ANALYSE DRY SPELLS IN SOUTHERN REGION OF PENINSULAR MALAYSIA USING DROUGHT INDICES

CHUA YI WEI

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

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2019

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.

Signature	:	
Name	:	CHUA YI WEI
ID No.	:	1405462
Date	:	

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"ANALYSE DRY SPELLS IN SOUTHERN REGION OF PENINSULAR MALAYSIA USING DROUGHT INDICES"** was prepared by **CHUA YI WEI** 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.

Approved by,

Signature	:	___________________________
Supervisor	:	IR DR HUANG YUK FENG
Date	:	___________________________

Signature	:	___________________________
Co-Supervisor	:	___________________________
Date	:	___________________________

The copyright of this report belongs to the author under the terms of the copyright Act 1987 as qualified by Intellectual Property Policy of Universiti Tunku Abdul Rahman. Due acknowledgement shall always be made of the use of any material contained in, or derived from, this report.

© 2019, Chua Yi Wei. All right reserved.

AKNOWLEDGEMENTS

This work would not made possible without the support and invaluable advice from Ir. Dr. Huang Yuk Feng and also senior Mr. Fung Kit Fai for sharing all the information with me. As my supervisor and mentor, Dr. Huang and Mr. Fung have provided me extensive personal and professional guidance about this scientific research and life in general. They have taught me more than I could ever give them credit for here.

Next, I would like to express my appreciation to each of the person I worked with whom shared their helpful information and suggestion with me. It is a pleasure for me to work with each of you.

I am grateful to all of those with whom had supported me during this and other related projects, especially my friend and family for their unending support and encouragement during this project.

ABSTRACT

Drought is one of the natural hazards, which occurred frequently in Malaysia. Typically, drought can be categorized as three main types based on their characteristics and impacts; which are the meteorological, agricultural, and hydrological drought. This study aimed at developing and evaluating drought indices that are feasible to apply with the appropriate time-scales for southern region of Peninsular Malaysia. This includes the Standardized Precipitation Index (SPI), the Standardized Precipitation Evaporation Index (SPEI) and the Streamflow Drought Index (SDI) under 1-month, 3-month, 6-month, 12-month time-scales. Drought characteristics in frequency, duration, severity, intensity and peak of drought were estimated for spatial analysis on the droughts that had occurred in southern region of Peninsular Malaysia. The accuracy test for each drought index is assessed with the probability of detection, mean absolute error (MAE), the mean bias error (MBE), the on and offset detection of computed drought with historical drought events. This study proved that the SPEI-1 was able to predict the drought event in southern region rather well, with the highest probability of detection of 100% and mean absolute error below 1.0. SPEI-1 was also able to detect the drought not only half month earlier, but as well as ending at half month later, and this implied that the SPEI-1 has more margin period in water management and planning. In the average moving range, SPEI-1 showed more fluctuating trend in the 1-month computation in southern region of Peninsular Malaysia. As Malaysia is located at the equatorial zone, it has dry and humid weather throughout the year, with the rainy day almost equivalent to non-rainy day in terms of number, and the atmospheric condition affected by monsoons and inter-monsoons period. Therefore, a shorter time-scale computation method is more applicable in this study region. The SPEI-1 also showed a decreasing trend in February, June, July and August, which are the periods for the inter-monsoon and the south-west monsoon season.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

°C	degree Celsius.
km	kilometer.
km^2	square kilometer.
m	meter.
mm	millimeter.

ADI	Aggregate Drought Index
AMR	Average Moving Range
CART	Classification and Regression Tree
CMI	Crop Moisture Index
DID	Department of Drainage
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FELDA	Federal Land Development Authority
GWP	Global Water Partnership
IDW	Inverse Distance Weighting
JBA	Jabatan Bekalan Air
JPS	Jabatan Pengairan dan Saliran
MAE	Mean Absolute Error
MBE	Mean Bias Error
MDD	Mean Drought Duration
MDI	Mean Drought Intensity
MDP	Mean Drought Peak
MDS	Mean Drought Severity
MET	Malaysian Meteorological Department
MMD	Malaysian Meteorological Department
NAHRIM	National Hydraulic Research Institute of Malaysia
NASA	National Aeronautics and Space Administration
NDMC	National Drought Mitigation Center
NDVI	Normalized Difference Vegetation Index
OK	Ordinary Kriging
PDSI	Palmer Drought Severity Index
POD	Probability of Detection

PUB	Public Utilities Board
QGIS	Quantum Geographic Information System
RBF	Radial Basis Functions
RDI	Reconnaissance Drought Index
SDI	Streamflow Drought Index
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SWSI	Surface Water Supply Index
UK	Universal Kriging
USDM	United States Drought Monitor
VegDRI	Vegetation Drought Response Index
WMO	World Meteorological Organization

INTRODUCTION

1.1 General Introduction

Drought is a natural hazard where a shortage of water occurred over a period of time, causing a deficit in water supply and also precipitation. The scarcity of water will have a huge impact on the environment and socio-economic especially at nowadays which most of the living beings could not survive with absence of water. Typically, drought can be categorized as three main types based on their characteristics and impacts, which are meteorological, agricultural, and hydrological drought for assessment and analyzing with the different data to be considered. By understanding the concept of different droughts, preparation can be made earlier and hence to further mitigate damages on environment and prevent more casualties to living beings.

Over past 20 years, Peninsular Malaysia had experienced three severe drought events which were all induced by the El-Nino phenomenon: an event which the temperature becomes warmer in central and eastern Pacific Ocean, leading to the cool nutrient-rich water replaced by the warm nutrient-poor water (Low and Tangang, 2016; Jailan Simon, 2015). The occurrence of this warm phase will cause a large-scale drought and unusual dry period in the western Pacific regimes, which included Malaysia. The 1998 water crisis is the worst water crisis ever recorded in Klang Valley where the dry spells lasted longer than expected, hence causing the water levels of the dam and catchment areas dropped significantly. Consequently, the drought lead to a water rationing period of approximately 150 days in Klang Valley and it affected 3.2 million residents.

Furthermore, on 2016 it was reported that a severe shortage in water resources at due to lack of precipitation at several reservoirs induced long period of dry spells in Johor. Due to the critical condition that was never encountered by the state authorities, Johor government had to purchase clean water from Singapore: an opposite action unlike before as Johor was actually being the main supplier of clean water to Singapore over last few decades. The impacts of drought on socio-economics include low yields of agricultural crops that might heavily damage palm oil industry which is the major exports of Malaysia (Olaniyi, et al. 2012).

To categorize drought by its nature is difficult as the duration, magnitude, intensity and spatial covered varies from each of the event. However, it is essential to classify them as it enables application of drought monitoring and analysis for estimation of the coming potential hazard event. Drought indices is a quantitative expression for the state of drought, in which different time scales can be considered nevertheless the commonly used time scales is in year. It classifies the severity of a drought event based on calculations which comprehends the indicators into numerical value. The most common drought indices used include the Palmer drought severity index (PDSI; Palmer 1965), the Standardized precipitation index (SPI; McKee, et al. 1993), and the Standardized Precipitation Evapotranspiration Index (SPEI; Vicente-Serrano, et al., 2010).

In addition to this, essentially all drought indices apply different meteorological elements such as precipitation, evapotranspiration or soil moisture. For instance, the Crop moisture index (CMI) combined precipitation and temperature (Palmer, 1968), while the Reconnaissance drought index (RDI) applied precipitation and potential evapotranspiration for the studies (Tsakiris and Vangelis, 2005). The number of drought indices available for research purposes has increased and new indices are still keeps developed until nowadays to represent different climate changes, geographical and hydrologic extent, or specific applications to a certain area. With each of the indices have their own limitations and weaknesses, a situation arises whenever a suitable index has been chosen to analyze the drought (Karamouz, Rasouli and Nazif, 2009).

1.2 Importance of Study

The significance of this study is to forecast the return period from the previous drought based on the characteristics, rainfall and water level recorded for past 35 years. This research concentrates on analyzing the dry spells occurred in Johor, Malacca and Negeri Sembilan with data supported by Malaysian Meteorological Department (MMD) and Department of Irrigation and Drainage (DID) incorporated with National Hydraulic Research Institute of Malaysia (NAHRIM).

The reason of introducing drought indices to study the condition in southern region is for engineers to monitor and plan for water resources system and management in Peninsular Malaysia with reliable reference in resources of data and methodologies. Up to today, due to southern region of Peninsular Malaysia is located in a coastal region which is rich in raw water resources, study never focus on the possibilities of dry spells to be occurred, even though that in fact Peninsular Malaysia being located at the tropical zone where it receives high rainfall and contain high humidity, there are recently more reports on the shortage of water in several states of Malaysia. Thus, more research work and mitigation about the drought return period and shortage of water should be paid attention since it is no longer unaffected by the climate changes around the globe.

1.3 Problem Statement

Since Malaysia is located at the tropical zone based on the geographical position on Earth, high humidity and rain seasons throughout the year are expected. In addition to this, long period of dry spells occurred but is less likely to cause massive impacts on society and economics of Malaysia.

However, according to the report from National Aeronautics and Space Administration (NASA), with the occurrence of the El-Nino event becomes more shorter and stronger this issue can no longer be ignored as the drought is getting unavoidably intense and disastrous (Carlowicz, 2015). Such destructive natural hazard will affect specifically states with considerable fields of plantations. According to an article in New Straits Times by Ooi Tee Ching (2017), Malaysia has harvested up to RM 122 billion solely depends on the plantation commodity exports, which shows that the plantations are the major sector that support the economy of country other than tourism and manufacturing sectors. Therefore, more studies on characteristics and impacts of drought in southern region of Peninsular Malaysia should be inspected to minimize the damage on the plantations sector.

According to the Department of Statistics Malaysia (2017), with the total population hitting 32 million in year 2017, southern region of Peninsular Malaysia has occupied by total of 17.8% with a growth rate of 1.3%, which is 5.69 million of persons. This implicates that the water resources management and dry spells monitoring should be given more concerns as it affects extensively amount of populations here, especially for main city such as Johor Bahru, Seremban and Malacca City with majority of population gathered and lived.

Due to drought event has always been distinctive and not persisted in terms of duration, magnitude or intensity, hence a question arises that to what extent the preparation should be made to accommodate the economic feasibility. Drought indices can be adopted in weather monitoring as well as forecasting since it has an advantage in identifying the characteristics, commencement and end date of drought, giving that it could quantify the hydrological data into assessable weather analysis. In other word, drought indices act as an important role to determine the condition of the dry spells with respect to the past records in case of further indicating the overall scales of the drought occurred and potential severity of the forthcoming drought event.

1.4 Aim and Objectives

The aim of this study is to analyze the dry spells in southern region of Peninsular Malaysia using drought indices. The specific objectives of this research are stated as below:

i. To develop and assess the drought indices based on the rainfall, streamflow and temperature data for the southern region of Peninsular Malaysia.

ii. To evaluate and categorize the occurrence and magnitude of the dry spells using spatial and temporal analysis from the results obtained from drought index with different time-scales.

1.5 Scope and Limitations of the Study

This study primarily concerns on analyzing the dry spells in southern region of Peninsular Malaysia which included Johor, Malacca and Negeri Sembilan based on the drought indices. The scope of study includes the application by software such as station markings using Google Earth Pro, Quantum Geographic Information System (QGIS), and with aids of Microsoft Excel spreadsheet.

Appropriate drought indices will be selected to conduct analyzing and monitoring of the dry spells under Southern region of Peninsular Malaysia. This study also includes repairing of data for the rainfall and water level stations up to previous 35 years. Stations with repaired data can be used for further studies such as basin or river model analysis.

There are certain limitations in this research, this included the incompleteness and ambiguousness on rainfall and water level stations data. Due to some of the stations were inactivated long ago, more approaches are required to complete the inputs of data. This might increase the biased on the outcomes of this research.

1.6 Contribution of the Study

The study on characteristics and occurrence period of drought helps in reducing drought impact and damage for the social and economy of country. With increasing of water demands due to increase in population size, the assurance on substantial water supply becomes utterly crucial. This study will show the climatic patterns and characteristics in the southern region of Peninsular Malaysia by spatial and temporal analysis. To allow for possible development and allocation of new catchment areas, drought indices will be developed based on the precipitation, streamflow and temperature data in various time-scales, and further analysis will be done to see whichever method is more feasible to describe the condition in southern region of Peninsular Malaysia.

As drought indices can be sensitive to the parameters and inputs, a sustainable drought index that fits into local factors such as water-supply demand and environmental framework should be used (Mishra, 2010). By developing an appropriate drought index which can be adapted to the unique temporal and spatial factor in southern region of Peninsular Malaysia, future research can be more specified and problems can be related to the latest situation to plan for preparation and mitigation for the coming dry spells. Moreover, a more complex model can be made to analyze the patterns of the dry spells in the research area as the availability of data sources has been further interpreted by current study with respect to future research.

1.7 Outline of the Report

This report comprises 5 chapters. Chapter 1 includes the introduction, background information, aims and objectives, scopes and limitations, significance, contribution of the study, and outline of the report.

Chapter 2 reviews the definitions of drought and drought indices used in various scenarios. This entails the review about the characteristics of droughts, performance of drought indices, and the suitability for each of the drought indices to be used in specific conditions and time scales

In Chapter 3 Methodology part describes the flow of the project. It includes type of analysis and software practiced in this study. The parameters used in this study is further reviewed with calculations and formulas.

Chapter 4 shows the results obtained and discussion on the outcomes of the study. The occurrence and magnitude of the previous drought event will be revealed based on calculations and analyzing the value developed by the drought index. Next, drought index which is the most feasible will be used to interpret an appropriate time-scale to describe the dry pattern of southern region of Peninsular Malaysia.

Chapter 5 concludes the study on this research. This chapter includes conclusion made with respective objectives based on the results obtained from the software. Recommendations to improve the data will also be listed for future studies.

[redacted]

[redacted] INTRODUCTION

2.1 Definitions of Drought

Drought has its own distinct definitions. To give drought a suitable definition is depending on the purpose or specific interest of a study or people. In other words, drought has no perfectly appropriate definition, however most of it shares the same concern, which is the "effect of a relatively prolonged weather irregularly" (Palmer, 1965). Thus, it is essential to narrow down the definitions as it solves for unnecessary obstacles in studying drought.

Drought can be classified as conceptual and operational. Conceptual definition of drought refers to the one stated in corresponding general, which can provide navigation from the concepts to the extent of boundaries of the drought studies. Various studies done by researchers have their very own view on conceptual drought. In article by McGuire and Palmer (1957), they defined the droughts as monthly or annual precipitation less than some particular percentage of normal, while in the research done by Wilhite, Svoboda and Hayes (2007) have defined drought as critical deficiencies in moisture that go below normal level to the extent that it restrains some types of activity that demanded on the water. On the other hand, operational definition of drought tells the researchers that how does drought function and operate, with defining the onset and end, as well as severity of a drought event. Since operational drought differs in various circumstances, water resources planners and policy makers are incapable of forecasting and monitor comparing with other natural disasters. Until now, most of the decision makers are heavily relied on the mathematic indices to monitor along with mitigate drought in water resources planning and management. Operational drought typically compares the current situation with the historical data over certain period. Efforts in developing climatology of drought helps to provide a better understanding in characteristics and return period of drought at different levels of severity, intensity, duration as well as peak. This information is especially important in the water scarcity mitigation and preparation for the next dry event.

2.2 Indicators

In order to have better understanding on drought, drought indicators are required as a converter to reorganize the environmental data such as rainfall or streamflow into index. Indicators are a group of variables used to describe drought condition and communicate information about the water resources system. With different models or approaches, these indicators are used together to develop a drought index. These indicators include precipitation, cloud cover, streamflow, potential evapotranspiration and more developed by scientists and researchers to fit various approaches (WMO and GWP, 2016). The relationship between the environmental data, indicators and also index is shown in Figure 2.1.

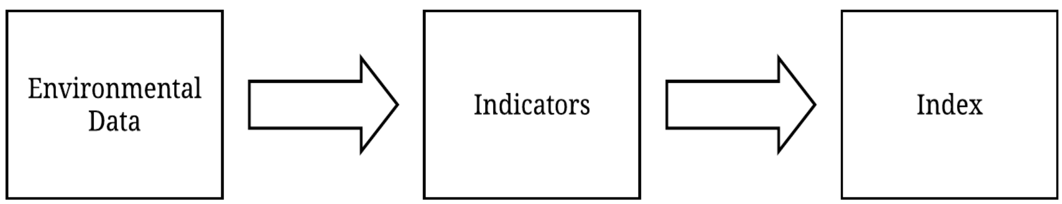

Figure 2.1: Collection of Information in Water Resources Management

2.3 Types of Drought

Typically, drought can be categorized as three main types for assessment and analyzing with the different data to be considered:

i. Meteorological drought can be defined as a continued deficit in precipitation and usually it is determined by comparing the precipitation of a particular region with the average precipitation of that region for a long term. Climatic variables such as precipitation and humidity in certain period are the common data used to analyze for the meteorological drought (Katsanos, et al., 2018; Yao, et al., 2018). This drought usually leads to other types of drought and involves extensive areas, where the scarcity of precipitation could further progress to the extent of lack of water supply failure and moisture content in ground soil.

ii. Agricultural drought commonly refers to a period of moisture deficit following declined of crops yields with no relevance to surface water resources. An agricultural drought triggers when there is a shortage of water at the time the crop's growth cycle that it needs water most. Failing to gain water at its initial planting stage would affect the rate of crop yields when the plants reach full growth stage. Agricultural drought also links different characteristics of meteorological as well as hydrological drought into an impact on agricultural, while primarily focusing on aspects such as actual and potential evapotranspiration, temperature or soil water deficits (Wilhite and Glantz, 1985).

iii. Hydrological drought can be defined as the insufficient flows, in terms of subsurface or surface water. The frequency and severity of a hydrological drought reflects directly on watershed or river basin scale. In hydrological drought, more concerns are on how this type of drought would affect the hydrologic chain or system within a regime. Hydrological drought commonly links to effect of precipitation deficiency to the components within the system such as streamflow, groundwater and reservoir level. The main factors that manipulate the hydrological drought is the geology of a regime (Vogel and Kroll, 1992).

Other than that, there are other types of drought which are induced by the natural occurrence phenomenon. Ecological drought is one of the new terms introduced in 21th century, which can be defined as the deficit in water availability which stimulates ecosystems beyond threshold of vulnerability, affects ecosystem duty, and cause reaction in human or natural system (Crausbay, et al, 2018). Generally, natural responses and ability for an ecosystem to a drought event will be neglected as a variable in drought monitoring, as human needs of water are higher against the ecosystems needs. In fact, massive growing of mankind population and climate change induced by human activities pressurizes the vulnerability of nature or ecosystems to survive the drought. Socio-economical drought is one of the popular types proposed by researchers as the main category of drought (Mishra and Singh, 2010; Tsakiris, et al, 2013; American Meteorological Society, 2013; National Drought Mitigation Center, 2018; Wilhite and Glantz, 1985). It is correlated with the scarcity in water resources in meeting water demands for human activities and economics use. Due to nature climate variability water supply will be substantial in some years but soon incapable to meet human and environmental demands in other years. It is triggered by the demand for an economic good exceeds supply as a result of a shortage in water supply relating to weather. The impacts on socio-economic, social and environment due to increase in human activities is the main reason that socio-economic drought should not be neglected.

According to Van Lanen and Peters (2000), groundwater drought is the decrease of groundwater level from months to years. When groundwater systems get affected by drought event due to low precipitation and high evapotranspiration, a deficiency in soil moisture content can be seen and in turn, causes low recharge rate. Others cause such as overexploitation and abstraction of groundwater by human activities may also induce groundwater drought. As the total amount of water available underground is difficult to determine, there is only few researches related to this type of drought. Although these three droughts do not illustrate as a natural hazard, nonetheless they could cause water shortfall which is caused by intense dry spells event, or inappropriate operations of water resources.

Apart from type, drought also can be characterized in three dimensions, which is severity, duration, and spatial distribution. Other characteristics such as frequency, magnitude, interarrival time, intensity, peak and trend are also commonly used by researchers (Mishra and Singh, 2010; Esfahanian, et al, 2016; Ganguli and Ganguly, 2015; Ayantobo, et al, 2017). Thus, a generally adopted terminology of Salas (1993) is applied, which includes:

i. Duration (D): Time-scales expressed depending on the region in between week to year, during which the drought index is below an established critical level.
ii. Severity (S): Indicates the cumulate deficit and impacts due to a drought period below critical level.
iii. Magnitude: Accumulated deficit of water below the threshold during a drought event.
iv. Intensity (I): The drought magnitude to duration ratio.
v. Geographic extent: The coverage area for a drought period to be occurred, which is irregular during the event. The coverage area can be one or more regions or watersheds.

vi. Frequency: The arrival time for the next drought event. It is also an average time between two drought events that share same or greater severity.

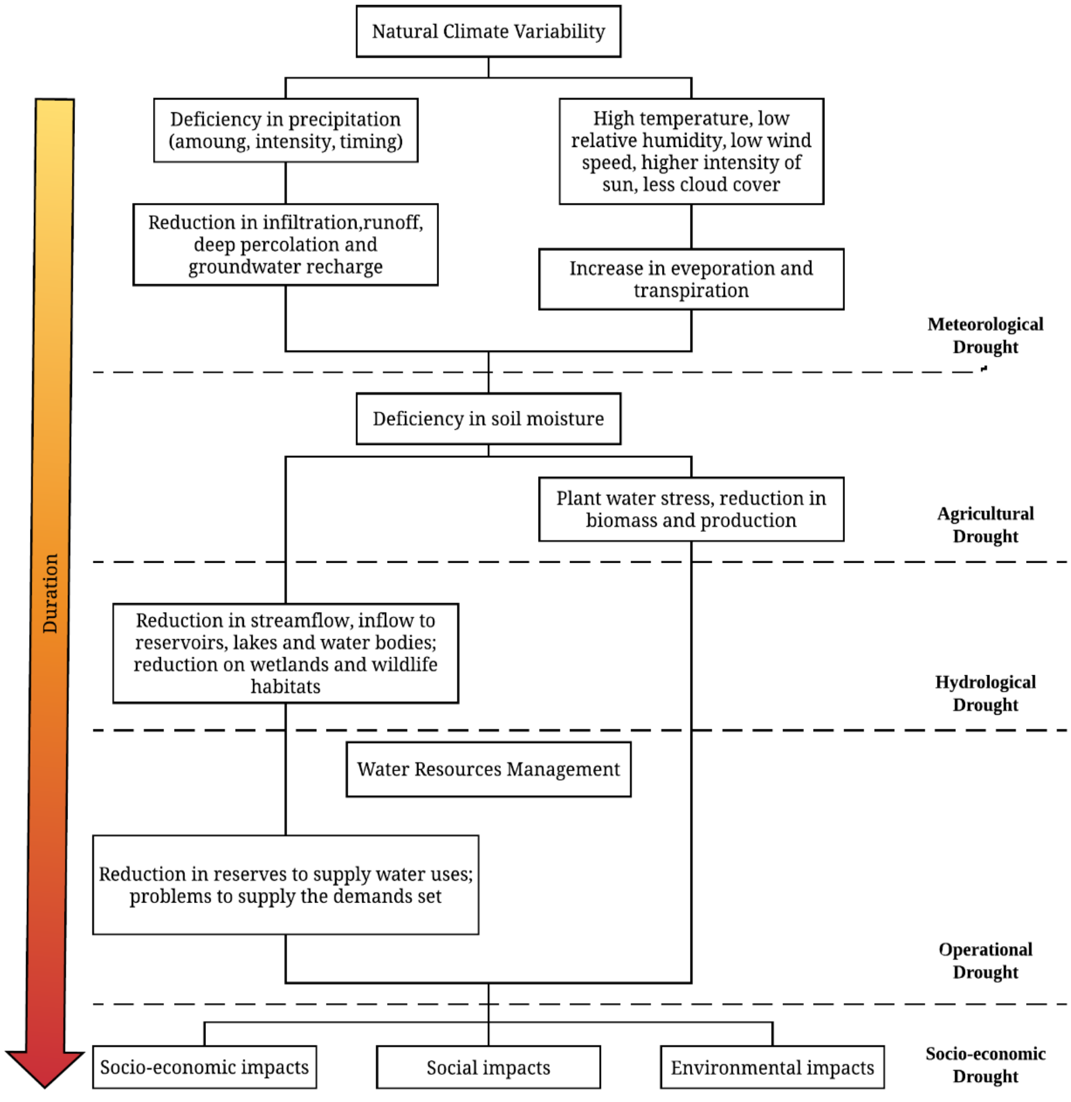

Figure 2.2: Relationship Between Different Types of Drought Event (Modified from NDMC ,2006).

2.4 Drought Indices

Drought indices are computed in numerical form of drought effects by using the indicators into a single numerical value. In other words, it combines the results from indicators into a single value to represent a drought event. It provides a quantitative assessment for droughts severity, intensity, duration and spatial extent for drought analysis for a given period. To analyze a drought, a time scale must be given as a framework to evaluate drought parameters of concern, the typical time scale is in year, which is most suitable for regional behaviors and also in month, which is more preferable in analyzing water supply or agriculture situations. Drought index functions as the following purposes:

i. Drought detection, monitoring, and evaluation (Niemeyer, 2008).
ii. Announcing the start and end period for a given drought event (Tsakiris, et al., 2007).
iii. For the authorities to inform drought levels and initiate responses measure.
iv. Coordinate activities in accordance to drought situations (Massachusetts Drought Management Plan, 2013).
v. Illustrate the impacts in variables geography and time extend.

