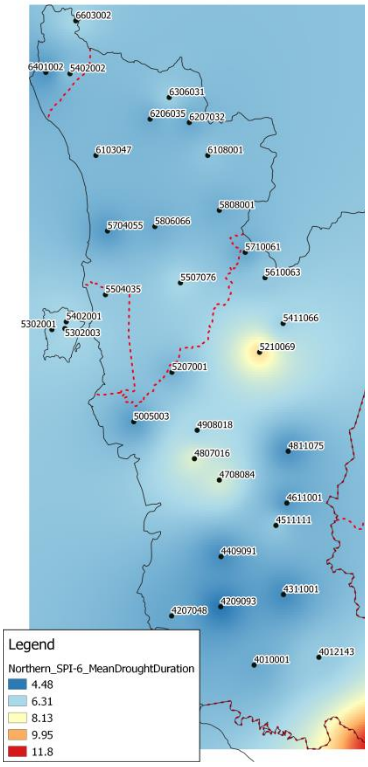
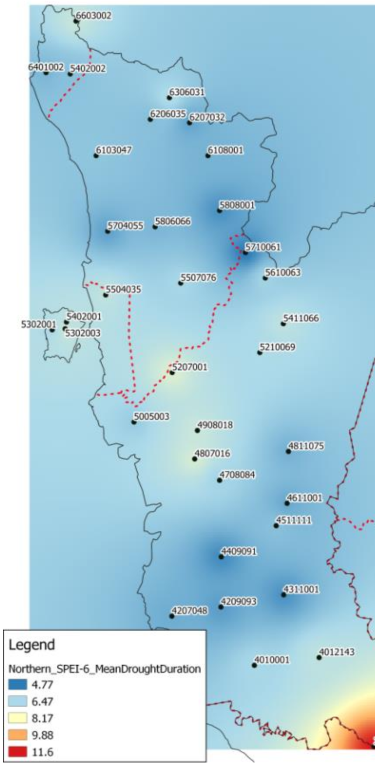


Figure 4.22: Spatial Map of Mean Drought Duration

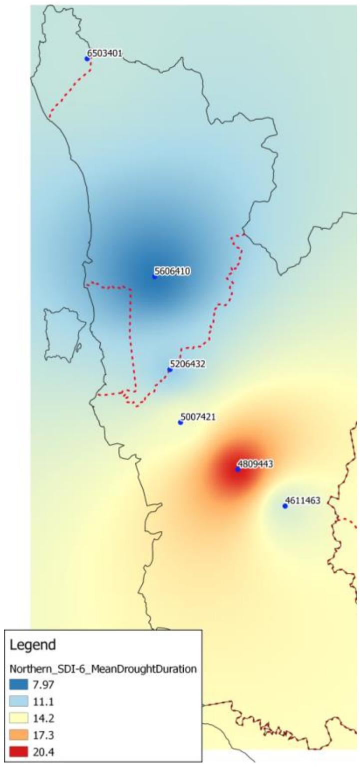
SPI-6



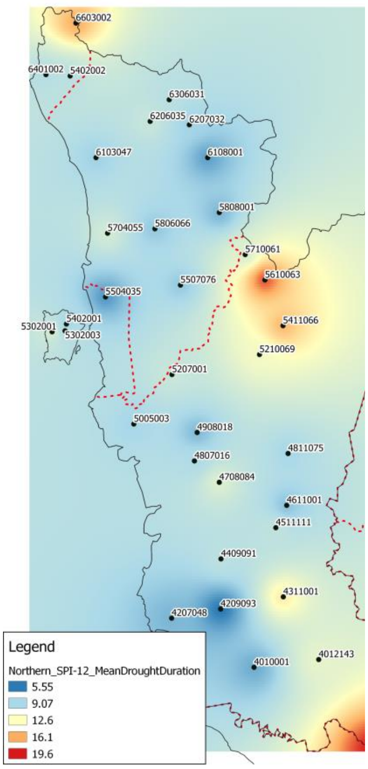
SPEI-6



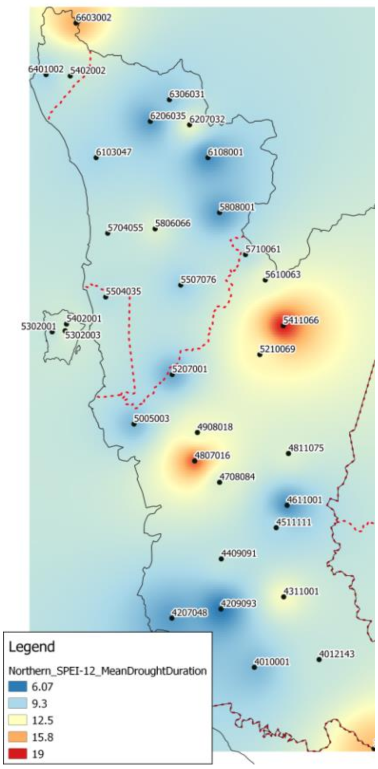
SDI-6



SPI-12



SPEI-12



SDI-12

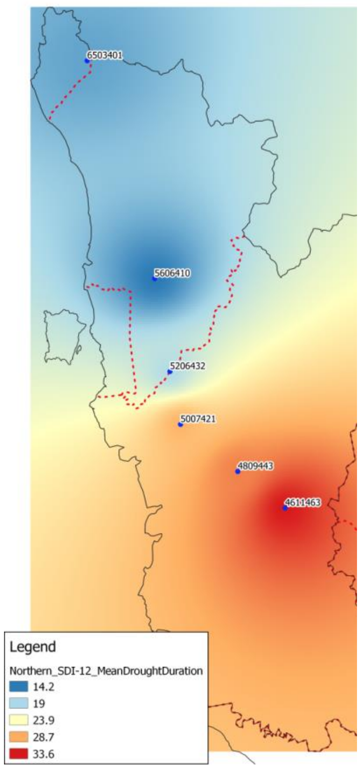


Figure 4.22 (Continued)

Based on the plotting map of mean drought duration of short-term meteorological drought in figure 4.22, mean drought duration was greatest for northwest part of the region based as resulted by the SPI-1. In other words, northwest part always experienced a longer rainfall deficit. But for the SPEI-1, the places which experienced longer duration of rainfall deficit were more distributed.

For the plotting map of mean drought duration of seasonal meteorological drought, again, the SPI-3 shown that west part of the region experienced greater mean drought duration than the east part but the diagram of the SPEI-3 shown that stations with greater mean drought duration were distributed. On the other hand, the SDI-3 which measured a short-term hydrological drought shown that northwest and southeast experienced greater mean drought duration.

The plotting map of mean drought duration of medium-term agricultural drought computed by the SPI-6 and the SPEI-6 based on data from 35 rainfall stations in northern region of Malaysia shown that the mean drought duration for most stations was evenly low. The only station with relatively long mean drought duration was station 5210069 located in Perak computed by the SPI-6. This seemed similar to the SDI-6 which measured a great mean duration at station 4809443 in Perak state also.

As a result of mean drought duration of long–term hydrological drought, hydrological drought with greatest mean drought duration is located at stations 6603002 in Perlis, 5610063 and 5411066 in Perak for the SPI-12. For the SPEI-12, the stations are 6603002 in Perlis, 5411066, 5210069 and 4807016 in Perak. Meanwhile, the result of the SDI-12 shown that the mean drought duration was great in Perak state.

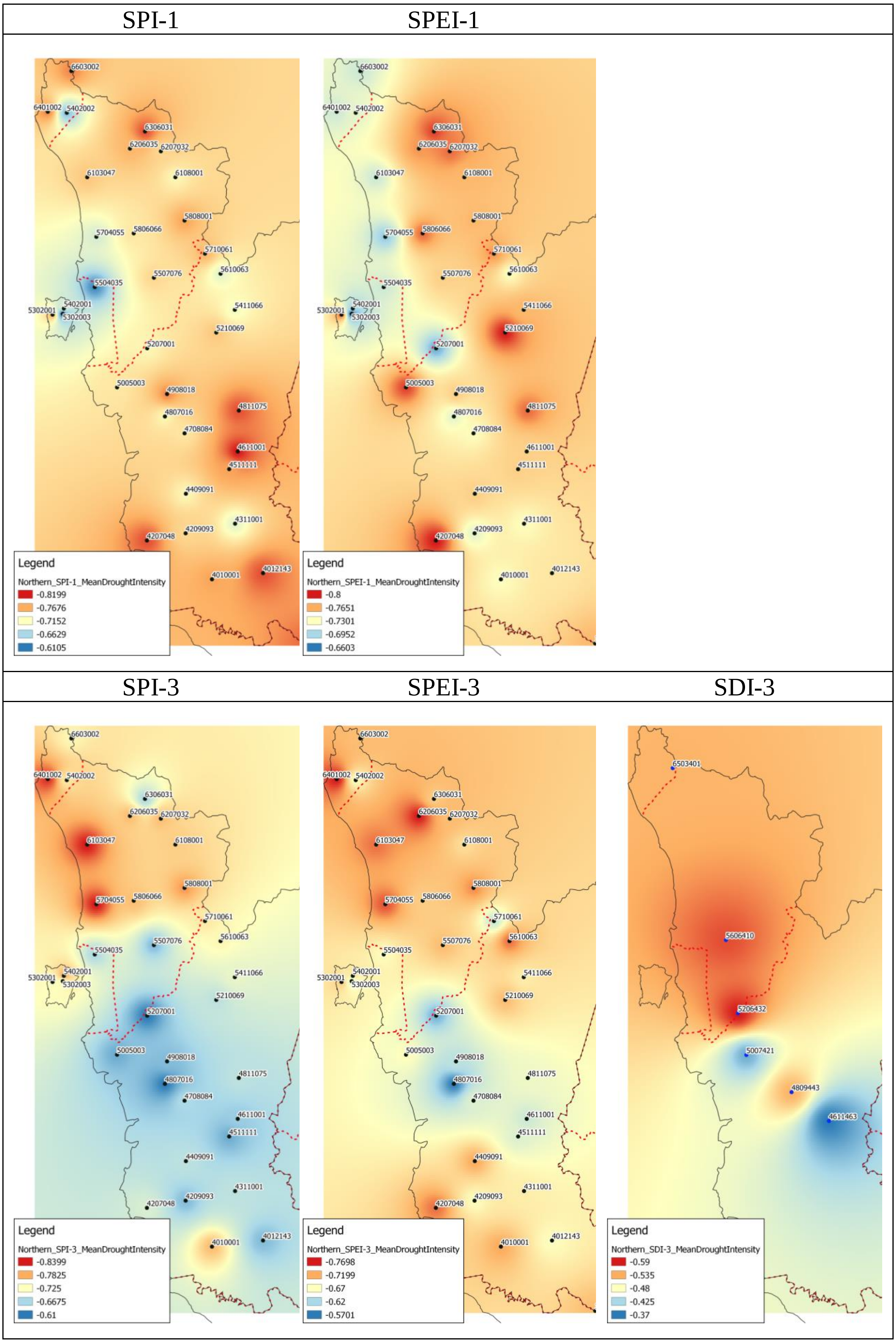


Figure 4.23: Spatial Map of Mean Drought Intensity

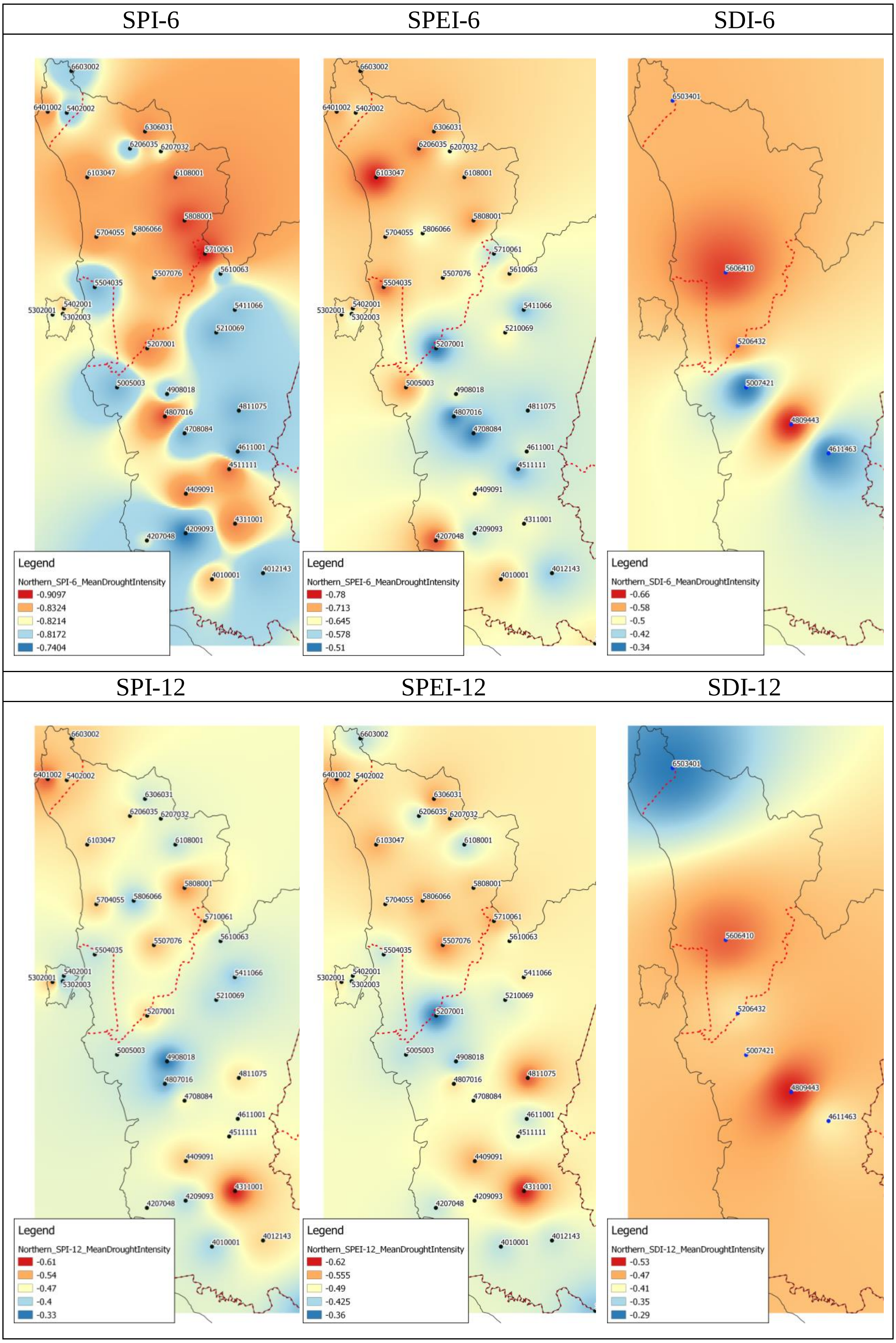


Figure 4.23 (Continued)

In Figure 4.23, both plotting map of mean drought intensity of short-term meteorological drought computed by the SPI-1 and the SPEI-1 shown that most of the east part was intense than west part.

The plotting map of mean drought intensity of seasonal meteorological drought computed by the SPI-3 and the SPEI-3 together with the short-term hydrological drought resulted by the SDI-3 shown that the north part which mainly included Perlis and Kedah state has higher intensity.

Medium-term agricultural drought computed by the SPI-6, the SPEI-6 and medium-term hydrological drought computed by the SDI-6 also shown higher intensity at Kedah and some part in Perak.

The most intense part shifted from Kedah to Perak for long-term hydrological drought computed by the SPI-12, the SPEI-12 and the SDI-12.

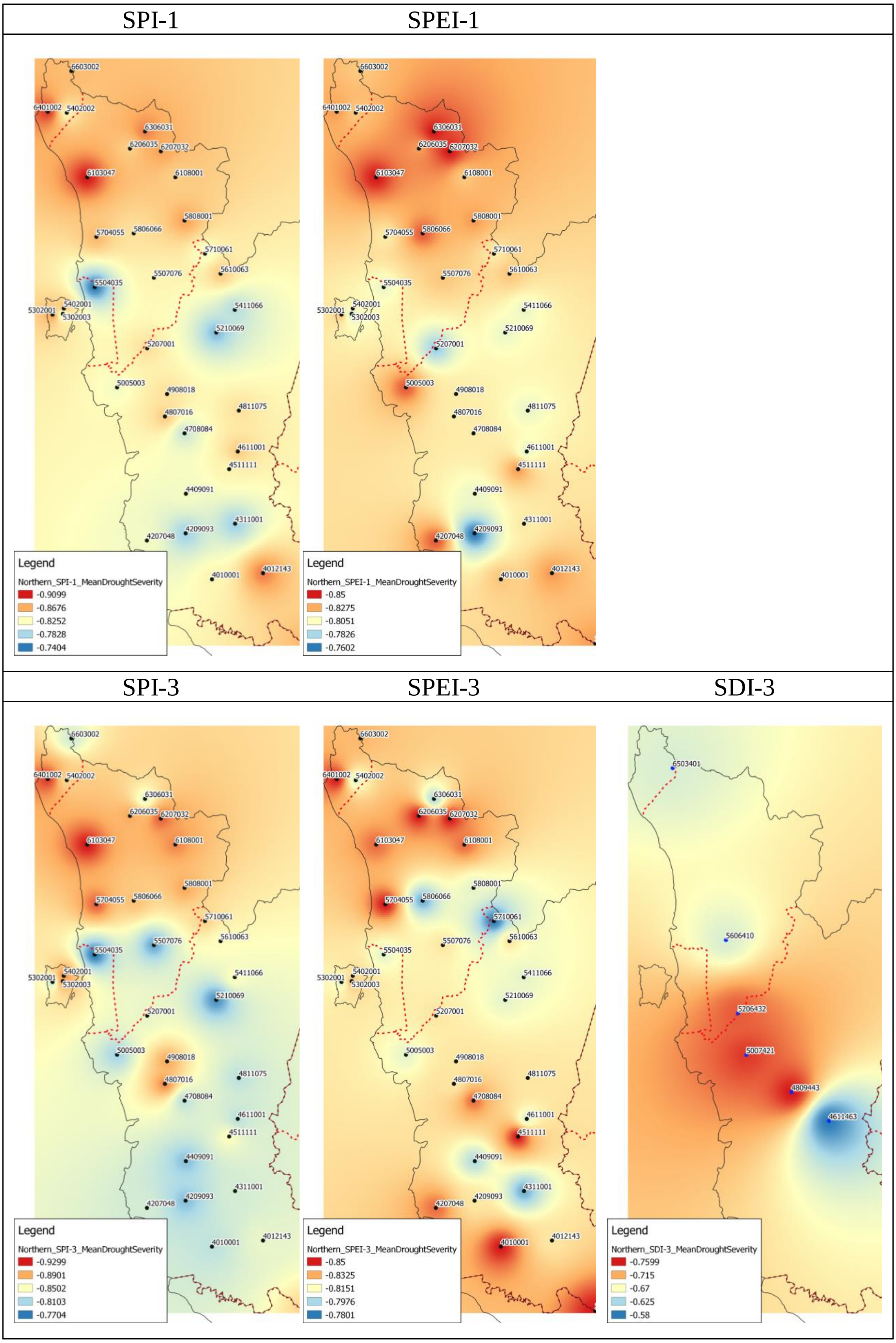


Figure 4.24: Spatial Map of Mean Drought Severity

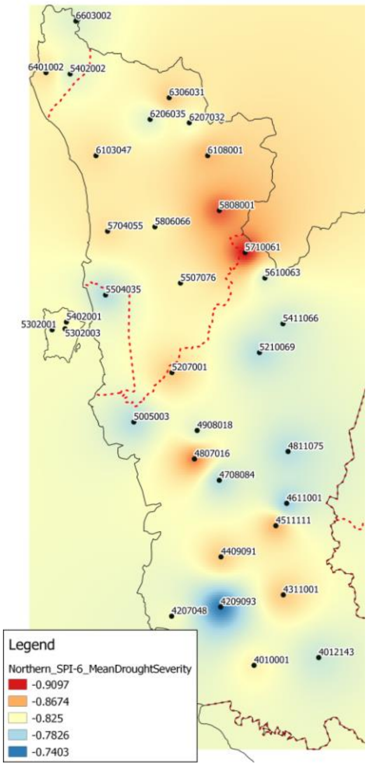
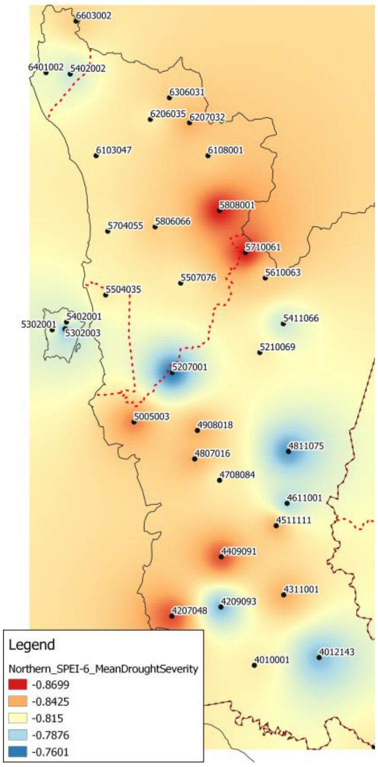
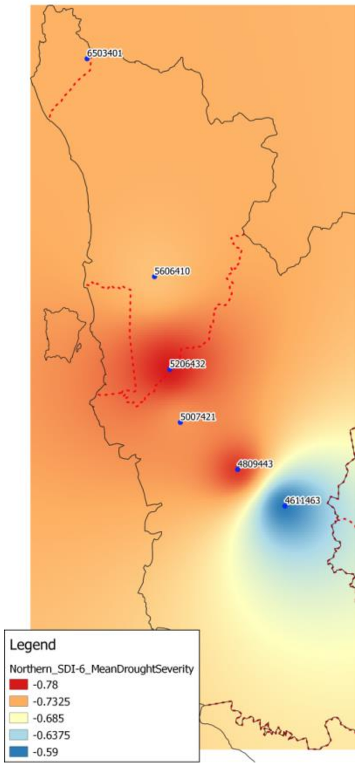
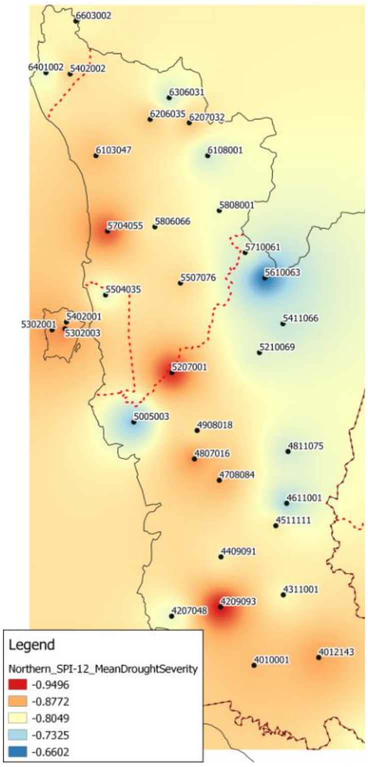
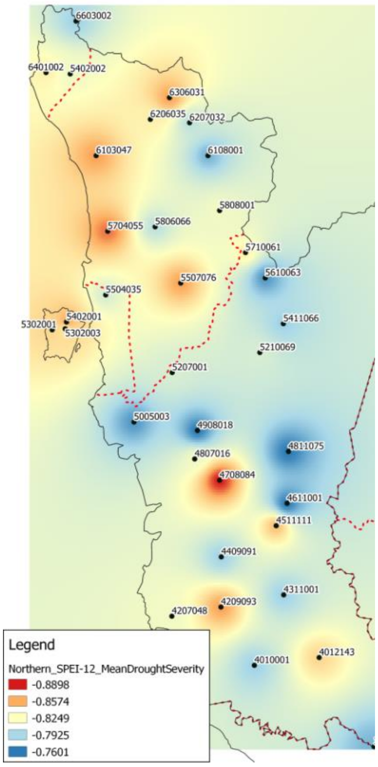
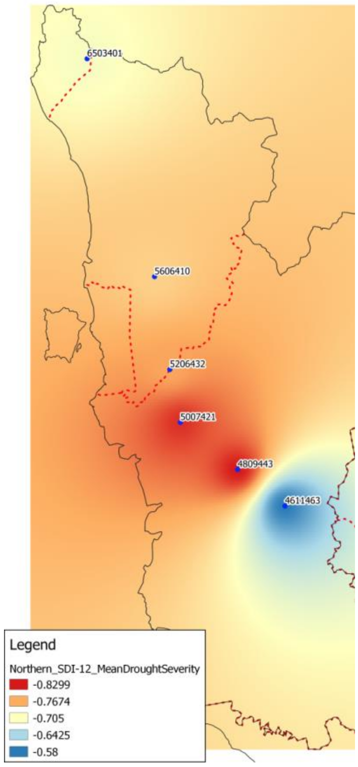
SPI-6	SPEI-6	SDI-6
		