Categorization of drought indices is mainly based on the impacts and variables. Three basic categories of drought indices are:

i. Meteorological drought indices that depend more on data availability. The data is commonly obtained from the meteorological stations from the authority. To have a better understanding about temporal tendency of temperature, others meteorological variables will be added to establish a more suitable and thorough indices.
ii. Agricultural drought indices that depend on soil water balance and deficit in soil moisture during drought event to portray a simplified climate model.
iii. Hydrological drought indices which depend on the water balance approach in a catchment for water management purposes, from the entire water cycle perspective. It specifically focuses on discharge processing process such as melt down of snow.

Researchers Niemeyer (2008) further adds three categories into the list, which are: comprehensive, remote-sensing and combined based drought indices. In comprehensive drought indices, typical soil moisture information was proposed to analyze together with meteorological parameters. PDSI is one of the drought indices that applies this approach. Remote-sensing based drought applies information from observation satellites equipped with sensors to derive the spatial condition of the land with persistent method and high repetition rate.

In the previous researches, scientists and researchers applied only single indicator or index since the data availability is very less, as well as the limited time to collect and compute all the data into the indices. Over the past decades, various indicators and indices were developed to tackle with diverse applications and situations, in terms of temporal and spatial. However, none of this indicators and indices is being cross-checked by each other. The advanced geographic information systems and computational capabilities nowadays have increased the ability to superimpose various map, indicators and indices which allow multiple indicators or indices to justify each other. This would provide a more details and informative results on drought event to the public.

Generally, the methods used for combining drought indices can be classified as: decision matrix analysis, classification and regression tree (CART) analysis, and regression technique. Decision matrix analysis is derived from where the final outcome is guided by numerous benchmarks at the beginning. The US Drought Monitor (Svoboda, et al, 2002) is one of the combined meteorological drought indices (PDSI and SPI) with hydrologic and remote sensing information, where percentage weight is assigned for each index and are averaged to compute the results. The CART analysis establishes a set of decision rules to frame a predictive model. It involves selection of input variables to be used and explicit split or cut-point on the variables until the suitable results are obtained. The Vegetation Drought Response Index (VegDRI) by Brown, et al. (2008) combined meteorological indices, satellite-based vegetation measures, and biophysical information to establish an empirical model for different seasons. The regression technique approximates the linear and nonlinear behavior for the dependent and independent variables. Aggregate Drought Index (ADI) that considers meteorological, hydrological and agricultural indices aggregated six hydrologic variables such as precipitation, streamflow and soil moisture using principle component analysis (Keyantash and Dracup, 2004).

2.4.1 Percent of Normal Precipitation

The percent of normal precipitation is a meteorological drought index. It is a simple calculation by dividing actual precipitation by normal precipitation, commonly corresponds to be a 30-year mean that describes the drought as precipitation deviation from the normal. This method is competent in analyzing single region or season, and it is suitable for various time scales, including monthly, seasonal, and annual year. The percent of normal precipitation is famous among TV forecasters as its simplicity and transparency allow general public to understand more on the drought levels (Keyantash and Dracup, 2002).

The disadvantage of this approach is that the mean precipitation is usually different with the median precipitation as there are no statistical transformation in the distribution (Hayes, 2006). Besides, this approach cannot be applied to compare droughts situation across seasons and regions as the distributions are completely different. Thus, this method is lacks of sturdy standing point for operational use in planning and management (Zargar, et al., 2011).

2.4.2 Standardized Precipitation Index (SPI)

SPI (McKee, et al., 1993) is a widely used meteorological drought index which is calculated merely based on the long-term precipitation record for a given period. It is typically used to assess duration and magnitude of drought events. The raw precipitation data are commonly fitted to a gamma or Pearson Type III distribution, which is then transformed into a normal distribution. Since it is normalized, the wetter or drier climates can be illustrated in the same way.

Value produced by SPI can be interpreted as the number of standard deviations, by which the observed scenario is anomaly if cumulative deficit deviates from the average. Values above zero illustrates a wet period, while below zero indicates dry period, as shown in Figure 2.1. The drought event is said to be ended when the SPI becomes positive. One of the advantages of SPI is that computation for different time scales are achievable, typically in 1-to-36 months periods and this adaptability of SPI allows it to monitor for short-term water supplies. It is the most comparable across regions with distinct climates and it requires less complexity to calculate as it only requires precipitation as an input (Hayes, et al, 2011).

One of the key limitations of SPI is related to its input, which it can only be used to measure the water supply only (Vincente-Serrano, 2010). The limitations of SPI to deal with evapotranspiration makes it difficult to capture the effect of increased temperatures due to climate change, which is a major challenge in monitoring drought event nowadays. Besides, its sensitivity to the length of precipitation data limits the consistency SPI values. Different in data length might lead to considerably variance in results. This is due to the difference in distribution from length of record contributes to significantly change in shape as well as scale parameters.

In the study done by Guttman (1998) in comparison of drought indices in USA, SPI was preferred rather than PDSI as its simplicity and can be calibrated to any user established time periods. In other words, PDSI was complex and could only be interpreted under fixed time periods. Furthermore, according to a research done in USA, SPI more flexible in short or long-term drought monitoring (Hayes, Svoboda and Wilhite, 2000). However, due to the simplicity of SPI, it is also suggested that it should be applied together with other remote sensing input to ensure a more thorough analysis.

Table 2.1: The Range of SPI Values

SPI Values	
2 or more	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 or less	Extremely Dry

2.4.3 Palmer Drought Severity Index (PDSI)

PDSI (Palmer, 1965) is the first index developed to identify droughts using more than just precipitation data. It is formulated by using precipitation and temperature for measuring moisture supply based on the supply-and-demand concept from water balance equation. It is best effective in evaluating long-term drought over low and middle latitudes. For many years, PDSI was the only operational drought index and nowadays it is still popular and applicable around the world especially in United States government agencies. The main applications of PDSI is to identify the impacts of droughts to the agriculture (Alley, 1984).

PDSI uses precipitation and temperature data to approximate the relative dryness that scales from -4 (dry) to +4 (wet), as shown in Table 2.2. Past conditions are covered as for long-term drought is in cumulative form, the intensity of drought at that particular time is fully depending on the previous months and current conditions. It evaluates moisture received from the precipitation as well as moisture that stored in the soil, accounting for the potential loss of moisture due to temperature factors. All the fundamental parameters of water balance equation are determined from the inputs of data, such as soil recharge rate, runoff, moisture loss and evapotranspiration.

The key advantage of PDSI is that the availability of precipitation and temperature data, with local Available Water Content from past 9-12 months make it powerful for identifying droughts. Unlike SPI, PDSI can capture the effect due to temperature, a basic consequence of global warming through changes in potential evapotranspiration. PDSI does not only provide users with an assessment on the abnormality of latest weather events for a particular region’s current conditions in a historical perspective, but also spatial and temporal representations of past drought event (Karl and Koscielny, 1982).

The limitations of the PDSI is its time lagging problem in computation. As PDSI has a timescale of roughly nine months, it leads to a lag in identifying drought conditions based on simplification of the soil moisture component within the calculations. Other than that, the precipitation data is considered as immediate rain and thus does not account for delayed runoff such as snow or frozen ground. In other words, it might be inaccurate in the winter months or mountainous area. Other than that, the limitations of PDSI have been further studied in several researches (Guttman,1998; Alley, 1984; Hayes, et al., 1999), which included the elevation of the study area will affect the value computed and runoff to be under-estimated frequently as it only accounts for saturated soil condition.

Table 2.2: The Range of PDSI Values

Palmer Classifications	
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to-0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Slightly dry
-2.0 to -2.99	Moderately dry
-3.0 to -3.99	Very dry
-4.0 or less	Extremely dry

2.4.4 Surface Water Supply Index (SWSI)

SWSI (Shafer and Dezman, 1982) is commonly used when mountain snowpack is the key factor of water supply in Western United States. It serves specifically to monitor the abnormalities in surface water supply resources and can cover both hydrological and climatological features for each river basin. Four inputs that required by SWSI are: snowpack, streamflow, precipitation and reservoir storage. Since the water supply is season-dependent, snowpack, precipitation and reservoir storage are used during the Winter months; while streamflow, precipitation and reservoir storage are used to compute SWSI equation during the Summer months.

As SWSI covers one of the weaknesses of PDSI, in which it covers large topographic variations across a region and consider snow accumulation. Its main function is as a complement to PDSI for moisture condition for mountainous and winter areas. The simplicity in calculation for SWSI gives a fast and convenient way to evaluate surface water supplies abnormalities across the state. Besides, according to research done by Heim (2002) which focused on river basins in Western United States, it was observed that the temporal and spatial scale were different with the surface water supply as it involved hydroclimatic variability. In another research, the SWSI was more feasible in water scarcity planning (Pedro-Monzonis, et al., 2015).

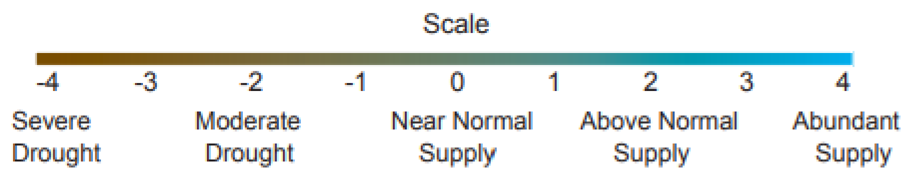

Figure 2.3: SWSI Severity Indicator

Due to every set of data is unique to a specific basin or region, it has no meaning to compare the values between basins or regions (Doesken, et al., 1991). The entire SWSI computational method might need to be re-developed to account for changes in the weight of each component if there are changes in water management for a basin. Hence, it is very hard to maintain a similar time series for this index.

2.4.5 Crop Moisture Index (CMI)

The reason behind the development of this index is that due to the PDSI could only measure long-term moisture conditions for week-to-week crop conditions, Palmer (1968) has invented another way to deal with the short-term moisture conditions, by using weekly mean temperature and precipitation data to evaluate an uncomplicated moisture budget. CMI is a meteorological approach which has fast responds to a changing condition weighted by location and time.

Since it is specifically developed for short term evaluation, using CMI in long-term droughts monitoring could be misleading. As it was developed for the grain-producing regions in the United States, it may provide inaccurate recovery sense from long-term droughts, as enhancements in the short term might be inadequate to compensate long term issues (Pedro-Monzonis, et al., 2015). Moreover, CMI usually begins and ends each growing season with a value close to zero. This approach banned the CMI being used to monitor moisture conditions outside the general growing season, even during droughts that last over few years. In short, CMI is most feasible only when identifying agricultural droughts at warm seasons (Heim, 2002).

2.4.6 Standardized Precipitation Evapotranspiration Index (SPEI)

SPEI (Vicente-Serrano, et al., 2010) can be defined as an extent version of SPI, as it uses precipitation and potential evapotranspiration which SPI never considered in computation. It uses monthly or weekly difference between precipitation and potential evapotranspiration which can be represented as a simple climatic water balance obtained at different time scales. Since it takes potential evapotranspiration into account, SPEI can capture the effects of increase in temperature on water demand, thus addressing the consequences of climate change on drought behavior.

The main advantage of SPEI is that it has wide range of time scales, from 1 up to 48 months (Zargar, et al, 2011). At bigger time scales, it is proven that SPEI is correlated with the self-calibrating PDSI (sc-PDSI). SPEI incorporates the advantage of SPI which is multi-scalar, and also boosts the reliability and sensitivity on climate change issues. One of the clever ways that SPEI was to deal with the potential evapotranspiration data problem is the estimation by Thornthwaite Method. In this method, variables that could possibly affect the potential evapotranspiration such as wind speed, and solar radiation are assumed to be negligible, as the data are scarce and even if it is available, these variables can have large uncertainties.

As for the limitation of SPEI, comparing with the SPI method it requires more data than SPI and is very sensitive to the method used to calculate potential evapotranspiration according to a study in European area (Stagge, et al., 2014). Since SPEI uses monthly data, it might be unable to identify a rapidly developing drought event.

2.4.7 United States Drought Monitor (USDM)

USDM (Svoboda, et al., 2002) is a composite drought index. It combined and integrated many indicators and inputs and is able to compare current data with historical conditions equivalently. Due to its composite nature, it can cope with different types of user including water planner up to agriculture industry. It is a trending index which is commonly used among the organizations, research and press media.

Currently, USDM can analyze and involve up to 50 inputs. Drought indices, climatological inputs, modelled inputs and remotely sensed inputs are all built in the analysis. Even if there are new indicators or indices, USDM is also flexible enough to include them into analysis of droughts. It can be applied in all seasons over all climate regimes.

One of the issues in applying USDM is that since the latest inputs will provide best results in the analysis, operational data will be required. If the inputs are not sufficient, the results might not be satisfied, but still relevant. Besides, according to a research done by Heim (2002), USDM will tend to portrait droughts at different temporal scales on just one map only, and this might cause certain issue in evaluating short-term to long-term drought.

2.4.8 Normalized Difference Vegetation Index (NDVI)

NDVI (Rouse, et al., 1974) is a remote-sensing based index that uses global vegetation index data which are obtained by measuring of 4 km daily radiance. The radiance obtained by both visible and near-infrared bands are used to evaluate NDVI. It can determine the stress induced by drought by vegetation, while reduce the noise from atmospheric conditions such as cloud contamination using the satellite data from Advanced Very High-Resolution Radiometer (AVHRR) and National Oceanic and Atmospheric Administration (NOAA).

When the vegetations are in healthy conditions, chlorophyll will absorb light and hence reflecting less visible red spectral reflectance, denoted as R. Lower R will then result to higher NDVI value. This method covers very wide area with high resolution, however, the data extracted from sensor is sometimes inaccurate as some of the area might be under-cover by taller obstructs (Nagler, et al., 2005). Another disadvantage is that the data often get contaminated by atmospheric interference such as smoke, haze or cloud. In the study done at northeastern South Africa, non-degraded and degraded areas were less stable (Wessels, et al., 2004)

2.4.9 Streamflow Drought Index (SDI)

SDI (Nalbantis and Tsakiris, 2009) uses the same normalization methods as in SPI, replacing precipitation with monthly streamflow data. Since the output is similar to SPI output, the severity and magnitude can be evaluated. SDI is a short and simple approach which the data is widely available and various time scales are allowed. As the input only deal with streamflow, it is not sensitive to change in temperature, which makes it only applicable in measuring water supply only. Another problem is when the river experiences period of no flow, it would misrepresent the results.

2.5 Spatial Interpolation

Spatial interpolation utilizes a variable which has significant values at every point within a region (such as temperature or water level) to predict values of this variable at every surrounding point. The basic of the interpolation is "Everything is related to everything else, but near things are more related than distant things." (Tobler, 1970) that near points are normally contain more weights than points which are far away. This basic interpolation further creates a raster image that covers the particular study areas. For any unknown point, values of surrounding points are average weighted to predict the value at the particular unknown point. It is only applicable and could be used when there is meaningful value of the variable at every point scattered within the region of interest. If the point merely showed the presence of an event, or physical phenomena, it would not provide any data or results that can be compatible, as it does not have quantities or detailed information to conduct an interpolation at that particular point.

Data collection is usually only conducted at several selected point due to high cost and limited resources. Thus, spatial interpolation among these points are essential to create a raster surface in order to further generate a continuous map. The results of the spatial interpolation can then be utilized for analyses which covered the whole desired area that is commonly known as a statistical surface. Other than precipitation, other types of data such as temperature, water level, and population density can also be computed using interpolation. For interpolation, there are two main groupings of techniques, which are deterministic and geostatistical methods (Johnston, 2004).

2.5.1 Deterministic Method

Deterministic method uses mathematical functions that govern either the extent of similarity of the values or the degree of smoothing in the surface to further create surfaces from measured points. Deterministic interpolation method can be separated into two sub-groups, which are global and local.

The global techniques evaluate predictions with entire dataset, while local techniques calculate predictions from the measured points within neighboring data points, which are usually a smaller spatial area within the larger study areas. Exact interpolator predicts a value which is identical to the measured value at a sample location, while inexact interpolator predicts a value which is different from the measured value to avoid sharp peaks or troughs at the output to produce a smoother surface.

2.5.1.1 Inverse Distance Weighting

Inverse distance weighted (IDW) function is an exact interpolator which makes an assumption that value of a variable at an unmeasured location can be predicted by using the measured values surrounding the prediction location. The measured values that are closed to the prediction location have more influence towards the predicted value than those which are farther away. It assumes that the local influence will be reduced with distance for each measured point, and give more weightage to the points which are closer to the prediction location.

The power parameter is a value to determine significance of known points on the interpolated values, based on the distance from output point. The power parameter is always a positive real number. By defining a higher power value, the nearest points will be given more weights, thus leading to more influence to the prediction location and details on the rough surface. Meanwhile, defining a lower power value will give more influence to surrounding point which is farther away that gives smooth surface.

To improve processing speed, IDW allows its user to limit the input points used in the calculation of each output cell value. In IDW method, number of points which will be included in the interpolation can be specified directly, or a fixed radius of distance can be defined to allow the searching of the neighborhood input points within a certain range. The search radius will keep increasing until it can encircle minimum number of input points to be interpolated. From the study of Bagheri (2016) in Iran, IDW is applicable for the interpolation of SPI or other indices that uses precipitation as input.

2.5.1.2 Radial Basis Functions

Radial Basis Functions (RBF) method is a sequence of exact interpolator, which the surface must go through each measure sample value. There are five different basis functions, which are thin-plate spline, spline with tension, completely regularized spline, multiquadric function, and inverse multiquadric spline. Each basis function has different shape and will result in slightly distinct interpolation surface.

RBF minimizes the total curvature or undulate condition of the surface. For an exact interpolator, unlike IDW method RBF will predict values above maximum or the below minimum measured value as shown in Figure 2.4. This allows a smoother surface compared to IDW method. A study conducted at Zayandehrud River basin by Safavi and Ahmadi (2015) has shown that RBF was able to discover the linear as well as non-linear relationships between the hydrological water quality parameters.

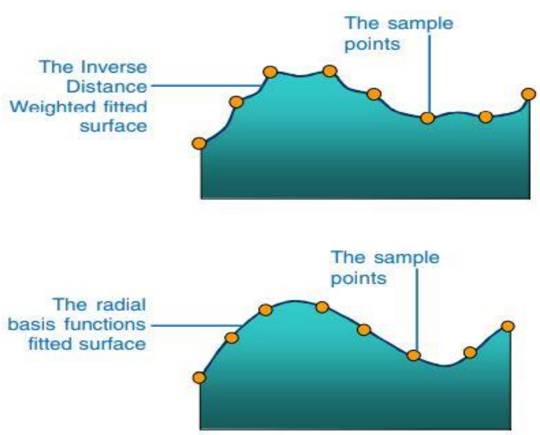

Figure 2.4: Comparison of The Surface Between IDW and RBF.

Radial basis functions create a smooth surface from a large number of data points, and thus it produces a good result for mild and gently deviating surfaces such as elevation. However, it is not suitable for a surface that has a large difference in surface values within a short horizontal distance, or when the sample data for input is prone to uncertainties.

2.5.2 Geostatistical Method

Geostatistical method applies both statistical and mathematical methods for creating the surfaces and assuming the uncertainty of predictions. It includes statistical relationships among the measured point that can assume an autocorrelation, which is a random process with dependence that links the relationships of values within a single variable at different time points or locations.

Geostatistics utilized the data twice to estimate the spatial autocorrelation, and then make the prediction for the dependency rules. To know the dependency rules, idea of stationarity is an often assumption used for spatial data which the mean or covariance is constant between two points. In general, statistics relies on the perception of replication, which estimation can be derived with the variation, and uncertainty of it can be studied from the repeated observation.

2.5.2.1 Ordinary Kriging

Ordinary kriging (OK) is a spatial estimation approach which the error variance is minimized of universal kriging (Lefohn, et al., 2005). This method is applied when the results from data spatial structure analysis shows a spatial structure. It is a prerequisite condition that a data set required to compute the kriging interpolation. OK method builds a mathematical function from the input data using a semivariogram. It creates a prediction surface to verify the built model with cross-checking.

There are 3 requirements that need to be fulfilled: normal distributed, stationary, and does not have trends. The data must have a normal distribution curve. This can be checked using a histogram function provided in ArcGIS. Additionally, a normal QQ plot can be used to check whether the data pairs linearly with the normally distribution data. If the data does not follow the normal distribution, normal score transformation will be required to do the normalization of the data. The normal score transformation is provided as simple kriging in ArcGIS. Stationary data means the variance between 2 data has to be constant in different areas of map. The data should consist of no orderly arranged changes in data across a study area (Gisgeography, 2018).

Kriging method relies heavily on the semivariogram, which is a graph that shows the variance of all pairs of data. It can quantify the autocorrelation according to the distance, where closer data will have a smaller semi-variance while further data are said to have less related with higher semi-variance.

2.5.2.2 Universal Kriging

Universal kriging (UK) also known as a kriging with a trend allows for a non-constant global structure calculation which OK could not provide, nonetheless it is similar with the OK method. Despite OK is the most common method and widely accepted, and is the default function for kriging method, it is inappropriate under certain scientific condition as it assumes that the constant mean is unknown.

UK models utilize the error to be autocorrelated. It uses “residuals” as a variable to construct a variogram for interpolation. Residuals indicate the difference between the observed value and predicted value. It can be applied only when there is a scientific justification to a known trend in the dataset. Based on the nature of the dataset, it is required that the trend should be in simple form and avoid extrapolation beyond available data. According to the study done at Sandrovac field in comparing UK and OK, UK was more applicable in most situation as it can identify and compute the trends in data to give an interpolated mapping result (Kis, 2016). In other words, UK can describe the regression better than OK by given the same directional variograms of a depth variable.

2.6 Summary

In summary, the definition of drought, types of input parameters and drought indices, and methods to interpolate the dry pattern map are discussed in detailed in this section. For the types of drought to be measured and assessed, agricultural, meteorological and hydrological drought events are easier to identified in southern region of Peninsular Malaysia as compared to the socio-economic drought, which requires water demand and supply data.

Drought indices are computed numerically and as representations of drought effects. SPI method normalized the long-term precipitation record, which further fitted into a normal distribution line, thus giving it less complexity compared to other drought indices as it only involved rainfall data. Compared to SPI method, the SPEI method includes temperature data so that it could capture the effect of climate change on drought behavior. SDI method which also normalized the data likewise with SPI method has a very straightforward computations to assess the river flow. Unlike other drought indices, SPI, SPEI and SDI involved only raw environment inputs on rainfall, streamflow and temperature in the development stage. They are easier to be applied compared to other indices such as PDSI, which requires atmospheric moisture content and soil moisture content.

In this study, deterministic and geostatistical methods of interpolation were inspected, which are inverse distance weighting (IDW), radial basis functions (RBF), ordinary kriging (OD) and universal kriging (UK). Study showed that deterministic interpolation method has better simplicity compared to geostatistical interpolation method as the spatial autocorrelation between the data points are not required. Instead, the value of unknown locations will be estimated based on similarity of the neighboring data points. Among the deterministic method, RBF method is not comparable with IDW as the stations data might have large difference in surface values within a short horizontal distance, or when the input data contains uncertainties. As this study involved rainfall, streamflow and temperature data only, IDW which has lesser complexity in fabricating the assumptions, seems to be functional well for environmental data analysis that involves rainfall, streamflow and temperature.

[redacted]

[redacted] METHODOLOGY

3.1 Workflow

This chapter will include the flow and methods to compute the drought analysis using the SPI, the SPEI, and the SDI in the southern region of Peninsular Malaysia. Parameters used will be further evaluated with calculations and formulas. It gives insight into how the drought index number will be calculated and evaluated into each scenario. Furthermore, evaluation of each drought index and time-scale will be computed to study the feasibilities in the southern region of Peninsular Malaysia.

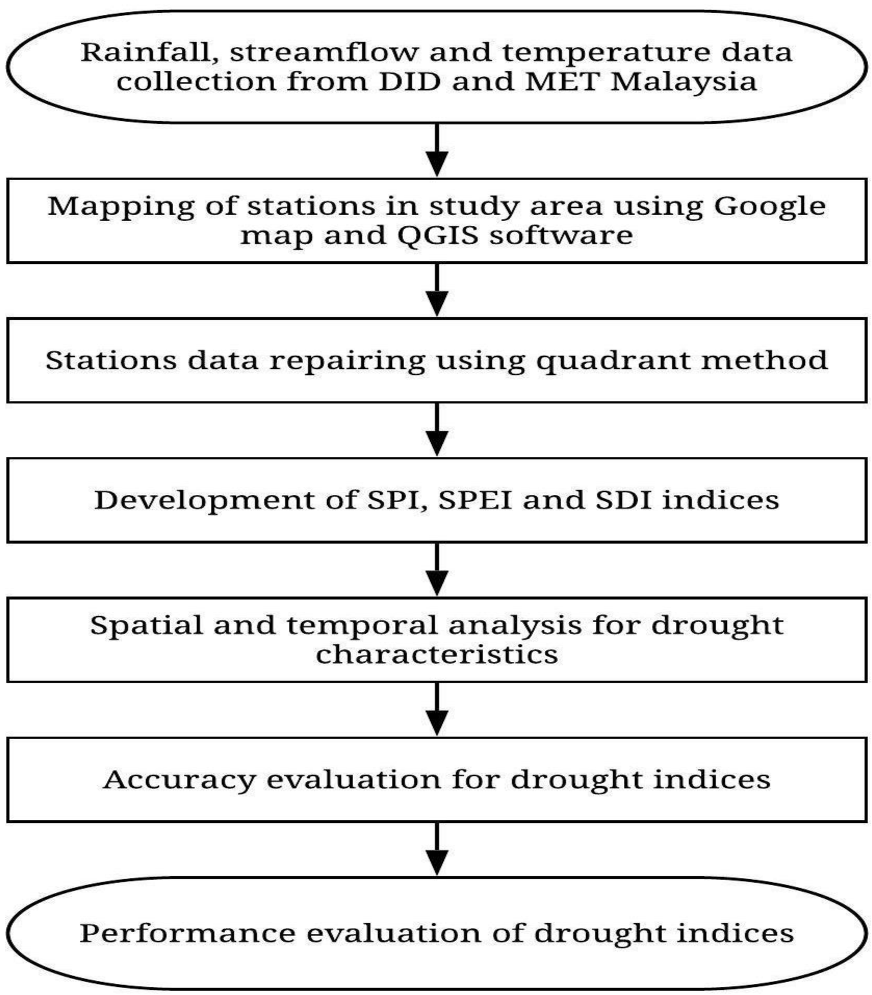

Figure 3.1: Flowchart of Drought Indices Analysis and Evaluation.