SPI-12	**SPEI-12**	**SDI-12**
		

Figure 4.24 (Continued)

Mean drought severity is the mean of indices value. For the mean drought severity of short-term meteorological as shown in Figure 4.24 which are the mean of the SPI-1 and the SPEI-1, they were higher at the north part.

The mean of the SPI-3 and the SPEI-3 also greater at the north part. Other than that, a few stations in Perak also shown greater mean of the SPEI-3 such as the stations 4511111, 4010001, 4207048 and 4708084. This is in coherent with the mean drought severity of short-term hydrological drought computed by the SDI-3, where streamflow station 5206532, 5007421 and 4809443 in Perak had greater severity.

For medium-term agricultural drought computed by the SPI-6 and the SPEI-6, the two stations with most severe value were 5808001 and 5710061 located at the border of Kedah-Perak. And based on the SDI-6 computation, the most severe part started from station 5206432 located at the border, and it extended until station 4809443.

The plotting map of mean drought severity of long-term hydrological drought computed by the SPI-12 shown that 5704055 in Kedah, 5207001 at the border, and 4209093 in Perak were the greatest; the SPEI-12 shown that 4708084 in Perak was the greatest. Same with the long-term hydrological drought computed by the SPI-12, station 4809443 in Perak had the greatest severity.

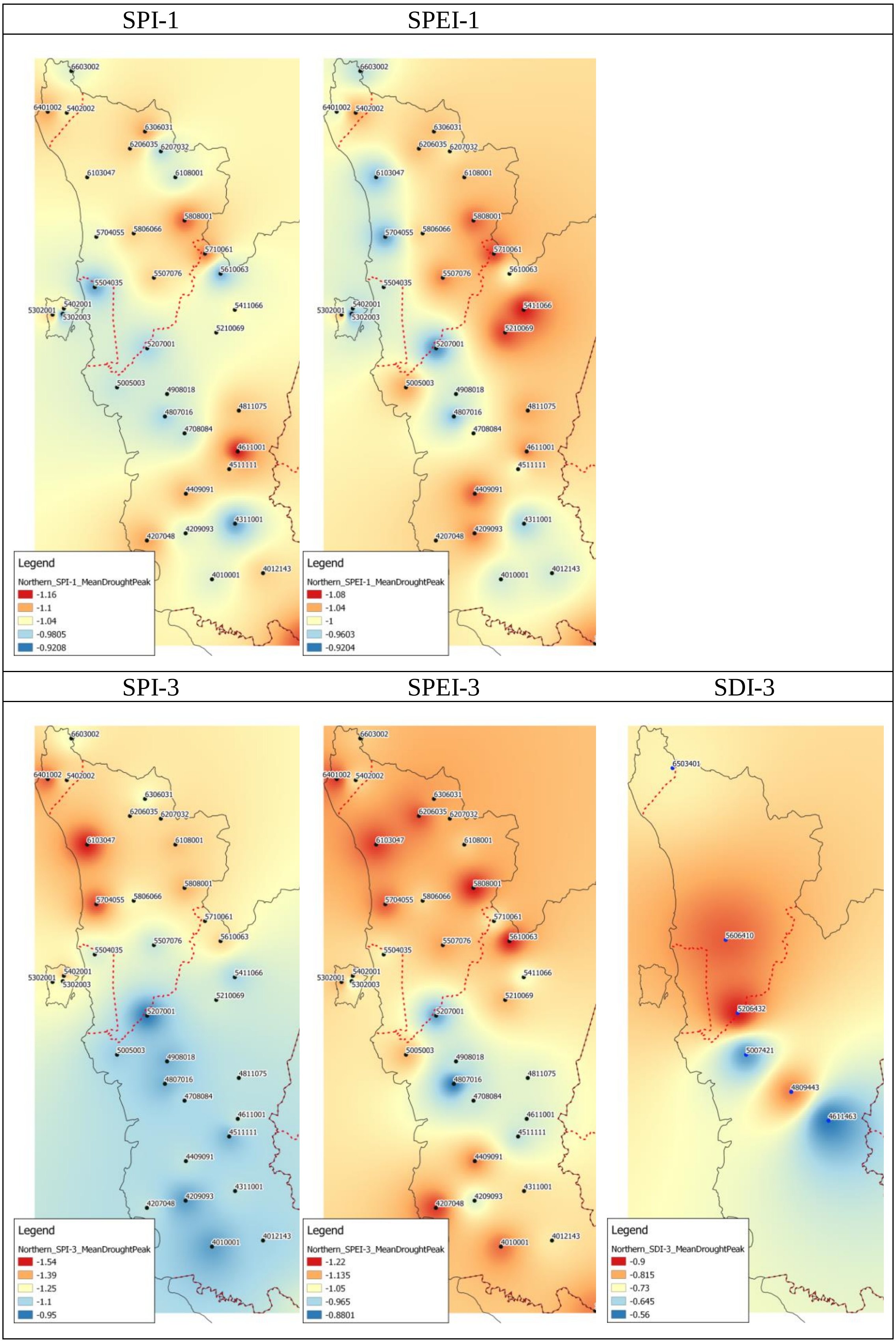
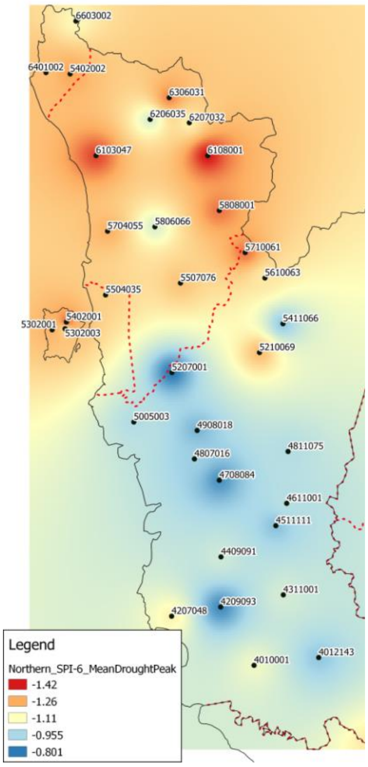
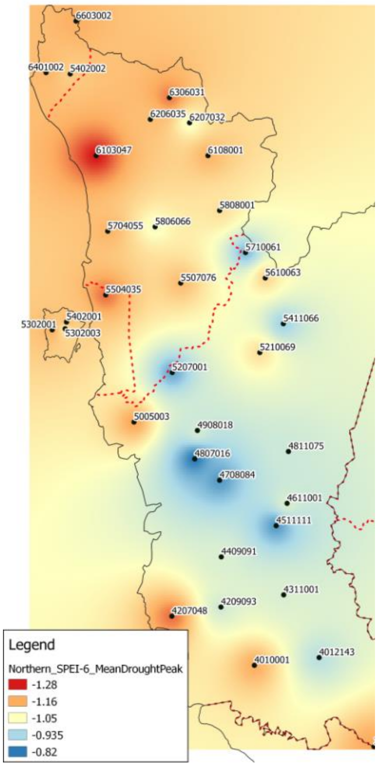


Figure 4.25: Spatial Map of Mean Drought Peak

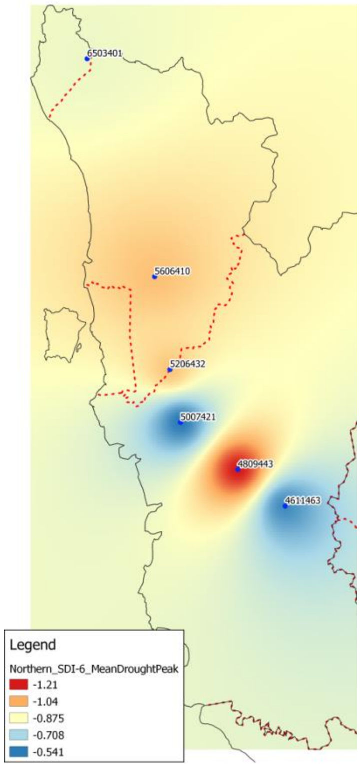
SPI-6



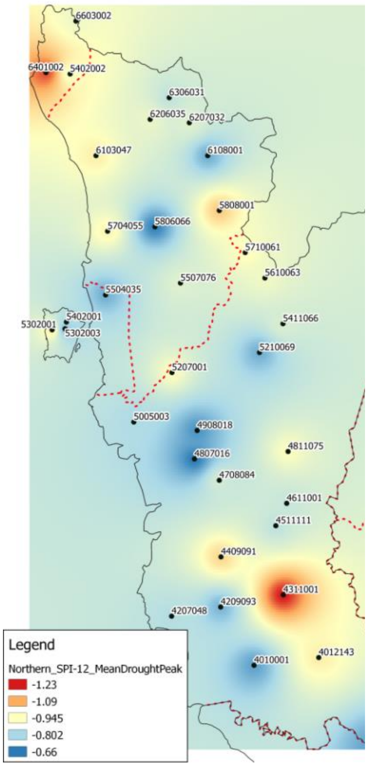
SPEI-6



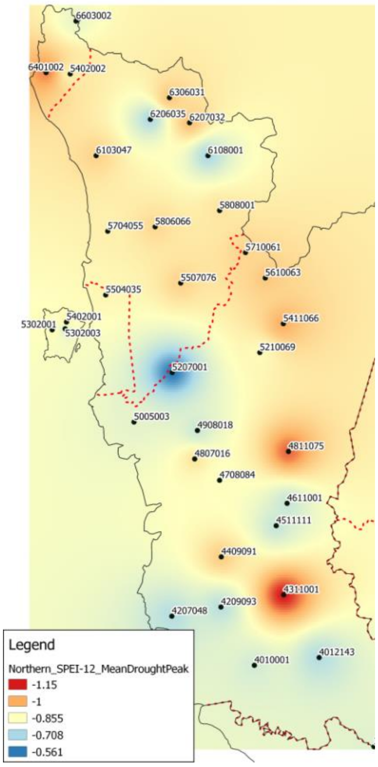
SDI-6



SPI-12



SPEI-12



SDI-12

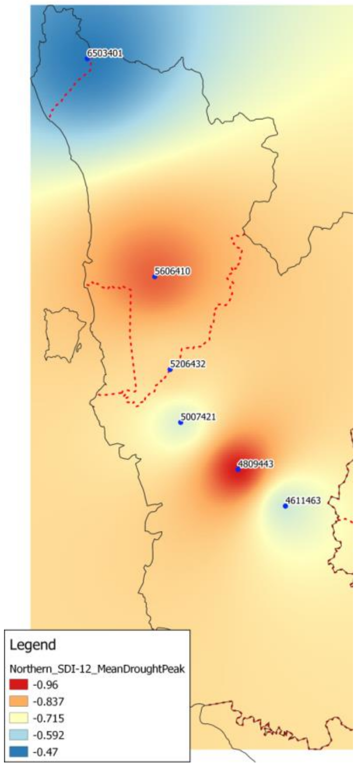


Figure 4.25 (Continued)

The peak of short-term meteorological drought was greatest in Perak as shown by map of mean drought peak of the SPI-1 and the SPEI-1 in Figure 4.25. Generally, east part was greater than west part on the map.

For the peak of seasonal meteorological drought, it was greater at the north part which included Perlis and Kedah state as shown by map of mean drought peak of the SPI-3. But for the SPEI-3, some stations in Perak such as 5610063 at the top and 4207048 at the bottom also had a high peak value. Furthermore, the SDI-3 also shown great value of mean drought peak in Perlis, Kedah and part of the Perak, where the greatest point is located at station 5206432 in between Kedah and Perak.

The peak of medium-term agricultural drought was also greatest in Kedah as shown by map of mean drought peak of the SPI-6 and the SPEI-6. But the peak of medium-term hydrological drought computed by the SDI-6 was highest at station 4809443 in Perak.

The greatest point of long-term hydrological drought was shifted to 4311001 in Perak based on map of mean drought peak of the SPI-12 and the SPEI-12. And the peak of long-term hydrological drought by the SDI-12 was highest at station 4809443 in Perak as well.

4.4 Temporal Analysis

Temporal analysis to find out the mean monthly drought indices in northern was done and summarized in Table 4.2 until Table 4.11 below. Mean monthly drought indices was found by finding the average value for each month. The negative mean indices value indicated that drought is likely to happen in that month over past 35 years.

Table 4.2 recorded the mean value of the SPI-1 for each month and Table 4.3 recorded the mean value of the SPEI-1 for each month over the past 35 years. According to Table 4.2 and Table 4.3, January, February, March, June, July, August and December shown a negative value generally, which mean a drought event always happened from (Dec.-Mar. of next year) and another drought event happened from (Jun.-Aug.). The result is in coherence with the statement, northern region is the driest region during the SWM season and this region also receives minimal rain during the NEM (Syafrina, Zalina and Juneng, 2015). SWM, the summer monsoon from (Jun.- Sept.) originates from the deserts of Australia exert a dry monsoon season to northern of Malaysia since the wind speed of SWM might largely blocked by high mountain ranges in Sumatra before it reached to Malaysia. Hence the rainfall brought by SWM was lesser (Tan et al., 2015). For NEM, the winter monsoon from (Nov.-Mar.) originates in China and the north Pacific tends to bring more rainfall to Malaysia but northern region of Malaysia is protected by the Titiwangsa Range which form a screen to block the rainfall brought by NEM to northern region of Malaysia (Tan et al., 2015).

Furthermore, result of SPI-3, SPEI-3 and SDI-3 were recorded in Table 4.4, Table 4.5 and Table 4.6. Temporal pattern of SPEI-3 were match with temporal of ocean atmosphere system with high SST. The detected period with negative value were (Jun.-Sept.) in the south Perak and (Jan.-Aug.) in Penang, Kedah, Perlis. SDI-3 was similar to SPEI-3, the negative values were found in period (Feb. -Aug.).

Figure 4.26 below was used to observe months with high SST. In facts, ONI, EMI, and DMI will not happen in the same period every year. Therefore, the results below only can be interpreted as high SST most likely to occurred in months with positive values but not definitely will happen. Figure 4.26 shown that higher ONI values in (Jan.-Aug.), higher EMI values in (Sept.), and higher DMI values in (Jun.-Sept.). Therefore, Perak might be related to EMI, DMI. Penang, Kedah, and Perlis might be related to ONI.

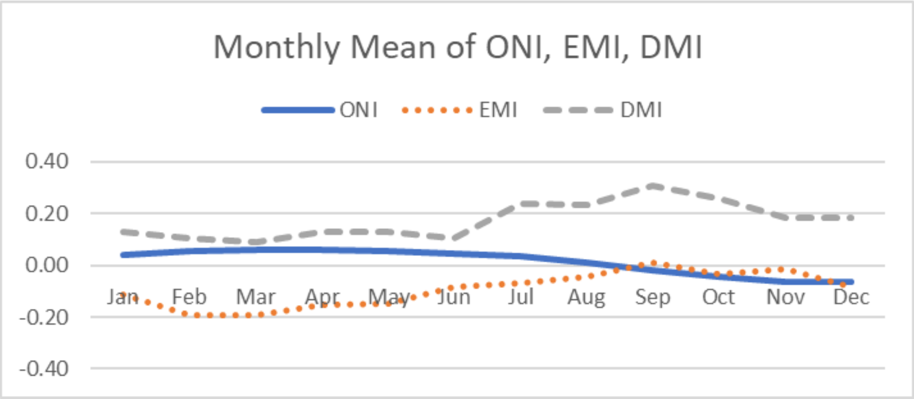


Figure 4.26: Monthly Mean of ONI, EMI and DMI

On the other hand, the SPI-6 in Table 4.7 and the SPEI-6 in Table 4.8, both of them shown that the medium-term agricultural drought for Perak happened from (Jun.-Oct.), but for Penang, Kedah, and Perlis, the drought happened from (Mar.-Jul.). This might show the coherency with high SST also. However, the SDI-6 in Table 4.9 shown that the drought of each states was mostly happened in (Apr.-Sept.) which are irrelevant.

Furthermore, for the results of the SPI-12 in Table 4.10, the SPEI-12 in Table 4.11, and the SDI-12 in Table 4.12 the negative values which indicated drought events were scattered. Therefore, it shown that there was no consistent temporal pattern for long term hydrological drought.

Table 4.2: Monthly Mean of the SPI-1 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	0.12	-0.18	0.23	-0.20	-0.12	0.22	-0.05	-0.11	-0.15	0.34	-0.06	0.17
Perak	**4010001**	0.29	-0.29	0.32	0.32	-0.05	-0.70	-0.49	-0.62	-0.06	0.30	0.85	0.51
Perak	**4012143**	-0.17	-0.24	0.15	0.56	0.15	-0.51	-0.47	-0.40	0.00	0.35	0.71	0.45
Perak	**4207048**	0.16	-0.60	-0.05	0.08	-0.14	-0.86	-0.40	-0.30	0.38	0.74	0.81	0.44
Perak	**4209093**	-0.08	-0.41	0.28	0.29	0.05	-0.78	-0.46	-0.22	0.26	0.37	0.80	0.39
Perak	**4311001**	-0.10	-0.06	0.33	0.58	0.11	-0.91	-0.62	-0.49	0.02	0.47	0.71	0.28
Perak	**4409091**	-0.03	-0.51	-0.12	0.31	0.06	-0.67	-0.53	-0.47	0.19	0.42	0.97	0.50
Perak	**4511111**	-0.45	-0.82	-0.01	0.37	0.17	-0.44	-0.37	-0.15	0.22	0.60	0.78	0.28
Perak	**4611001**	-0.55	-0.73	-0.14	0.28	0.50	-0.30	-0.38	0.07	0.19	0.57	0.74	0.02
Perak	**4708084**	-0.22	-0.36	0.09	0.23	-0.15	-0.53	-0.45	-0.26	0.31	0.64	0.84	0.04
Perak	**4807016**	-0.79	-0.83	-0.12	0.18	0.35	-0.15	-0.05	0.13	0.60	0.60	0.65	-0.27
Perak	**4811075**	-0.79	-0.58	-0.13	0.62	0.05	-0.26	-0.17	0.19	0.48	0.57	0.58	-0.09
Perak	**4908018**	-0.63	-0.47	0.21	0.53	0.22	-0.65	-0.45	-0.13	0.42	0.72	0.80	-0.28
Perak	**5005003**	-0.41	-0.46	-0.02	0.20	-0.02	-0.58	-0.46	-0.01	0.64	0.68	0.82	0.09
Perak	**5207001**	-0.57	-0.44	0.11	0.53	0.06	-0.58	-0.64	-0.08	0.54	0.87	0.63	-0.10
Perak	**5210069**	-0.98	-0.73	-0.11	0.46	0.22	-0.26	-0.22	-0.08	0.40	0.90	0.71	0.05
Perak	**5411066**	-1.09	-0.83	-0.17	0.39	0.37	0.00	-0.01	0.26	0.49	0.86	0.68	-0.13
Perak	**5610063**	0.00	0.32	0.51	0.89	0.68	-0.25	-1.10	-0.97	-0.19	0.38	0.37	0.02
Perak	**5710061**	-1.32	-1.01	-0.17	0.35	0.47	-0.05	-0.03	0.18	0.58	1.05	0.82	-0.33
Penang	**5302001**	-1.22	-1.05	-0.18	0.31	0.31	-0.11	0.23	0.45	0.92	0.91	0.39	-0.61
Penang	**5302003**	-1.06	-1.03	-0.42	0.07	0.24	-0.03	0.21	0.34	0.91	0.93	0.45	-0.39
Penang	**5402001**	-1.26	-1.14	-0.30	0.26	0.30	0.00	0.24	0.39	0.96	0.86	0.48	-0.59
Penang	**5402002**	-1.20	-1.12	-0.35	0.17	0.25	0.08	0.30	0.45	0.87	0.84	0.44	-0.52

Table 4.2 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	-0.99	-0.89	-0.44	0.35	0.25	-0.04	0.01	0.37	0.86	0.88	0.50	-0.50
Kedah	**5507076**	-1.25	-0.88	-0.15	0.40	0.13	-0.32	0.00	0.36	0.68	1.12	0.68	-0.41
Kedah	**5704055**	-1.31	-1.08	-0.41	-0.08	0.22	0.31	0.43	0.72	0.96	1.01	0.36	-0.72
Kedah	**5806066**	-1.38	-0.89	-0.14	0.46	0.33	-0.11	0.13	0.36	0.68	0.94	0.49	-0.55
Kedah	**5808001**	-1.39	-0.99	-0.04	0.37	0.33	-0.16	0.08	0.49	0.58	0.98	0.64	-0.37
Kedah	**6103047**	-1.39	-1.11	-0.25	0.03	0.30	0.24	0.44	0.79	0.89	0.86	0.46	-0.61
Kedah	**6108001**	-1.21	-1.20	-0.14	0.31	0.35	0.02	0.16	0.51	0.60	1.03	0.65	-0.23
Kedah	**6206035**	-1.34	-1.03	0.03	0.42	0.34	-0.09	0.09	0.37	0.70	0.95	0.53	-0.35
Kedah	**6207032**	-1.22	-1.01	0.02	0.53	0.44	0.01	0.11	0.33	0.58	0.91	0.43	-0.24
Kedah	**6306031**	-1.24	-1.14	-0.08	0.36	0.40	-0.04	0.06	0.35	0.62	1.00	0.64	-0.24
Perlis	**6401002**	-1.47	-1.15	-0.17	0.15	0.30	0.13	0.36	0.59	0.91	0.88	0.53	-0.39
Perlis	**6603002**	-1.15	-1.09	-0.19	0.24	0.14	0.04	0.02	0.37	0.58	0.87	0.73	0.33

Table 4.3: Monthly Mean of the SPEI-1 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	0.17	-0.07	0.10	-0.36	-0.35	0.08	-0.16	-0.17	-0.12	0.32	0.04	0.28
Perak	**4010001**	0.29	-0.21	0.17	0.17	-0.32	-0.86	-0.62	-0.69	-0.03	0.30	0.93	0.54
Perak	**4012143**	-0.22	-0.21	0.08	0.52	-0.01	-0.62	-0.57	-0.42	-0.04	0.36	0.76	0.48
Perak	**4207048**	0.29	-0.35	-0.19	-0.12	-0.40	-0.97	-0.52	-0.37	0.40	0.78	0.94	0.57
Perak	**4209093**	-0.03	-0.27	0.15	0.15	-0.22	-0.92	-0.60	-0.32	0.28	0.41	0.92	0.52
Perak	**4311001**	-0.12	-0.08	0.25	0.56	-0.06	-0.96	-0.65	-0.52	-0.03	0.56	0.83	0.32
Perak	**4409091**	0.01	-0.26	-0.25	0.15	-0.21	-0.84	-0.58	-0.45	0.21	0.50	1.13	0.61
Perak	**4511111**	-0.34	-0.67	-0.12	0.30	-0.03	-0.58	-0.46	-0.22	0.24	0.67	0.92	0.38
Perak	**4611001**	-0.47	-0.64	-0.26	0.20	0.30	-0.46	-0.43	0.00	0.23	0.63	0.84	0.10
Perak	**4708084**	-0.14	-0.21	-0.08	0.10	-0.39	-0.66	-0.51	-0.29	0.40	0.74	0.95	0.19
Perak	**4807016**	-0.76	-0.73	-0.24	0.07	0.22	-0.33	-0.19	0.06	0.62	0.67	0.73	-0.24
Perak	**4811075**	-0.71	-0.48	-0.25	0.53	-0.12	-0.43	-0.28	0.10	0.51	0.62	0.68	-0.02
Perak	**4908018**	-0.54	-0.38	0.08	0.41	0.00	-0.77	-0.56	-0.20	0.42	0.75	0.90	-0.16
Perak	**5005003**	-0.29	-0.33	-0.21	0.02	-0.35	-0.71	-0.59	-0.12	0.70	0.72	0.97	0.26
Perak	**5207001**	-0.50	-0.33	-0.01	0.45	-0.17	-0.72	-0.71	-0.17	0.57	0.91	0.74	-0.01
Perak	**5210069**	-0.72	-0.57	-0.32	0.33	-0.05	-0.52	-0.43	-0.17	0.45	1.03	0.88	0.17
Perak	**5411066**	-1.00	-0.76	-0.35	0.27	0.18	-0.20	-0.21	0.14	0.47	0.93	0.76	-0.11
Perak	**5610063**	-1.00	-0.84	-0.36	0.10	0.11	-0.25	-0.22	0.23	0.58	1.02	0.84	-0.16
Perak	**5710061**	-1.13	-0.89	-0.41	0.10	0.18	-0.33	-0.23	0.10	0.65	1.20	1.00	-0.21
Penang	**5302001**	-1.07	-0.86	-0.38	0.17	0.08	-0.30	0.11	0.40	1.01	0.98	0.48	-0.57
Penang	**5302003**	-0.91	-0.87	-0.56	-0.08	0.03	-0.16	0.17	0.31	1.03	1.02	0.57	-0.36
Penang	**5402001**	-1.09	-1.00	-0.45	0.12	0.09	-0.17	0.15	0.34	1.06	0.95	0.56	-0.53
Penang	**5402002**	-1.05	-0.98	-0.51	0.00	-0.03	-0.14	0.17	0.39	1.01	0.88	0.52	-0.49

Table 4.3 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	-0.85	-0.75	-0.61	0.15	-0.05	-0.24	-0.18	0.29	0.87	0.89	0.60	-0.40
Kedah	**5507076**	-1.03	-0.78	-0.34	0.19	-0.18	-0.52	-0.17	0.31	0.70	1.18	0.78	-0.36
Kedah	**5704055**	-1.15	-0.99	-0.57	-0.25	0.04	0.18	0.35	0.71	1.02	1.05	0.41	-0.68
Kedah	**5806066**	-1.15	-0.79	-0.32	0.33	0.10	-0.33	0.02	0.30	0.76	1.01	0.61	-0.47
Kedah	**5808001**	-1.11	-0.89	-0.27	0.18	0.08	-0.44	-0.08	0.43	0.64	1.12	0.77	-0.34
Kedah	**6103047**	-1.14	-0.99	-0.56	-0.25	-0.03	0.02	0.31	0.78	0.98	0.93	0.55	-0.57
Kedah	**6108001**	-1.08	-1.09	-0.43	0.06	0.05	-0.25	-0.03	0.43	0.66	1.17	0.78	-0.21
Kedah	**6206035**	-1.10	-0.89	-0.30	0.22	0.01	-0.34	-0.05	0.30	0.77	1.05	0.62	-0.24
Kedah	**6207032**	-1.05	-0.96	-0.30	0.27	0.15	-0.29	-0.06	0.22	0.64	1.04	0.52	-0.24
Kedah	**6306031**	-1.01	-1.01	-0.40	0.06	0.09	-0.29	-0.09	0.26	0.68	1.10	0.74	-0.15
Perlis	**6401002**	-1.16	-1.06	-0.50	-0.16	-0.06	-0.15	0.17	0.53	1.06	1.00	0.62	-0.36
Perlis	**6603002**	-0.96	-0.98	-0.51	-0.06	-0.21	-0.19	-0.16	0.27	0.60	0.95	0.82	0.38

Table 4.4: Monthly Mean of the SPI-3 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	0.05	0.01	0.04	-0.12	-0.08	-0.07	0.03	0.05	-0.14	0.04	0.03	0.16
Perak	**4010001**	0.32	-0.23	0.32	0.32	-0.05	-0.70	-0.49	-0.62	-0.06	0.30	0.85	0.51
Perak	**4012143**	0.37	-0.04	-0.19	0.21	0.38	0.11	-0.42	-0.67	-0.42	-0.05	0.43	0.59
Perak	**4207048**	0.72	0.07	-0.26	-0.35	-0.12	-0.53	-0.82	-0.90	-0.21	0.43	0.96	1.01
Perak	**4209093**	0.54	-0.01	-0.15	0.06	0.28	-0.23	-0.67	-0.81	-0.24	0.18	0.66	0.74
Perak	**4311001**	0.41	-0.01	0.03	0.38	0.46	-0.08	-0.74	-1.08	-0.57	-0.01	0.57	0.68
Perak	**4409091**	0.69	0.00	-0.36	-0.13	0.11	-0.19	-0.62	-0.89	-0.41	0.08	0.77	0.93
Perak	**4511111**	0.30	-0.48	-0.67	-0.20	0.25	0.05	-0.35	-0.52	-0.17	0.31	0.73	0.76
Perak	**4611001**	0.13	-0.60	-0.79	-0.33	0.25	0.19	-0.08	-0.33	-0.10	0.39	0.69	0.62
Perak	**4708084**	0.32	-0.27	-0.25	-0.04	0.02	-0.23	-0.58	-0.62	-0.19	0.34	0.81	0.70
Perak	**4807016**	0.32	-0.27	-0.25	-0.04	0.02	-0.23	-0.58	-0.62	-0.19	0.34	0.81	0.70
Perak	**4811075**	-0.09	-0.72	-0.80	-0.05	0.27	0.19	-0.20	-0.17	0.18	0.54	0.70	0.44
Perak	**4908018**	0.01	-0.61	-0.42	0.11	0.39	0.03	-0.47	-0.62	-0.11	0.42	0.79	0.52
Perak	**5005003**	0.24	-0.42	-0.49	-0.19	-0.01	-0.24	-0.63	-0.59	0.05	0.59	0.97	0.74
Perak	**5207001**	-0.03	-0.53	-0.40	0.11	0.29	0.00	-0.57	-0.62	-0.06	0.60	0.86	0.61
Perak	**5210069**	0.01	-0.90	-1.05	-0.23	0.24	0.16	-0.24	-0.41	-0.05	0.62	1.00	0.86
Perak	**5411066**	-0.19	-1.01	-1.07	-0.30	0.22	0.27	0.06	-0.01	0.23	0.70	0.88	0.64
Perak	**5610063**	-0.23	-1.13	-1.13	-0.42	0.14	0.23	0.07	0.04	0.31	0.75	0.88	0.59
Perak	**5710061**	-0.28	-1.39	-1.34	-0.46	0.21	0.27	0.06	-0.08	0.27	0.85	1.13	0.79
Penang	**5302001**	-0.61	-1.40	-1.16	-0.40	0.14	0.18	0.10	0.18	0.67	1.00	0.98	0.37
Penang	**5302003**	-0.38	-1.11	-1.15	-0.61	-0.09	0.06	0.11	0.15	0.64	0.96	1.00	0.47
Penang	**5402001**	-0.52	-1.42	-1.26	-0.50	0.07	0.20	0.17	0.22	0.69	0.99	1.02	0.39
Penang	**5402002**	-0.49	-1.30	-1.23	-0.55	-0.01	0.16	0.19	0.29	0.68	0.96	0.97	0.37

Table 4.4 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	-0.34	-1.02	-1.04	-0.37	0.07	0.23	0.08	0.13	0.52	0.79	0.82	0.34
Kedah	**5507076**	-0.36	-1.25	-1.13	-0.29	0.11	0.04	-0.17	-0.06	0.42	0.97	1.09	0.67
Kedah	**5704055**	-0.65	-1.43	-1.28	-0.71	-0.18	0.15	0.36	0.56	0.84	1.09	0.95	0.34
Kedah	**5806066**	-0.57	-1.36	-1.12	-0.23	0.25	0.23	0.07	0.08	0.48	0.86	0.91	0.46
Kedah	**5808001**	-0.42	-1.41	-1.16	-0.33	0.18	0.16	-0.01	0.08	0.46	0.92	0.98	0.62
Kedah	**6103047**	-0.58	-1.51	-1.31	-0.63	-0.03	0.18	0.33	0.56	0.83	1.02	0.89	0.33
Kedah	**6108001**	-0.33	-1.38	-1.36	-0.48	0.14	0.17	0.07	0.17	0.48	0.92	0.97	0.68
Kedah	**6206035**	-0.52	-1.36	-1.14	-0.22	0.31	0.21	0.01	0.05	0.43	0.86	0.92	0.52
Kedah	**6207032**	-0.51	-1.29	-1.08	-0.21	0.37	0.34	0.10	0.06	0.37	0.71	0.78	0.48
Kedah	**6306031**	-0.31	-1.28	-1.22	-0.37	0.22	0.20	0.05	0.03	0.36	0.80	0.96	0.66
Perlis	**6401002**	-0.46	-1.39	-1.36	-0.54	0.06	0.14	0.21	0.37	0.73	0.97	0.95	0.45
Perlis	**6603002**	0.06	-0.81	-1.23	-0.49	-0.03	0.04	-0.08	0.06	0.31	0.73	0.89	0.82

Table 4.5: Monthly Mean of the SPEI-3 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	0.20	0.17	0.11	-0.14	-0.28	-0.30	-0.18	-0.09	-0.19	0.02	0.10	0.28
Perak	**4010001**	0.81	0.32	0.10	0.05	0.01	-0.48	-0.88	-1.05	-0.64	-0.19	0.58	0.81
Perak	**4012143**	0.44	0.00	-0.20	0.18	0.28	-0.04	-0.57	-0.77	-0.49	-0.03	0.52	0.72
Perak	**4207048**	0.86	0.29	-0.12	-0.34	-0.36	-0.75	-0.94	-0.93	-0.25	0.42	1.01	1.09
Perak	**4209093**	0.71	0.13	-0.09	0.00	0.04	-0.52	-0.88	-0.93	-0.31	0.20	0.78	0.89
Perak	**4311001**	0.50	0.03	0.00	0.34	0.36	-0.23	-0.84	-1.06	-0.62	0.03	0.69	0.84
Perak	**4409091**	0.84	0.16	-0.25	-0.15	-0.13	-0.44	-0.78	-0.91	-0.40	0.12	0.88	1.06
Perak	**4511111**	0.46	-0.28	-0.55	-0.21	0.10	-0.12	-0.53	-0.64	-0.23	0.33	0.86	0.91
Perak	**4611001**	0.27	-0.44	-0.68	-0.34	0.11	0.00	-0.32	-0.45	-0.11	0.41	0.81	0.76
Perak	**4708084**	0.47	-0.12	-0.22	-0.10	-0.15	-0.43	-0.75	-0.70	-0.18	0.41	0.95	0.85
Perak	**4807016**	-0.11	-0.76	-0.78	-0.42	0.01	-0.04	-0.16	-0.25	0.21	0.61	0.91	0.54
Perak	**4811075**	0.05	-0.58	-0.72	-0.11	0.10	0.01	-0.43	-0.32	0.13	0.60	0.87	0.63
Perak	**4908018**	0.12	-0.53	-0.42	0.03	0.20	-0.19	-0.64	-0.74	-0.19	0.47	0.98	0.74
Perak	**5005003**	0.48	-0.17	-0.42	-0.26	-0.27	-0.51	-0.80	-0.67	0.01	0.61	1.09	0.91
Perak	**5207001**	0.10	-0.41	-0.41	0.04	0.11	-0.22	-0.78	-0.76	-0.14	0.65	1.04	0.79
Perak	**5210069**	0.26	-0.55	-0.86	-0.29	-0.03	-0.13	-0.52	-0.59	-0.09	0.66	1.12	1.02
Perak	**5411066**	-0.10	-0.83	-1.01	-0.41	0.03	0.09	-0.15	-0.17	0.15	0.72	1.02	0.77
Perak	**5610063**	-0.08	-0.90	-1.00	-0.51	-0.10	-0.07	-0.22	-0.16	0.25	0.85	1.11	0.82
Perak	**5710061**	-0.08	-1.01	-1.17	-0.58	-0.09	-0.06	-0.23	-0.27	0.22	0.94	1.32	1.00
Penang	**5302001**	-0.51	-1.12	-1.08	-0.51	-0.09	-0.05	-0.11	0.06	0.69	1.10	1.14	0.49
Penang	**5302003**	-0.29	-0.93	-1.04	-0.66	-0.29	-0.12	-0.03	0.09	0.67	1.05	1.15	0.61
Penang	**5402001**	-0.45	-1.16	-1.15	-0.60	-0.15	-0.02	-0.03	0.10	0.71	1.06	1.14	0.49
Penang	**5402002**	-0.42	-1.11	-1.11	-0.64	-0.25	-0.10	-0.04	0.16	0.69	0.98	1.05	0.46

Table 4.5 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	-0.29	-0.93	-1.02	-0.54	-0.23	-0.07	-0.23	-0.07	0.49	0.94	1.03	0.55
Kedah	**5507076**	-0.21	-0.97	-0.96	-0.38	-0.11	-0.21	-0.41	-0.19	0.42	1.07	1.25	0.85
Kedah	**5704055**	-0.61	-1.19	-1.17	-0.81	-0.36	-0.06	0.22	0.51	0.88	1.19	1.08	0.40
Kedah	**5806066**	-0.44	-1.09	-1.03	-0.37	0.01	-0.01	-0.16	-0.05	0.49	0.98	1.09	0.62
Kedah	**5808001**	-0.28	-1.06	-1.06	-0.48	-0.05	-0.13	-0.27	-0.07	0.45	1.05	1.18	0.79
Kedah	**6103047**	-0.52	-1.15	-1.17	-0.81	-0.41	-0.16	0.09	0.49	0.91	1.20	1.09	0.42
Kedah	**6108001**	-0.22	-1.04	-1.19	-0.68	-0.18	-0.11	-0.19	0.02	0.46	1.07	1.23	0.88
Kedah	**6206035**	-0.36	-1.03	-1.06	-0.43	-0.02	-0.09	-0.24	-0.09	0.46	1.02	1.16	0.71
Kedah	**6207032**	-0.34	-1.01	-1.08	-0.46	0.03	0.02	-0.18	-0.13	0.34	0.91	1.07	0.69
Kedah	**6306031**	-0.16	-0.94	-1.11	-0.60	-0.14	-0.12	-0.22	-0.12	0.35	0.94	1.17	0.85
Perlis	**6401002**	-0.37	-1.08	-1.18	-0.76	-0.34	-0.20	-0.06	0.22	0.77	1.13	1.17	0.59
Perlis	**6603002**	0.19	-0.63	-1.09	-0.70	-0.37	-0.25	-0.30	-0.08	0.28	0.80	1.04	0.98

Table 4.6: Monthly Mean of the SDI-3 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**4611463**	0.42	-0.02	-0.39	-0.43	-0.20	-0.07	-0.08	-0.24	-0.19	0.09	0.47	0.63
Perak	**4809443**	0.67	0.22	-0.22	-0.36	-0.21	-0.16	-0.20	-0.36	-0.39	-0.09	0.35	0.75
Perak	**5007421**	0.25	-0.34	-0.50	-0.26	0.02	0.02	-0.19	-0.35	-0.24	0.21	0.68	0.70
Perak	**5206432**	0.37	-0.48	-0.82	-0.58	-0.18	-0.09	-0.29	-0.51	-0.24	0.49	1.20	1.13
Kedah	**5606410**	0.42	-0.50	-0.87	-0.73	-0.44	-0.37	-0.40	-0.42	-0.04	0.70	1.37	1.28
Perlis	**6503401**	0.17	-0.38	-0.54	-0.29	-0.13	-0.25	-0.31	-0.30	0.03	0.44	0.81	0.74