3.2 Location of Study and Data Acquisition

The location of interest in this study will be the southern region of Peninsular Malaysia, which consists of three states: Johor, Malacca, and Negeri Sembilan. The boundaries of the study location and process of retrieving the data will be discussed further in the following sections.

3.2.1 Map of Study Area with Stations

Figure 3.2: Main Study Area in Southern Peninsular Malaysia with 16 Rainfall Stations And 8 Streamflow Stations.

3.2.2 Characteristics of Study Area

Peninsular Malaysia, or also known as West Malaysia is an island surrounding by the South China Sea, Pacific Ocean, and the Indian Ocean and has occupied an area of approximately 131,598 square kilometers and contribute 81 % for the total population and economy of the Malaysia. Positioned near the equator, climates of Malaysia are hot and humid throughout the year, with 27 °C and annual rainfall of 2500 mm a year for every state. The climate of Peninsular Malaysia is mainly influenced by the Southwest Monsoon (April to October) originated from the deserts in Australia, and Northeast Monsoon (October to March) originated from the China and South China Sea which brings in more rainfall compared to Southwest Monsoon. Local climates are commonly divided into: highlands, lowlands, and coastal regions.

The southern region of Peninsular Malaysia consists of three states, which is from south to north: Johor, Malacca, and Negeri Sembilan as illustrated in Figure 3.2. Three of the state made up to a total of 27,560 km^2 (Department of Statistics Peninsular Malaysia, 2010), contributing 20.94% of lands for Peninsular Malaysia. In the southern regions of Peninsular Malaysia, most of the areas are coastal regions and lowlands, with only a mountain which has maximum elevation of 1276 m above sea level on border line of Johor and Melaka as shown in Figure 3.3 in the southern region.

Table 3.1: Area of Each State in Southern Region of Peninsular Malaysia

States	Area (km^2)
Johor	19,210
Malacca	1,664
Negeri Sembilan	6,686

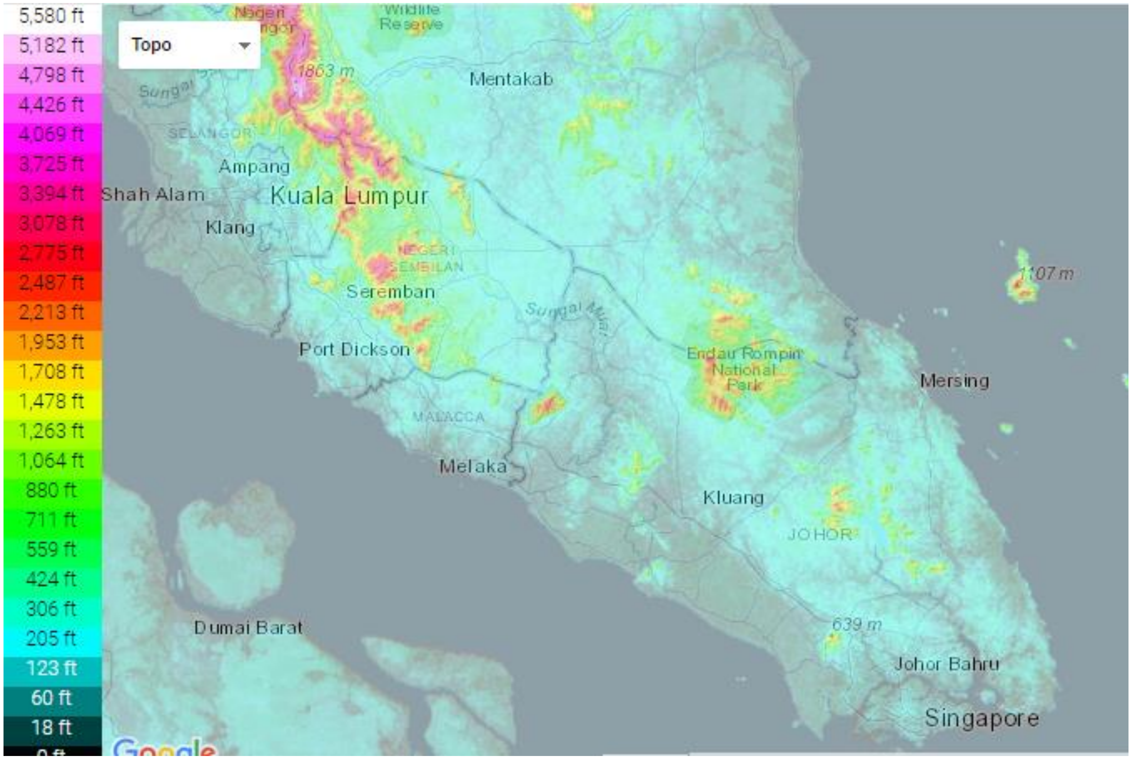

Figure 3.3: The Topography of The Southern Region Peninsular Malaysia (Modified from Google Map, n.d.).

While the coastal region has more sunny climates and less rainfall ranging from 100 mm to 300 mm a month, the lowlands area has a more peculiar rainfall pattern with very high humidity. In the southern region, there are 5 basins: Johor Basin, Muar Basin, Batu Pahat Basin, Linggi Basin and parts of Pahang Basin. However, as Pahang state is beyond the boundary of the study area, Pahang Basin is therefore not considered in the analysis. Among the 4 major basins, Muar Basin is the largest basin with an area up to 6,138 km^2 and primarily contributes to the Muar River that spans over 329 km which widely covers Johor, Melaka, Seremban and Pahang as shown in Table 3.2 (Yun et al, 2015). Common land use such as rubber, oil palm, urban and forest can be found at the southern region of Peninsular Malaysia (Hazdy et al., 2017). Agricultural activities in the southern region of Peninsular Malaysia mainly involved Palm Oil Plantation which covers up to 9807.37 km^2, 36.6% of total area for Oil Palm in Peninsular Malaysia that are managed by FELDA, FELCRA, private estate etc.

Table 3.2: Area of Each Basin in The Southern Region of Peninsular Malaysia (Modified from JPS, 2011)

Basins	**Area (*km*^{2})**	**Main Rivers**	**States**
Johor	2,286	Johor River, Linggiu River, Sayong River	Johor
Muar	6,138	Muar River, Gemencheh River, Palong River, Segamat River	Muar Pahang Malacca Negeri Sembilan
Batu Pahat	2,049	Batu Pahat River, Simpang Kiri River, Simpang Kanan River, Lenik River, Bekok River, Sembrong River	Johor
Linggi	1,298	Linggi River	Negeri Sembilan Malacca

The water supply dams in Peninsular Malaysia are critical as they govern not only the daily usage of water for the citizens, but also for water trading scheme that provides extra incomes for the local authorities. Freshwater shortage is getting more concern by residents in these three states, as the El-Nino-induced drought. Amongst all the dams, the Linggiu reservoir dam plays the most crucial rule in terms of water supplying issue. It served as the main source of water for Singapore and is currently operated by Singapore’s national water agency Public Utilities Board (PUB) since year 1961 until 2061. A total of 11 water supply dams can be found in the southern region as shown in Table 3.3.

Table 3.3: Water Supply Dam Available at Each State (Modified from JBA, n.d).

States	Water supply dams
Johor	1. Congok
	2. Juaseh
	3. Lebam
	4. Mount Pulai 1
	5. Mount Pulai 2
	6. Mount Pulai 3
	7. Pontian Kecil
	8. Layang (Lower)
	9. Layang (Upper)
	10. Gunung Ledang
	11. Linggiu
Malacca	1. Durian Tunggal
	2. Asahan
	3. Bunded Storage Durian Tunggal
	4. Jus
Negeri Sembilan	1. Kelinchi
	2. Beringin River/ Pedas Baru
	3. Terip River
	4. Ulu Muar
	5. Gemenceh
	6. Batu Hampar

3.2.3 Details of Station

All the data were taken from the website and servers of the Department of Irritation and Drainage. The stations are separated into 2 types: Rainfall and streamflow data as shown in Table 3.4 and Table 3.5.

Table 3.4: Available Rainfall Stations in Southern Region of Peninsular Malaysia (16 Stations).

Station	Function	Name	State	District	Latitude	Longitude
1437116	Rainfall	Stor JPS Johor Bahru	Johor	Johor Bahru	1.4708	103.7528
1534002	Rainfall	Pusat Kemajuan Per. Pekan Nanas	Johor	Pontian	1.5153	103.4944
1541139	Rainfall	Johor Silica	Johor	Kota Tinggi	1.5264	104.1847
1732004	Rainfall	Parit Madirono, Site 4	Johor	Pontian	1.7083	103.2736
1737001	Rainfall	Sek. Men. Bkt. Besar di Kota Tinggi	Johor	Kota Tinggi	1.7639	103.7194
1931003	Rainfall	Empangan Sg. Sembrong di Air Hitam	Johor	Batu Pahat	1.9736	103.1792
2025001	Rainfall	Pintu Kawalan Tg. Agas di Muar	Johor	Muar	2.0514	102.5778
2231001	Rainfall	Ldg. Chan Wing di Pagoh	Johor	Segamat	2.2500	103.1333
2235163	Rainfall	Ibu Bekalan Kahang di Kluang	Johor	Kluang	2.2292	103.5986
2330009	Rainfall	Ldg. Sg. Labis di Labis	Johor	Segamat	2.3847	103.0167
2636170	Rainfall	Stor JPS Endau	Johor	Mersing	2.6500	103.6208
2224038	Rainfall	Chin Chin (Tepi Jalan)	Melaka	Jasin	2.2889	102.4917
2321006	Rainfall	Ldg. Lendu	Melaka	Alor Gajah	2.3639	102.1931
2719001	Rainfall	Setor JPS Sikamat Seremban	Negeri Sembilan	Seremban	2.7375	101.9556
2725083	Rainfall	Ldg. New Rompin	Negeri Sembilan	Kuala Pilah	2.7194	102.5125
3020016	Rainfall	Kg. Chennah	Negeri Sembilan	Jelebu	3.0931	102.0736

Table 3.5: Streamflow Stations in Southern Region of Peninsular Malaysia (8 Stations).

Station	Function	Name	State	District	Latitude	Longitude
1737451	Streamflow	Sg. Johor di Rantau Panjang	Johor	Kota Tinggi	1.7806	103.7458
2235401	Streamflow	Sg. Kahang di Bt.26 Jln. Kluang	Johor	Kluang	2.2514	103.5875
2237471	Streamflow	Sg. Lenggor di Bt.42 Kluang/Mersing	Johor	Mersing	2.2583	103.7361
2528414	Streamflow	Sg. Segamat di Segamat	Johor	Segamat	2.5069	102.8181
2533474	Streamflow	Sg. Endau di Kuala Jemakah	Johor	Mersing	2.5319	103.3750
2322415	Streamflow	Sg.Durian Tunggal di B.11 Air Resam	Melaka	Melaka	2.3236	102.2931
2519421	Streamflow	Sg. Linggi di Sua Betong	Negeri Sembilan	Port Dickson	2.6811	101.9275
2722413	Streamflow	Sg. Muar di Kuala Pilah	Negeri Sembilan	Kuala Pilah	2.7486	102.2486

3.3 Data Repairing

Rainfall is the primary data used in all hydrological studies, and hence it is a necessity as well as prerequisite parameters that errors have to be minimized. As the data obtained from the DID consists of uncertainties and missing data, data repairing steps are conducted to eliminate of these.

The Quadrant method is adopted in this analysis in order to compensate the missing rainfall data. The to-be-determined station is marked with O as an origin, followed by 2 sets of axes that will be established through the O which are defined by north-south and east-west lines, dividing the area around the station into four quadrants. Typically, the quadrant method adopts only one station at each quadrant, which makes a total of 4 stations in total. The computation method is shown in Equation 3.1:

$$P_O = \frac{\sum \frac{P}{d^2}}{\sum \frac{1}{d^2}} \tag{3.1}$$

where P_x is the missing rainfall data at station O and n is the rainfall data for each particular station within 35 years, at a distance of d between 2 stations.

However, due to the uncertainties in data provided by DID, 3 nearest stations at each quadrant will be selected and measured with distance. This is to ensure that if the nearest station has a missing or misleading data on a particular single day, the one cell of data in second nearest station could be further applied. This further extends to the third nearest station if the data in second nearest station could not be used.

Next, the dataset chose are used to predict 16 conditions of the station's data. The computation for the 16 conditions is essential as it determine equations to be applied in repairing the data. The samples for two computations will be shown in Equation 3.2 and 3.3.

Table 3.6: 16 Conditions for Each Day Given at Station.

Availability of data set	Condition					
All data are available	0000					
1 data not available	X000	0X00	00X0	000X		
2 data not available	XX00	X0X0	X00X	0X0X	0XX0	00XX
3 data not available	XXX0	XX0X	X0XX	0XXX		
All data are not available	XXXX					

$$Given\ 1\ data\ are\ not\ available\ (00X0), P_O = \frac{\frac{P_1}{d_1^2} + \frac{P_2}{d_2^2} + \frac{P_4}{d_4^2}}{\frac{1}{d_1^2} + \frac{1}{d_2^2} + \frac{1}{d_4^2}} \tag{3.2}$$

$$Given\ 2\ data\ are\ not\ available\ (X0X0), P_O = \frac{\frac{P_2}{d_2^2} + \frac{P_4}{d_4^2}}{\frac{1}{d_2^2} + \frac{1}{d_4^2}} \tag{3.3}$$

3.4 Drought Index

There are a few indices that will be computed in this study in order to get the optimum value to represent the dry spells in southern region of Peninsular Malaysia. The indices include the SPI, the SPEI and the SDI.

3.4.1 Standardized Precipitation Index (SPI)

The SPI analyzes the drought characteristics by normalizing the probability distribution of long-term precipitation data by using the gamma distribution function. The data are to be transformed into a log normal value with mean rainfall equals to zero, standard deviation of rainfall to 1, and skewness of existing data to 0. The skewness of a given rainfall is shown as Equation 3.1:

$$Skew = \frac{N}{(N-1)(N-2)}\sum\left(\frac{X-\bar{X}}{s}\right)^3 \tag{3.4}$$

where,

$$Mean = \bar{X} = \frac{\sum X}{N} \tag{3.5}$$

$$\text{Standard deviation, } s = \sqrt{\frac{\sum(X-\bar{X})^2}{N}} \tag{3.6}$$

where X is the precipitation and N is the number of rainfall stations.

After that, the normalized values will then compute by statistic U, shape and scale parameters of gamma distribution function which is showed from Equation 3.7 to 3.10:

$$\log mean = \overline{X_{ln}} = \ln \bar{X} \tag{3.7}$$

$$U = \overline{X_{ln}} - \frac{\sum \ln(X)}{N} \tag{3.8}$$

$$Shape\ parameter = \beta = \frac{1+\sqrt{\frac{4U}{3}}}{4U} \tag{3.9}$$

$$Scale\ parameter = \alpha = \frac{\bar{X}}{\beta} \tag{3.10}$$

The computed parameters above will then apply in the cumulative probability which is denoted by Equation 3.11:

$$G(X) = \frac{\int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} dx}{\beta^{\alpha}\Gamma(\alpha)} \tag{3.11}$$

Considered x = 0 and a rainfall distribution is zero, the cumulative probability changes to as given by Equation 3.12:

$$H(x) = q + (1 - q)G(x) \tag{3.12}$$

where q is the probability of zero.

Subsequently, cumulative probability $H(x)$ will convert to the standard normal random variable Z by Abramowitz and Stegun approximate conversion as shown by Equation 3.13 or Equation 3.14:

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^2}\right) \quad for\ 0 < H(x) \leq 0.5 \tag{3.13}$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^2}\right) \quad for\ 0 < H(x) \leq 1.0 \tag{3.14}$$

where,

$$t = \sqrt{\ln(\frac{1}{H(x)^2})} \qquad for\ 0 < H(x) \leq 0.5 \tag{3.15}$$

$$t = \sqrt{\ln\left[\frac{1}{(1.0 - H(x))^2}\right]} \qquad for\ 0 < H(x) \leq 1.0 \tag{3.16}$$

where,
c_0 = 2.515517, c_1 = 0.802583, c_2 = 0.010328;
d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308.

3.4.2 Standardized Precipitation-Evapotranspiration Index (SPEI)

The computation of SPEI is very similar to SPI, but with additional parameter which is the Potential Evapotranspiration PET. To compute the monthly PET values, Thorthwaite method are to be used as shown in Equation 3.17:

$$PET = PET_{non-corrected}(\frac{N}{12} \cdot \frac{d}{30}) \tag{3.17}$$

where,

N= Theoretical sunshine hours for each month

d= Number of days for each month

Table 3.5: Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes (Doorenbos and Pruitt, 1977).

Northen Lats	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Southern Lats	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
50°	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	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

Monthly water surplus or deficit can be calculated by using the Equation 3.18:

$$D_i = P_i - PET_i \tag{3.18}$$

where,

D_i = Water surplus (+) or deficit (-)

P_i = Precipitation of the measure station i

PET_i = Potential Evapotranspiration of measure station i

Log-logistic distribution will then be applied to model the D series using the scale, shape and origin parameter from L-moment procedure as shown from Equation 3.19 to 3.22:

$$\alpha = \frac{(w_0 - 2w_1)\beta}{\Gamma(1+\frac{1}{\beta})\Gamma(1-\frac{1}{\beta})} \tag{3.19}$$

$$\beta = \frac{2w_1 - w_0}{6w_1 - w_0 - 6w_2} \tag{3.20}$$

$$\gamma = w_0 - \alpha\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right) \tag{3.21}$$

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2} \tag{3.22}$$

The Probability Weighted Moments (PWMs) will then resolve the PWMS of order s by plotting-position approach, together with computed log-logistic parameters as shown in Equation 3.23 and 3.24:

$$F_i = \frac{i - 0.35}{N} \tag{3.23}$$

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

where,

N = Number of data available

F_i = Frequency estimator

D_i = Difference between Precipitation P and PET for month i

i = Range of observations in increasing order

The probability distribution function of the D series based on log-logistic distribution is denoted by Equation 3.25:

$$F(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{3.25}$$

The standardized value of F(x) can now be determined by SPEI with classical approximation of Abramowitz and Stegun (1965):

$$SPEI = W - \frac{c_0 + c_1 w + c_2 w^2}{1 + d_1 w + d_2 w^2 + d_3 w^2} \quad (3.26)$$

$$W = \sqrt{-2\ln(P)} \qquad for\ P \leq 0.5 \quad (3.27)$$

where,

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

3.4.4 Streamflow Drought Index (SDI)

As the SDI adopts same methodology and calculations as the fundamental work, it is a simple drought index which only requires 1 input, which is streamflow data. Similar to the SPI, the SDI requires relatively small sets of data for computation and the results can be still interpreted and applied in actual drought monitoring applications. The standard deviation and mean computed in SPI are now used to analyze the water shortage for a stream or river.

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \quad (3.28)$$

$$SDI_{i,k} = \frac{V_{i,k} - \bar{V}_k}{s_k} \quad (3.29)$$

For a smaller basin, the SDI is approximated by Gamma distribution functions. Normalisation is computed by two-parameter log-normal distribution.

$$SDI_{i,k} = \frac{y_{i,k} - \bar{y}_k}{s_{y,k}} \quad (3.30)$$

$$y_{i,k} = \ln(V_{i,k}) \quad (3.31)$$

where,

$V_{i,k}$ = Cumulative streamflow volume for i year

$\bar{V}_k$ = Mean of cumulative streamflow volume given period k

s_k = Standard deviation of cumulative streamflow volume given period k

$\bar{y}_k$ = Natural logarithms of mean cumulative streamflow volume

$s_{y,k}$ = Natural logarithms of standard deviation cumulative streamflow volume

also note that,

i = 1, 2, …for hydrological year

j = 1, 2, 3, …12 for month within hydrological year

$$k = \begin{cases} 1 \; for\ October\ to\ December \\ 2 \; for\ October\ to\ March \\ 3 \; for\ October\ to\ June \\ 4 \; for\ October\ to\ September \end{cases}$$

3.5 Temporal Analysis

Temporal analysis is carried out to determine whether the drought indices' values is dependent to different time scales. The 35 years available data are analyzed under monthly variations by plotting graphs of the SPI, the SPEI and the SDI values in y-axis against time scales in x-axis to picturize the duration, intensity, and frequency of drought. The time-scales adopted in this study including 1-month, 3-month, 6-month and 12-month.

3.5.1 Monthly Variations of Drought Duration, Intensity and Frequency

Variations of drought in same month from different 35 years are plotted under 12 graphs to indicate each month. 35 series of data will be plotted on the graph, indicating a particular constant month within 35 years started from 1983 to 2017. The time-scale on x-axis will be shown as in number of days within a month manner, which is in 29, 30, or 31 days for each different month.

3.6 Spatial Analysis

Spatial analysis is used to determine whether the drought indices' values are dependent on a certain location or region. The outcomes are predicted to be regional dependent as the data are associated under certain distance of nearest data set.

3.6.1 Data Spatial Structure Analysis

After the drought indices values are computed, it will be stored as an encoding approach that needs to be categorized further. It can be shown as a raster or vector datafile depending on the user of GIS and use to describe how the regional drought pattern would be. The computations efficiency is heavily relying on the length of data available. The conceptual models can be either objects or fields, in which objects have well-defined boundaries, commonly structures in real world; While fields are an event that varies continuously across the geographic space and does not have a fixed shape, or the boundaries are "blurred", typically a climates pattern. Drought indices output values will predict the regional pattern and interpolation methods will be chose depending on the results of analysis.

3.6.2 Inverse Distance Weighting

IDW interpolation, somehow compute alike 4 quadrant method, are commonly used when the data spatial structure analysis shows no spatial structure or when available sets of data are less than 50. It estimates the unknown points with known values through interpolation and works best if the data is dense and scattered evenly. The fundamental assumption of IDW method is the spatial autocorrelation, that near dataset are more comparable than far dataset. The equation to compute the IDW interpolation is shown as Equation 3.32:

$$z_p = \frac{\sum_{i=1}^{n} \frac{z_i}{d_i}}{\sum_{i=1}^{n} \frac{1}{d_i}} \tag{3.32}$$

IDW interpolation is very adaptable to various situations as it can set up interpolation in different approaches. It can set create a barrier which prevents the computations from searching for the input sample points.

3.7 Drought Characteristics

Drought characteristics is a series of drought event indices computed based on several aspects to investigate the spatiotemporal distribution and pattern of drought events in the southern region of Peninsular Malaysia. This includes the occurrence of drought: frequency and duration; and also, magnitude of drought: severity, intensity and peak. Simple arithmetic means of the corresponding characteristics are computed under 35-year analysis with different time-scales.

3.7.1 Drought Frequency

Drought frequency is the number of drought occurrence along the study period (1987 to 2017), which quantify the drought events that occurred into numbers. The drought occurrence is determined when the drought indices value shows negative (below 0) until the value becomes positive, which indicating the drought has ended, up to that particular previous month.

3.7.2 Mean Drought Duration

Drought duration is the number of months between the drought commencement month and the end month for each particular drought event. Mean drought duration will be computed to generalize the overall duration for the drought events from year 1987 until 2017 of a single location as shown in Equation 3.33.

$$Mean\ drought\ duration, MDD = \frac{\sum_{i=1}^{N} DD_i}{N} \tag{3.33}$$

where,

DD_i = Drought duration for single drought event in month i

N = Number of drought events observed during study period of 35 years

3.7.3 Mean Drought Severity

Drought severity is directly taken from the value computed by the drought indices, and will be further adopted in mean drought severity computation to represent and summarize the general drought severity in that particular station area.

$$Drought\ severity, DS = Drought\ indices\ value \tag{3.34}$$

$$Mean\ drought\ severity, MDS = \frac{\sum_{j=1}^{N} DS_j}{N} \tag{3.35}$$

where,

DS= Drought severity in negative value for that particular drought event period j

N = Number of drought events observed during study period of 35 years

3.7.4 Mean Drought Intensity

Drought intensity is the average of drought indices value within the drought duration, which is computed by drought severity divided by drought duration. For each drought event, the intensity will be sum up and used to measure the mean drought intensity to represent the average drought intensity in that location.

$$Drought\ intensity, DI = \frac{\sum_{j=1}^{DD} Drought\ Severity_j}{DD} \tag{3.36}$$

$$Mean\ drought\ intensity, MDI = \frac{\sum_{j=1}^{N} DI_j}{N} \tag{3.37}$$

where,

DI= Drought intensity in negative value for that particular drought event period j

N = Number of drought events observed during study period of 35 years

3.7.5 Mean Drought Peak

Drought peak is the highest indices value within a drought event period. It is represented by a single monthly value computed by the drought indices. Mean drought peak is further evaluated to describe the peak of each drought event along the study period (year 1987 to 2017).

$$Drought\ peak, DP = max\{drought\ indices\ value_i\}, 1 \leq i \leq DD \qquad (3.38)$$

$$Mean\ drought\ peak, MDP = \frac{\sum_{j=1}^{N} DP_j}{N} \qquad (3.39)$$

where,

DP= Maximum negative indices value for that particular drought event period j

N = Number of drought events observed during study period of 35 years

3.8 Accuracy

To evaluate which methods and time-scales are best feasible to describe the climate condition for the study area, several accuracy tests are required to assess whichever the SPI, the SPEI and the SDI could portrait a better result in identifying drought events occurred in southern region of Peninsular Malaysia. This includes the ability of each drought index to capture the drought event, drought period prediction as well as late or early detection of drought.