Table 4.7: Monthly Mean of the SPI-6 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	0.03	0.01	0.10	-0.04	-0.01	0.00	-0.05	-0.02	-0.13	0.03	0.05	0.03
Perak	**4010001**	0.38	0.50	0.63	0.65	0.31	-0.14	-0.41	-0.51	-0.67	-0.65	-0.23	0.15
Perak	**4012143**	0.13	0.17	0.25	0.38	0.21	-0.09	-0.17	-0.20	-0.28	-0.36	-0.14	0.13
Perak	**4207048**	0.77	0.71	0.60	0.30	-0.07	-0.61	-0.86	-0.77	-0.60	-0.24	0.16	0.60
Perak	**4209093**	0.33	0.30	0.40	0.39	0.13	-0.26	-0.38	-0.34	-0.36	-0.33	-0.04	0.25
Perak	**4311001**	0.26	0.37	0.51	0.56	0.30	-0.09	-0.26	-0.39	-0.53	-0.56	-0.27	0.11
Perak	**4409091**	0.26	0.37	0.51	0.56	0.30	-0.09	-0.26	-0.39	-0.53	-0.56	-0.27	0.11
Perak	**4511111**	0.36	0.18	0.13	0.07	-0.14	-0.43	-0.40	-0.20	-0.12	-0.04	0.18	0.40
Perak	**4611001**	0.28	0.06	-0.05	-0.15	-0.23	-0.43	-0.32	-0.04	0.07	0.19	0.27	0.36
Perak	**4708084**	0.38	0.35	0.30	0.19	-0.14	-0.35	-0.42	-0.40	-0.32	-0.14	0.19	0.35
Perak	**4807016**	0.22	0.02	-0.17	-0.33	-0.43	-0.44	-0.24	0.01	0.22	0.35	0.44	0.41
Perak	**4811075**	0.30	0.07	-0.15	-0.17	-0.39	-0.51	-0.29	-0.02	0.20	0.21	0.36	0.41
Perak	**4908018**	0.23	0.14	0.13	0.06	-0.15	-0.31	-0.26	-0.15	-0.10	-0.01	0.18	0.28
Perak	**5005003**	0.55	0.42	0.24	0.05	-0.31	-0.56	-0.60	-0.46	-0.21	0.00	0.35	0.54
Perak	**5207001**	0.31	0.21	0.09	-0.02	-0.17	-0.32	-0.33	-0.22	-0.09	0.05	0.22	0.34
Perak	**5210069**	0.45	0.22	-0.01	-0.24	-0.49	-0.67	-0.43	-0.18	0.03	0.27	0.47	0.59
Perak	**5411066**	0.32	0.02	-0.24	-0.44	-0.58	-0.57	-0.29	0.04	0.27	0.46	0.56	0.52
Perak	**5610063**	0.36	-0.04	-0.27	-0.54	-0.72	-0.68	-0.35	0.05	0.30	0.56	0.70	0.63
Perak	**5710061**	0.45	0.04	-0.28	-0.69	-0.91	-0.86	-0.43	0.02	0.33	0.69	0.86	0.80
Penang	**5302001**	0.33	-0.08	-0.54	-0.85	-0.89	-0.76	-0.32	0.14	0.57	0.82	0.86	0.73
Penang	**5302003**	0.41	0.10	-0.35	-0.73	-0.84	-0.74	-0.39	-0.04	0.40	0.71	0.80	0.70
Penang	**5402001**	0.36	-0.05	-0.56	-0.84	-0.95	-0.76	-0.32	0.12	0.59	0.81	0.88	0.73
Penang	**5402002**	0.36	-0.03	-0.52	-0.85	-0.96	-0.77	-0.33	0.11	0.56	0.81	0.89	0.73

Table 4.7 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	0.37	0.03	-0.42	-0.71	-0.82	-0.66	-0.37	0.02	0.50	0.73	0.77	0.59
Kedah	**5507076**	0.44	0.08	-0.20	-0.59	-0.84	-0.84	-0.45	-0.03	0.27	0.60	0.79	0.76
Kedah	**5704055**	0.39	-0.08	-0.58	-1.12	-1.18	-0.81	-0.28	0.23	0.65	0.99	1.02	0.79
Kedah	**5806066**	0.23	-0.12	-0.38	-0.70	-0.77	-0.68	-0.22	0.15	0.44	0.68	0.73	0.63
Kedah	**5808001**	0.43	-0.05	-0.31	-0.72	-0.90	-0.88	-0.42	0.12	0.39	0.70	0.84	0.80
Kedah	**6103047**	0.37	-0.17	-0.63	-1.05	-1.13	-0.83	-0.28	0.29	0.67	0.95	1.01	0.80
Kedah	**6108001**	0.46	-0.05	-0.35	-0.80	-0.95	-0.91	-0.46	0.12	0.42	0.77	0.90	0.84
Kedah	**6206035**	0.26	-0.11	-0.38	-0.64	-0.70	-0.69	-0.27	0.15	0.39	0.63	0.71	0.65
Kedah	**6207032**	0.16	-0.19	-0.36	-0.58	-0.62	-0.59	-0.20	0.21	0.43	0.61	0.64	0.56
Kedah	**6306031**	0.37	0.01	-0.25	-0.64	-0.77	-0.76	-0.39	0.05	0.32	0.61	0.74	0.71
Perlis	**6401002**	0.40	-0.10	-0.55	-0.92	-1.03	-0.91	-0.36	0.20	0.61	0.88	0.97	0.84
Perlis	**6603002**	0.50	0.15	-0.07	-0.37	-0.66	-0.88	-0.53	-0.10	0.16	0.41	0.64	0.75

Table 4.8: Monthly Mean of the SPEI-6 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	0.14	0.16	0.21	0.05	-0.03	-0.10	-0.19	-0.23	-0.29	-0.09	0.01	0.07
Perak	**4010001**	0.44	0.59	0.66	0.64	0.22	-0.28	-0.58	-0.74	-0.81	-0.75	-0.27	0.18
Perak	**4012143**	0.25	0.31	0.33	0.41	0.18	-0.17	-0.27	-0.33	-0.37	-0.42	-0.15	0.21
Perak	**4207048**	0.85	0.88	0.72	0.40	-0.04	-0.62	-0.92	-0.94	-0.75	-0.36	0.15	0.64
Perak	**4209093**	0.65	0.66	0.62	0.53	0.09	-0.45	-0.66	-0.68	-0.65	-0.51	-0.02	0.49
Perak	**4311001**	0.39	0.52	0.62	0.65	0.30	-0.19	-0.39	-0.55	-0.65	-0.62	-0.24	0.25
Perak	**4409091**	0.66	0.73	0.63	0.51	0.03	-0.49	-0.69	-0.77	-0.64	-0.49	0.05	0.53
Perak	**4511111**	0.50	0.37	0.28	0.18	-0.10	-0.46	-0.51	-0.37	-0.26	-0.14	0.17	0.48
Perak	**4611001**	0.44	0.26	0.12	-0.01	-0.21	-0.48	-0.47	-0.25	-0.09	0.08	0.27	0.48
Perak	**4708084**	0.54	0.54	0.43	0.25	-0.17	-0.44	-0.55	-0.57	-0.42	-0.19	0.24	0.47
Perak	**4807016**	0.30	0.09	-0.15	-0.32	-0.48	-0.55	-0.39	-0.17	0.11	0.32	0.49	0.51
Perak	**4811075**	0.49	0.28	0.03	-0.04	-0.36	-0.54	-0.41	-0.20	0.07	0.13	0.42	0.55
Perak	**4908018**	0.38	0.33	0.23	0.10	-0.23	-0.44	-0.45	-0.40	-0.29	-0.13	0.24	0.44
Perak	**5005003**	0.71	0.64	0.39	0.16	-0.32	-0.67	-0.77	-0.70	-0.38	-0.11	0.36	0.65
Perak	**5207001**	0.50	0.44	0.28	0.11	-0.22	-0.46	-0.53	-0.47	-0.27	-0.08	0.25	0.48
Perak	**5210069**	0.62	0.49	0.21	-0.07	-0.46	-0.75	-0.66	-0.49	-0.20	0.10	0.45	0.67
Perak	**5411066**	0.45	0.16	-0.12	-0.36	-0.57	-0.65	-0.41	-0.12	0.15	0.39	0.60	0.64
Perak	**5610063**	0.54	0.20	-0.09	-0.42	-0.69	-0.77	-0.53	-0.20	0.09	0.44	0.71	0.74
Perak	**5710061**	0.64	0.26	-0.10	-0.50	-0.81	-0.93	-0.66	-0.32	0.04	0.53	0.87	0.93
Penang	**5302001**	0.46	0.09	-0.38	-0.73	-0.89	-0.86	-0.48	-0.06	0.45	0.76	0.88	0.81
Penang	**5302003**	0.53	0.24	-0.24	-0.65	-0.83	-0.81	-0.52	-0.18	0.34	0.71	0.86	0.81
Penang	**5402001**	0.46	0.08	-0.42	-0.73	-0.91	-0.84	-0.49	-0.08	0.46	0.75	0.89	0.80
Penang	**5402002**	0.42	0.08	-0.41	-0.76	-0.96	-0.85	-0.50	-0.10	0.40	0.68	0.82	0.73

Table 4.8 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	0.46	0.18	-0.28	-0.62	-0.85	-0.77	-0.57	-0.25	0.26	0.55	0.71	0.66
Kedah	**5507076**	0.62	0.30	-0.05	-0.46	-0.79	-0.88	-0.61	-0.26	0.10	0.52	0.84	0.89
Kedah	**5704055**	0.48	0.01	-0.50	-1.00	-1.11	-0.90	-0.46	0.08	0.58	0.99	1.08	0.87
Kedah	**5806066**	0.42	0.09	-0.24	-0.61	-0.81	-0.82	-0.44	-0.07	0.31	0.63	0.81	0.78
Kedah	**5808001**	0.60	0.14	-0.18	-0.59	-0.84	-0.94	-0.62	-0.14	0.19	0.62	0.89	0.94
Kedah	**6103047**	0.49	-0.06	-0.55	-0.92	-1.09	-0.96	-0.54	0.04	0.55	0.95	1.13	0.96
Kedah	**6108001**	0.66	0.15	-0.23	-0.67	-0.91	-0.99	-0.68	-0.16	0.23	0.71	0.99	1.01
Kedah	**6206035**	0.48	0.11	-0.24	-0.56	-0.78	-0.86	-0.52	-0.11	0.27	0.61	0.83	0.85
Kedah	**6207032**	0.43	0.05	-0.28	-0.57	-0.73	-0.81	-0.51	-0.11	0.25	0.58	0.75	0.78
Kedah	**6306031**	0.54	0.19	-0.15	-0.54	-0.77	-0.87	-0.61	-0.23	0.14	0.56	0.80	0.85
Perlis	**6401002**	0.54	0.05	-0.43	-0.78	-0.98	-0.98	-0.61	-0.13	0.40	0.80	1.02	0.97
Perlis	**6603002**	0.63	0.33	0.02	-0.31	-0.68	-0.92	-0.70	-0.34	-0.01	0.33	0.67	0.84

Table 4.9: Monthly Mean of the SDI-6 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**4611463**	0.29	0.25	0.15	0.00	-0.12	-0.26	-0.28	-0.25	-0.15	0.00	0.12	0.24
Perak	**4809443**	0.34	0.34	0.33	0.19	0.02	-0.23	-0.33	-0.34	-0.32	-0.18	-0.01	0.20
Perak	**5007421**	0.29	0.21	0.14	0.00	-0.19	-0.29	-0.27	-0.20	-0.14	0.00	0.18	0.26
Perak	**5206432**	0.59	0.47	0.23	-0.11	-0.43	-0.62	-0.59	-0.48	-0.23	0.12	0.46	0.59
Kedah	**5606410**	0.80	0.61	0.30	-0.20	-0.65	-0.89	-0.81	-0.62	-0.30	0.21	0.67	0.88
Perlis	**6503401**	0.38	0.27	0.15	-0.07	-0.31	-0.48	-0.38	-0.27	-0.14	0.07	0.31	0.47

Table 4.10: Monthly Mean of the SPI-12 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.01	-0.01	-0.02	-0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00
Perak	**4010001**	-0.02	-0.01	0.00	0.02	0.02	0.01	0.00	0.01	0.00	0.01	0.01	-0.03
Perak	**4012143**	0.01	-0.02	-0.03	-0.01	0.01	0.00	-0.01	0.00	-0.01	0.02	0.02	0.03
Perak	**4207048**	0.00	0.00	0.00	-0.01	0.00	0.00	-0.02	-0.01	-0.01	0.01	0.03	0.00
Perak	**4209093**	-0.02	-0.03	-0.01	-0.01	0.00	0.00	0.01	0.01	0.00	0.02	0.03	0.01
Perak	**4311001**	0.00	-0.01	-0.01	0.01	0.02	0.01	-0.01	0.00	-0.02	0.00	0.00	0.01
Perak	**4409091**	0.00	-0.01	-0.01	-0.02	-0.01	-0.02	-0.02	0.00	0.01	0.04	0.05	0.01
Perak	**4511111**	-0.01	-0.01	-0.01	-0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	-0.02
Perak	**4611001**	-0.01	-0.01	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.02	0.02	-0.02
Perak	**4708084**	0.02	0.00	0.01	0.01	0.00	-0.01	-0.02	-0.01	-0.02	0.01	0.02	0.00
Perak	**4807016**	0.00	0.01	0.01	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	0.01
Perak	**4811075**	0.02	0.02	0.03	0.04	0.03	0.03	0.00	-0.01	-0.03	-0.03	-0.05	-0.05
Perak	**4908018**	-0.02	-0.02	0.00	0.01	0.00	0.01	0.01	0.02	0.01	0.01	0.01	0.00
Perak	**5005003**	0.00	-0.01	0.00	0.01	0.01	0.01	0.00	0.00	-0.01	0.00	0.01	-0.02
Perak	**5207001**	0.00	-0.02	-0.02	-0.01	-0.01	-0.01	-0.01	0.01	0.02	0.02	0.03	0.02
Perak	**5210069**	0.01	0.00	-0.01	0.01	0.02	0.01	0.01	0.01	-0.02	-0.02	-0.01	-0.01
Perak	**5411066**	0.02	0.02	0.01	0.02	0.01	-0.01	-0.01	-0.02	-0.03	0.00	0.00	0.00
Perak	**5610063**	0.02	0.02	0.01	0.02	0.01	0.00	-0.01	-0.03	-0.02	-0.01	-0.01	-0.02
Perak	**5710061**	-0.01	-0.02	-0.01	0.01	0.00	0.01	0.01	-0.01	-0.01	0.00	0.02	0.00
Penang	**5302001**	0.00	0.00	0.00	0.00	-0.01	0.00	-0.01	-0.01	0.01	0.00	0.01	0.00
Penang	**5302003**	-0.01	-0.01	0.00	0.01	0.00	0.00	-0.01	-0.01	0.00	0.01	0.03	0.01
Penang	**5402001**	-0.01	-0.02	-0.01	0.00	-0.01	-0.01	-0.02	0.00	0.01	0.01	0.03	0.02

Table 4.10 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5402002**	-0.03	-0.03	-0.01	0.00	-0.01	-0.01	0.00	0.02	0.02	0.02	0.03	0.00
Penang	**5504035**	0.02	0.01	0.01	0.01	-0.03	-0.04	-0.04	-0.02	0.01	0.01	0.05	0.03
Kedah	**5507076**	-0.03	-0.02	-0.02	0.00	-0.02	-0.02	-0.01	0.01	0.03	0.02	0.05	0.01
Kedah	**5704055**	0.01	0.00	0.01	0.00	-0.02	-0.01	-0.01	-0.01	0.00	-0.01	0.02	0.02
Kedah	**5806066**	-0.05	-0.04	-0.01	0.00	-0.01	-0.02	0.00	0.00	0.04	0.04	0.07	-0.02
Kedah	**5808001**	-0.03	-0.03	-0.01	0.01	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00
Kedah	**6103047**	-0.01	-0.01	-0.01	0.00	0.02	0.01	0.00	0.00	-0.02	-0.01	0.01	0.02
Kedah	**6108001**	-0.02	-0.01	-0.02	0.01	0.01	0.01	-0.01	-0.01	0.00	0.01	0.03	0.02
Kedah	**6206035**	-0.03	-0.03	-0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.01	-0.01
Kedah	**6207032**	-0.02	-0.02	-0.02	0.01	0.00	0.01	0.01	0.02	0.01	-0.01	0.01	0.01
Kedah	**6306031**	-0.03	-0.02	-0.02	0.00	0.01	0.01	0.00	0.01	0.00	-0.01	0.01	0.03
Perlis	**6401002**	-0.01	-0.02	-0.02	0.00	0.00	0.00	0.00	-0.01	0.00	0.01	0.04	0.02
Perlis	**6603002**	-0.02	-0.02	0.00	0.02	0.02	0.01	0.01	-0.01	-0.01	-0.01	-0.01	0.00

Table 4.11: Monthly Mean of the SPEI-12 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.02	-0.02	-0.03	-0.03	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.01	-0.02
Perak	**4010001**	-0.07	-0.08	-0.07	-0.06	-0.05	-0.05	-0.07	-0.07	-0.08	-0.06	-0.06	-0.10
Perak	**4012143**	-0.02	-0.01	-0.02	-0.01	-0.01	-0.01	0.00	-0.03	-0.05	-0.04	-0.02	0.00
Perak	**4207048**	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.01	0.03	0.04	0.00
Perak	**4209093**	0.01	0.03	0.04	0.06	0.04	0.02	0.00	-0.01	-0.03	-0.01	0.05	0.02
Perak	**4311001**	0.03	0.02	0.01	0.03	0.03	0.02	0.00	0.00	-0.02	-0.01	0.03	0.03
Perak	**4409091**	0.01	0.01	0.00	0.01	0.02	0.01	0.00	0.01	0.02	0.04	0.07	0.02
Perak	**4511111**	0.01	0.00	0.00	0.01	0.04	0.04	0.03	0.03	0.03	0.04	0.04	0.00
Perak	**4611001**	-0.02	-0.01	0.02	0.05	0.05	0.06	0.05	0.05	0.04	0.05	0.03	-0.02
Perak	**4708084**	0.03	0.01	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.03	0.04	0.00
Perak	**4807016**	-0.02	-0.02	-0.02	0.00	-0.01	-0.02	-0.04	-0.05	-0.04	-0.03	0.00	-0.01
Perak	**4811075**	0.05	0.05	0.07	0.08	0.08	0.08	0.06	0.05	0.02	0.01	0.00	-0.02
Perak	**4908018**	-0.02	-0.02	-0.04	-0.02	-0.03	-0.03	-0.04	-0.03	-0.04	-0.01	0.05	0.04
Perak	**5005003**	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.03	-0.03	-0.03	-0.01	0.01	-0.02
Perak	**5207001**	-0.03	-0.02	-0.01	0.02	0.01	0.03	0.03	0.00	0.01	0.01	0.01	-0.01
Perak	**5210069**	-0.01	-0.02	-0.02	0.00	0.00	-0.01	0.00	0.00	-0.03	-0.03	-0.02	-0.03
Perak	**5411066**	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.02	0.00	0.00	-0.01	0.00
Perak	**5610063**	0.03	0.04	0.03	0.04	0.03	0.00	-0.01	-0.05	-0.03	-0.02	-0.01	-0.01
Perak	**5710061**	-0.01	-0.02	-0.01	0.02	0.02	0.03	0.03	0.00	-0.01	-0.01	0.00	-0.01
Penang	**5302001**	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.01	0.00	0.01	-0.01
Penang	**5302003**	0.01	0.01	0.02	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.05	0.03
Penang	**5402001**	-0.02	-0.02	0.00	0.01	-0.01	0.00	-0.01	-0.01	0.01	0.00	0.03	0.00
Penang	**5402002**	-0.05	-0.05	-0.04	-0.05	-0.06	-0.06	-0.07	-0.07	-0.06	-0.07	-0.07	-0.02

Table 4.11 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	-0.01	-0.02	-0.04	-0.06	-0.11	-0.11	-0.11	-0.11	-0.07	-0.08	-0.05	0.00
Kedah	**5507076**	0.01	0.01	0.02	0.03	0.02	0.02	0.02	0.03	0.04	0.04	0.08	0.04
Kedah	**5704055**	0.01	0.02	0.03	0.03	0.01	0.02	0.01	-0.01	0.01	-0.01	0.01	0.02
Kedah	**5806066**	-0.02	-0.02	0.00	0.01	0.01	0.01	0.02	0.02	0.05	0.05	0.07	0.00
Kedah	**5808001**	-0.02	-0.01	-0.01	0.01	0.03	0.03	0.04	0.02	0.03	0.02	0.01	0.00
Kedah	**6103047**	-0.03	-0.02	-0.01	0.00	0.00	0.00	-0.03	0.01	0.03	0.02	0.01	0.00
Kedah	**6108001**	-0.01	-0.01	-0.01	0.03	0.03	0.03	0.04	0.04	0.03	0.03	0.06	0.02
Kedah	**6206035**	0.01	0.01	0.02	0.04	0.03	0.03	0.01	0.02	0.03	0.02	0.04	0.02
Kedah	**6207032**	-0.03	-0.04	-0.05	-0.02	-0.03	-0.01	0.01	0.02	0.02	0.02	0.03	0.00
Kedah	**6306031**	-0.03	-0.02	-0.02	0.00	0.01	0.02	0.01	0.00	-0.01	-0.02	-0.01	0.02
Perlis	**6401002**	-0.04	-0.03	-0.03	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.03	0.00
Perlis	**6603002**	-0.03	-0.03	-0.01	0.01	0.01	0.01	0.00	-0.01	-0.01	-0.01	-0.02	-0.01

Table 4.12: Monthly Mean of the SDI-12 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**4611463**	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01
Perak	**4809443**	0.00	0.00	-0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	-0.03
Perak	**5007421**	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.03
Perak	**5206432**	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	-0.01	-0.01	0.00	-0.04
Kedah	**5606410**	-0.01	-0.01	0.00	0.01	0.02	0.01	0.01	0.01	-0.01	-0.02	-0.01	-0.01
Perlis	**6503401**	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	-0.01	-0.02	-0.03

4.5 Trend Analysis

Based on trend analysis of the SPI-1 in Table 4.13 and trend analysis of the SPEI-1 in Table 4.14 below, northern region may experience drier condition during NEM season (Dec.-Mar.) and during SWM season (Jun.-Aug.) in future.

For trend analysis of the SPI-3 in Table 4.15 and trend analysis of the SPEI-3 in Table 4.16, they were more related to months with high Sea Surface Temperature (SST) which were shown in Figure 4.27 below. The positive value above zero on trend analysis of ONI, EMI, and DMI, stands for increasing trend of SST which might related to drought. South part of the northern region experienced drier trend in (May. -Sept.), matching with the trend of DMI which has an increasing trend in (May.-Sept.). Meanwhile, the north part experienced drier trend in (Jan. -Aug.), matching with the trend of ONI which has an increasing trend in (Jan.-Aug.). Besides. trend analysis of SDI-3 in Table 4.17 shown increasing drought trend in (Feb.-Aug.).

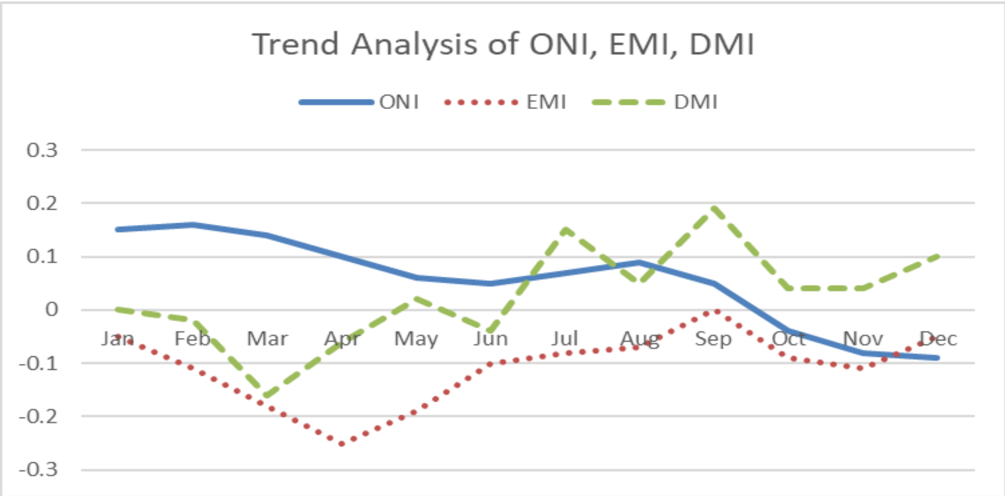


Figure 4.27: Trend Analysis of ONI, EMI and DMI

Furthermore, for an agricultural drought, stations at the south part of Perak experienced negative trend in (May.-Nov.) which may in coherent with trend of DMI. Meanwhile, other stations experienced a negative trend in (Feb.-Aug.) similar to the trend analysis of ONI as shown in the SPI-6 in Table 4.18 and the SPEI-6 in Table 4.19. But for the SDI-6 in Table 4.20, only stations 5206432, 5606410 and 6503401 have negative trend during (Apr. -Aug.).

On the other hand, the trend for drought analysis with a timescale of 12 months varies locally. For example, the monthly trend analysis of the SPI-12 in Table 4.21 shown stations 3615003, 4010001, 4207048, 4209093, 4311001, 4409091, 4511111, 4611001, 4708084, 5210069, 5710069 in Perak, 5302001, 5302003, 5402002, 5504035 in Penang, and 5507076, 5704055, 5806066, 6103047, 6108001, 6206035, 6207032, 6306031 in Kedah have a negative trend for every month. Fewer stations shows a negative trend in monthly trend analysis of the SPEI-12 in Table 4.22, the stations are 3615003, 4010001, 4311001, 4409091, 4511111, 4611001, 4708084, 5210069, 5710061, in Perak, and 5704055, 5806066, 6103047, 6108001, 6206035, 6207032, 6306031 in Kedah which have negative trend throughout the year. But for the SDI in Table 4.23, only station 5606410 in Kedah has a negative trend in September. Therefore, the trend is undefined.

Table 4.13: Trend Analysis of the SPI-1 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.38	-0.64	-0.27	-0.48	-0.12	-0.02	-0.43	-0.88	-0.59	0.17	0.00	-0.10
Perak	**4010001**	0.01	-0.31	0.33	0.12	-0.21	-0.77	-0.44	-0.59	0.02	0.07	0.28	0.61
Perak	**4012143**	0.17	0.36	0.38	0.54	0.33	-0.18	-0.47	-0.49	0.33	0.47	0.67	0.65
Perak	**4207048**	0.14	-0.43	0.17	0.27	-0.28	-1.06	-0.22	-0.62	0.22	0.22	0.78	0.67
Perak	**4209093**	0.01	-0.26	0.34	0.21	0.23	-0.67	-0.45	-0.28	0.10	-0.02	0.37	0.39
Perak	**4311001**	-0.68	0.14	0.37	0.17	-0.14	-0.68	-0.09	-0.74	0.12	0.54	0.59	0.18
Perak	**4409091**	-0.28	-0.27	-0.29	0.34	0.13	-0.90	-0.57	-0.94	-0.08	-0.06	0.43	0.50
Perak	**4511111**	-1.39	-0.74	0.24	-0.01	-0.11	-0.52	0.03	-0.74	0.47	0.42	0.58	-0.15
Perak	**4611001**	-1.45	-0.52	-0.38	-0.10	0.53	-0.39	-0.04	-0.51	0.01	0.63	0.44	-0.36
Perak	**4708084**	-0.48	0.07	0.01	0.33	-0.14	-0.59	-0.47	-0.28	0.27	0.25	0.46	-0.47
Perak	**4807016**	-1.19	-0.62	0.06	0.31	0.35	-0.06	0.40	-0.04	0.69	1.12	0.73	-0.17
Perak	**4811075**	-1.19	-0.11	-0.41	0.35	0.37	-0.36	0.02	0.17	0.88	1.00	0.45	-0.40
Perak	**4908018**	-1.19	-0.12	0.62	0.64	0.62	-0.50	-0.45	-0.30	0.73	0.93	0.81	-0.05
Perak	**5005003**	-0.40	-0.36	0.21	0.05	0.16	-0.45	-0.14	-0.23	0.51	0.78	0.71	-0.06
Perak	**5207001**	-0.64	-0.27	0.62	0.72	0.66	-0.57	-0.33	-0.38	0.40	0.92	0.37	-0.14
Perak	**5210069**	-1.43	-0.62	-0.08	0.30	0.34	-0.38	-0.03	-0.46	0.44	1.11	0.33	-0.28
Perak	**5411066**	-1.65	-0.55	0.52	0.69	0.74	0.44	0.22	0.55	0.65	1.20	0.68	-0.06
Perak	**5610063**	0.41	0.95	0.77	0.97	0.77	-0.26	-1.60	-0.77	0.50	0.52	1.04	0.34
Perak	**5710061**	-1.87	-0.87	-0.18	0.24	0.57	-0.14	-0.17	0.16	0.63	1.05	0.64	-0.51
Penang	**5302001**	-1.82	-0.92	-0.02	0.37	0.61	-0.13	0.36	0.30	0.67	0.82	-0.06	-0.94
Penang	**5302003**	-1.47	-1.16	-0.69	-0.18	0.37	-0.32	0.24	0.22	0.62	1.02	0.18	-0.49
Penang	**5402001**	-1.47	-1.19	-0.32	0.22	0.45	0.02	0.28	0.32	1.08	0.96	0.24	-0.83
Penang	**5402002**	-1.48	-1.11	-0.30	-0.13	0.29	0.01	0.29	0.21	0.95	0.99	0.33	-0.81

Table 4.13 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	-1.14	-0.93	-0.49	0.08	0.35	-0.05	-0.06	0.33	0.62	0.75	0.15	-0.85
Kedah	**5507076**	-1.80	-0.92	-0.04	0.27	0.65	-0.47	0.15	0.32	0.53	1.24	0.25	-0.61
Kedah	**5704055**	-1.56	-1.23	-0.41	0.14	0.25	0.05	0.61	0.57	1.07	0.89	-0.03	-0.86
Kedah	**5806066**	-1.93	-1.19	-0.38	0.23	0.45	-0.16	0.24	0.10	0.25	0.93	-0.17	-0.94
Kedah	**5808001**	-2.18	-1.24	0.12	0.38	0.40	-0.20	0.37	0.62	0.75	1.32	0.35	-0.83
Kedah	**6103047**	-1.85	-1.17	-0.22	-0.23	0.21	0.00	0.35	0.71	0.78	0.70	0.12	-0.79
Kedah	**6108001**	-1.87	-1.29	-0.01	-0.02	0.47	-0.04	0.08	0.49	0.74	1.01	0.42	-0.59
Kedah	**6206035**	-1.96	-1.15	-0.07	0.08	0.32	-0.36	0.02	0.13	0.40	0.97	0.06	-0.61
Kedah	**6207032**	-1.93	-1.03	0.27	0.20	0.53	-0.22	-0.07	0.38	0.82	1.16	0.30	-0.33
Kedah	**6306031**	-2.00	-1.41	-0.10	-0.15	0.27	-0.09	-0.18	0.16	0.36	0.93	0.39	-0.56
Perlis	**6401002**	-1.60	-1.26	0.01	-0.06	0.41	0.18	0.42	0.71	0.92	1.00	0.19	-0.51
Perlis	**6603002**	-1.64	-1.02	-0.10	0.07	0.21	0.37	0.11	0.74	0.75	1.11	0.67	0.31

Table 4.14: Trend Analysis of the SPEI-1 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.22	-0.43	-0.32	-0.59	-0.19	-0.03	-0.40	-0.84	-0.43	0.28	0.13	0.12
Perak	**4010001**	0.09	-0.17	0.25	0.03	-0.43	-0.81	-0.49	-0.55	0.16	0.13	0.39	0.69
Perak	**4012143**	0.03	0.28	0.35	0.50	0.16	-0.28	-0.50	-0.47	0.31	0.46	0.72	0.72
Perak	**4207048**	0.33	-0.07	0.16	0.20	-0.40	-0.90	-0.23	-0.60	0.35	0.35	0.97	0.95
Perak	**4209093**	0.12	-0.08	0.29	0.14	0.08	-0.67	-0.51	-0.28	0.21	0.07	0.54	0.56
Perak	**4311001**	-0.74	0.06	0.26	0.10	-0.31	-0.81	-0.28	-0.69	0.12	0.58	0.65	0.26
Perak	**4409091**	-0.06	0.02	-0.37	0.18	-0.06	-0.89	-0.71	-0.75	0.01	0.07	0.57	0.68
Perak	**4511111**	-1.20	-0.63	0.09	-0.15	-0.24	-0.58	-0.06	-0.70	0.59	0.55	0.72	-0.03
Perak	**4611001**	-1.27	-0.44	-0.47	-0.19	0.39	-0.46	-0.07	-0.53	0.16	0.71	0.55	-0.24
Perak	**4708084**	-0.31	0.19	-0.06	0.20	-0.36	-0.75	-0.52	-0.33	0.40	0.34	0.61	-0.16
Perak	**4807016**	-1.07	-0.53	-0.09	0.25	0.24	-0.11	0.38	-0.09	0.76	1.20	0.81	-0.13
Perak	**4811075**	-1.03	-0.15	-0.51	0.20	0.25	-0.44	-0.10	0.14	0.96	1.08	0.55	-0.28
Perak	**4908018**	-0.98	-0.02	0.55	0.59	0.48	-0.57	-0.47	-0.30	0.79	0.98	0.90	0.06
Perak	**5005003**	-0.10	-0.18	0.16	-0.02	0.03	-0.41	-0.08	-0.15	0.66	0.94	0.87	0.20
Perak	**5207001**	-0.48	-0.15	0.54	0.64	0.53	-0.63	-0.30	-0.30	0.52	1.03	0.51	0.00
Perak	**5210069**	-0.91	-0.43	-0.21	0.12	0.14	-0.55	-0.13	-0.48	0.55	1.24	0.51	-0.07
Perak	**5411066**	-1.42	-0.50	0.32	0.63	0.67	0.38	0.16	0.48	0.73	1.37	0.80	0.05
Perak	**5610063**	-1.30	-0.67	0.33	0.31	1.03	0.14	0.35	0.98	0.96	1.13	0.92	-0.11
Perak	**5710061**	-1.43	-0.74	-0.40	0.04	0.41	-0.33	-0.27	0.11	0.81	1.27	0.82	-0.40
Penang	**5302001**	-1.39	-0.62	-0.13	0.28	0.54	-0.23	0.35	0.32	0.81	0.95	0.01	-0.79
Penang	**5302003**	-1.11	-0.82	-0.64	-0.34	0.31	-0.36	0.35	0.30	0.84	1.19	0.33	-0.38
Penang	**5402001**	-1.15	-0.93	-0.33	0.13	0.36	-0.08	0.31	0.35	1.24	1.12	0.31	-0.71
Penang	**5402002**	-1.00	-0.77	-0.17	-0.13	0.18	0.01	0.38	0.30	1.14	1.17	0.51	-0.61

Table 4.14 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	-0.72	-0.50	-0.31	0.11	0.29	0.00	0.04	0.55	0.82	0.98	0.46	-0.51
Kedah	**5507076**	-1.23	-0.61	-0.04	0.11	0.26	-0.48	0.01	0.35	0.57	1.16	0.36	-0.57
Kedah	**5704055**	-1.26	-1.03	-0.56	-0.01	0.15	-0.10	0.60	0.59	1.18	0.98	0.02	-0.74
Kedah	**5806066**	-1.46	-0.98	-0.47	0.07	0.30	-0.34	0.18	0.06	0.35	1.06	-0.03	-0.81
Kedah	**5808001**	-1.56	-1.00	-0.13	0.20	0.18	-0.39	0.31	0.64	0.93	1.61	0.46	-0.73
Kedah	**6103047**	-1.37	-0.95	-0.49	-0.50	-0.02	-0.19	0.30	0.72	0.92	0.80	0.24	-0.66
Kedah	**6108001**	-1.53	-1.08	-0.30	-0.31	0.32	-0.21	-0.05	0.46	0.89	1.21	0.53	-0.48
Kedah	**6206035**	-1.48	-0.87	-0.36	-0.07	0.13	-0.50	-0.04	0.11	0.51	1.15	0.15	-0.46
Kedah	**6207032**	-1.57	-0.93	-0.10	-0.10	0.33	-0.50	-0.11	0.33	0.96	1.40	0.38	-0.27
Kedah	**6306031**	-1.55	-1.16	-0.41	-0.48	0.05	-0.28	-0.21	0.14	0.52	1.12	0.52	-0.33
Perlis	**6401002**	-1.24	-1.10	-0.35	-0.25	0.22	-0.01	0.31	0.78	1.15	1.24	0.31	-0.41
Perlis	**6603002**	-1.31	-0.81	-0.40	-0.16	-0.01	0.26	0.01	0.77	0.85	1.29	0.81	0.44

Table 4.15: Trend Analysis of the SPI-3 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.25	-0.56	-0.72	-0.73	-0.47	-0.29	-0.28	-0.59	-0.94	-0.60	-0.21	-0.01
Perak	**4010001**	0.14	-0.08	0.33	0.12	-0.21	-0.77	-0.44	-0.59	0.02	0.07	0.28	0.61
Perak	**4012143**	0.57	0.45	0.31	0.53	0.54	0.27	-0.21	-0.55	-0.30	0.19	0.63	0.74
Perak	**4207048**	0.71	0.29	-0.21	-0.07	-0.02	-0.54	-0.94	-1.13	-0.41	-0.09	0.60	0.85
Perak	**4209093**	0.40	0.18	-0.05	0.13	0.37	-0.08	-0.49	-0.74	-0.35	-0.13	0.18	0.32
Perak	**4311001**	0.04	-0.25	-0.15	0.25	0.12	-0.42	-0.66	-0.90	-0.42	0.01	0.63	0.63
Perak	**4409091**	0.32	0.07	-0.53	-0.12	0.03	-0.23	-0.83	-1.39	-0.89	-0.49	0.11	0.39
Perak	**4511111**	-0.38	-1.12	-1.14	-0.30	-0.06	-0.34	-0.39	-0.69	-0.14	0.14	0.67	0.37
Perak	**4611001**	-0.62	-1.14	-1.29	-0.59	-0.03	0.00	0.07	-0.51	-0.33	0.08	0.49	0.25
Perak	**4708084**	-0.22	-0.44	-0.22	0.16	0.10	-0.19	-0.64	-0.68	-0.18	0.11	0.46	0.09
Perak	**4807016**	-0.22	-0.44	-0.22	0.16	0.10	-0.19	-0.64	-0.68	-0.18	0.11	0.46	0.09
Perak	**4811075**	-0.53	-0.81	-0.88	-0.17	0.20	0.19	-0.02	-0.15	0.47	0.95	1.00	0.46
Perak	**4908018**	-0.13	-0.63	-0.32	0.47	0.78	0.36	-0.15	-0.61	0.02	0.65	1.08	0.73
Perak	**5005003**	0.26	-0.37	-0.33	-0.14	0.13	-0.14	-0.29	-0.47	0.03	0.52	0.94	0.70
Perak	**5207001**	-0.13	-0.44	-0.09	0.48	0.81	0.34	-0.13	-0.64	-0.12	0.49	0.74	0.53
Perak	**5210069**	-0.63	-1.26	-1.14	-0.39	0.13	-0.01	-0.13	-0.60	-0.08	0.56	0.88	0.54
Perak	**5411066**	-0.32	-0.95	-0.74	0.30	0.78	0.80	0.59	0.46	0.57	1.05	1.11	0.84
Perak	**5610063**	-0.27	-1.17	-0.75	0.11	0.83	0.75	0.75	0.69	0.90	1.15	1.09	0.70
Perak	**5710061**	-0.63	-1.70	-1.51	-0.49	0.19	0.24	0.03	-0.22	0.22	0.84	1.07	0.60
Penang	**5302001**	-1.08	-1.60	-1.20	-0.20	0.40	0.37	0.30	0.15	0.51	0.75	0.65	0.00
Penang	**5302003**	-0.54	-1.18	-1.41	-0.85	-0.17	-0.09	0.07	0.00	0.47	0.84	0.83	0.34
Penang	**5402001**	-0.70	-1.48	-1.28	-0.48	0.21	0.30	0.26	0.23	0.80	1.05	1.01	0.22
Penang	**5402002**	-0.58	-1.33	-1.22	-0.69	-0.06	0.07	0.19	0.16	0.58	0.95	1.01	0.29

Table 4.15 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	-0.58	-1.14	-1.16	-0.59	-0.02	0.16	0.10	0.08	0.37	0.57	0.51	-0.02
Kedah	**5507076**	-0.80	-1.53	-1.31	-0.34	0.30	0.16	0.14	-0.07	0.36	0.91	0.86	0.44
Kedah	**5704055**	-0.90	-1.52	-1.41	-0.64	-0.09	0.09	0.33	0.46	0.91	1.01	0.79	0.06
Kedah	**5806066**	-1.27	-1.84	-1.62	-0.59	0.11	0.14	0.14	-0.06	0.15	0.47	0.35	-0.07
Kedah	**5808001**	-0.97	-2.07	-1.51	-0.33	0.25	0.14	0.13	0.29	0.78	1.26	1.11	0.50
Kedah	**6103047**	-0.90	-1.70	-1.47	-0.74	-0.18	-0.10	0.12	0.36	0.71	0.85	0.64	0.04
Kedah	**6108001**	-0.76	-1.89	-1.60	-0.68	0.06	0.04	0.08	0.10	0.52	0.98	0.92	0.41
Kedah	**6206035**	-1.08	-1.74	-1.57	-0.53	0.04	-0.07	-0.15	-0.25	0.12	0.61	0.56	0.15
Kedah	**6207032**	-0.74	-1.65	-1.30	-0.35	0.26	0.08	-0.02	-0.08	0.48	1.03	1.00	0.54
Kedah	**6306031**	-0.71	-1.99	-1.83	-0.82	-0.16	-0.17	-0.14	-0.19	0.08	0.54	0.68	0.41
Perlis	**6401002**	-0.71	-1.53	-1.35	-0.67	0.05	0.15	0.30	0.48	0.81	1.08	0.88	0.32
Perlis	**6603002**	-0.09	-0.88	-1.35	-0.53	-0.06	0.18	0.15	0.45	0.65	1.09	1.05	0.90

Table 4.16: Trend Analysis of the SPEI-3 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.01	-0.24	-0.51	-0.65	-0.55	-0.38	-0.30	-0.57	-0.77	-0.46	-0.02	0.21
Perak	**4010001**	0.53	0.40	0.05	0.06	-0.07	-0.59	-0.88	-0.91	-0.43	-0.10	0.29	0.54
Perak	**4012143**	0.64	0.45	0.26	0.49	0.44	0.16	-0.34	-0.60	-0.31	0.16	0.71	0.86
Perak	**4207048**	0.95	0.59	0.09	0.06	-0.07	-0.56	-0.77	-0.88	-0.28	0.08	0.82	1.08
Perak	**4209093**	0.63	0.41	0.10	0.18	0.27	-0.24	-0.57	-0.74	-0.26	0.01	0.40	0.58
Perak	**4311001**	0.14	-0.18	-0.27	0.16	-0.03	-0.52	-0.72	-0.90	-0.44	0.04	0.72	0.75
Perak	**4409091**	0.55	0.33	-0.20	-0.06	-0.13	-0.36	-0.76	-1.12	-0.69	-0.31	0.32	0.63
Perak	**4511111**	-0.16	-0.81	-0.88	-0.37	-0.18	-0.49	-0.47	-0.68	-0.08	0.26	0.86	0.57
Perak	**4611001**	-0.46	-0.86	-1.06	-0.54	-0.14	-0.16	-0.07	-0.54	-0.21	0.17	0.69	0.43
Perak	**4708084**	-0.02	-0.21	-0.17	0.08	-0.09	-0.38	-0.79	-0.75	-0.15	0.20	0.65	0.30
Perak	**4807016**	-0.13	-0.66	-0.79	-0.23	0.09	0.11	0.16	0.05	0.44	0.87	1.26	0.87
Perak	**4811075**	-0.37	-0.63	-0.83	-0.26	0.00	0.02	-0.15	-0.21	0.49	1.13	1.26	0.67
Perak	**4908018**	-0.03	-0.47	-0.24	0.46	0.71	0.21	-0.30	-0.67	0.00	0.73	1.24	0.87
Perak	**5005003**	0.51	-0.01	-0.09	-0.04	0.07	-0.20	-0.24	-0.30	0.19	0.70	1.16	0.95
Perak	**5207001**	0.03	-0.28	-0.10	0.43	0.71	0.21	-0.24	-0.61	-0.07	0.64	0.97	0.75
Perak	**5210069**	-0.26	-0.72	-0.85	-0.39	-0.04	-0.18	-0.28	-0.63	-0.01	0.69	1.09	0.81
Perak	**5411066**	-0.19	-0.71	-0.77	0.20	0.72	0.76	0.54	0.43	0.59	1.22	1.36	1.08
Perak	**5610063**	-0.08	-0.83	-0.72	-0.01	0.74	0.67	0.70	0.65	1.05	1.40	1.36	0.95
Perak	**5710061**	-0.39	-1.12	-1.25	-0.57	-0.03	0.03	-0.13	-0.30	0.29	1.05	1.34	0.87
Penang	**5302001**	-0.88	-1.12	-1.01	-0.19	0.31	0.27	0.25	0.14	0.62	0.92	0.85	0.18
Penang	**5302003**	-0.39	-0.90	-1.12	-0.72	-0.25	-0.16	0.09	0.09	0.60	1.00	1.03	0.54
Penang	**5402001**	-0.58	-1.13	-1.09	-0.46	0.09	0.18	0.21	0.24	0.91	1.21	1.19	0.38
Penang	**5402002**	-0.36	-1.02	-0.87	-0.45	-0.04	0.03	0.21	0.26	0.79	1.11	1.21	0.55