3.8.1 Probability of Detection

Probability of detection is adopted to check the correct prediction of historical drought with the observed drought computed by the SPI, the SPEI and the SDI method under different time-scales. The probability of detection for each method will be computed by using Equation 3.40:

$$Probability\ of\ detection, P.o.D = \frac{n}{N} \times 100\% \qquad (3.40)$$

where,

n =Number of computed droughts observed using drought indices of different time-scales.

N =Number of historical drought cases observed in southern region of Peninsular Malaysia.

3.8.2 Mean Absolute Error

To evaluate whether the forecasted duration of computed drought by using drought indices under different time-scales is accurate to the historical drought, mean absolute error is the sum of absolute differences between the actual historical drought and forecast drought using drought indices under different time-scales divided by the number of cases observed.

$$Mean\ absolute\ error, MAE = \frac{\sum_{t=1}^{n} |A_t - P_t|}{n} \tag{3.41}$$

where,

A_t= Actual historical drought duration under case *t*

P_t= Predicted drought duration of drought indices under case *t*

$n =$ Number of cases

3.8.3 Mean Bias Error

Mean bias error is used to estimate the tendencies of a drought index under certain time-scale to predict the exact drought duration as the actual historical drought duration.

$$Mean\ bias\ error, MAE = \frac{\sum_{t=1}^{n} P_t - A_t}{n} \tag{3.42}$$

where,

A_t= Actual historical drought duration under case *t*

P_t= Predicted drought duration of drought indices under case *t*

$n =$ Number of cases

After that, the mean bias error obtained from each case and drought index will be categorized as Equation 3.43:

$$If\ MAE \begin{cases} < 0, Under - predicted \\ = 0, Predicted \\ > 0, Over - predicted \end{cases} \tag{3.43}$$

3.8.4 Onset and End Detection

Onset and end of computed drought were compared with the actual onset and end of the historical drought. The commencement and end detection of drought is important as it identified whether a drought can be forecasted early or later as well as the duration of the forecasted to be longer for mitigation purposes. The date of commencement and end of historical drought will be utilized to scrutinize with the drought date computed by each drought index. Early detection will be marked as negative "-", while late detection will be marked as positive "+".

$$Mean\ onset\ detection = \sum_{t=1}^{n} \frac{OD_t}{n} \tag{3.44}$$

where,

OD_t= Onset detection of drought month under case t

n= Number of cases

$$Mean\ end\ detection = \sum_{t=1}^{n} \frac{ED_t}{n} \tag{3.45}$$

where,

ED_t= End detection of drought month under case t

n= Number of cases

3.8.5 Trend Analysis

Trend analysis is used to compute and interpret the trend pattern of dry events for each month. Under trend analysis, the values computed by each drought index will be evaluated under monthly time series along the study period of 35 years (1987 to 2017) with linear regression method. Linear regression is a simple linear approach to test for the relationship between two variables and it is widely adopted in predictions. The trend equation for each station will be computed as shown in Equation 3.46 to 3.51.

$$y = a + bx \tag{3.46}$$

$$a = \bar{Y} - b\bar{X} \tag{3.47}$$

$$b = \frac{\sum XY - n\bar{X}\bar{Y}}{\sum X^2 - n\bar{X}^2} \tag{3.48}$$

$$\bar{X} = \frac{\sum X}{n} \tag{3.49}$$

$$\bar{Y} = \frac{\sum Y}{n} \tag{3.50}$$

$$b = \frac{\sum XY - n\bar{X}\bar{Y}}{\sum X^2 - n\bar{X}^2} \tag{3.51}$$

where,

a= Y-intercept of graph

b= Slope of the regression line

x=Independent value in time

X=X-axis value of each data point plotted

Y=Y-axis value of each data point plotted

$\bar{X}$=Arithmetic mean of all Y

$\bar{Y}$=Arithmetic mean of all X

n=Number of months per year

3.8.6 Average Moving Range

Moving range is the absolute difference between 2 data for certain time-scale. The average moving range is further computed to show the fluctuation of the datasets along the study period as shown in Equation 3.52 and 3.53:

$$Average\ moving\ range, AMR = \frac{\sum_{t=1}^{n} \left| D_j - D_i \right|}{n} \tag{3.52}$$

where,

D_j= Data of current month

b= Data of previous month

n=Number of data available for each month in 35-year study period

3.9 Summary

For results analysis obtained by the SPI, the SPEI and the SDI method under different time-scales, several sections are included, which is the spatiotemporal pattern of dry events, accuracy test and trend of dry pattern in southern region of Peninsular Malaysia. The discussion on the spatial and temporal distribution of dry pattern will be based on drought characteristics such as frequency, duration, severity, intensity and peak computed with the SPI, the SPEI method under time-scales of 1-, 3-, 6- and 12-month, as well as the SDI method under time-scales of 3-, 6- and 12- month variables. Next, the analysis on the accuracy of drought indices will be discussed by comparing the probability of detection, mean absolute error, mean bias error and onset and end detection of drought date. Consequently, the average moving range will be evaluated to assess a feasible time-scale which can be adopted in this study, following by trend of the drought index shown which will be analyzed and discussed.

[redacted]

[redacted] RESULTS AND DISCUSSION

4.1 General Discussion

For general discussion of drought characteristics, spatial and temporal distribution of dry pattern in southern region of Peninsular Malaysia will be reviewed with the SPI, the SPEI and the SDI method under different time-scales. The drought characteristics distribution included occurrence and magnitude of drought. The occurrence of drought has included drought frequency and mean drought duration, while the magnitude of drought involved mean drought intensity, mean drought severity and mean drought peak.

4.1.1 Spatio-temporal Distribution of SPI

For identification of drought event in this study, the drought frequency and duration were measured using the SPI monthly data obtained at rainfall stations from 1983 to 2017. The occurrence of drought in the southern region using the SPI at 1-, 3-, 6- and 12-month lags were found in all stations and the results shown in Table 4.1 are represented in Figure 4.1 to Figure 4.4.

The SPI-1 identified the most frequent short-term drought occurred in the north-west and the south-east part of the southern region, while the north-east part of the southern region has the least short-term drought to be occurred. In the results evaluated by the SPI-3, all stations showed the similar frequency of drought, except for the 3 stations at the north-west of the southern region, which are displayed more frequently for a 3-month drought to occur. Station 2636170 which is located at the north-east of the southern region has less frequency for a 3-month drought to be occurred.

The SPI-6 illustrated that 3 separated areas had more frequent drought: the north-west, the north-east and the south part of the southern region. The remaining stations showed similar frequency of 32 sets along 35 years. The SPI-12 illustrated a more uniform drought frequency in the southern region. the south area of the southern region has more frequent long-term drought compared to other locations. Meanwhile, the south-east and the north part of the southern region showed a lesser drought frequency.

Thus, the SPI identified meteorological drought is more likely to be appeared at the north-west part of the southern region which is the east of Negeri Sembilan, while the south area of the southern region which is the south of Johor is more likely to have droughts with longer time scales. Other than that, the east coast of the southern region is the least prone zone to the drought events with shorter time scales.

In the SPI-1, the duration of the drought identified is relatively similar across the southern region except for the north-east part, where the drought lasted for almost 3 months. Even the SPI-1 which utilizes 1-month cumulative rainfall in the computation, however at the tropical zone, the drought usually dispersed after 2 to 3 months. This caused the drought duration identified by the SPI-1 to be longer. In the SPI-3 case, the duration of drought identified is almost constant across the southern region except also for the north-east part, which is similar to the cases in the SPI-1, where both the drought duration increases in 3-month length. The duration is lengthened due to less fluctuations in the SPI value given since the computation is based on 3-month cumulative rainfall. The SPI-1 and the SPI-3 shows a similar trend in identifying the short-term drought.

SPI-6 shows that the drought duration is longer with almost 7 months at the south-east and also the north-west part in the southern region. Meanwhile, the south-west, the central and the north-east area of the southern region indicate a shorter drought duration of 5 months even with 6-month cumulative rainfall. This prolonged drought duration of 1 month is due to the long-term drought that met with the south-west monsoon season which brings lesser precipitation and more heat temperature. The SPI-12 shows that the longest drought occurred at the north part of the southern region which lasts for 15 months, while the remaining area across the southern region have similar duration of 9 months.

We can conclude that the north area of the southern region, which is also the north part of Negeri Sembilan are prone to long-term hydrological drought events. Furthermore, the north-east part of the southern region, which near the borderline between Johor and Pahang is more susceptible to meteorological or agricultural drought events.

Table 4.1: Occurrence of Drought Determined by SPI under Different Time Scale for 16 Rainfall Stations.

Station	SPI							
	SPI-1		SPI-3		SPI-6		SPI-12	
	Frequency	Duration	Frequency	Duration	Frequency	Duration	Frequency	Duration
1437116	91	2.13	55	3.67	39	5.44	27	7.89
1534002	86	2.36	48	3.81	35	5.03	23	8.43
1541139	98	1.99	51	4.10	32	6.53	17	10.35
1732004	82	2.44	45	4.42	33	5.73	20	9.65
1737001	88	1.94	47	4.06	31	6.32	15	12.47
1931003	85	2.11	47	3.96	34	5.41	19	10.47
2025001	86	2.07	48	3.96	31	6.06	22	7.73
2224038	111	1.78	58	3.36	37	5.68	22	9.68
2231001	90	2.20	47	4.13	32	5.88	24	8.46
2235163	90	2.20	47	4.13	32	5.88	24	8.46
2321006	86	2.07	57	3.25	30	6.83	23	8.96
2330009	89	2.12	47	4.11	30	6.37	19	9.89
2636170	76	2.96	35	6.91	38	5.55	19	9.63
2719001	90	2.24	50	4.00	31	6.23	19	9.53
2725083	91	2.20	55	3.55	32	6.19	22	8.77
3020016	85	2.34	45	4.40	30	6.47	13	15.54
Average	**89**	**2.20**	**49**	**4.11**	**33**	**5.98**	**21**	**9.74**

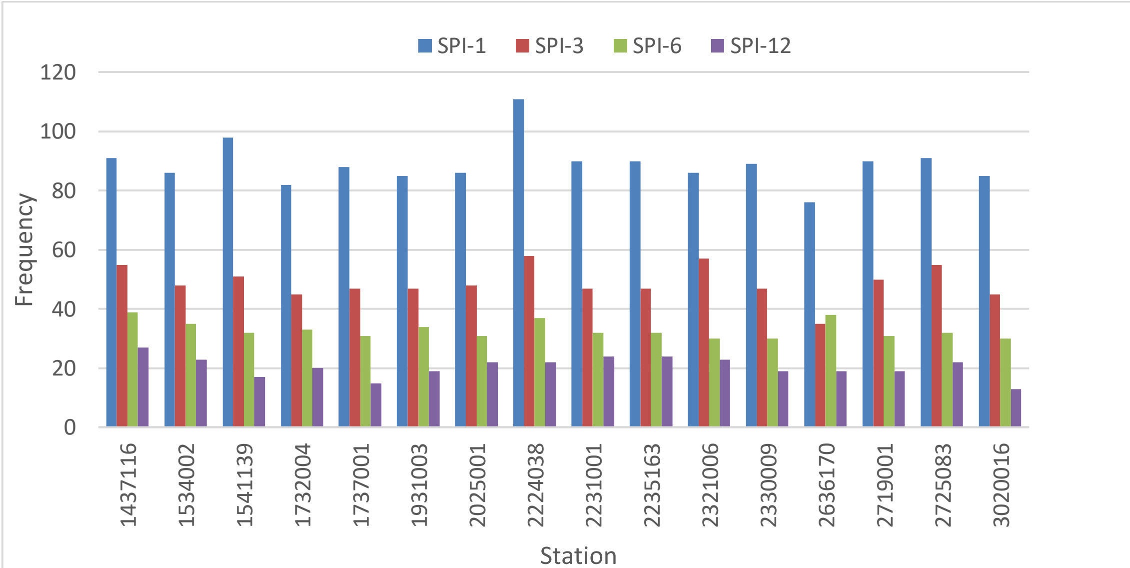

Figure 4.1: Frequency of Drought Determined by SPI under Different Time Scale for 16 Rainfall Stations.

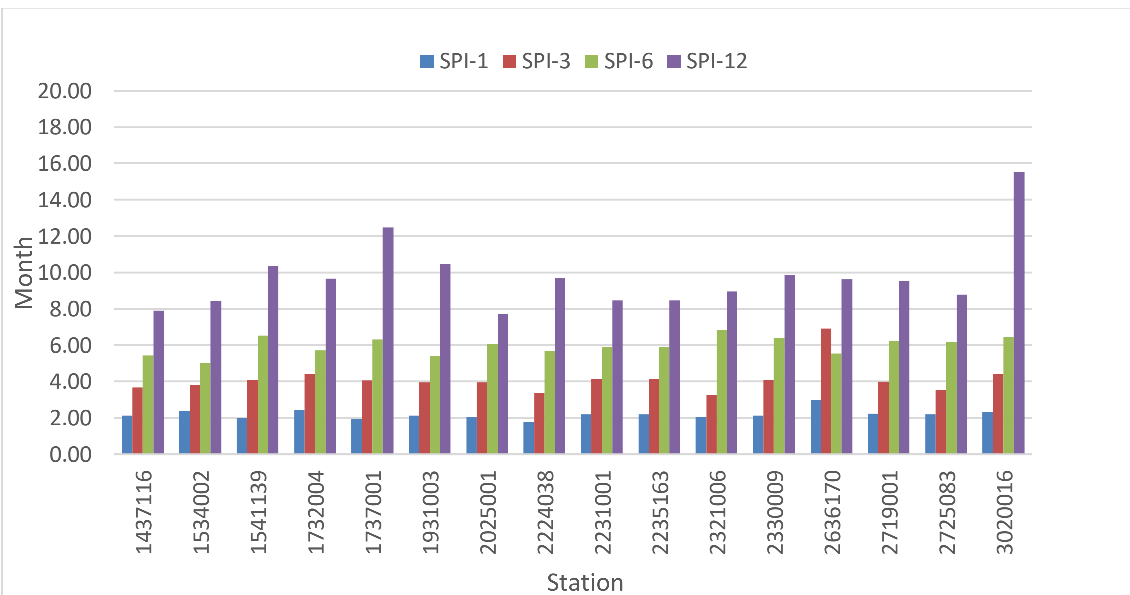

Figure 4.2: Duration of Drought Determined by SPI under Different Time Scale for 16 Rainfall Stations.

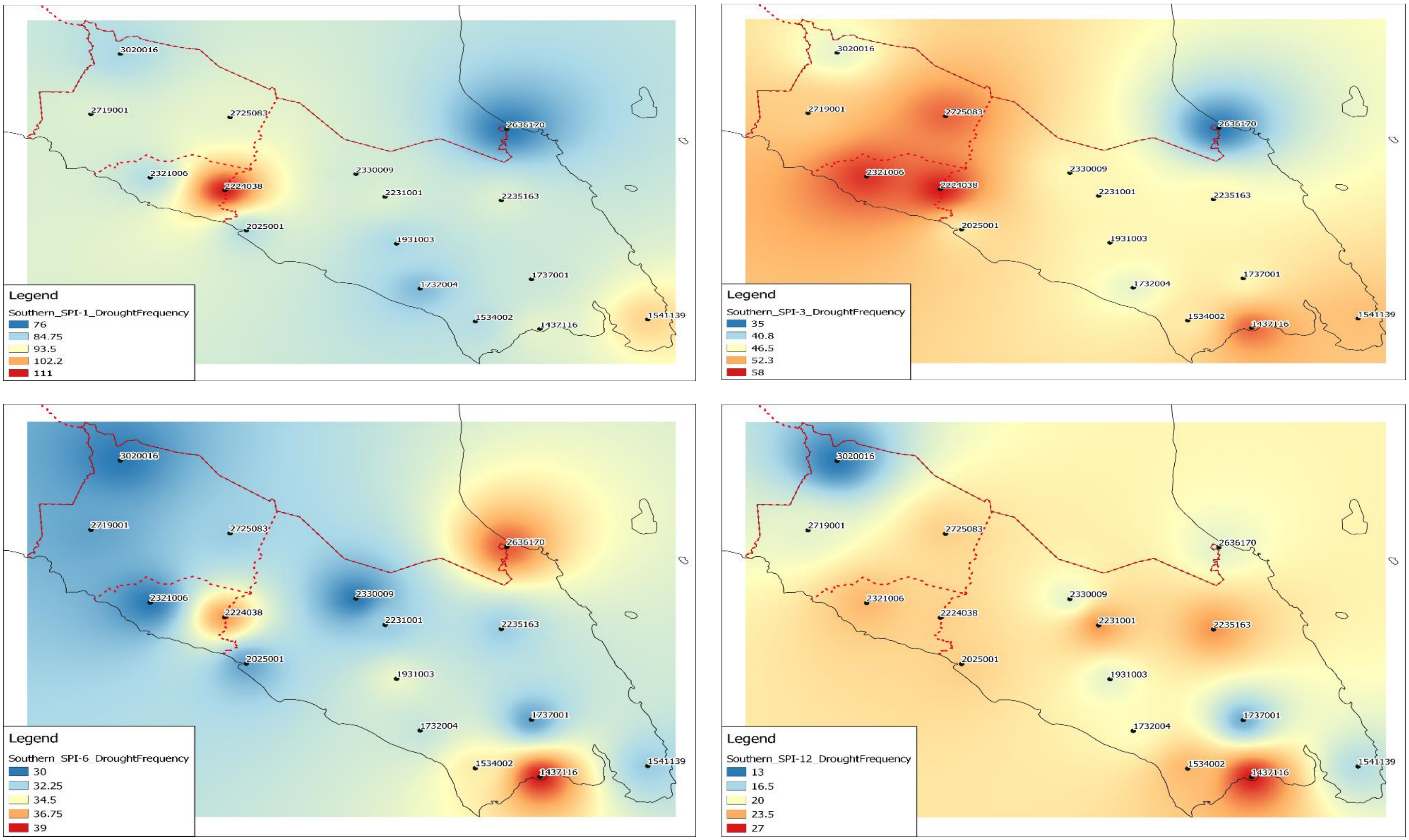

Figure 4.3: Heat Map of Drought Frequency Identified by SPI over Whole Southern Region.

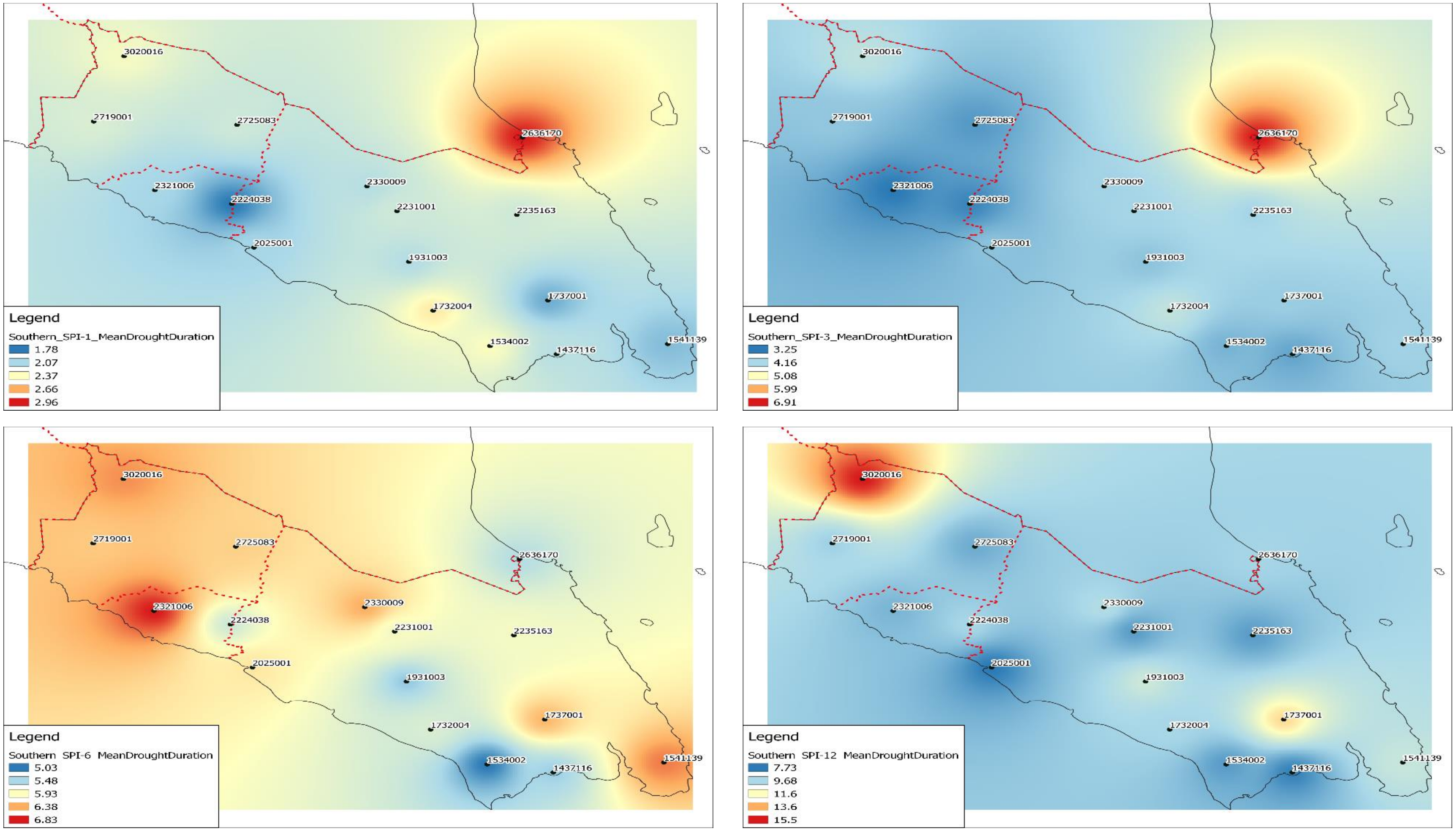

Figure 4.4: Heat Map of Drought Duration Identified by SPI over Whole Southern Region.

4.1.2 Spatio-temporal Distribution of SPEI

The SPEI monthly data acquired at all the rainfall stations from 1983 to 2017 is used to determine the drought event in this study. Occurrence of the drought in the southern region using the SPEI at 1-, 3-, 6- and 12-month lags were found in all stations and the results shown in Table 4.2 are represented in Figure 4.5 to Figure 4.8.

The SPEI-1 identified the most frequent location to have drought events are only at the north-west of the southern region, whilst the remaining areas have the same drought frequency across the southern region. From the results illustrated by the SPEI-3 computation, it shows drought events will more likely to occur at the north-west and the south part of the southern region. The SPEI-6 shows that at the north-west and the south of the southern region are having more drought events than the remaining areas. Meanwhile, from the results of the SPEI-12, it is indicated that the south-west and the south of the southern region are more likely to have drought events.

The heat map computed by the SPEI results have less significant variations in terms of spatial distribution of the drought, only that the south area of the southern region is less prone to agricultural or meteorological drought events. Other than that, drought events are mostly concentrated and happened frequently at the south or the north-west of the southern region. The heat map shows that meteorological drought will occur more regularly at the north-west part of the southern region, which is also the borderline between Johor and Negeri Sembilan. Meanwhile, drought episodes with longer time scales will occur more often at the north-west and the south of the southern region, which are the whole Malacca, east to the south area of Negeri Sembilan, and also the south of Johor.

In the SPEI-1, the duration of drought identified is non-identical across the southern region. The north-east and the south-west of the southern region exhibit a longer duration of drought (almost 3 months) even though 1-month cumulative rainfall is used in the computation. The east, the central and the north-west of the southern region show a relatively low duration compared to other areas. The SPEI-3 further illustrates the inconsistency drought duration across the study area. The north-east and the central region show a comparatively long duration (6 months) compared to other areas.

In the SPEI-6, most of the areas have shown an addition of 1-month prolonged drought duration with 6-month cumulative rainfall. The areas with long drought duration are: the north, the north-west, central, the north-east, and the south-east of the southern region. The south and part of the north-west have indicated relatively short drought duration of 5 months. In the SPEI-12, the trend has changed such that the areas with longer drought duration have narrowed down. The north-west, the south and east coast areas are no longer having prolonged drought duration even if the SPEI-12 was computed using 12-month cumulative rainfall. For the SPEI-12, there are several areas left with longer drought duration which are the north and the central of the southern region with almost 15 months drought event.

In conclusion, the north-east area of the southern region which at the borderline between Johor and Pahang is more prone to agricultural or meteorological drought event with prolonged duration. Meanwhile, the north part of the southern region, which is also the north of Negeri Sembilan will face hydrological drought event possibly with prolonged duration.

Table 4.2: Occurrence of Drought Determined by SPEI under Different Time Scale for 16 Rainfall Stations.