Table 4.16 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	-0.31	-0.83	-0.75	-0.42	-0.02	0.11	0.09	0.22	0.62	0.97	0.95	0.45
Kedah	**5507076**	-0.60	-1.07	-1.07	-0.44	0.13	-0.03	0.02	-0.08	0.47	1.09	1.09	0.69
Kedah	**5704055**	-0.75	-1.16	-1.26	-0.74	-0.23	-0.06	0.24	0.45	1.01	1.16	0.94	0.14
Kedah	**5806066**	-1.01	-1.35	-1.36	-0.69	-0.09	-0.06	0.00	-0.11	0.21	0.63	0.57	0.15
Kedah	**5808001**	-0.78	-1.35	-1.26	-0.50	0.05	-0.06	0.00	0.27	0.91	1.52	1.40	0.73
Kedah	**6103047**	-0.71	-1.16	-1.24	-0.90	-0.50	-0.39	-0.05	0.30	0.83	1.06	0.87	0.17
Kedah	**6108001**	-0.63	-1.28	-1.35	-0.84	-0.17	-0.14	-0.03	0.07	0.61	1.22	1.23	0.62
Kedah	**6206035**	-0.80	-1.22	-1.30	-0.61	-0.13	-0.22	-0.26	-0.25	0.24	0.83	0.83	0.40
Kedah	**6207032**	-0.57	-1.17	-1.24	-0.61	-0.03	-0.21	-0.20	-0.19	0.56	1.30	1.33	0.77
Kedah	**6306031**	-0.49	-1.23	-1.42	-1.00	-0.46	-0.44	-0.28	-0.22	0.17	0.81	0.97	0.64
Perlis	**6401002**	-0.55	-1.09	-1.20	-0.76	-0.19	-0.05	0.20	0.47	0.97	1.36	1.19	0.53
Perlis	**6603002**	0.12	-0.58	-1.14	-0.63	-0.27	0.02	0.09	0.47	0.75	1.28	1.28	1.16

Table 4.17: Trend Analysis of the SDI-3 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**4611463**	0.94	0.47	0.02	-0.03	0.34	0.48	0.51	0.19	0.26	0.69	1.19	1.45
Perak	**4809443**	1.57	1.06	0.46	0.12	0.16	0.23	0.27	0.11	0.06	0.59	1.31	1.92
Perak	**5007421**	0.75	0.00	-0.38	-0.08	0.43	0.55	0.29	-0.01	0.25	1.00	1.64	1.63
Perak	**5206432**	0.34	-0.47	-0.84	-0.52	0.03	0.16	-0.03	-0.26	0.15	1.12	1.74	1.47
Kedah	**5606410**	0.24	-0.59	-1.06	-1.03	-0.70	-0.53	-0.28	-0.29	0.28	1.09	1.71	1.38
Perlis	**6503401**	0.31	-0.20	-0.62	-0.47	-0.29	-0.24	-0.02	0.06	0.52	0.94	1.28	1.18

Table 4.18: Trend Analysis of the SPI-6 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.47	-0.45	-0.41	-0.57	-0.52	-0.58	-0.59	-0.63	-0.72	-0.51	-0.49	-0.51
Perak	**4010001**	0.11	0.21	0.31	0.39	0.25	-0.42	-0.60	-0.68	-0.83	-0.81	-0.57	-0.08
Perak	**4012143**	0.55	0.73	0.70	0.72	0.58	0.34	0.19	0.02	-0.02	-0.05	0.08	0.37
Perak	**4207048**	0.44	0.57	0.53	0.55	0.18	-0.59	-0.68	-0.80	-0.75	-0.73	-0.26	0.35
Perak	**4209093**	0.20	0.22	0.30	0.38	0.35	-0.09	-0.23	-0.23	-0.31	-0.44	-0.36	-0.02
Perak	**4311001**	0.02	0.25	0.29	0.20	-0.13	-0.49	-0.33	-0.61	-0.70	-0.53	-0.16	0.16
Perak	**4409091**	0.02	0.25	0.29	0.20	-0.13	-0.49	-0.33	-0.61	-0.70	-0.53	-0.16	0.16
Perak	**4511111**	-0.20	-0.23	-0.35	-0.49	-0.71	-1.04	-0.58	-0.53	-0.38	-0.19	0.06	0.15
Perak	**4611001**	-0.45	-0.43	-0.59	-0.82	-0.67	-0.89	-0.41	-0.38	-0.20	0.06	0.01	-0.05
Perak	**4708084**	-0.09	-0.06	-0.13	-0.03	-0.17	-0.31	-0.32	-0.39	-0.28	-0.36	-0.15	-0.09
Perak	**4807016**	0.41	0.30	0.08	-0.14	-0.30	-0.35	0.07	0.22	0.40	0.62	0.76	0.72
Perak	**4811075**	0.18	0.08	-0.30	-0.52	-0.48	-0.56	-0.20	-0.04	0.39	0.70	0.69	0.61
Perak	**4908018**	0.38	0.35	0.28	0.24	0.15	0.00	0.20	0.18	0.23	0.31	0.40	0.52
Perak	**5005003**	0.49	0.44	0.36	0.14	-0.09	-0.33	-0.28	-0.23	-0.15	0.16	0.40	0.53
Perak	**5207001**	0.21	0.21	0.26	0.21	0.30	0.12	0.17	0.16	0.10	0.21	0.13	0.25
Perak	**5210069**	-0.16	-0.22	-0.46	-0.95	-0.89	-0.93	-0.52	-0.44	-0.18	0.24	0.24	0.28
Perak	**5411066**	0.41	0.20	0.14	-0.11	-0.07	0.06	0.48	0.75	0.83	1.03	1.00	0.87
Perak	**5610063**	0.67	0.16	0.00	-0.21	-0.06	0.03	0.56	1.10	1.21	1.40	1.29	1.16
Perak	**5710061**	0.09	-0.16	-0.55	-0.98	-1.12	-1.01	-0.51	-0.13	0.26	0.66	0.70	0.57
Penang	**5302001**	-0.23	-0.51	-0.81	-0.89	-0.64	-0.59	0.01	0.32	0.58	0.74	0.54	0.32
Penang	**5302003**	0.17	-0.08	-0.48	-0.86	-0.88	-0.99	-0.54	-0.21	0.20	0.61	0.59	0.53
Penang	**5402001**	0.28	-0.08	-0.64	-0.79	-0.80	-0.67	-0.19	0.23	0.72	0.95	0.90	0.69

Table 4.18 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5402002**	0.27	0.00	-0.44	-0.81	-0.98	-0.86	-0.36	0.00	0.44	0.81	0.84	0.63
Penang	**5504035**	-0.01	-0.32	-0.71	-1.00	-1.05	-0.82	-0.50	-0.11	0.29	0.56	0.45	0.17
Kedah	**5507076**	0.09	-0.29	-0.54	-0.95	-0.80	-0.87	-0.29	0.09	0.30	0.76	0.59	0.55
Kedah	**5704055**	0.16	-0.26	-0.88	-1.19	-1.13	-0.96	-0.30	0.20	0.68	0.91	0.83	0.66
Kedah	**5806066**	-0.62	-0.93	-1.09	-1.38	-1.17	-1.05	-0.45	-0.08	0.12	0.43	0.17	-0.05
Kedah	**5808001**	0.33	-0.27	-0.68	-1.22	-1.21	-1.13	-0.35	0.33	0.68	1.17	1.14	0.97
Kedah	**6103047**	0.02	-0.49	-0.94	-1.33	-1.31	-1.20	-0.56	0.00	0.36	0.65	0.65	0.48
Kedah	**6108001**	0.16	-0.33	-0.77	-1.31	-1.26	-1.23	-0.62	0.00	0.36	0.85	0.80	0.63
Kedah	**6206035**	-0.37	-0.70	-0.90	-1.17	-1.10	-1.29	-0.70	-0.32	-0.11	0.28	0.17	0.09
Kedah	**6207032**	0.28	-0.10	-0.40	-0.89	-0.89	-1.02	-0.48	-0.01	0.31	0.76	0.68	0.67
Kedah	**6306031**	-0.09	-0.47	-0.74	-1.29	-1.48	-1.48	-0.94	-0.44	-0.20	0.28	0.35	0.28
Perlis	**6401002**	0.36	-0.18	-0.64	-1.12	-1.02	-0.99	-0.35	0.31	0.70	1.05	0.97	0.79
Perlis	**6603002**	0.66	0.27	-0.01	-0.35	-0.66	-0.82	-0.34	0.21	0.50	0.88	1.05	1.04

Table 4.19: Trend Analysis of the SPEI-6 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.23	-0.16	-0.17	-0.34	-0.36	-0.51	-0.57	-0.66	-0.69	-0.45	-0.35	-0.32
Perak	**4010001**	0.28	0.42	0.48	0.51	0.31	-0.34	-0.57	-0.72	-0.73	-0.69	-0.42	0.08
Perak	**4012143**	0.59	0.77	0.74	0.79	0.62	0.26	0.11	-0.10	-0.10	-0.14	0.05	0.41
Perak	**4207048**	0.73	0.92	0.87	0.82	0.40	-0.34	-0.50	-0.71	-0.63	-0.53	-0.01	0.61
Perak	**4209093**	0.46	0.54	0.61	0.68	0.54	-0.08	-0.31	-0.39	-0.42	-0.43	-0.25	0.21
Perak	**4311001**	0.18	0.40	0.41	0.26	-0.14	-0.60	-0.43	-0.66	-0.69	-0.50	-0.12	0.31
Perak	**4409091**	0.23	0.48	0.40	0.44	0.23	-0.39	-0.63	-0.91	-0.76	-0.76	-0.62	-0.07
Perak	**4511111**	0.04	0.04	-0.11	-0.29	-0.56	-0.92	-0.57	-0.58	-0.41	-0.14	0.21	0.36
Perak	**4611001**	-0.21	-0.14	-0.30	-0.57	-0.57	-0.85	-0.45	-0.49	-0.27	0.07	0.13	0.19
Perak	**4708084**	0.10	0.19	0.07	0.11	-0.11	-0.40	-0.47	-0.56	-0.36	-0.36	-0.06	0.08
Perak	**4807016**	0.50	0.40	0.12	-0.12	-0.37	-0.50	-0.09	0.05	0.34	0.68	0.90	0.87
Perak	**4811075**	0.45	0.36	-0.07	-0.33	-0.39	-0.60	-0.32	-0.19	0.34	0.72	0.84	0.86
Perak	**4908018**	0.51	0.56	0.47	0.39	0.21	-0.07	0.07	-0.03	0.08	0.27	0.40	0.59
Perak	**5005003**	0.77	0.76	0.66	0.40	0.11	-0.20	-0.22	-0.21	-0.04	0.31	0.61	0.81
Perak	**5207001**	0.43	0.45	0.43	0.29	0.27	-0.03	0.03	0.03	0.04	0.27	0.26	0.48
Perak	**5210069**	0.19	0.20	-0.08	-0.52	-0.63	-0.82	-0.58	-0.57	-0.22	0.27	0.39	0.53
Perak	**5411066**	0.67	0.46	0.36	0.05	0.00	0.02	0.51	0.80	0.95	1.23	1.28	1.19
Perak	**5610063**	0.88	0.44	0.24	0.01	0.04	-0.02	0.47	0.98	1.16	1.43	1.40	1.35
Perak	**5710061**	0.43	0.19	-0.22	-0.64	-0.83	-0.95	-0.59	-0.31	0.16	0.72	0.89	0.88
Penang	**5302001**	0.01	-0.21	-0.50	-0.64	-0.53	-0.55	0.00	0.30	0.62	0.84	0.71	0.53
Penang	**5302003**	0.37	0.14	-0.24	-0.63	-0.69	-0.85	-0.44	-0.14	0.28	0.74	0.76	0.73
Penang	**5402001**	0.44	0.12	-0.39	-0.60	-0.68	-0.66	-0.23	0.18	0.74	1.04	1.04	0.86
Penang	**5402002**	0.51	0.28	-0.15	-0.56	-0.80	-0.58	-0.19	0.12	0.57	0.92	1.01	0.85

Table 4.19 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	0.44	0.15	-0.23	-0.58	-0.76	-0.49	-0.26	0.07	0.42	0.75	0.81	0.66
Kedah	**5507076**	0.34	0.04	-0.24	-0.72	-0.69	-0.86	-0.38	-0.04	0.28	0.85	0.76	0.80
Kedah	**5704055**	0.30	-0.11	-0.71	-0.96	-0.99	-0.96	-0.38	0.13	0.70	0.98	0.95	0.81
Kedah	**5806066**	-0.28	-0.56	-0.77	-1.12	-1.08	-1.11	-0.58	-0.22	0.06	0.49	0.37	0.24
Kedah	**5808001**	0.58	0.02	-0.41	-0.90	-0.97	-1.03	-0.43	0.18	0.64	1.28	1.34	1.24
Kedah	**6103047**	0.22	-0.26	-0.69	-1.01	-1.12	-1.17	-0.69	-0.17	0.32	0.74	0.84	0.72
Kedah	**6108001**	0.43	-0.07	-0.54	-0.99	-1.05	-1.12	-0.67	-0.13	0.34	0.96	1.01	0.91
Kedah	**6206035**	-0.02	-0.31	-0.59	-0.93	-0.93	-1.10	-0.62	-0.30	-0.01	0.46	0.45	0.44
Kedah	**6207032**	0.51	0.11	-0.27	-0.76	-0.87	-1.09	-0.63	-0.21	0.25	0.90	0.92	0.97
Kedah	**6306031**	0.22	-0.15	-0.48	-0.98	-1.18	-1.32	-0.93	-0.54	-0.20	0.41	0.58	0.56
Perlis	**6401002**	0.62	0.09	-0.39	-0.79	-0.81	-0.87	-0.43	0.14	0.66	1.16	1.18	1.07
Perlis	**6603002**	0.87	0.55	0.20	-0.19	-0.52	-0.76	-0.37	0.10	0.49	0.94	1.18	1.23

Table 4.20: Trend Analysis of the SDI-6 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**4611463**	0.87	0.85	0.76	0.54	0.48	0.27	0.26	0.29	0.40	0.66	0.76	0.94
Perak	**4809443**	1.22	1.29	1.29	1.03	0.78	0.39	0.22	0.15	0.16	0.48	0.81	1.13
Perak	**5007421**	0.95	0.84	0.65	0.43	0.27	0.09	0.11	0.24	0.46	0.74	0.94	1.09
Perak	**5206432**	0.89	0.73	0.44	0.01	-0.19	-0.47	-0.37	-0.16	0.20	0.73	0.99	1.08
Kedah	**5606410**	0.84	0.64	0.17	-0.47	-0.86	-1.14	-0.94	-0.71	-0.18	0.57	1.01	1.18
Perlis	**6503401**	0.69	0.54	0.26	-0.07	-0.28	-0.53	-0.30	-0.15	0.17	0.55	0.81	1.03

Table 4.21: Trend Analysis of the SPI-12 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.61	-0.59	-0.59	-0.58	-0.56	-0.57	-0.54	-0.57	-0.56	-0.54	-0.53	-0.64
Perak	**4010001**	-0.40	-0.34	-0.31	-0.26	-0.29	-0.28	-0.28	-0.29	-0.31	-0.29	-0.26	-0.42
Perak	**4012143**	0.47	0.50	0.49	0.49	0.46	0.47	0.49	0.46	0.41	0.41	0.39	0.45
Perak	**4207048**	-0.13	-0.09	-0.09	-0.10	-0.12	-0.11	-0.15	-0.16	-0.22	-0.16	-0.14	-0.19
Perak	**4209093**	-0.09	-0.08	-0.08	-0.08	-0.05	-0.05	-0.04	-0.02	-0.07	-0.06	-0.07	-0.17
Perak	**4311001**	-0.31	-0.29	-0.27	-0.23	-0.26	-0.26	-0.25	-0.23	-0.29	-0.31	-0.30	-0.30
Perak	**4409091**	-0.61	-0.58	-0.55	-0.53	-0.58	-0.58	-0.53	-0.52	-0.54	-0.50	-0.50	-0.70
Perak	**4511111**	-0.49	-0.47	-0.42	-0.41	-0.40	-0.42	-0.41	-0.42	-0.47	-0.46	-0.47	-0.54
Perak	**4611001**	-0.56	-0.56	-0.53	-0.54	-0.52	-0.54	-0.51	-0.51	-0.53	-0.52	-0.49	-0.61
Perak	**4708084**	-0.31	-0.33	-0.31	-0.28	-0.30	-0.29	-0.26	-0.22	-0.26	-0.26	-0.20	-0.29
Perak	**4807016**	0.30	0.31	0.30	0.31	0.31	0.28	0.28	0.25	0.19	0.19	0.20	0.25
Perak	**4811075**	-0.02	0.00	0.02	0.05	0.03	0.02	0.01	0.00	-0.05	0.03	0.09	0.08
Perak	**4908018**	0.42	0.41	0.40	0.43	0.40	0.38	0.37	0.34	0.25	0.27	0.29	0.35
Perak	**5005003**	0.16	0.16	0.19	0.20	0.18	0.20	0.16	0.19	0.11	0.16	0.21	0.14
Perak	**5207001**	0.24	0.25	0.25	0.25	0.24	0.25	0.26	0.23	0.21	0.23	0.24	0.20
Perak	**5210069**	-0.43	-0.45	-0.44	-0.49	-0.54	-0.55	-0.52	-0.49	-0.56	-0.55	-0.47	-0.43
Perak	**5411066**	0.58	0.60	0.60	0.59	0.56	0.55	0.57	0.58	0.58	0.57	0.60	0.61
Perak	**5610063**	0.83	0.84	0.86	0.86	0.85	0.86	0.88	0.88	0.83	0.85	0.87	0.87
Perak	**5710061**	-0.27	-0.25	-0.28	-0.27	-0.33	-0.33	-0.33	-0.31	-0.34	-0.32	-0.31	-0.33
Penang	**5302001**	-0.23	-0.22	-0.20	-0.16	-0.17	-0.16	-0.17	-0.16	-0.21	-0.23	-0.21	-0.25
Penang	**5302003**	-0.23	-0.23	-0.21	-0.19	-0.21	-0.20	-0.21	-0.20	-0.25	-0.20	-0.20	-0.28
Penang	**5402001**	0.10	0.10	0.12	0.16	0.10	0.12	0.10	0.13	0.08	0.11	0.12	0.04

Table 4.21 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5402002**	-0.07	-0.06	-0.02	0.01	-0.04	-0.01	0.01	0.03	-0.03	0.00	-0.01	-0.15
Penang	**5504035**	-0.48	-0.48	-0.46	-0.42	-0.50	-0.51	-0.49	-0.45	-0.52	-0.47	-0.45	-0.52
Kedah	**5507076**	-0.12	-0.15	-0.18	-0.14	-0.18	-0.18	-0.16	-0.16	-0.16	-0.11	-0.08	-0.23
Kedah	**5704055**	-0.19	-0.18	-0.18	-0.18	-0.24	-0.24	-0.27	-0.28	-0.35	-0.30	-0.28	-0.24
Kedah	**5806066**	-0.82	-0.78	-0.73	-0.73	-0.81	-0.82	-0.77	-0.74	-0.71	-0.62	-0.56	-0.88
Kedah	**5808001**	0.03	0.04	0.02	0.04	0.02	0.03	0.02	-0.06	-0.10	-0.01	0.00	-0.04
Kedah	**6103047**	-0.67	-0.66	-0.65	-0.62	-0.65	-0.64	-0.63	-0.67	-0.76	-0.76	-0.74	-0.73
Kedah	**6108001**	-0.38	-0.37	-0.38	-0.37	-0.36	-0.38	-0.39	-0.40	-0.48	-0.37	-0.38	-0.46
Kedah	**6206035**	-0.84	-0.83	-0.81	-0.71	-0.71	-0.70	-0.69	-0.74	-0.77	-0.76	-0.78	-0.89
Kedah	**6207032**	-0.20	-0.18	-0.13	-0.11	-0.14	-0.14	-0.10	-0.13	-0.19	-0.19	-0.24	-0.27
Kedah	**6306031**	-0.71	-0.69	-0.71	-0.72	-0.73	-0.73	-0.72	-0.74	-0.84	-0.84	-0.90	-0.84
Perlis	**6401002**	0.00	0.01	0.05	0.08	0.08	0.09	0.09	0.07	-0.02	-0.04	0.00	-0.09
Perlis	**6603002**	0.33	0.35	0.35	0.37	0.35	0.33	0.32	0.26	0.24	0.26	0.26	0.27