Station	SPEI							
	SPEI-1		SPEI-3		SPEI-6		SPEI-12	
	Frequency	**Duration**	**Frequency**	**Duration**	**Frequency**	**Duration**	**Frequency**	**Duration**
1437116	91	2.32	51	4.20	39	5.23	26	7.77
1534002	86	2.55	51	4.08	35	5.71	28	7.64
1541139	93	2.33	46	4.54	32	6.66	18	10.33
1732004	79	2.72	44	4.93	35	5.86	15	13.93
1737001	93	2.24	51	4.25	35	6.00	16	13.25
1931003	85	2.38	47	4.32	32	6.06	16	13.31
2025001	91	2.33	51	4.08	34	6.00	16	12.19
2224038	106	1.99	57	3.63	41	5.46	25	8.68
2231001	85	2.52	45	4.80	31	6.74	18	12.28
2235163	92	2.25	40	5.33	31	6.65	19	10.37
2321006	95	2.19	53	4.00	32	6.66	26	8.04
2330009	92	2.23	42	5.17	33	6.36	18	11.50
2636170	80	2.76	41	5.59	34	6.29	18	11.06
2719001	87	2.48	45	4.71	30	6.83	18	11.11
2725083	92	2.35	47	4.40	36	5.75	26	7.38
3020016	83	2.59	50	4.16	29	6.76	14	14.57
Average	**89**	**2.39**	**48**	**4.51**	**34**	**6.19**	**20**	**10.84**

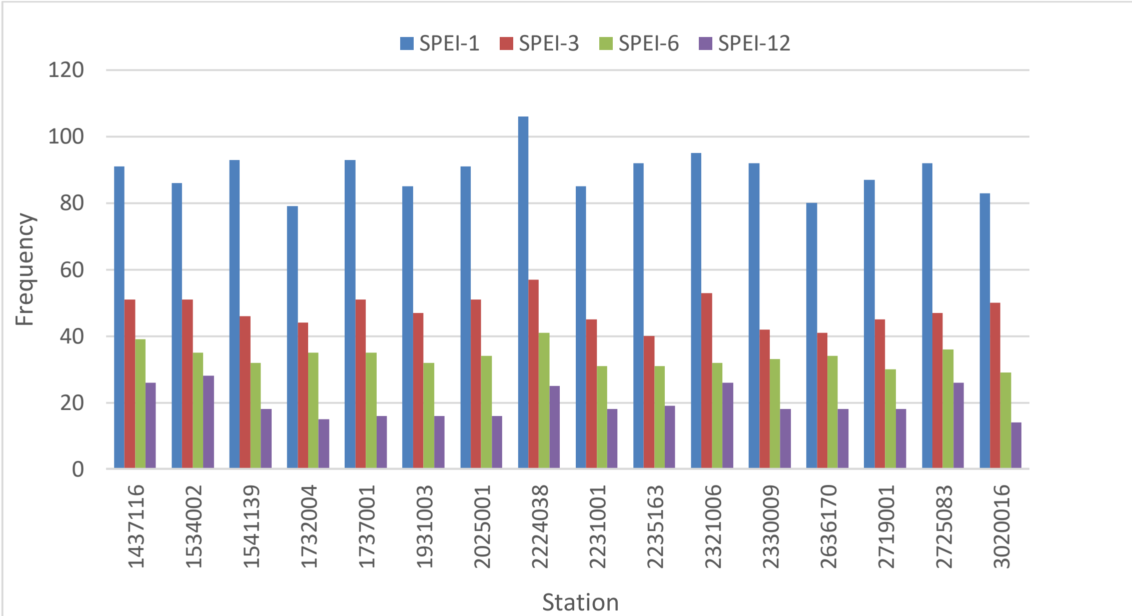

Figure 4.5: Frequency of Drought Determined by SPEI under Different Time Scale for 16 Rainfall Stations.

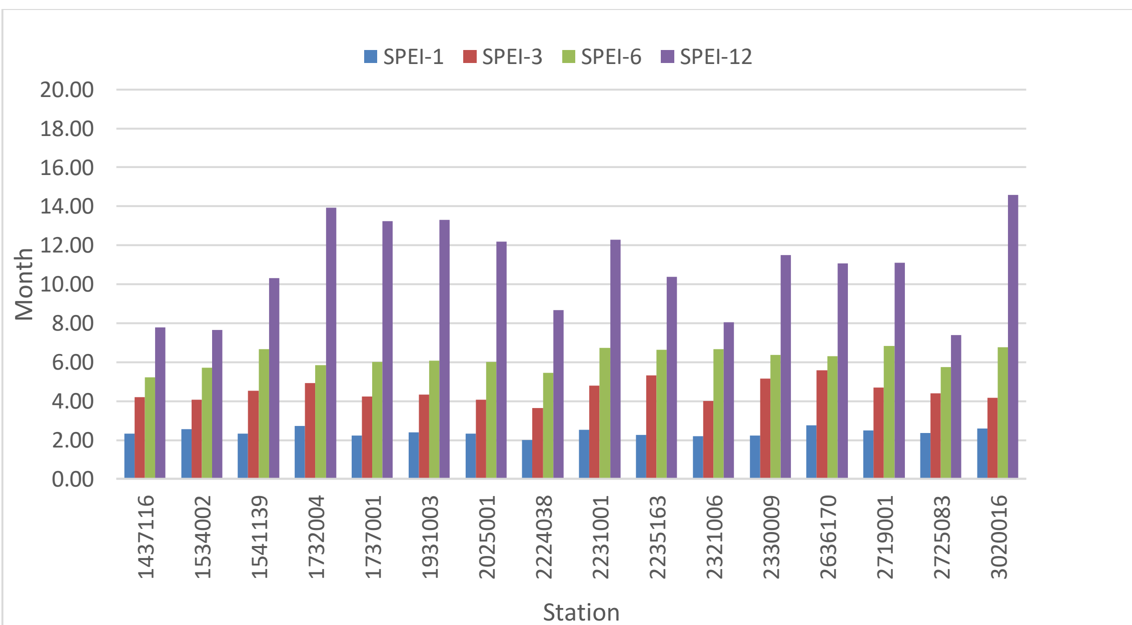

Figure 4.6: Duration of Drought Determined by SPEI under Different Time Scale for 16 Rainfall Stations.

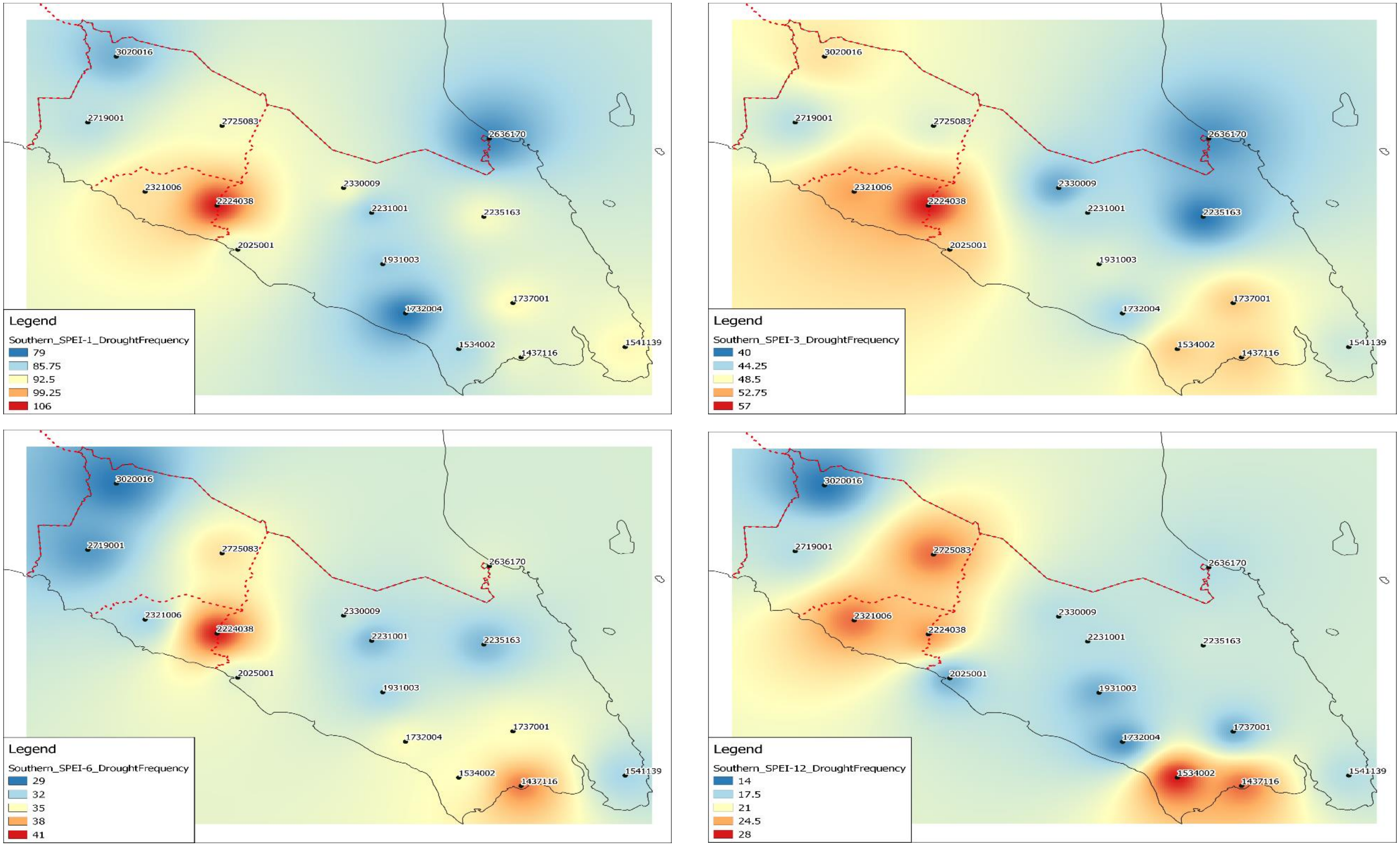

Figure 4.7: Heat Map of Drought Frequency Identified by SPEI over Whole Southern Region.

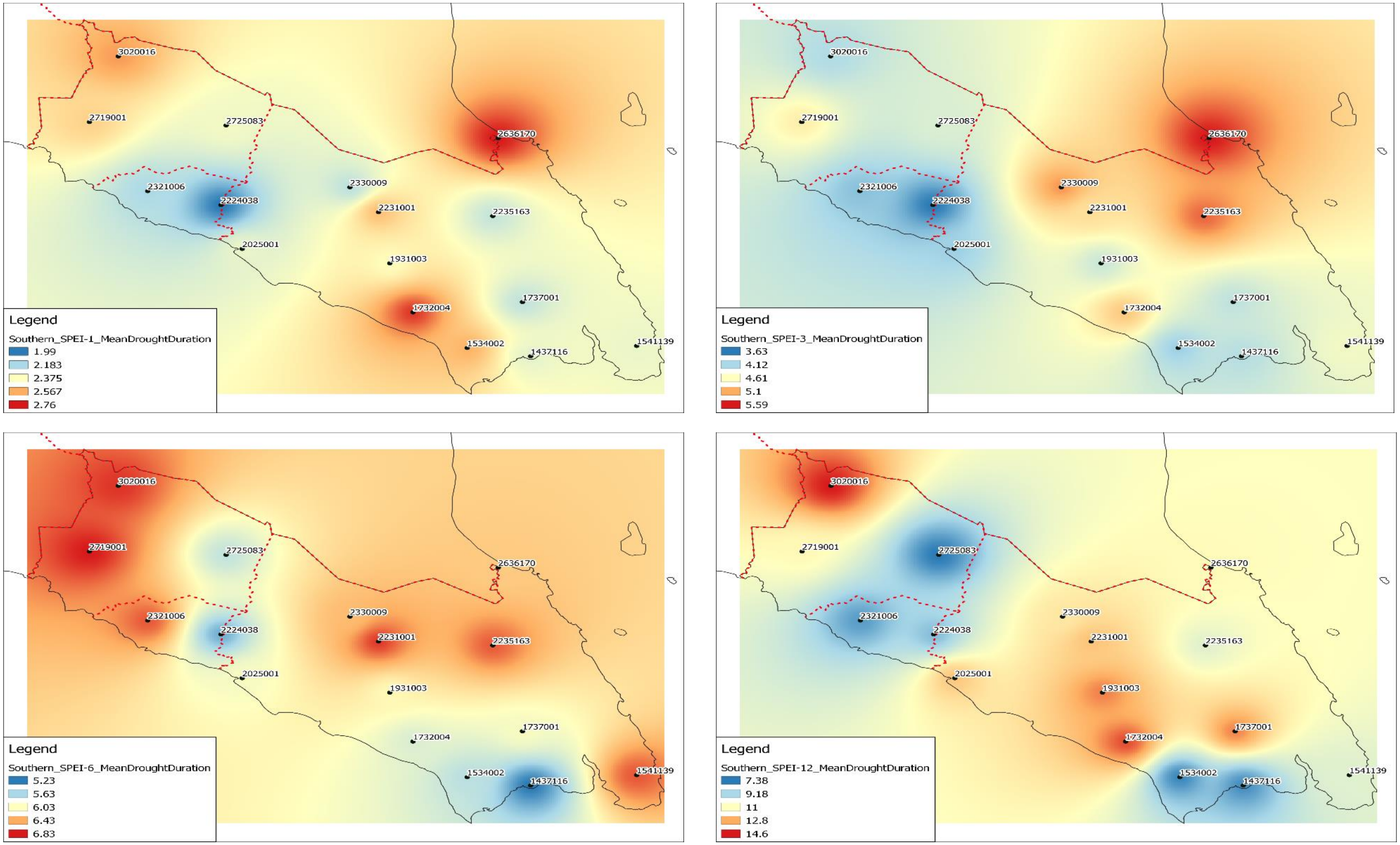

Figure 4.8: Heat Map of Drought Duration Identified by SPEI over Whole Southern Region.

4.1.3 Spatio-temporal Distribution of SDI

To determine the drought event in this study, the SDI monthly data obtained at the streamflow station from 1983 to 2017 is used. Occurrence of the drought in the southern region using the SDI at 3-, 6- and 12-month lags were found in all stations and the results shown in Table 4.3 are represented in Figure 4.9 to Figure 4.12.

Heat map of the SDI-3 shows that the north and east of the southern region have relatively lesser drought event compared to the remaining areas. The north-west and the central of the southern region are having a more frequent drought event. When it comes to the SDI-6, the trend has changed such that the north-west and the east coast have comparatively less drought event compared to the central area of the southern region. In the SDI-12, it shows that only the north of the southern region tends to have more drought events compared to the remaining areas across the southern region.

In conclusion, the SDI identified that the north-west of the southern region, which is the west of Negeri Sembilan is more prone to meteorological drought, while the north of the southern region, which is the central of Negeri Sembilan tends to have drought events with longer time-scales.

In determining the duration of the drought by using the SDI monthly data, it was observed that the east coast area of the southern region, which is also the east of Johor tends to have prolonged drought duration compared to other places. The location is where the Mersing River located, and the Mersing River is the main raw water sources for the Mersing River water treatment plant and as a backup raw water sources for the Congok Dam and the Tenglu water treatment plant (Chuah B. K., 2016; Halim Said, 2016). When the El-Nino hit Malaysia, the river could not supply these water facilities with such a massive volume of water. As the El-Nino effect prolongs the drought episodes, the duration of water woes at the particular area could escalate up to 3 years for the river to be at critical water level.

Table 4.3: Occurrence of Drought Determined by SDI under Different Time Scale for 8 Streamflow Stations.

Station	SDI-3		SDI-6		SDI-12	
	Frequency	Duration	Frequency	Duration	Frequency	Duration
1737451	36	7.31	20	12.4	11	21.45
2235401	27	9.93	18	14.56	7	39.43
2237471	24	12.58	14	20.43	8	34.88
2322415	30	8.87	20	12.85	13	18.77
2519421	38	5.87	16	14.94	11	20.91
2528414	35	7.89	23	11.48	12	18.08
2533474	36	7.31	20	12.4	11	24.15
2722413	25	9.16	19	10.58	18	11.06
Average	**31**	**8.62**	**19**	**13.71**	**11**	**23.59**

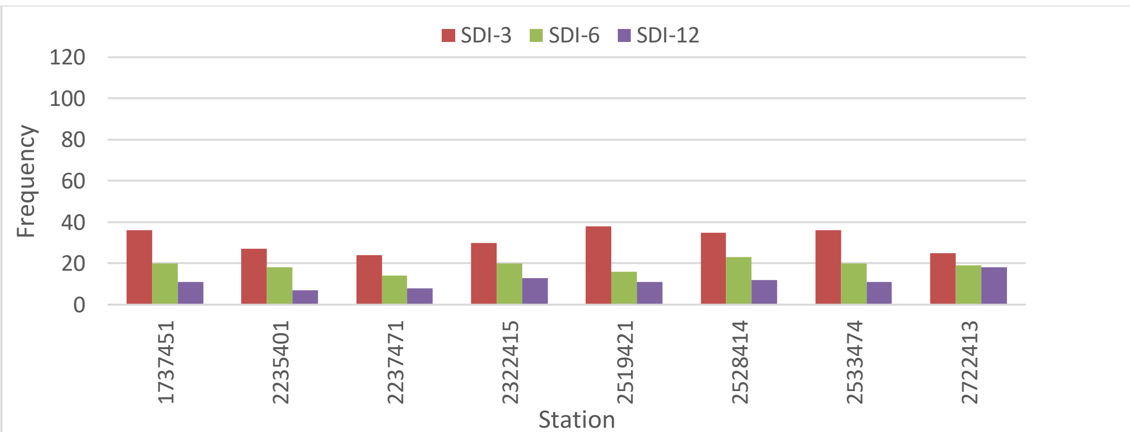

Figure 4.9: Frequency of Drought Determined by SPEI under Different Time Scale for 8 Streamflow Station.

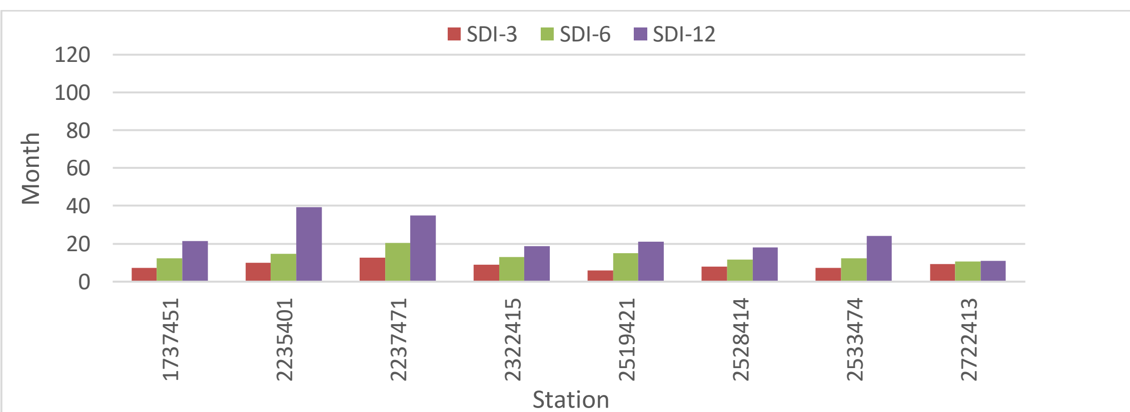

Figure 4.10: Duration of Drought Determined by SPEI under Different Time Scale for 8 Streamflow Stations.

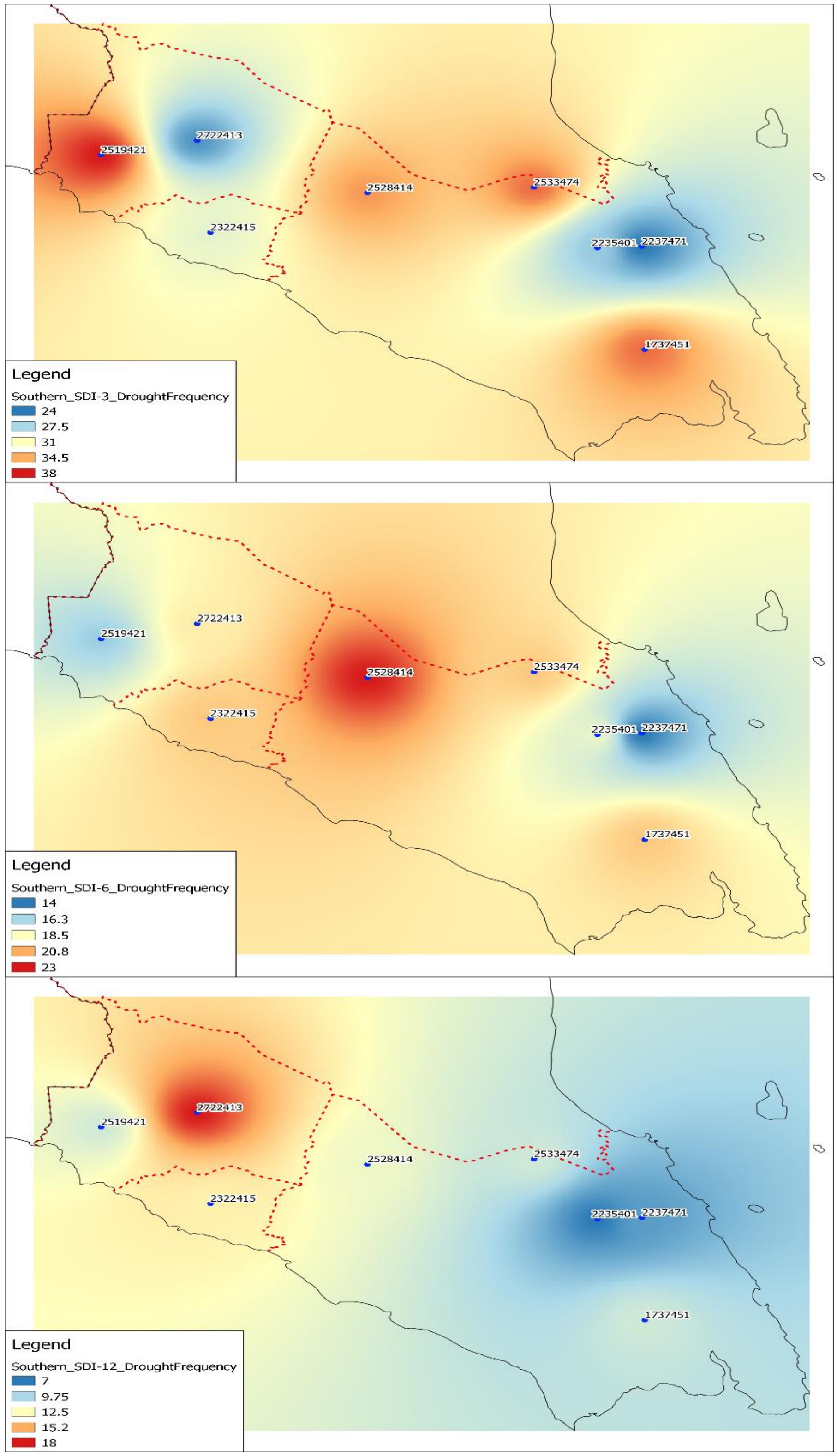

Figure 4.11: Heat Map of Drought Frequency Identified by SDI over Whole Southern Region.

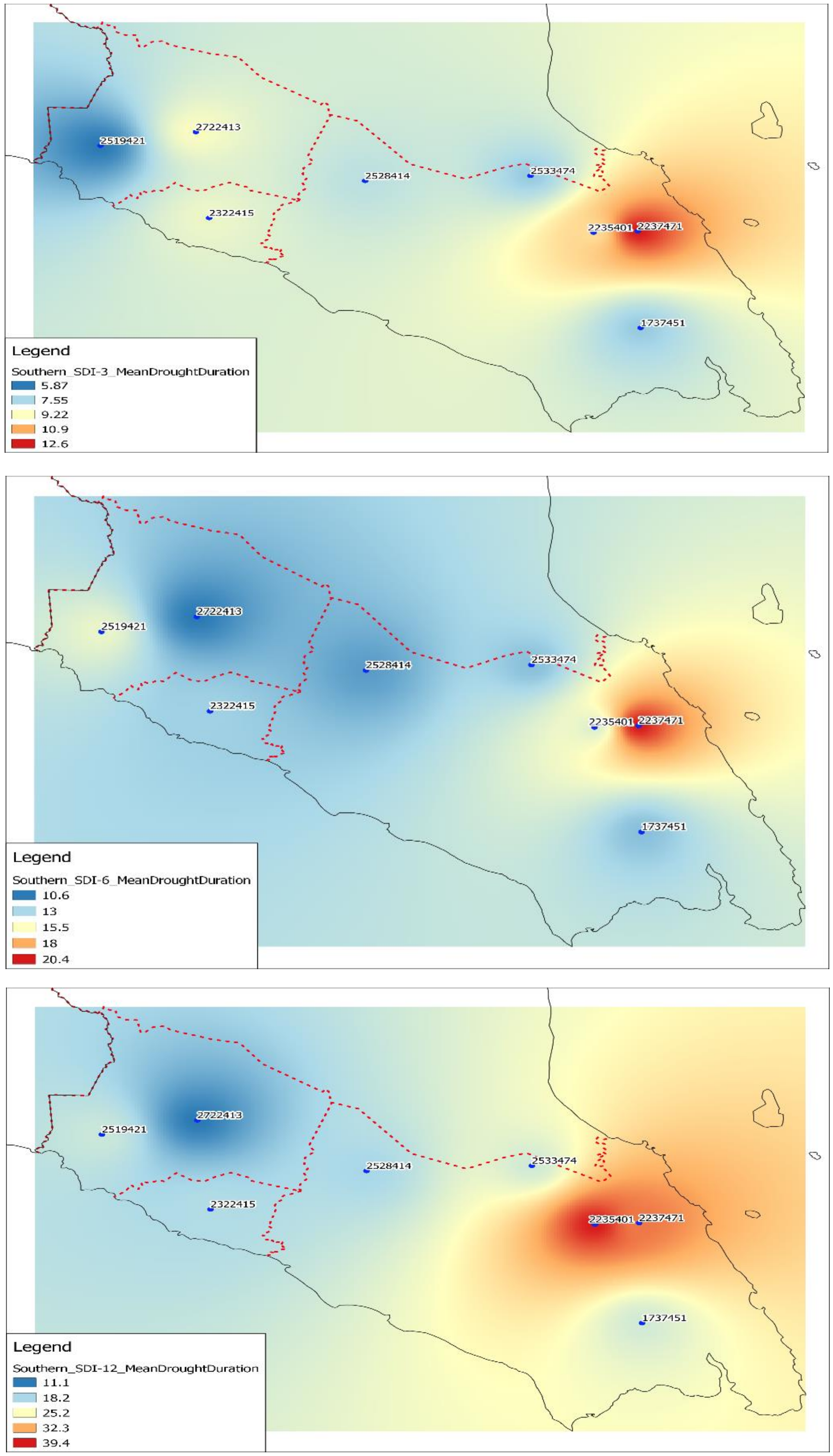

Figure 4.12: Heat Map of Drought Duration Identified by SDI over Whole Southern Region.

4.1.4 Magnitude of Drought for SPI

For studying the magnitude of drought events in this study, drought severity, intensity and peak were measured using the SPI monthly data which obtained at rainfall station from 1983 to 2017. Magnitude of the drought in the southern region using the SPI at 1-, 3-, 6- and 12-month lags were found in all stations and the results shown in Table 4.4 are represented in Figure 4.13 to Figure 4.18.

The SPI-1 identified that at the south area and the north-west of the southern region have the most severe drought events occurring along these 35 years (1983 to 2017). Meanwhile, the north-of the southern region, tends to have less severe drought events. At these places with much severe drought events, there is increase in the SPI-3, which covers from the south-west (Johor) along the west-coastal area until the north-west (Negeri Sembilan) and also the central area of the southern region. On the other hand, the north-east and the south-east of the southern region were having comparatively minor drought events. Up to 3-month lags, the heat maps have shown a comparable trend with no significant variation on the location of severe drought events.

In the SPI-6, it was illustrated that the south and part of the north-west area of the southern region encounter drought events with minor mean severity, whilst the central of the southern region which is entirely within the Johor state have more severe conditions with the SPI values just near normal. This spatio-temporal trend however, is completely changed in heat map computed by the SPI with 12-month time lags. The only area with severe drought events is at the south-east of the southern region (Johor) with value of -0.95, which almost reached the “normally dry” pointer as computed by the SPI-12. Meanwhile, the remaining locations show a comparatively normal severity especially the central of the southern region (Johor) which shows minor severity along these 35 years.

The SPI-1 shows that for mean drought intensity, several areas have shown a relatively low value, which is: the south-east, the south-west, the north and also the north-east of the southern region. Meanwhile, the south and the central of the southern region show high mean drought intensity throughout these 35 years. This indicates that the south and the central of the southern region have experienced relatively stronger meteorological drought events compared to other areas. In the SPI-3, the only area with low intensity shown in heat map is the south-east of the southern region (Johor), whilst the remaining areas remain a similar value across the southern region. The only area with high mean drought intensity is at the north-west of the southern region, which happens to be the north-west of Malacca.

In the SPI-6, more locations have indicated below average drought intensity. The south and part of the central of the southern region illustrate a relatively low intensity compared to other areas. Meanwhile, the north-east and the north-west have shown a high intensity value. The SPI-12 shows a rather low mean intensity across the southern region. The intensity is comparably higher at the south and the north-west areas, while several areas are below average, which is: the central and the south-east of the southern region. Nevertheless, the mean drought intensity shown by the SPI across the southern region was at near normal condition, where the weather is not too dry and likewise the drought is not too intense.

For the mean drought peak, the SPI-1 identifies that at the south and the south-west areas of the southern region, the highest drought peak could ascent until -1.11, which in the SPI value listing indicates that the weather is moderately dry at these locations. At the south-east and the central region, the drought peak measured was below average. In the SPI-3, it was shown that at the north-west, the south-west and the north-east of the southern region experienced higher drought peak, while the remaining areas have drought peak at below average. In short, the meteorological or agricultural drought occurred in the southern region have average peak value around -1.0, which is “moderately dry” in accordance to the SPI short time- scales computation.

The SPI-6 on the other hand, identified that mean drought peak for the southern region is mostly above average except for the south, the south-east and part of the central region. Locations such as the north-west and the south-west experienced comparably drier weather than other locations. In the SPI-12, the central and the south-east of the southern region only encountered near normal weather. Meanwhile, at the south, the north-west and the north of the southern region, the weather is moderately dry. In other words, according to the SPI long time-scales computation, it was proved that the hydrological or drought with longer time scales brings at most moderately dry weather to the southern region.

Table 4.4: Magnitude of Drought Determined by SPI under Different Time Scale for 16 Rainfall Stations.

Station	SPI											
	SPI-1			SPI-3			SPI-6			SPI-12		
	Severity	Intensity	Peak	Severity	Intensity	Peak	Severity	Intensity	Peak	Severity	Intensity	Peak
1437116	-0.82	-0.79	-1.09	-0.80	-0.63	-1.11	-0.77	-0.56	-0.93	-0.74	-0.42	-0.77
1534002	-0.79	-0.72	-1.00	-0.88	-0.69	-1.04	-0.80	-0.50	-0.90	-0.79	-0.47	-0.94
1541139	-0.77	0.70	-0.92	-0.74	-0.54	-1.03	-0.79	-0.43	-0.79	-0.97	-0.40	-0.66
1732004	-0.77	0.70	-0.98	-0.82	-0.70	-1.23	-0.85	-0.64	-1.18	-0.89	-0.51	-0.89
1737001	-0.89	-0.82	-1.05	-0.83	-0.64	-1.18	-0.82	-0.52	-1.02	-0.88	-0.59	-1.09
1931003	-0.85	-0.79	-1.02	-0.87	-0.64	-1.12	-0.87	-0.51	-0.91	-0.77	-0.37	-0.71
2025001	-0.86	-0.76	-0.99	-0.86	-0.69	-1.12	-0.86	-0.50	-0.95	-0.92	-0.35	-0.65
2224038	-0.84	-0.80	-1.03	-0.84	-0.71	-1.19	-0.80	-0.65	-1.17	-0.79	-0.47	-0.88
2231001	-0.78	-0.74	-1.00	-0.85	-0.65	-1.03	-0.86	-0.62	-1.00	-0.76	-0.37	-0.71
2235163	-0.78	-0.74	-1.00	-0.85	-0.65	-1.03	-0.86	-0.62	-1.00	-0.76	-0.37	-0.71
2321006	-0.88	-0.79	-1.11	-0.88	-0.74	-1.27	-0.83	-0.69	-1.15	-0.80	-0.60	-1.06
2330009	-0.81	-0.74	-0.94	-0.81	-0.60	-1.06	-0.81	-0.52	-0.96	-0.80	-0.46	-0.91
2636170	-0.70	-0.67	-1.03	-0.68	-0.63	-1.24	-0.82	-0.68	-1.11	-0.92	-0.55	-0.94
2719001	-0.82	-0.75	-1.02	-0.82	-0.65	-1.12	-0.85	-0.52	-0.93	-0.90	-0.45	-0.88
2725083	-0.84	-0.82	-1.08	-0.84	-0.62	-1.01	-0.81	-0.55	-0.98	-0.85	-0.51	-0.93
3020016	-0.78	-0.70	-1.01	-0.81	-0.69	-1.14	-0.83	-0.56	-1.05	-0.78	-0.57	-1.10
Average	**-0.81**	**-0.58**	**-1.02**	**-0.82**	**-0.65**	**-1.12**	**-0.83**	**-0.57**	**-1.00**	**-0.83**	**-0.47**	**-0.86**

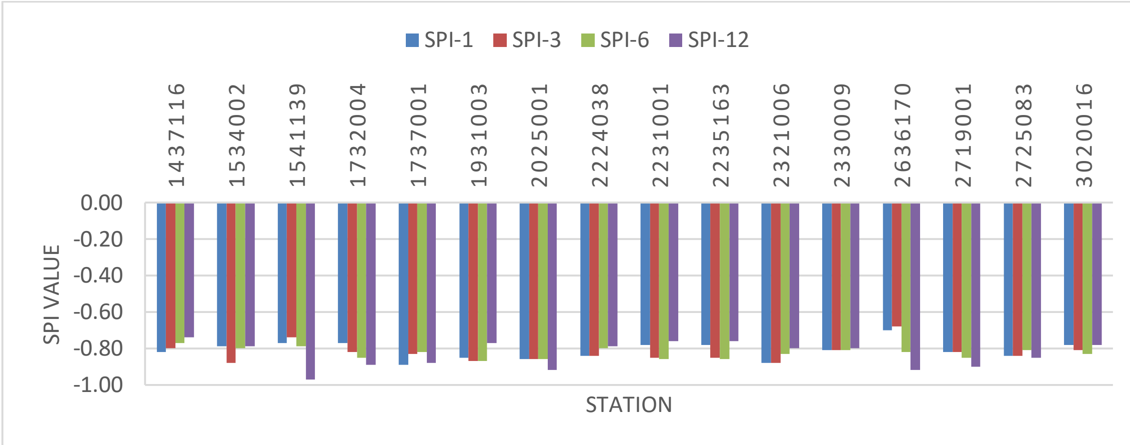

Figure 4.13: Mean Drought Severity for SPI Indices.

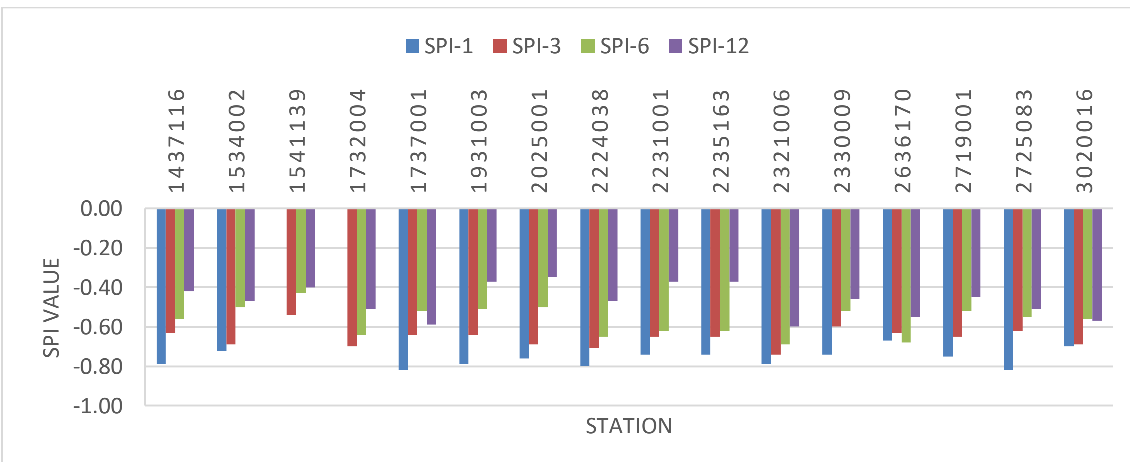

Figure 4.14: Mean Drought Intensity for SPI Indices.

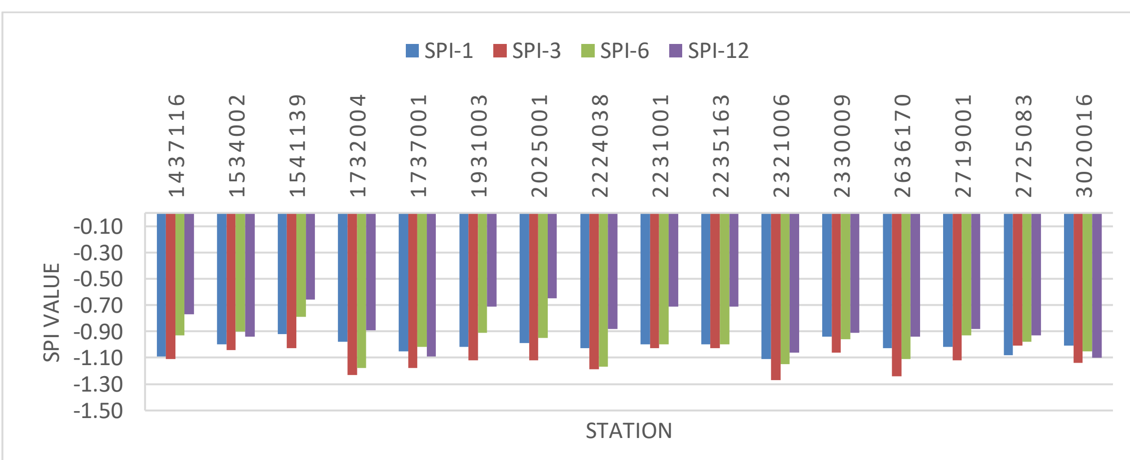

Figure 4.15: Mean Drought Peak for SPI Indices.

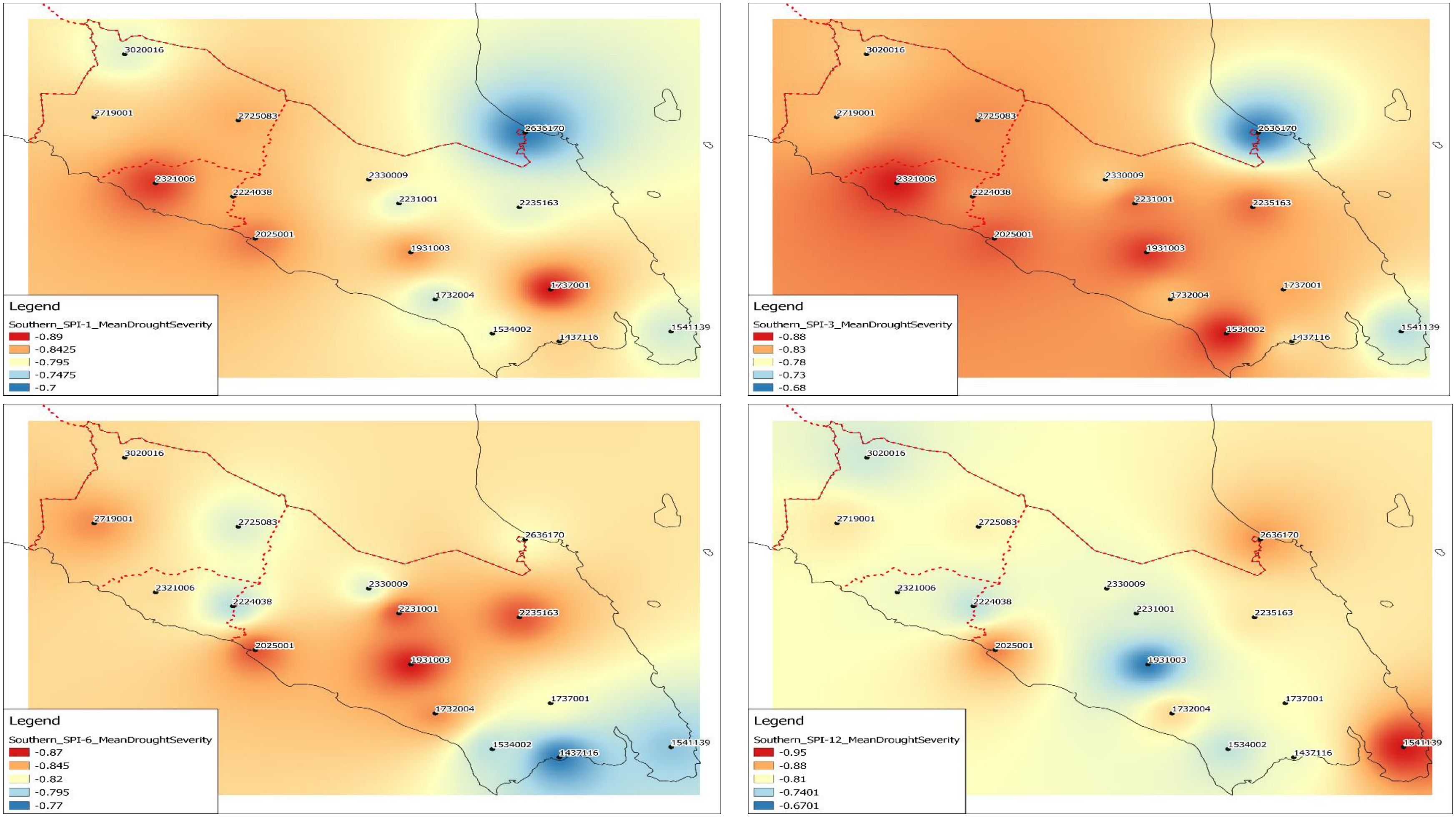

Figure 4.16: Heat Map of Mean Drought Severity Identified by SPI over Whole Southern Region.

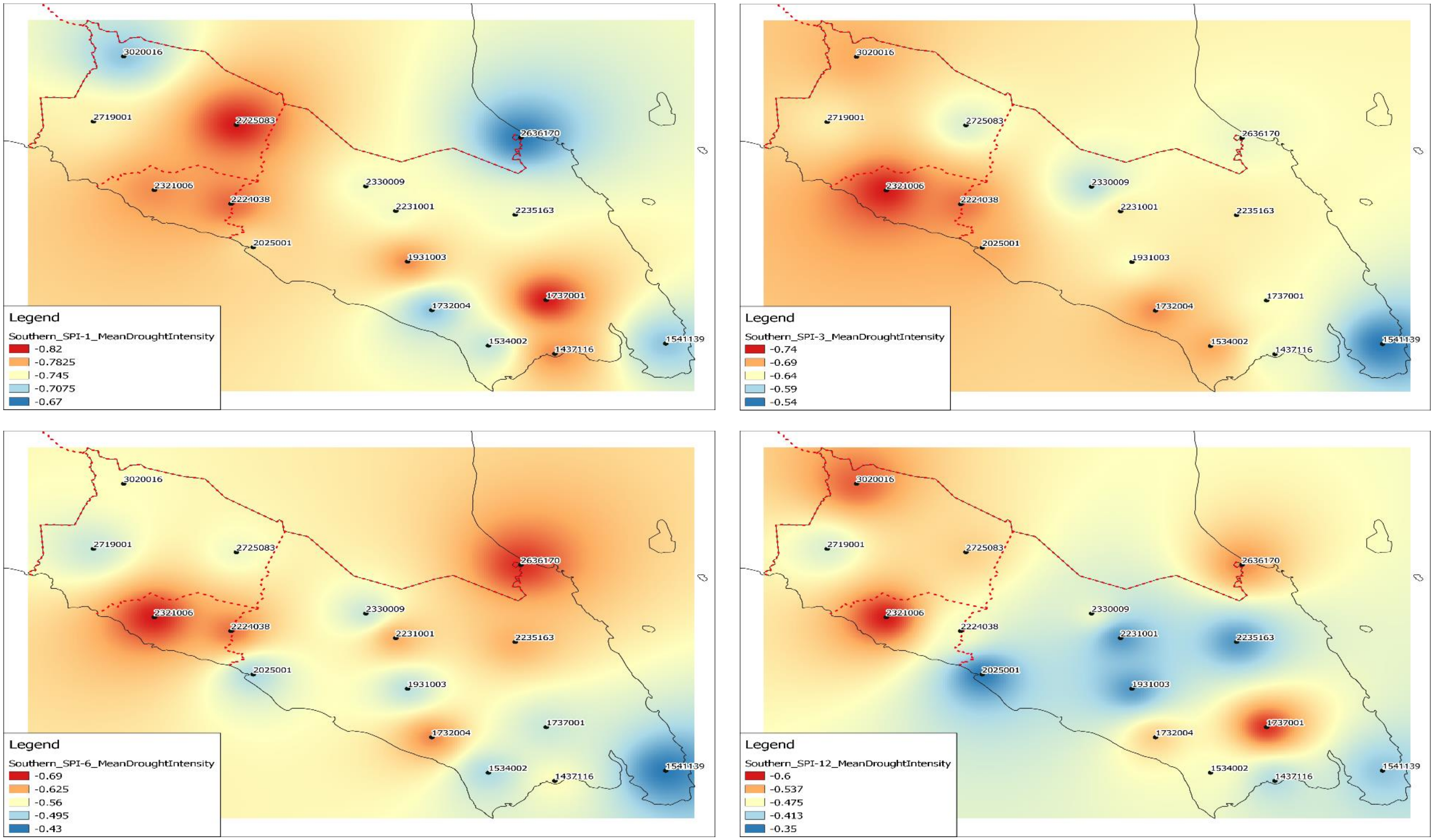

Figure 4.17: Heat Map of Mean Drought Intensity Identified by SPI over Whole Southern Region.

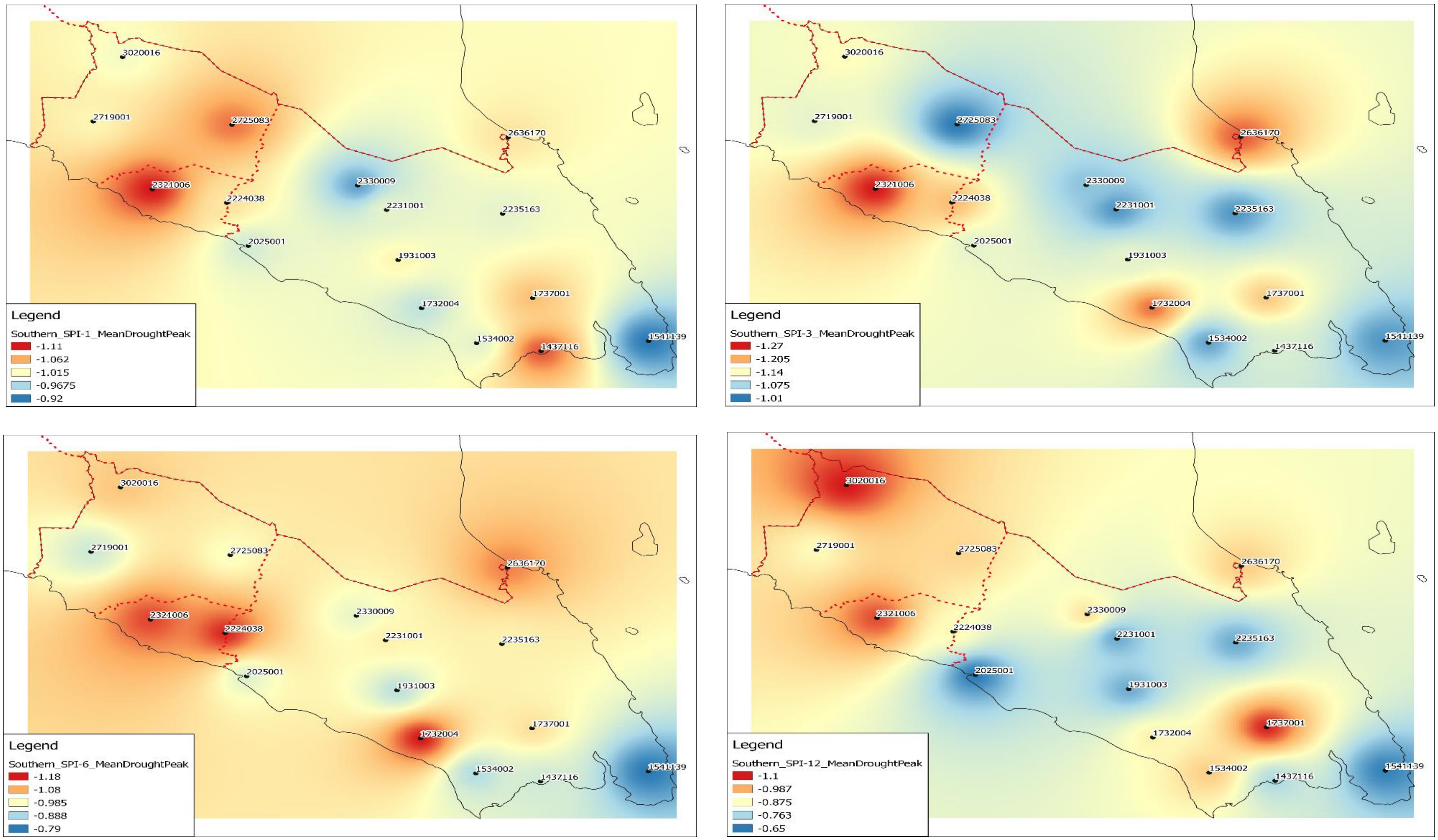

Figure 4.18: Heat Map of Mean Drought Peak Identified by SPI over Whole Southern Region.

4.1.5 Magnitude of Drought for SPEI

The SPEI monthly data obtained at rainfall stations from 1983 to 2017 is used to conduct the study on the magnitude of drought events in this study, which include drought severity, intensity and peak. The magnitude of the drought in the southern region using the SPEI at 1-, 3-, 6- and 12-month lags were found in all stations and the results shown in Table 4.5 are represented in Figure 4.19 to Figure 4.24.

The SPEI-1 illustrates a heat map which the southern region is generally at an average mean drought severity. However, the north-east, the south-east and the south-west areas experienced less severe drought events over the 35 years from 1983 to 2017. The central and the south region have the highest record on severity. In the SPEI-3, only part of the central region and the north-east of the southern region are indicated with below average severity. While the south-west and the north region being recorded with higher severity, the remaining areas maintained an average severity of -0.8 across the southern region. This shows that the meteorological or agricultural drought events at the southern region caused the weather to be just in “slightly dry” according to the SPEI range classification.

In the SPEI-6, only the north-west area and part of the central region encounter less severe drought events, whilst the north of the southern region, which is also the north of Negeri Sembilan has displayed highest severity compared to the remaining areas across the southern region. The trend however, has changed in the SPEI-12. The SPEI-12 indicates that the most severe drought events occur at the south-east of the southern region (Johor). Meanwhile, the central region maintained a low mean drought severity along 35 years. In short, the SPEI long time-scales computations have shown that several locations are vulnerable to severe drought events, which are: the north, the south-east and the south-west of Johor, and the north of Negeri Sembilan.