Table 4.22: Trend Analysis of the SPEI-12 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**3615003**	-0.45	-0.42	-0.43	-0.42	-0.41	-0.42	-0.38	-0.41	-0.39	-0.38	-0.37	-0.48
Perak	**4010001**	-0.21	-0.16	-0.12	-0.10	-0.11	-0.10	-0.10	-0.11	-0.14	-0.10	-0.08	-0.22
Perak	**4012143**	0.43	0.44	0.44	0.48	0.47	0.50	0.51	0.47	0.42	0.41	0.39	0.40
Perak	**4207048**	0.27	0.32	0.34	0.33	0.32	0.33	0.31	0.30	0.23	0.26	0.28	0.22
Perak	**4209093**	0.14	0.16	0.22	0.31	0.26	0.24	0.24	0.26	0.19	0.19	0.27	0.12
Perak	**4311001**	-0.20	-0.20	-0.18	-0.13	-0.18	-0.19	-0.19	-0.19	-0.26	-0.27	-0.22	-0.23
Perak	**4409091**	-0.30	-0.25	-0.23	-0.19	-0.23	-0.22	-0.19	-0.19	-0.24	-0.22	-0.18	-0.36
Perak	**4511111**	-0.32	-0.30	-0.27	-0.23	-0.22	-0.24	-0.24	-0.26	-0.31	-0.29	-0.28	-0.37
Perak	**4611001**	-0.43	-0.42	-0.39	-0.36	-0.35	-0.34	-0.31	-0.32	-0.35	-0.36	-0.33	-0.48
Perak	**4708084**	-0.27	-0.27	-0.25	-0.21	-0.21	-0.19	-0.16	-0.14	-0.17	-0.16	-0.10	-0.23
Perak	**4807016**	0.26	0.28	0.33	0.40	0.37	0.32	0.31	0.27	0.19	0.18	0.18	0.21
Perak	**4811075**	0.12	0.14	0.18	0.20	0.18	0.17	0.15	0.13	0.08	0.18	0.24	0.18
Perak	**4908018**	0.44	0.45	0.51	0.60	0.58	0.56	0.55	0.51	0.38	0.36	0.33	0.32
Perak	**5005003**	0.51	0.50	0.52	0.50	0.49	0.50	0.46	0.49	0.41	0.48	0.53	0.47
Perak	**5207001**	0.34	0.37	0.38	0.41	0.41	0.39	0.38	0.36	0.30	0.30	0.34	0.27
Perak	**5210069**	-0.22	-0.23	-0.22	-0.26	-0.30	-0.32	-0.29	-0.26	-0.32	-0.29	-0.21	-0.21
Perak	**5411066**	0.74	0.79	0.79	0.76	0.74	0.73	0.75	0.76	0.75	0.72	0.75	0.78
Perak	**5610063**	0.90	0.93	0.95	0.94	0.91	0.91	0.95	0.94	0.88	0.90	0.93	0.97
Perak	**5710061**	-0.02	0.01	0.01	0.03	0.00	-0.01	-0.02	-0.01	-0.05	-0.03	-0.03	-0.06
Penang	**5302001**	0.00	0.01	0.04	0.10	0.07	0.08	0.07	0.08	0.02	0.01	0.04	-0.01
Penang	**5302003**	0.00	-0.01	0.01	0.03	0.01	0.03	0.05	0.06	0.05	0.05	0.06	-0.04
Penang	**5402001**	0.27	0.27	0.29	0.32	0.27	0.29	0.28	0.30	0.28	0.29	0.31	0.22
Penang	**5402002**	0.32	0.30	0.32	0.27	0.22	0.23	0.22	0.21	0.17	0.17	0.13	0.30

Table 4.22 (Continued)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Penang	**5504035**	0.10	0.06	0.05	0.04	-0.02	-0.02	-0.04	-0.03	-0.08	-0.09	-0.08	0.10
Kedah	**5507076**	0.11	0.07	0.04	0.08	0.05	0.05	0.06	0.06	0.05	0.12	0.17	0.03
Kedah	**5704055**	-0.05	-0.03	-0.04	-0.01	-0.06	-0.06	-0.08	-0.11	-0.18	-0.15	-0.13	-0.09
Kedah	**5806066**	-0.59	-0.59	-0.57	-0.58	-0.63	-0.61	-0.59	-0.55	-0.53	-0.44	-0.41	-0.66
Kedah	**5808001**	0.24	0.29	0.29	0.33	0.30	0.32	0.33	0.23	0.18	0.28	0.23	0.20
Kedah	**6103047**	-0.45	-0.43	-0.43	-0.37	-0.43	-0.41	-0.42	-0.43	-0.53	-0.50	-0.52	-0.53
Kedah	**6108001**	-0.15	-0.13	-0.11	-0.10	-0.12	-0.12	-0.08	-0.13	-0.21	-0.13	-0.16	-0.24
Kedah	**6206035**	-0.50	-0.48	-0.48	-0.44	-0.46	-0.44	-0.42	-0.45	-0.45	-0.42	-0.45	-0.55
Kedah	**6207032**	-0.02	-0.01	0.06	0.12	0.07	0.05	0.10	0.04	-0.04	-0.03	-0.07	-0.11
Kedah	**6306031**	-0.46	-0.46	-0.48	-0.46	-0.49	-0.48	-0.47	-0.48	-0.57	-0.55	-0.60	-0.56
Perlis	**6401002**	0.27	0.29	0.33	0.40	0.41	0.41	0.40	0.37	0.28	0.25	0.26	0.19
Perlis	**6603002**	0.49	0.51	0.52	0.53	0.51	0.50	0.49	0.45	0.43	0.45	0.43	0.43

Table 4.23: Trend Analysis of the SDI-12 for Northern Region

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Perak	**4611463**	0.61	0.61	0.61	0.62	0.63	0.63	0.63	0.63	0.62	0.62	0.63	0.64
Perak	**4809443**	0.83	0.84	0.85	0.87	0.88	0.89	0.90	0.92	0.90	0.93	0.96	0.87
Perak	**5007421**	0.56	0.56	0.57	0.59	0.60	0.60	0.61	0.62	0.61	0.63	0.66	0.65
Perak	**5206432**	0.30	0.32	0.35	0.39	0.41	0.43	0.45	0.47	0.45	0.48	0.51	0.37
Kedah	**5606410**	0.04	0.03	0.03	0.03	0.02	0.01	0.01	0.02	-0.02	0.01	0.02	0.03
Perlis	**6503401**	0.23	0.23	0.24	0.25	0.26	0.26	0.27	0.28	0.29	0.31	0.32	0.31

4.6 Historical Drought Comparison

Comparison of historical events was used to check the performance of drought indices in drought detection. There was a total of 16 historical drought event cases happened in northern region of Malaysia recorded in Table 4.24 below. The table below only presented the significant historical drought events that were reported in the past, some other not reported drought events might be missed out.

Based on the comparison of 16 cases of historical events, it was obviously shown that different indices with different timescales will have different performance for different cases. There was no a particular index with a particular timescale which can perfectly describe all the drought events. This was the reasons why different indices with different timescales were calculated to describe the moisture condition in this project. The explanation was as below.

Based on Table 4.24 below, Case 1 was a historical meteorological drought happened at Sungai Kerian, Selama in Perak state, started from April 2005 and ended in June 2005 (Hydrology and Water Resources Division Department of Irrigation and Drainage Malaysia, 2005). The corresponding drought index results were referred to the SPI, the SPEI at rainfall station 5207001, and the SDI at streamflow station 5206432. All indices successfully detected the drought event Case 1. However, all of them had over-estimated the duration. SPI-1 and the SPEI-1 indices with smallest difference between detected duration and historical duration were describing this meteorological drought event more appropriately. For indices with longer timescale, the overestimation of drought duration became more severe.

For Case 2 to Case 13, they were agricultural droughts and socioeconomic droughts which affected Perak, Penang, Kedah and Perlis in northern region during January to April of 2016 (Channel News Asia, 2016; Kumaran, 2016). As mentioned earlier, timescale of 3 months and 6 months will be suitable to represent agricultural drought, the result found in this section was incoherent with this statement. SPEI-3 and SPEI-6 index fully detected all the agricultural drought of Case 2 to Case 13 without any undetected or under-estimated result. However, for Case 10, the SPI-6 shown an undetected result. the SPI-1, the SPI-3, the SPI-12 and the SPEI-1 under-estimated the duration of this agricultural drought, which shown that these timescales cannot detect the agricultural drought appropriately. Only the SPEI-3 and the SPEI-6 shown 100% detection without un-detection and underestimation for all the agricultural droughts in Case 2 to Case 13.

Furthermore, Case 14, Case 15 and Case 16 were hydrological drought happened at the Ahning, Muda and Pedu Dam started from January until March of 2017 (Astro Awani, 2017; Majid, 2017). Indication of hydrological drought was the low water level at these dams, this will only appear after a long-term of insufficient precipitation to charge the dams. Timescale of 12 months was suitable to measure these cases. As a result, only SPEI-12 shown 100% detection and no underestimation for all three hydrological drought cases, and other indices with different timescale shown relatively poor estimation. Last but not least, SDI which measured the streamflow instead of precipitation were generally referring to hydrological drought. However, only SDI-12 successfully detected hydrological drought events Cases 14 to Cases 16 without under-estimation. But the difference between the duration detected and duration recorded were 57 months, the overestimation was huge for the SDI-12.

Based on Table 4.26, the indices with 100% probability of detection (POD) are the SPI-1, the SPEI-1, the SPEI-3 and the SDI-3. In Table 4.25, SPI-1 and SPEI-1 underestimated the duration of a total of 5 cases which included 2 agricultural droughts and 3 agricultural droughts; SPEI-3 under-estimated 3 hydrological drought cases. Although the SDI-3 only under-estimated 1 case, but the duration error analysis in Table 4.27 shown that its Mean Absolute Error (MAE) is 20.50, Mean Bias Error (MBE) is 20.38, and Root Mean Square Error (RMSE) is 28.51. SPI-1 had the lowest MAE, MBE and RMSE, followed with SPEI-1 and SPEI-3. Although, SPEI-3 with MAE of 3.31, MBE of 2.69, and RMSE of 3.91 are higher than SPI-1 and SPEI-1, but it will only under estimate the hydrological drought cases, unlike SPI-1 and SPEI-1 which tend to under estimate for agricultural and hydrological droughts.

To further validate the accuracy of drought indices in detecting the onset of drought, the difference between the detected onset and historical onset for all cases was compared and recorded in Table 4.28. Based on the summary in Table 4.29, the SPEI-3 had accurately detected the onset for 7 cases which is the greatest among all indices. The only early-detected drought case of SPEI-3 is the meteorological drought Case 1 by 4 months. The number of cases of delayed detection by the SPEI-3 is 8, and the average/delay magnitude for it is 0.67 which means it most likely will has a delayed onset detection of 0.67. The average/delay magnitude of SPI-1 and SPEI-1 are lowest, but this might due to the negative magnitude balanced out the positive magnitude as SPI-1 had 9 early detection to balance out with 5 delayed detection; and SPEI-1 had 10 early detection to balance out with 5 delayed detection. Meanwhile, the inconsistency of SPEI-1 and SPI-1 in early and delay onset detection tends to reduce their reliability for application.

Table 4.24: Comparison of Drought Duration Detected by Drought Indices to Drought Duration of Historical Drought Event

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
Historical Drought Event	Case 1. (Location: Sungai Kerian@Selama , Onset: 04/2005 , End: 06/2005) (Hydrology and Water Resources Division the the Department of Irrigation and Drainage Malaysia, 2005)										
Nearest Station	5207001				5207001				5206432		
Distance (km)	4.073				4.073				1.667		
Onset	04/2005	12/2004	5/2004	10/2004	04/2005	12/2004	5/2004	10/2004	01/2005	04/2004	04/2003
End	09/2005	10/2005	11/2006	06/2007	09/2005	10/2005	11/2006	08/2007	10/2005	08/2006	10/2006
Duration (Months)	6	11	31	33	6	11	31	35	10	29	43
Detect– Historical Duration	3	8	28	30	3	8	28	32	7	26	40
Detection	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
Maximum Severity	-2.19	-2.69	-2.76	-2.28	-2.12	-2.21	-2.2	-1.94	-1.55	-1.91	-1.74
Historical Drought Event	Case 2. (Location: Beris Dam , Onset: 01/2016 , End: 04/2016) (Yeh, 2016 ; USDA, 2016)										
Nearest Station	5808001				5808001				5606410		
Distance (km)	17.087				17.087				41.758		
Onset	02/2016	02/2016	04/2016	-	02/2016	02/2016	03/2016	-	02/2016	-	-
End	04/2016	06/2016	03/2017	-	04/2016	11/2016	03/2017	-	10/2016	-	-
Duration (Months)	3	5	12	-	3	10	13	-	9	-	-
Detect– Historical Duration	-1	1	8	-	-1	6	9	-	5	-	-
Detection	Under	Over	Over	Undetect	Under	Over	Over	Undetect	Over	Undetect	Undetect
Maximum Severity	-2.22	-2.03	-1.62	-	-2.29	-2.15	-1.93	-	-1.04	-	-

Table 4.24 (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
Historical Drought Event	Case 3. (Location: Jitra , Onset: 01/2016 , End: 04/2016) (Today Online, 2016 ; USDA, 2016)										
Nearest Station	6103047				6103047				6503401		
Distance (km)	16.285				16.285				27.822		
Onset	12/2015	02/2016	03/2016	-	12/2015	01/2016	03/2016	-	01/2015	09/2012	01/2013
End	04/2016	05/2016	07/2016	-	04/2016	06/2016	08/2016	-	12/2017	12/2017	12/2017
Duration (Months)	5	4	5	-	5	6	6	-	36	64	60
Detect– Historical Duration	1	0	1	-	1	2	2	-	32	60	56
Detection	Over	Exact	Over	Undetect	Over	Over	Over	Undetect	Over	Over	Over
Maximum Severity	-1.98	-2.87	-2.34	-	-2.26	-2.26	-2.19	-	-1.14	-1.31	-1.63
Historical Drought Event	Case 4. (Location: Kubang Pasu , Onset: 01/2016 , End: 04/2016) (Today Online, 2016 ; USDA, 2016)										
Nearest Station	6206035				6206035				6503401		
Distance (km)	24.043				24.043				17.645		
Onset	12/2015	01/2016	03/2016	-	12/2015	01/2016	03/2016	04/2016	01/2015	09/2012	01/2013
End	04/2016	05/2016	07/2016	-	04/2016	06/2016	08/2016	04/2016	12/2017	12/2017	12/2017
Duration (Months)	5	5	5	-	5	6	6	1	36	64	60
Detect– Historical Duration	1	1	1	-	1	2	2	-3	32	60	56
Detection	Over	Over	Over	Undetect	Over	Over	Over	Under	Over	Over	Over
Maximum Severity	-1.85	-2.56	-2.36	-	-2.36	-2.45	-2.33	-0.13	-1.14	-1.31	-1.63

Table 4.24 (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
Historical Drought Event	Case 5. (Location: Padang Saga Dam , Onset: 01/2016 , End: 04/2016) (Today Online, 2016 ; USDA, 2016)										
Nearest Station	6401002				6401002				6503401		
Distance (km)	47.615				47.615				65.016		
Onset	12/2015	02/2016	03/2016	04/2016	12/2015	01/2016	03/2016	12/2015	01/2015	09/2012	01/2013
End	04/2016	06/2016	08/2016	05/2016	04/2016	09/2016	09/2016	6/2017	12/2017	12/2017	12/2017
Duration (Months)	5	5	6	2	5	9	7	19	36	64	60
Detect– Historical Duration	1	1	2	-2	1	5	3	15	32	60	56
Detection	Over	Over	Over	Under	Over	Over	Over	Over	Over	Over	Over
Maximum Severity	-1.95	-3.07	-2.33	-0.38	-2.25	-2.29	-2.2	-2.19	-1.14	-1.31	-1.63
Historical Drought Event	Case 6. (Location: Air Itam Dam , Onset: 01/2016 , End: 04/2016) (The Star Online, 2016 ; USDA, 2016)										
Nearest Station	5302003				5302003				5606410		
Distance (km)	1.548				1.548				46.310		
Onset	12/2015	02/2016	03/2016	-	12/2015	02/2016	03/2016	04/2016	02/2016	-	-
End	04/2016	06/2016	08/2016	-	05/2016	06/2016	08/2016	05/2016	10/2016	-	-
Duration (Months)	5	5	6	-	6	5	6	2	9	-	-
Detect– Historical Duration	1	1	2	-	2	1	2	-2	5	-	-
Detection	Over	Over	Over	Undetect	Over	Over	Over	Under	Over	Undetect	Undetect
Maximum Severity	-1.67	-1.82	-1.67	-	-1.72	-1.89	-1.73	-0.11	-1.04	-	-

Table 4.24 (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**
Historical Drought Event	Case 7. (Location: Penang Hill , Onset: 01/2016 , End: 04/2016) (The Star Online, 2016 ; USDA, 2016)										
Nearest Station	5402001				5402001				5606410		
Distance (km)	1.548				1.548				43.997		
Onset	12/2015	01/2016	03/2016	12/2015	12/2015	01/2016	03/2016	12/2015	02/2016	-	-
End	04/2016	06/2016	08/2016	09/2016	04/2016	06/2016	06/2016	10/2016	10/2016	-	-
Duration (Months)	5	6	6	10	5	6	4	11	9	-	-
Detect– Historical Duration	1	2	2	6	1	2	0	7	5	-	-
Detection	Over	Over	Over	Over	Over	Over	Exact	Over	Over	Undetect	Undetect
Maximum Severity	-1.5	-2.24	-1.88	-0.43	-1.85	-1.98	-1.85	-0.76	-1.04	-	-
Historical Drought Event	Case 8. (Location: Seberang Prai , Onset: 01/2016 , End: 04/2016) (Astro Awani, 2016)										
Nearest Station	5402002				5402002				5606410		
Distance (km)	15.664				15.664				35.485		
Onset	12/2015	01/2016	02/2016	08/2015	12/2015	01/2016	02/2016	04/2015	02/2016	-	-
End	04/2016	05/2016	08/2016	11/2016	04/2016	08/2016	08/2016	02/2017	10/2016	-	-
Duration (Months)	5	5	7	16	5	8	7	23	9	-	-
Detect– Historical Duration	1	1	3	12	1	4	3	19	5	-	-
Detection	Over	Over	Over	Over	Over	Over	Over	Over	Over	Undetect	Undetect
Maximum Severity	-2.19	-2.85	-1.87	-0.97	-2.48	-2.43	2.12	-1.52	-1.04	-	-

Table 4.24 (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
Historical Drought Event	Case 9. (Location: Teluk Bahang Dam , Onset: 01/2016 , End: 04/2016) (The Star Online, 2016)										
Nearest Station	5302001				5302001				5606410		
Distance (km)	4.971				4.971				49.087		
Onset	12/2015	02/2016	03/2016	-	12/2015	02/2016	03/2016	04/2016	02/2016	-	-
End	04/2016	05/2016	07/2016	-	04/2016	06/2016	08/2016	04/2016	10/2016	-	-
Duration (Months)	5	4	5	-	5	5	6	1	9	-	-
Detect– Historical Duration	1	0	1	-	1	1	2	-3	5	-	-
Detection	Over	Exact	Over	Undetect	Over	Over	Over	Under	Over	Undetect	Undetect
Maximum Severity	-1.44	-2.26	-1.82	-	-1.72	-2.06	-1.798	-0.2	-1.04	-	-
Historical Drought Event	Case 10. (Location: Bukit Merah Dam , Onset: 01/2016 , End: 04/2016) (Channel News Asia, 2016 ; Kumaran, 2016)										
Nearest Station	5005003				5005003				5007421		
Distance (km)	10.752				10.752				9.075		
Onset	03/2016	03/2016	-	06/2016	03/2016	03/2016	03/2016	01/2016	02/2011	02/2011	04/2011
End	04/2016	05/2016	-	06/2016	04/2016	08/2016	10/2016	03/2017	12/2017	12/2017	12/2017
Duration (Months)	2	3	-	1	2	6	8	15	83	83	81
Detect– Historical Duration	-2	-1	-	-3	-2	2	4	11	79	79	77
Detection	Under	Under	Undetect	Under	Under	Over	Over	Over	Over	Over	Over
Maximum Severity	-2.26	-0.90	-	-0.11	-1.07	-1.74	-1.9	-1.02	-1.38	-1.61	-1.81

Table 4.24 (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
Historical Drought Event	Case 11. (Location: Kerian , Onset: 01/2016 , End: 04/2016) (Yeh, 2016)										
Nearest Station	5207001				5207001				5206432		
Distance (km)	9.898				9.898				7.775		
Onset	01/2016	01/2016	01/2016	01/2016	11/2015	01/2016	12/2015	11/2015	02/2016	03/2016	10/2010
End	05/2016	09/2016	10/2016	03/2017	08/2016	10/2016	10/2016	04/2017	10/2017	12/2017	12/2017
Duration (Months)	5	9	10	15	10	10	11	18	21	22	87
Detect– Historical Duration	1	5	6	11	6	6	7	14	17	18	83
Detection	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
Maximum Severity	-2.14	-2.78	-2.99	-1.65	-2.36	-2.6	-2.44	-1.86	-1.81	-2.07	-2
Historical Drought Event	Case 12. (Location: Tasek Takong , Onset: 01/2016 , End: 04/2016) (The Straits Times, 2016)										
Nearest Station	5710061				5710061				5606410		
Distance (km)	2.266				2.266				42.288		
Onset	12/2015	02/2016	03/2016	-	12/2015	02/2016	02/2016	02/2016	02/2016	-	-
End	04/2016	06/2016	09/2016	-	04/2016	09/2016	09/2016	03/2017	10/2016	-	-
Duration (Months)	5	5	7	-	5	8	8	14	9	-	-
Detect– Historical Duration	1	1	3	-	1	4	4	10	5	-	-
Detection	Over	Over	Over	Undetect	Over	Over	Over	Over	Over	Undetect	Undetect
Maximum Severity	-2.17	-2.49	-2.14	-	-2.32	-2.4	-2.09	-1.78	-1.04	-	-