For mean drought intensity, the SPEI-1 shows that only the south area across the southern region experienced an average drought intensity that above average comparing to other location (-0.77). Besides, the north-east and the south-west region tend to have relatively lower intensity. In the SPEI-3, the east coast areas, the south and the central zone of the southern region have relatively low intensity which is below average compared with the south coast and the north zone where drought events with stronger intensity tend to happen.

In the SPEI-6, there are several locations which are recorded with intensity stronger than any other areas; these locations include the north-east, the north and part of the central region. The south and part of the north-west areas experienced drought events with weaker intensity compared to other locations. The SPEI-12 further illustrates the situation of long time-scales drought that the north-west and the north areas are more likely to encounter drought events with high intensity. Other locations such as the central or the south areas of the southern region experienced drought events with weaker intensity that is below average.

The SPEI computation with different time-scales have illustrate that agricultural or meteorological drought with strong intensity is more likely to appear at the south and the south-west of Johor as well as west of Malacca, while the north of Negeri Sembilan, the south of Malacca and the north-east of Johor will tend to have hydrological droughts with strong intensity.

SPEI-1 shows that for mean drought peak, drought events are much weaker at the central zone of the southern region. Meanwhile, at the south and the north region, drought events can be major, study shows that the peak at the south and the north region could reach up to -1.00. In the SPEI-3, the south-west and the north-west areas of the southern region experienced drought events with mean peak which is above average compared to the remaining locations, especially the central of the southern region that has relatively minor drought peak value. Study of drought with short time-scales the SPEI computation have found that the meteorological or agricultural droughts bring moderately dry weather in the southern region.

In the SPEI-6, the north, the north-west and the north-east of the southern region have recorded with mean drought peak up to -1.12 which falls in moderately dry weather range. Meanwhile, the south-east and part of the central region experience lower drought peak which is categorized as slightly dry weather according to the SPEI value range classification. the SPEI-12 illustrates that the recorded highest drought peak only occurs at the north area of the southern region, while the central and the south-east zone remain had drought events which brought slightly dry weather along these 35 years. Nonetheless, study has shown that the hydrological drought events will only bring at most moderately dry weather condition in the southern region.

Table 4.5: Magnitude of Drought Determined by SPEI under Different Time Scale for 16 Rainfall Stations.

Station	SPEI											
	SPEI-1			SPEI-3			SPEI-6			SPEI-12		
	Severity	Intensity	Peak	Severity	Intensity	Peak	Severity	Intensity	Peak	Severity	Intensity	Peak
1437116	-0.81	-0.75	-1.04	-0.79	-0.64	-1.06	-0.82	-0.59	-0.95	-0.80	-0.43	-0.72
1534002	-0.78	-0.69	-0.97	-0.82	-0.64	-0.64	-0.83	-0.61	-0.97	-0.76	-0.42	-0.74
1541139	-0.78	-0.72	-0.96	-0.80	-0.59	-1.02	-0.81	-0.45	-0.76	-0.95	-0.37	-0.54
1732004	-0.80	-0.72	-1.01	-0.81	-0.71	-1.15	-0.83	-0.66	-0.06	-0.84	-0.55	-0.99
1737001	-0.83	-0.77	-1.00	-0.79	-0.63	-1.04	-0.82	-0.57	-0.97	-0.81	-0.53	-0.93
1931003	-0.78	-0.73	-0.96	-0.77	-0.60	-0.90	-0.77	-0.53	-0.84	-0.67	-0.34	-0.66
2025001	-0.82	-0.73	-0.96	-0.84	-0.68	-1.02	-0.85	-0.53	-0.85	-0.90	-0.49	-0.81
2224038	-0.82	-0.75	-0.91	-0.81	-0.63	-0.96	-0.73	-0.56	-0.94	-0.76	-0.42	-0.72
2231001	-0.80	-0.71	-0.98	-0.81	-0.67	-1.04	-0.84	-0.68	-1.01	-0.78	-0.42	-0.74
2235163	-0.81	-0.74	-0.95	-0.81	-0.60	-1.02	-0.84	-0.62	-0.99	-0.83	-0.42	-0.71
2321006	-0.82	-0.73	-0.99	-0.81	-0.72	-1.18	-0.82	-0.66	-1.08	-0.80	-0.59	-0.99
2330009	-0.84	-0.75	-0.95	-0.80	-0.68	-1.08	-0.81	-0.57	-0.91	-0.80	-0.49	-0.87
2636170	-0.75	-0.70	-1.00	-0.74	-0.61	-1.10	-0.82	-0.71	-1.12	-0.89	-0.54	-0.85
2719001	-0.79	-0.74	-0.99	-0.81	-0.65	-1.04	-0.82	-0.57	-1.04	-0.83	-0.52	-0.93
2725083	-0.80	-0.75	-0.98	-0.82	-0.64	-0.98	-0.78	-0.53	-0.90	-0.82	-0.43	-0.70
3020016	-0.81	-0.73	-1.03	-0.83	-0.69	-1.06	-0.87	-0.71	-1.12	-0.77	-0.58	-1.10
Average	**-0.80**	**-0.73**	**-0.98**	**-0.80**	**-0.65**	**-1.02**	**-0.82**	**-0.60**	**-0.91**	**-0.81**	**-0.47**	**-0.81**

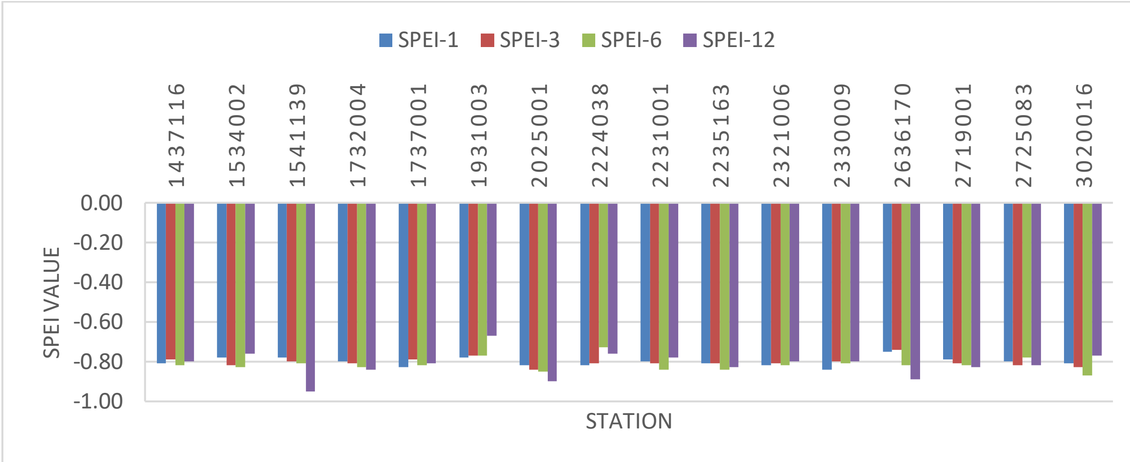

Figure 4.19: Mean Drought Severity for SPEI Indices.

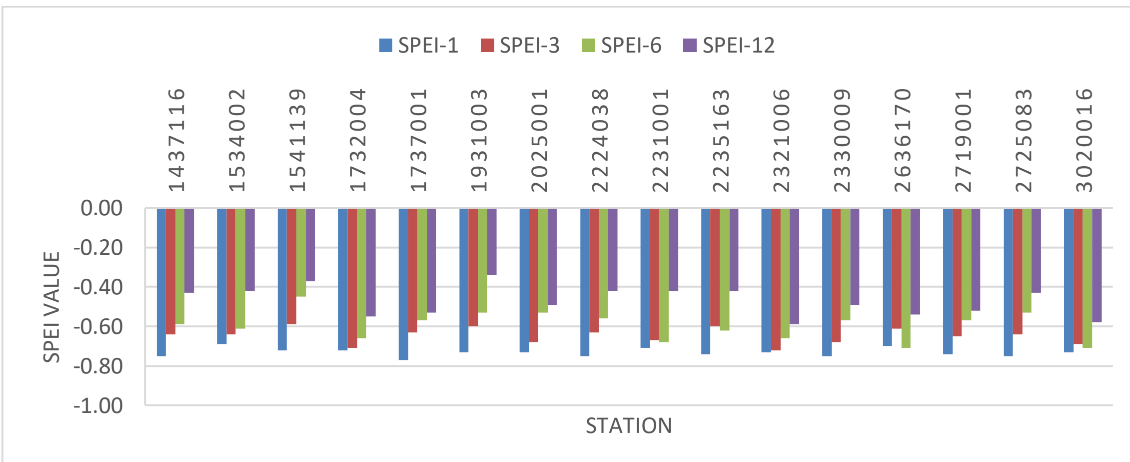

Figure 4.20: Mean Drought Intensity for SPEI Indices.

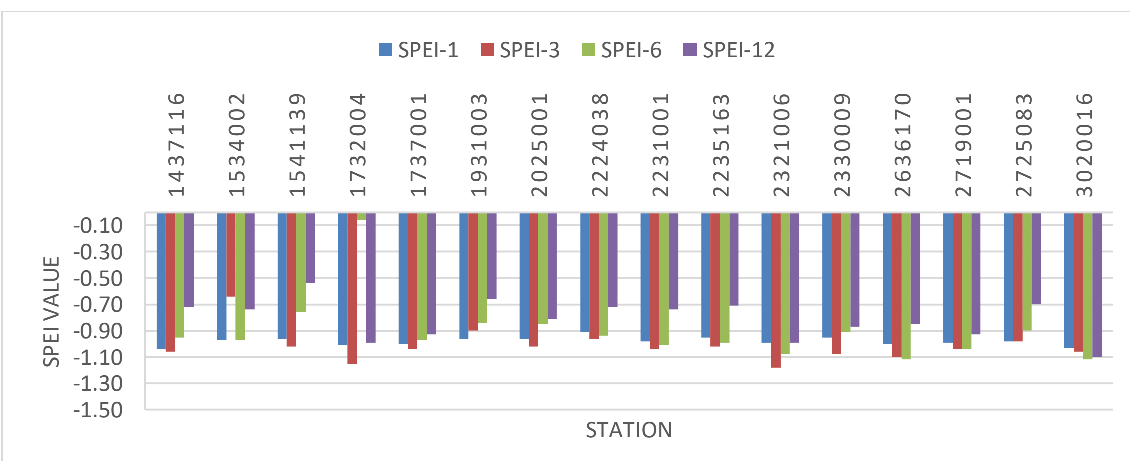

Figure 4.21: Mean Drought Peak for SPEI Indices.

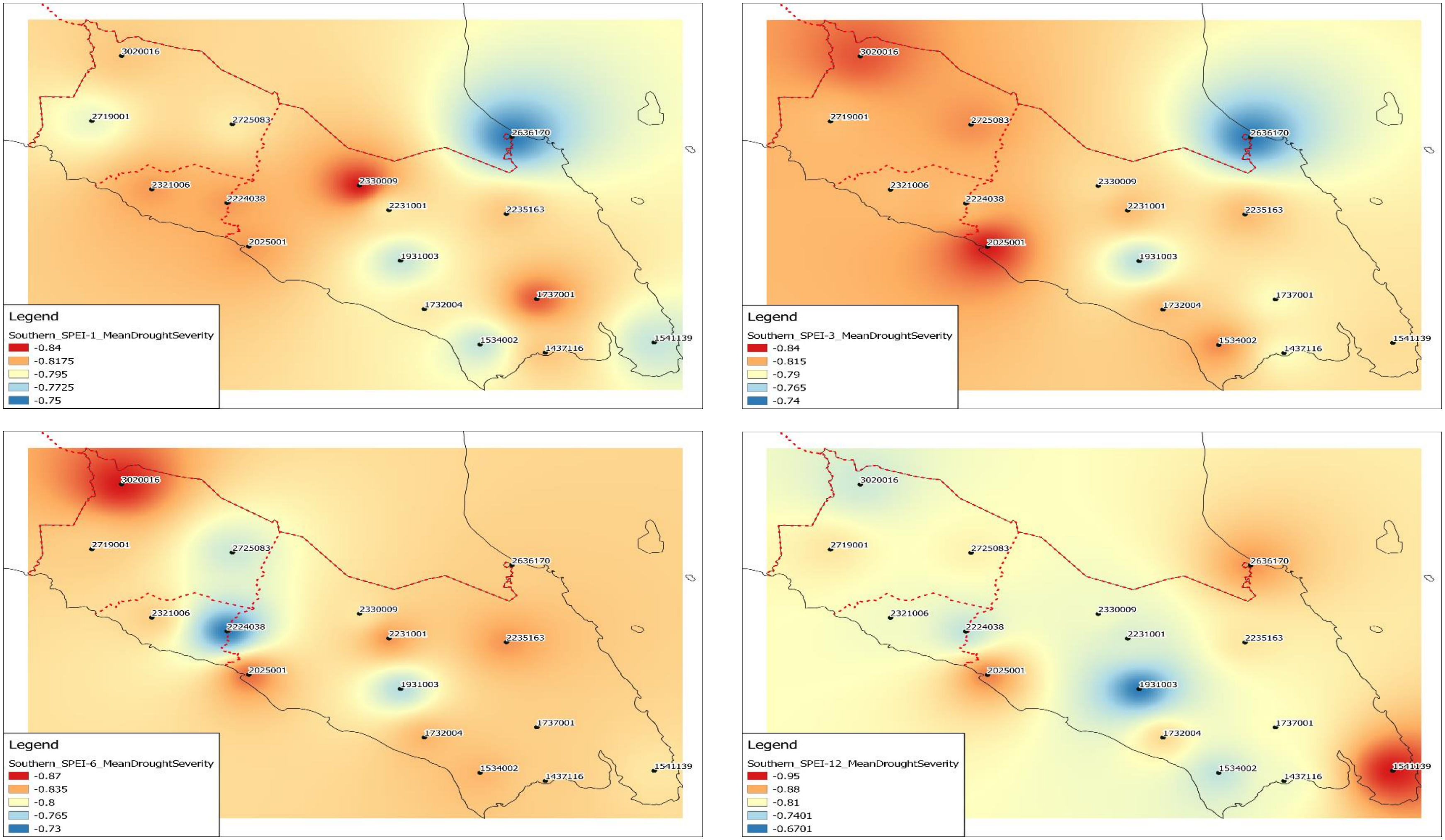

Figure 4.22: Heat Map of Drought Severity Identified by SPEI over Whole Southern Region.

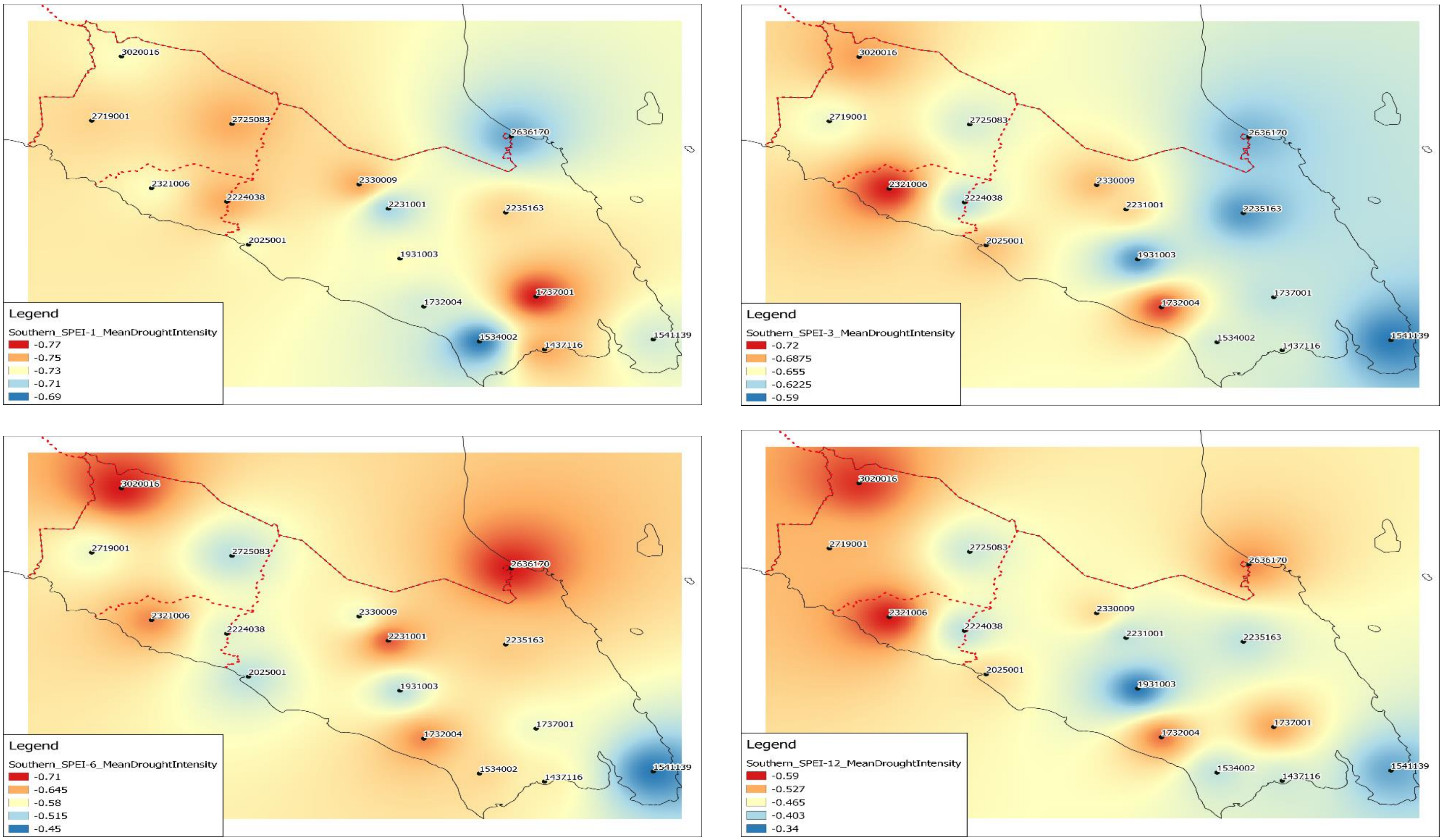

Figure 4.23: Heat Map of Drought Intensity Identified by SPEI over Whole Southern Region.

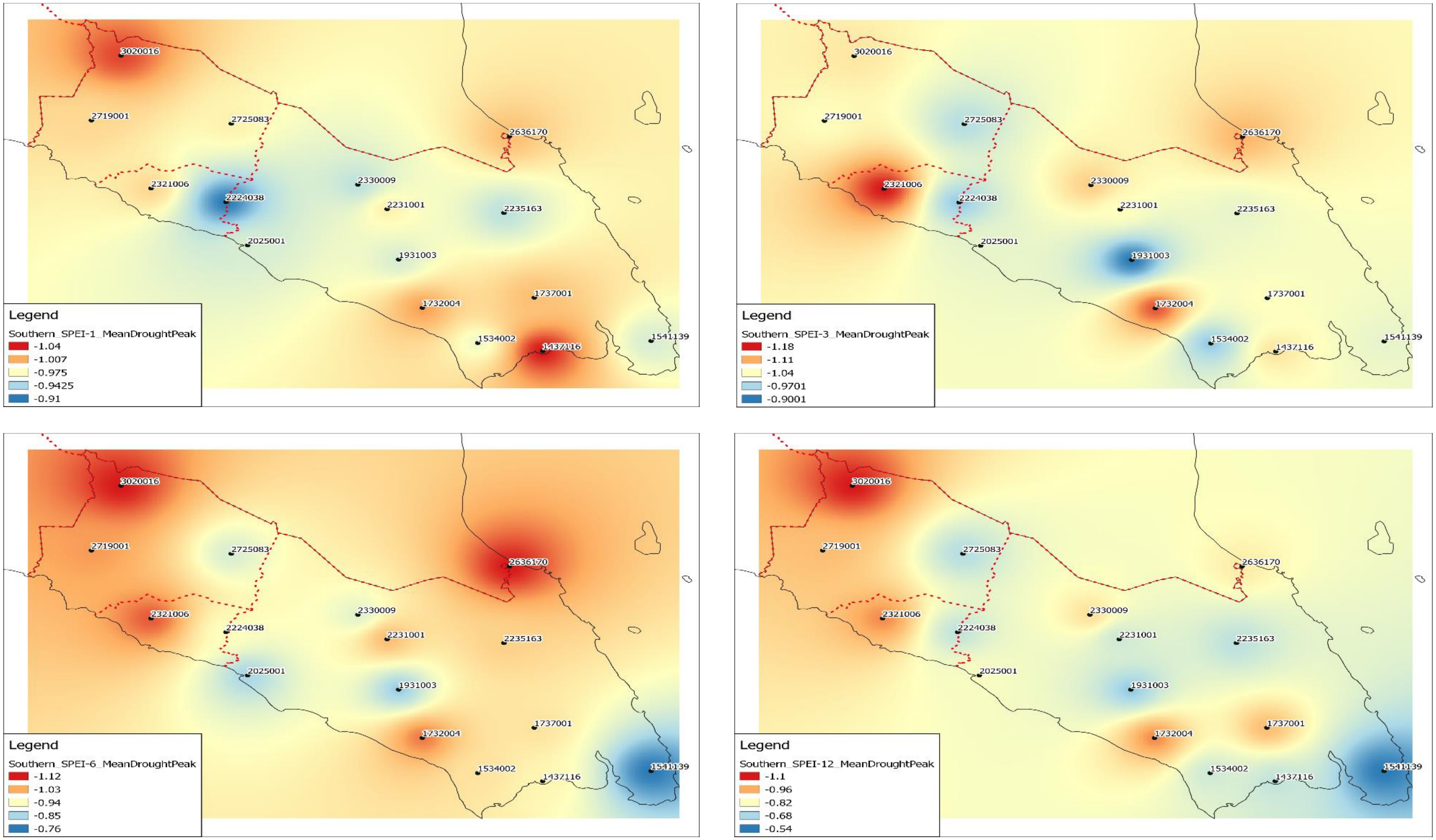

Figure 4.24: Heat Map of Drought Peak Identified by SPEI over Whole Southern Region.

4.1.6 Magnitude of Drought for SDI

For studying the magnitude of drought events in this study, drought severity, intensity and peak were measured using the SDI monthly data which obtained at streamflow station from 1983 to 2017. The magnitude of the drought in the southern region using the SDI at 3-, 6- and 12-month lags were found in all stations and the results shown in Table 4.6 are represented in Figure 4.25 to Figure 4.30.

In identifying the mean drought severity, the SDI-3 shows uniform spatial distribution with less significant variation, in which the most severe drought tends to occur at the north of the southern region. Meanwhile, the east coast and the central region are described with drought events which below average mean drought severity. The SDI has shown that across the southern region, Negeri Sembilan state is more prone to severe drought events.

For mean drought intensity, studies of the SDI with 3- and 6-month time lag computation have found that at the south-west of the southern region drought events are more intense. At the SDI-12, the north of Johor state has same mean drought intensity recorded with the south of Negeri Sembilan, indicating that these 2 locations tend to have more intense drought with longer durations. At the east coast line of the southern region, the drought events recorded are less intense in various time-scales computation. At the central region of Negeri Sembilan, it is observed that drought events with long time scales have weaker intensity according to the SDI-12 computation even though the south region has the highest mean intensity within the southern region. Nonetheless, the SDI has illustrated that the south of Negeri Sembilan and Johor northern area are more prone to intense drought events with various duration, while east coast does not seem to have intense drought events across these 35 years.

The SDI-3 has shown that for the mean drought peak, the southern area of Negeri Sembilan has recorded the highest peak compared to other locations in different time scales computation. The east coast line of the southern region has comparably low mean drought peak. The SDI studies have shown that the southern area of Negeri Sembilan experienced moderate dry weather once the drought events occur along these 35 years.

Table 4.6: Magnitude of Drought Determined by SDI under Different Time Scale for 8 Streamflow Stations.

Station	SDI-3			SDI-6			SDI-12		
	Severity	**Intensity**	**Peak**	**Severity**	**Intensity**	**Peak**	**Severity**	**Intensity**	**Peak**
1737451	-0.59	-0.48	-0.73	-0.64	-0.53	-0.84	-0.68	-0.42	-0.68
2235401	-0.52	-0.36	-0.52	-0.57	-0.36	-0.57	-0.55	-0.25	-0.46
2237471	-0.35	-0.24	-0.35	-0.40	-0.30	-0.43	-0.45	-0.24	-0.39
2322415	-0.59	-0.40	-0.61	-0.63	-0.46	-0.75	-0.64	-0.37	-0.61
2519421	-0.73	-0.64	-0.99	-0.69	-0.68	-1.26	-0.71	-0.51	-0.88
2528414	-0.49	-0.41	-0.61	-0.56	-0.50	-0.78	-0.70	-0.52	-0.77
2533474	-0.59	-0.48	-0.73	-0.64	-0.53	-0.84	-0.68	-0.42	-0.68
2722413	-0.74	-0.52	-0.74	-0.85	-0.61	-0.86	-0.80	-0.32	-0.48
Average	**-0.58**	**-0.44**	**-0.66**	**-0.62**	**-0.50**	**-0.79**	**-0.65**	**-0.38**	**-0.62**

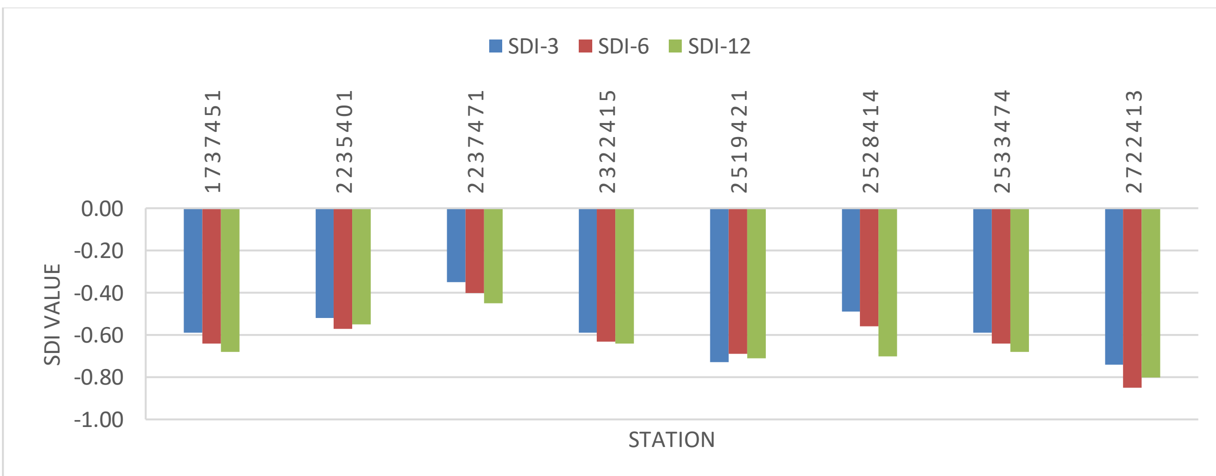

Figure 4.25: Mean Drought Severity for SDI Indices.