Table 4.24 (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
Historical Drought Event	Case 13. (Location: Kaki Bukit , Onset: 01/2016 , End: 04/2016) (Yeh, 2016)										
Nearest Station	6603002				6603002				6503401		
Distance (km)	12.779				12.779				21.690		
Onset	12/2015	01/2016	03/2016	-	12/2015	01/2016	02/2016	12/2015	01/2015	09/2012	01/2013
End	03/2016	06/2016	09/2016	-	04/2016	09/2016	11/2016	3/2017	12/2017	12/2017	12/2017
Duration (Months)	4	6	7	-	5	9	10	16	36	64	60
Detect–Historical Duration	0	2	3	-	1	5	6	12	32	60	56
Detection	Exact	Over	Over	Undetect	Over	Over	Over	Over	Over	Over	Over
Maximum Severity	-1.61	-2.27	-1.66	-	-2.36	-2.17	-2.1	-1.68	-1.14	-1.31	-1.63
Historical Drought Event	Case 14. (Location: Ahning Dam , Onset: 01/2017 , End: 03/2017) (Astro Awani, 2017 ; Majid, 2017)										
Nearest Station	6306031				6306031				6503401		
Distance (km)	6.002				6.002				45.632		
Onset	02/2017	-	-	-	02/2017	02/2017	-	06/2016	01/2015	09/2012	01/2013
End	02/2017	-	-	-	02/2017	02/2017	-	02/2017	12/2017	12/2017	12/2017
Duration (Months)	1	-	-	-	1	1	-	9	36	64	60
Detect– Historical Duration	-2	-	-	-	-2	-2	-	6	33	61	57
	Under	Undetect	Undetect	Undetect	Under	Under	Undetect	Over	Over	Over	Over
Maximum Severity	-1.37	-	-	-	-1.24	-1.20	-	-1.59	-1.14	-1.31	-1.63

Table 4.24 (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
Historical Drought Event	Case 15. (Location: Muda Dam , Onset: 01/2017 , End: 03/2017) (Astro Awani, 2017 ; Majid, 2017)										
Nearest Station	5806066				5806066				5606410		
Distance (km)	3.57				3.57				21.392		
Onset	02/2017	02/2017	-	-	02/2017	02/2017	-	06/2016	02/2017	-	09/2016
End	02/2017	02/2017	-	-	02/2017	02/2017	-	02/2017	03/2017	-	04/2017
Duration (Months)	1	1	-	-	1	1	-	9	2	-	8
Detect– Historical Duration	-2	-2	-	-	-2	-2	-	6	-1	-	5
Detection	Under	Under	Undetect	Undetect	Under	Under	Undetect	Over	Under	Undetect	Over
Maximum Severity	-0.49	-0.43	-	-	-0.61	-0.4	-	-0.96	-0.42	-	-1.01
Historical Drought Event	Case 16. (Location: Pedu Dam , Onset: 01/2017 , End: 03/2017) (Astro Awani, 2017 ; Majid, 2017)										
Nearest Station	6207032				6207032				6503401		
Distance (km)	2.866				2.866				52.356		
Onset	02/2017	03/2017	-	07/2016	02/2017	03/2017	-	03/2016	01/2015	09/2012	01/2013
End	03/2017	04/2017	-	03/2017	03/2017	04/2017	-	04/2017	12/2017	12/2017	12/2017
Duration (Months)	2	2	-	9	2	2	-	14	36	64	60
Detect– Historical Duration	-1	-1	-	6	-1	-1	-	11	33	61	57
Detection	Under	Under	Undetect	Over	Under	Under	Undetect	Over	Over	Over	Over
Maximum Severity	-1.9	-1	-	-1.62	-1.69	-1.1	-	-1.99	-1.14	-1.31	-1.63

Table 4.25: Summary of Detection of Duration

Detection of 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**
Exact	1	2	0	0	0	0	1	0	0	0	0
Over	10	10	12	5	11	13	12	11	15	9	10
Under	5	3	0	2	5	3	0	3	1	0	0
Undetected	0	1	4	9	0	0	3	2	0	7	6
Total Cases	16	16	16	16	16	16	16	16	16	16	16

Table 4.26: Table of Probability of Detection (POD)

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**
Undetected	0	1	4	9	0	0	3	2	0	7	6
Detected	16	15	12	7	16	16	13	14	16	9	10
POD	100.0%	93.8%	75.0%	43.8%	100.0%	100.0%	81.3%	87.5%	100.0%	56.3%	62.5%

Table 4.27: Table of Over/Under-estimated Duration Error Analysis

Over/Under-estimated Duration Error Analysis											
Drought Index	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SDI-3**	**SDI-6**	**SDI-12**
Mean Absolute Error (MAE)	1.25	1.80	5.00	10.00	1.69	3.31	5.54	10.79	20.50	53.89	54.30
Mean Bias Error (MBE)	0.25	1.27	5.00	8.57	0.69	2.69	5.54	9.64	20.38	53.89	54.30
Root Mean Square Error (RMSE)	1.41	2.70	8.78	13.36	2.11	3.91	8.84	13.19	28.51	56.85	57.87

Table 4.28: Comparison of Drought Onset Detected by Drought Indices to Drought Onset of Historical Drought Event

Drought Index	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SDI-3**	**SDI-6**	**SDI-12**
Historical Drought Event	Case 1. (Location: Sungai Kerian@Selama , Onset: 04/2005 , End: 06/2005) (Hydrology and Water Resources Division the the Department of Irrigation and Drainage Malaysia, 2005)										
Onset	04/2005	12/2004	5/2004	10/2004	04/2005	12/2004	5/2004	10/2004	01/2005	04/2004	04/2003
End	09/2005	10/2005	11/2006	06/2007	09/2005	10/2005	11/2006	08/2007	10/2005	08/2006	10/2006
Early/Delay Month(s)	0	-4	-11	-6	0	-4	-11	-6	-3	-12	-24
Detection of Onset	Exact	Early	Early	Early	Exact	Early	Early	Early	Early	Early	Early
Historical Drought Event	Case 2. (Location: Beris Dam , Onset: 01/2016 , End: 04/2016) (Yeh, 2016 ; USDA, 2016)										
Onset	02/2016	02/2016	04/2016	-	02/2016	02/2016	03/2016	-	02/2016	-	-
End	04/2016	06/2016	03/2017	-	04/2016	11/2016	03/2017	-	10/2016	-	-
Early/Delay Month(s)	1	1	3	-	1	1	2	-	1	-	-
Detection of Onset	Delay	Delay	Delay	Undetect	Delay	Delay	Delay	Undetect	Delay	Undetect	Undetect
Historical Drought Event	Case 3. (Location: Jitra , Onset: 01/2016 , End: 04/2016) (Today Online, 2016 ; USDA, 2016)										
Onset	12/2015	02/2016	03/2016	-	12/2015	01/2016	03/2016	-	01/2015	09/2012	01/2013
End	04/2016	05/2016	07/2016	-	04/2016	06/2016	08/2016	-	12/2017	12/2017	12/2017
Early/Delay Month(s)	-1	1	2	-	-1	0	2	-	-12	-51	-36
Detection of Onset	Early	Delay	Delay	Undetect	Early	Exact	Delay	Undetect	Early	Early	Early

Table 4.28 (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
Historical Drought Event	Case 4. (Location: Kubang Pasu , Onset: 01/2016 , End: 04/2016) (Today Online, 2016 ; USDA, 2016)										
Onset	12/2015	01/2016	03/2016	-	12/2015	01/2016	03/2016	04/2016	01/2015	09/2012	01/2013
End	04/2016	05/2016	07/2016	-	04/2016	06/2016	08/2016	04/2016	12/2017	12/2017	12/2017
Early/Delay Month(s)	-1	0	2	-	-1	0	2	3	-12	-51	-36
Detection of Onset	Early	Exact	Delay	Undetect	Early	Exact	Delay	Delay	Early	Early	Early
Historical Drought Event	Case 5. (Location: Padang Saga Dam , Onset: 01/2016 , End: 04/2016) (Today Online, 2016 ; USDA, 2016)										
Onset	12/2015	02/2016	03/2016	04/2016	12/2015	01/2016	03/2016	12/2015	01/2015	09/2012	01/2013
End	04/2016	06/2016	08/2016	05/2016	04/2016	09/2016	09/2016	6/2017	12/2017	12/2017	12/2017
Early/Delay Month(s)	-1	1	2	3	-1	0	2	-1	-12	-51	-36
Detection of Onset	Early	Delay	Delay	Delay	Early	Exact	Delay	Early	Early	Early	Early
Historical Drought Event	Case 6. (Location: Air Itam Dam , Onset: 01/2016 , End: 04/2016) (The Star Online, 2016 ; USDA, 2016)										
Onset	12/2015	02/2016	03/2016	-	12/2015	02/2016	03/2016	04/2016	02/2016	-	-
End	04/2016	06/2016	08/2016	-	05/2016	06/2016	08/2016	05/2016	10/2016	-	-
Early/Delay Month(s)	-1	1	2	-	-1	1	2	3	1	-	-
Detection of Onset	Early	Delay	Delay	Undetect	Early	Delay	Delay	Delay	Delay	Undetect	Undetect

Table 4.28 (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
Historical Drought Event	Case 7. (Location: Penang Hill , Onset: 01/2016 , End: 04/2016) (The Star Online, 2016 ; USDA, 2016)										
Onset	12/2015	01/2016	03/2016	12/2015	12/2015	01/2016	03/2016	12/2015	02/2016	-	-
End	04/2016	06/2016	08/2016	09/2016	04/2016	06/2016	06/2016	10/2016	10/2016	-	-
Early/Delay Month(s)	-1	0	2	-1	-1	0	2	-1	1	-	-
Detection of Onset	Early	Exact	Delay	Early	Early	Exact	Delay	Early	Delay	Undetect	Undetect
Historical Drought Event	Case 8. (Location: Seberang Prai , Onset: 01/2016 , End: 04/2016) (Astro Awani, 2016)										
Onset	12/2015	01/2016	02/2016	08/2015	12/2015	01/2016	02/2016	04/2015	02/2016	-	-
End	04/2016	05/2016	08/2016	11/2016	04/2016	08/2016	08/2016	02/2017	10/2016	-	-
Early/Delay Month(s)	-1	0	1	-5	-1	0	1	-9	1	-	-
Detection of Onset	Early	Exact	Delay	Early	Early	Exact	Delay	Early	Delay	Undetect	Undetect
Historical Drought Event	Case 9. (Location: Teluk Bahang Dam , Onset: 01/2016 , End: 04/2016) (The Star Online, 2016)										
Onset	12/2015	02/2016	03/2016	-	12/2015	02/2016	03/2016	04/2016	02/2016	-	-
End	04/2016	05/2016	07/2016	-	04/2016	06/2016	08/2016	04/2016	10/2016	-	-
Early/Delay Month(s)	-1	1	2	-	-1	1	2	3	1	-	-
Detection of Onset	Early	Delay	Delay	Undetect	Early	Delay	Delay	Delay	Delay	Undetect	Undetect

Table 4.28 (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
Historical Drought Event	Case 10. (Location: Bukit Merah Dam , Onset: 01/2016 , End: 04/2016) (Channel News Asia, 2016 ; Kumaran, 2016)										
Onset	03/2016	03/2016	-	04/2016	03/2016	03/2016	03/2016	01/2016	02/2011	02/2011	04/2011
End	04/2016	05/2016	-	04/2016	04/2016	08/2016	10/2016	03/2017	12/2017	12/2017	12/2017
Early/Delay Month(s)	2	2	-	3	2	2	2	0	1	1	3
Detection of Onset	Delay	Delay	Undetect	Delay	Delay	Delay	Delay	Exact	Delay	Delay	Delay
Historical Drought Event	Case 11. (Location: Kerian , Onset: 01/2016 , End: 04/2016) (Yeh, 2016)										
Onset	01/2016	01/2016	01/2016	01/2016	11/2015	01/2016	12/2015	11/2015	02/2016	03/2016	10/2010
End	05/2016	09/2016	10/2016	03/2017	08/2016	10/2016	10/2016	04/2017	10/2017	12/2017	12/2017
Early/Delay Month(s)	0	0	0	0	-2	0	-1	-2	1	2	-62
Detection of Onset	Exact	Exact	Exact	Exact	Early	Exact	Early	Early	Delay	Delay	Early
Historical Drought Event	Case 12. (Location: Tasek Takong , Onset: 01/2016 , End: 04/2016) (The Straits Times, 2016)										
Onset	12/2015	02/2016	03/2016	-	12/2015	02/2016	02/2016	02/2016	02/2016	-	-
End	04/2016	06/2016	09/2016	-	04/2016	09/2016	09/2016	03/2017	10/2016	-	-
Early/Delay Month(s)	-1	1	2	-	-1	1	1	1	1	-	-
Detection of Onset	Early	Delay	Delay	Undetect	Early	Delay	Delay	Delay	Delay	Undetect	Undetect

Table 4.28 (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
Historical Drought Event	Case 13. (Location: Kaki Bukit , Onset: 01/2016 , End: 04/2016) (Yeh, 2016)										
Onset	12/2015	01/2016	03/2016	-	12/2015	01/2016	02/2016	12/2015	01/2015	09/2012	01/2013
End	03/2016	06/2016	09/2016	-	04/2016	09/2016	11/2016	3/2017	12/2017	12/2017	12/2017
Early/Delay Month(s)	-1	0	2	-	-1	0	1	-1	-12	-51	-36
Detection of Onset	Early	Exact	Delay	Undetect	Early	Exact	Delay	Early	Early	Early	Early
Historical Drought Event	Case 14. (Location: Ahning Dam , Onset: 01/2017 , End: 03/2017) (Astro Awani, 2017 ; Majid, 2017)										
Onset	02/2017	-	-	-	02/2017	02/2017	-	06/2016	01/2015	09/2012	01/2013
End	02/2017	-	-	-	02/2017	02/2017	-	02/2017	12/2017	12/2017	12/2017
Early/Delay Month(s)	1	-	-	-	1	1	-	-7	-24	-63	-48
Detection of Onset	Delay	Undetect	Undetect	Undetect	Delay	Delay	Undetect	Early	Early	Early	Early
Historical Drought Event	Case 15. (Location: Muda Dam , Onset: 01/2017 , End: 03/2017) (Astro Awani, 2017 ; Majid, 2017)										
Onset	02/2017	02/2017	-	-	02/2017	02/2017	-	06/2016	02/2017	-	09/2016
End	02/2017	02/2017	-	-	02/2017	02/2017	-	02/2017	03/2017	-	04/2017
Early/Delay Month(s)	1	1	-	-	1	1	-	-7	1	-	-4
Detection of Onset	Delay	Delay	Undetect	Undetect	Delay	Delay	Undetect	Early	Delay	Undetect	Early

Table 4.28 (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
Historical Drought Event	Case 16. (Location: Pedu Dam , Onset: 01/2017 , End: 03/2017) (Astro Awani, 2017 ; Majid, 2017)										
Onset	02/2017	03/2017	-	07/2016	02/2017	03/2017	-	03/2016	01/2015	09/2012	01/2013
End	03/2017	04/2017	-	03/2017	03/2017	04/2017	-	04/2017	12/2017	12/2017	12/2017
Early/Delay Month(s)	1	2	-	-6	1	2	-	2	-24	-63	-48
Detection of Onset	Delay	Delay	Undetect	Early	Delay	Delay	Undetect	Delay	Early	Early	Early

Table 4.29: Summary of Detection of Onset

					Detection of Onset						
Drought Index	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SDI-3**	**SDI-6**	**SDI-12**
Exact	2	5	1	1	1	7	0	1	0	0	0
Early	9	1	1	4	10	1	2	8	7	7	9
Delay	5	9	10	2	5	8	11	5	9	2	1
Undetected	0	1	4	9	0	0	3	2	0	7	6
Total Cases	16	16	16	16	16	16	16	16	16	16	16
					Average Early/Delay Detection Magnitude						
Magnitude	-0.21	0.70	0.82	-2.00	-0.33	0.67	0.54	-1.69	-5.29	-37.67	-32.70

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Three drought indices with different input requirements were investigated in this study, and they are the SPI (rainfall), the SPEI (rainfall and temperature) and the SDI (streamflow). With different combinations of input variables considered, three types of drought namely, the meteorological drought, the agricultural drought and the hydrological drought were investigated. With a short timescale, both the SPI and the SPEI are able to measure the meteorological drought. With longer timescales, agricultural drought and hydrological drought that appear after a long time of meteorological drought can be measured. As a result, the timescale of 1 month is able to measure meteorological drought; 3 months can measure seasonal meteorological drought and agricultural drought; 6 months is also measuring agricultural drought; and a timescale of 12 months is able to measure long-term hydrological drought. The results shown that the SPI and the SPEI with same timescale was different in terms of the severity value when there was high SST, as shown in section 4.2.1 above. They were different when temperature was high, since SPEI incorporated both precipitation and temperature input; and SPI only incorporated precipitation input.

As for the SDI, it has the same computation method with the SPI but using streamflow as input. It measures the hydrological drought as the streamflow deficiency is considered, and is the same with the SPI-12 and the SPEI-12 which are also measuring hydrological drought through long term of rainfall deficiency. But results of the SDI had a very large difference in term of severity value to the severity value of model with other input such as the SPI-12 and the SPEI-12, although theoretical all of them are measuring the same type of drought, as shown in section 4.2.2.

Meanwhile in section 4.2.2, the computed frequency, duration, mean intensity, mean severity and peak of short-term meteorological drought are similar at all stations in a state. Moreover, with the AMR, it was shown that indices that measure meteorological drought will give a more detailed results and are more suitable for drought monitoring in Malaysia due to their high sensitivity to the monthly fluctuation of moisture condition in Malaysia.

Furthermore, spatial analysis of different types of drought computed by the different indices with different timescales was carried out and shown in section 4.3. The maps of different indices which indicated the different patterns of different types of drought are useful for various sectors. The SPEI-3 was proposed as the best index because its result is in conformity with the SDI-3 which measured based on different input. This might due to evapotranspiration will cause reduction of water level in water resources, therefore SPEI-3 which incorporation evapotranspiration was in conformity to SDI-3 which measure based on deficiency of streamflow.

Next, the temporal analysis in section 4.4 also shown that the seasonal meteorological drought pattern of the SPEI-3 can match with the monsoon seasons, and also the temporal trend of ocean-atmosphere systems measured by DMI, EMI, ONI indices which causes high temperature in the northern region of Malaysia. On the other hand, the trend analysis based on the SPEI-3 result in Table 4.16 shown that south part of the northern region will be drier during the (May.-Sept.) and the north part of the northern region will be drier during (Jan.-Aug.) in future.

Last but not least, the historical drought comparison in section 4.6 shown that SPI-1, SPEI-1, SPEI-3, and SDI-3 give a POD of 100% for all cases, including the meteorological, agricultural, and hydrological drought. For duration error analysis by MAE, MBE and RMSE, result shown that overestimation error of SPI-1 and SPEI-1 are lowest, followed with SPEI-3, and SDI-3. The error of SDI-3 is unacceptable as its overestimation is too huge. On the other hand, SPI-1 and SPEI-1 underestimated the duration of 5 cases (2 agricultural drought and 3 hydrological drought), and SPEI-3 only underestimated duration of 3 hydrological drought cases.

Furthermore, for the accuracy of drought indices in detecting the onset of drought, the SPEI-3 had accurately detected the onset for 7 cases which is the greatest among all indices. Although the average/delay magnitude of SPI-1 and SPEI-1 are lowest, but this might due to the negative magnitude balanced out the positive magnitude as SPI-1 had 9 early detection to balance out with 5 delayed detection; and SPEI-1 had 10 early detection to balance out with 5 delayed detection.

The only early-detected drought case of SPEI-3 is the meteorological drought Case 1. The number of cases of delayed detection by the SPEI-3 is 8, and the average/delay magnitude for it is 0.67 which means it most likely will has a delayed onset detection of 0.67.

In short, it is proved that the best index for drought detection was the SPEI-3 which gives a POD of 100%. Although the duration error analysis shown that its over estimation is slightly higher, but it will only under-estimate the duration for hydrological drought. Unlike SPI-1 and SPEI-1 with lowest error in overestimation, but they might under-estimate the duration of both agricultural drought and hydrological drought cases. At the same time, SPEI-3 is able to detect the onset most accurately and consistently. It will only early detect the meteorological drought; and delay detect for other droughts by an average/delay magnitude of 0.67. Theoretically, spatial analysis which shown that SPEI-3 is conformed with SDI-3, and temporal trend analysis which shown that results of SPEI-3 is related to global behaviour of ocean atmosphere interaction, both spatial and temporal analysis also explained why SPEI-3 is the best index for measuring the moisture conditions in northern region of Malaysia.

5.2 Recommendations for future work

The SPEI was found to be the best index to measure moisture condition in the northern region of Malaysia. The Thornthwaite model in the SPEI to calculate the PET is only an approximation and may not represent the exactly situation in fact. Therefore, to improve the accuracy of result, the model which measure the exact PET can be adopted. On the other hand, the topography of the region can be related for better spatial analysis. Also, the information on the streams, lakes and reservoirs in northern region can be applied together with the SDI indices to better understand the actual situation of these water resources bodies. All factors which might contribute to drought such as indices, interpolation method, and density of stations, seasonality and climate can be further studied to improve the accuracy of assessment. Social-economical types of drought which is the water scarcity that has caused economic, social and environmental impacts cannot be ignored too. It is related to supply of and demand of human mankind activities. It must be taken into consideration as the population and the water demand are increasing nowadays.

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