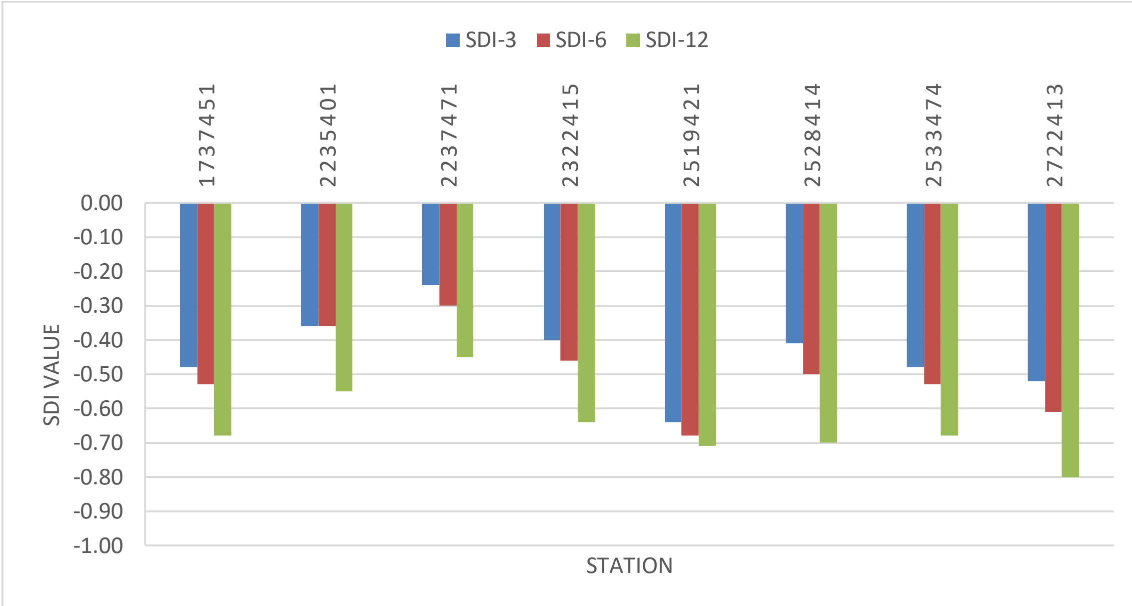

Figure 4.26: Mean Drought Intensity for SDI Indices.

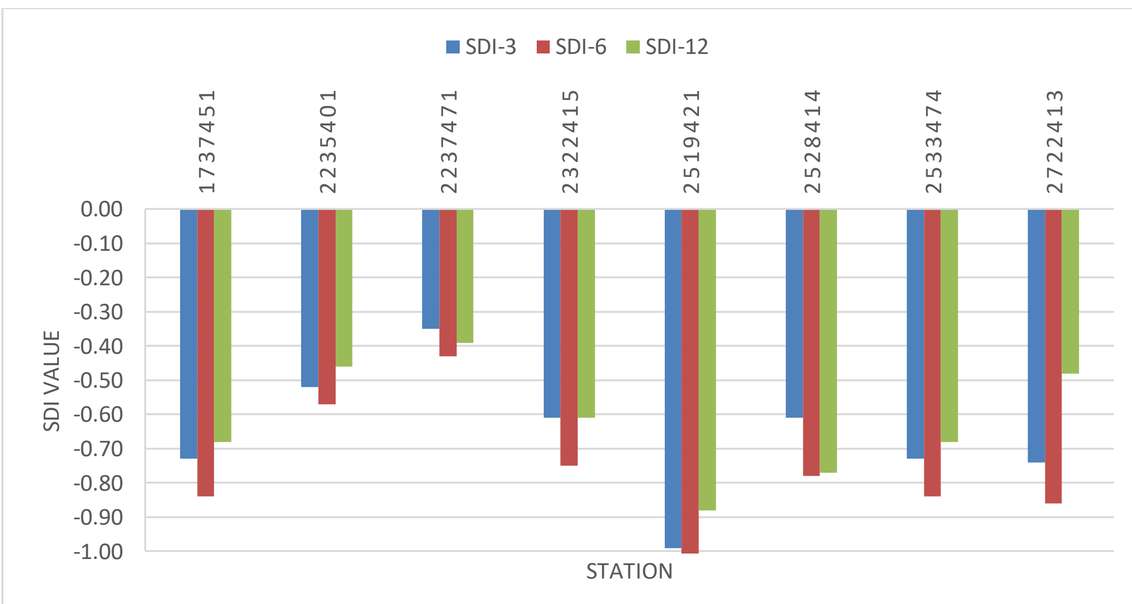

Figure 4.27: Mean Drought Peak for SDI Indices.

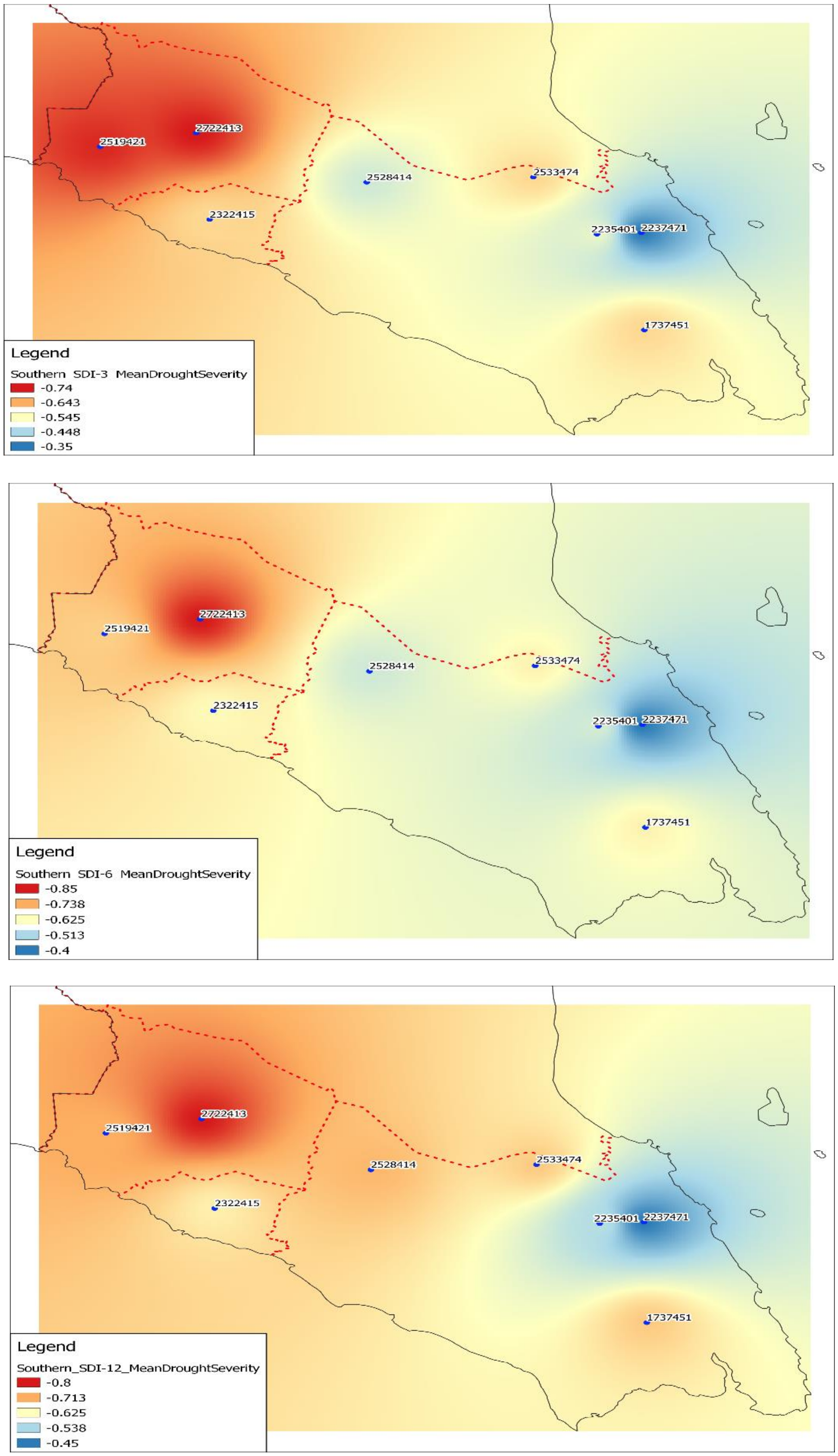

Figure 4.28: Heat Map of Drought Severity Identified by SDI over Whole Southern Region.

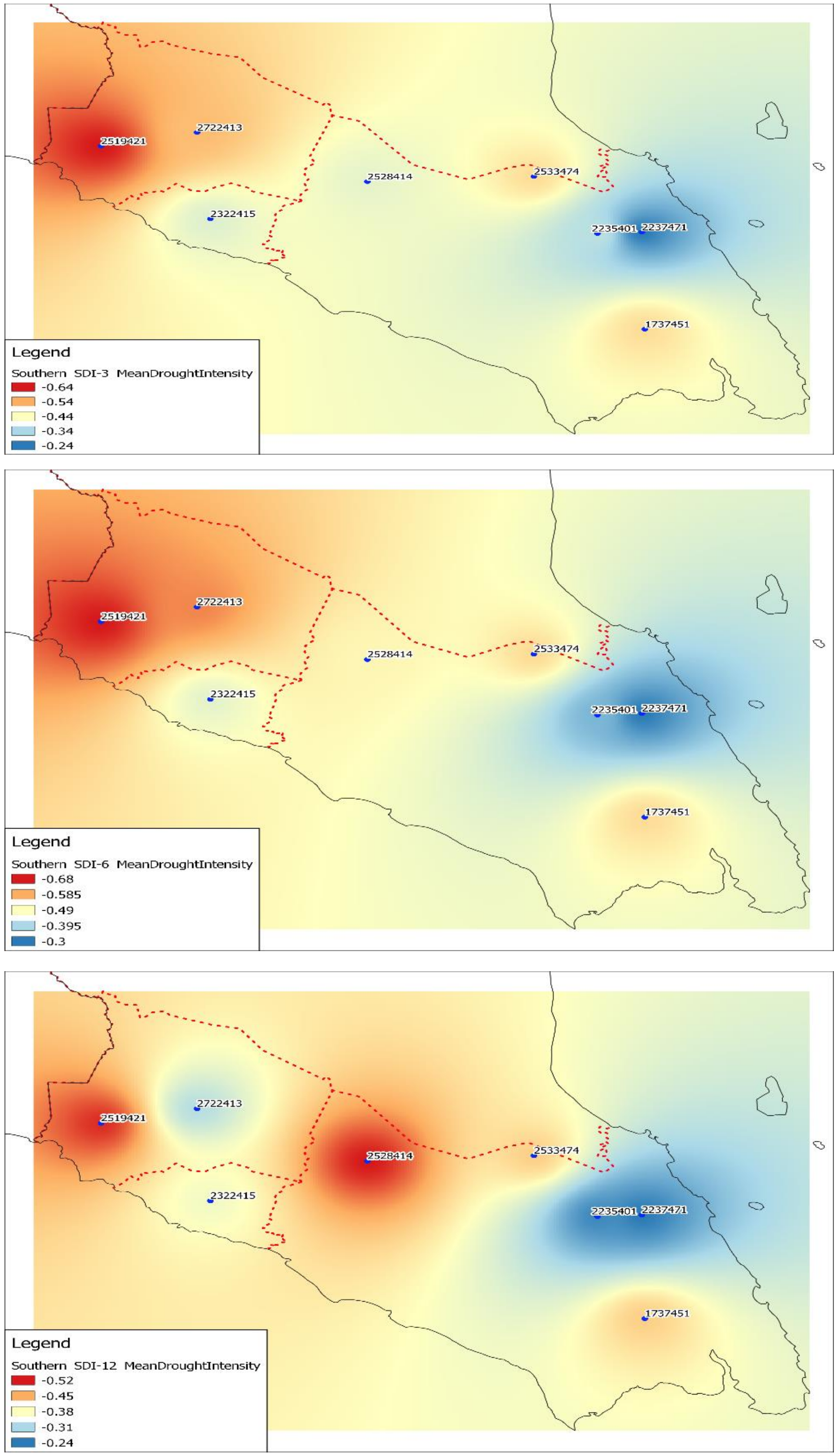

Figure 4.29: Heat Map of Drought Intensity Identified by SDI over Whole Southern Region.

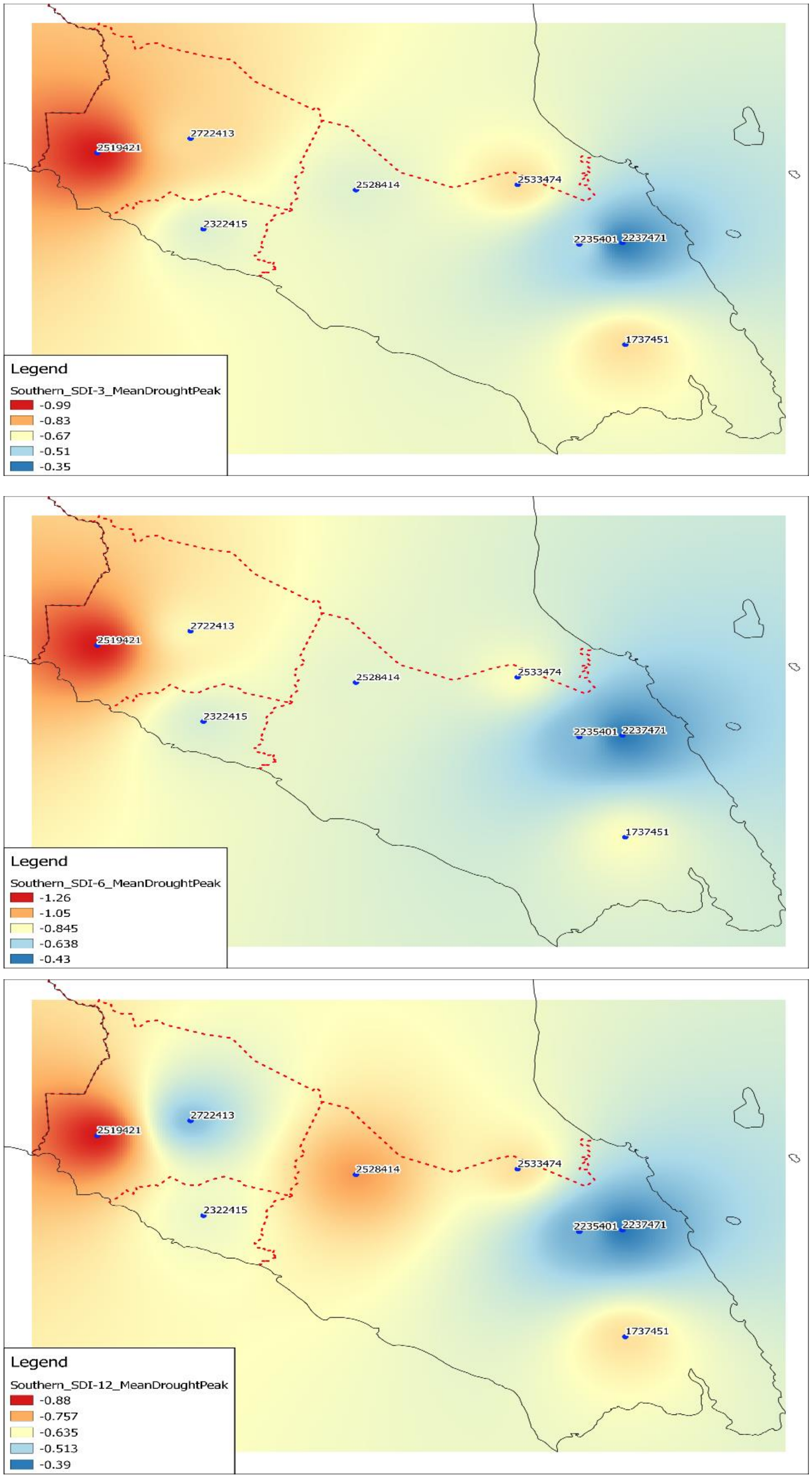

Figure 4.30: Heat Map of Drought Peak Identified by SDI over Whole Southern Region.

4.2 Historical Drought

The historical drought events that occurred in the southern region of Peninsular Malaysia is researched utilizing the newspapers, journal and online articles with reliable information. All of the 28 cases shown in Table 4.7 were referred as an official duration for each drought event, and the computed the SPI, the SPEI and the SDI results with different time-scales are to be compared with the official duration. The results are interpreted in Table 4.8 to 4.10.

Out of the SPI computations with time-scales of 1, 3, 6 and 9, the SPI-1 and SPI-3 has the highest probability of detection of 93% in detecting the drought events compared to the SPI-6 and SPI-12. However, the computed drought duration is relatively longer comparing with the actual cases and thus it caused the mean absolute error to be 0.45 and 0.98 individually. The SPI-6 and the SPI-12 have matching lowest probability in identifying the drought events among the SPI computations, which are 68% for both. In the SPI-12 case, no drought events could be detected throughout the actual period. This is due to the values are calculated based on the results from the previous 12 months with no deficit in rainfall, while the lengthened computation with more than 6 months could bring the values which shows the drought condition are led to next 6 months as the SPI tends to respond slowly to changes in precipitation, further leading to no exact prediction of drought event in the SPI-12. Other than that, two indices (SPI-6 and the SPI-12) are showing abnormally long for the drought durations with percentage of error above 1.0. The SPI-3 unlike the others, even though only has a mean absolute error of 0.98 in capturing drought events, however it successfully predicted 2 drought events with exact period. In other words, this means that it has a better precision in determining drought as a comparison with the SPI-6 and the SPI-12. Based on the results, it could be concluded that among the SPI-method the SPI-1 would satisfactorily identify drought events in the southern region of Peninsular Malaysia.

In the SPEI-1, -3, -6, -9 computation shows that all the 4 time-scales have a satisfactory probability of detection which is above 80% in identifying drought events. Similar to the SPI, the SPEI-1 and SPEI-3 has the highest probability (100%) in drought determination. However, the mean absolute error shows that the measured drought duration is too long with error above 1.0 in the SPEI-3. In other words, even though the

SPEI-3 has a probability of 100% in detecting drought, however it does not precisely describe the drought. The SPEI-1 has the highest probability (100%) in identifying drought event, furthermore this accuracy in other form is complemented by the lowest and the only absolute error with below 1.0 (0.58) among the SPEI methods. This means that the SPEI-1 could be used to identify the drought event more accurately and precisely comparing to the other 3 the SPEI time-scales and also the SPI methods.

The onset and offset time of the actual drought is compared with computed results from the SDI method for all cases. The SDI-3, -6, and -9 shows a relatively promising accuracy of above 90% in identifying drought events in the southern region, but at the same time the mean absolute error is extremely high, which is 8.15, 13.15 and 21.17 individually. This is due to the SDI detects tremendous duration of drought events from the streamflow data comparing to the SPI and the SPEI which utilized rainfall data. For example, in Case 2 the SDI method detected drought period of 29, 53 and 107 months individually, meanwhile the actual official drought cited was only 4 months from January until April of 2010. While the SDI merely represents the deficit in water level for a specific stream, the stream could cover up to cross-boundary of states' length and much information is required to identify the actual weather condition of the study area. Thus, the SDI method is not suitable to be applied for drought identification in the southern region of Peninsular Malaysia.

To compare the suitability between the SPI-1 and the SPEI-1 (whichever is more suitable to be used in describing drought in the southern region of Peninsular Malaysia), the mean bias error is computed to portray a better picture on the prediction results for both methods. In Table 4.10, the mean bias error of the SPI-1 has shown a negative value of -1.18, which indicating that the SPI-1 tends to under-estimate most of the drought duration. Meanwhile, in mean bias error computed by the SPEI-1, it is shown that the SPEI-1 over-estimated the drought duration (0.46). Other than that, the SPEI-1 has successfully predicted duration of 5 drought events to be exactly the same with the historical observed drought, while the SPI-1 only has 4. In the onset and end detection, the SPI-1 prediction is more likely to commence or end earlier (0.3 month earlier) than actual drought period. For the SPEI-1, it detects the drought event to be commenced earlier (0.7 month earlier) in the onset detection, while the drought is prone to end later (0.7

month later) in the end detection. The SPEI-1 has shown a good prediction model as it tends to over-estimate the drought duration with lowest absolute error, complementing with detection of drought period for approximately 1 month earlier and later.

Over the 35 years (Jan 1983 to Dec 2017), there are several drought events which have significant meaning to the southern region of Peninsular Malaysia. These severe drought events brought on unusual hot weather and inconvenience to the local citizens, with shortage of water, dying of agricultural crops, and more economic losses.

The drought that happened during May 2014 to October 2016 at Congok Dam Johor (Case 3) is one of the longest droughts to be detected in the southern region of Peninsular Malaysia, as shown in Figure 4.31. With the SPEI-1, the onset of the drought starts from February 2014 and lasting until October 2016 showing the drought duration to be 25 months with 7 months being normal condition. The SPEI-1 recorded a maximum drought severity of -2.75, indicating that the weather falls under “extremely dry” category according to the SPEI classification range.

In another extreme drought case, in 1991, Malacca has suffered shortage in water which lasted more than a year due to mistakes made by dam operators for Durian Tunggal Dam. This is one of the notable hydrological drought events that were mainly caused by man-made failures (Case 15). This recorded historical drought at Durian Tunggal Dam happened from January 1991 until February 1992, which is a 14-month duration drought in the southern region as shown in Figure 4.32. According to the SPEI-1 computation, the drought commenced in November 1990 which is 2 months earlier and ended in January 1992 which is 1 month earlier than the recorded historical drought. The SPEI-1 also recorded a maximum severity of -1.75 which is severely dry as stated in the SPEI classification range.

Another drought event which also occurred at Durian Tunggal Dam lasted 7 months from April to October of year 2016 (Case 18) as in Figure 4.33. The SPEI-1 shows the drought onset in December 2015 which is 4 months in advance of the recorded historical drought, while ended exactly in October 2016. With the SPEI-1, it was recorded highest severity (below -2) which indicating that this drought is capable to bring extremely dry weather to this area.

The Negeri Sembilan state has an immense drought event during year 2014 and the condition was apprehended in this study (Case 25). SPEI-1 has shown that the drought commenced in January to June 2014 and has a highest severity of below-2. According to SPEI-1, it identified the onset 1 month earlier and ended 2 months earlier than the recorded drought that started from February until August of 2014 as illustrated in Figure 4.34. From SPEI-1, it has indicated a shorter drought duration of 4 months compared to 7-month actual historical drought in this case.

Table 4.7: 27 Cases of Historical Drought as Comparison to the Accuracy of SPI, SPEI and SDI Indices to Identify Drought.

Drought Index	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPEI-1**	**SPEI-3**	**SPEI-6**	**SPEI-12**	**SDI-3**	**SDI-6**	**SDI-12**
1. Location: Southern Area of Johor, Onset: Jan 2014, End: Mar 2014, (ABC News, 2016)											
Nearest Station		1737001				1737001				1737451	
Distance (km)		15.354				15.354				18.518	
Onset	01/2014	02/2014			02/2014	02/2014		03/2014	03/2014	02/2014	02/2014
End	02/2014	04/2014			02/2014	04/2014		03/2014	12/2017	12/2014	12/2017
Duration (Months)	2	3			1	3		1	46	47	47
Maximum Severity	-1.91	-1.28			-1.83	-1.25		-0.04	-1.03	-0.15	-1.49
2. Location: Batu Pahat, Onset: Jan 2010, End: Apr 2010, (Benjamin, 2010)											
Nearest Station		1931003				1931003				2528414	
Distance (km)		31.309				31.309				74.661	
1st Onset	01/2010	06/2009	04/2009	07/2009	12/2009	06/2009	05/2009	06/2009	07/2008	09/2008	02/2009
1st End	02/2010	07/2010	12/2010	03/2011	07/2010	07/2010	11/2010	03/2011	11/2010	1/2013	12/2017
2nd Onset	04/2010										
2nd End	06/2010										
Duration (Months)	5	14	21	21	8	14	19	22	29	53	107
Maximum Severity	-1.87	-1.85	-1.77	-2.29	-1.82	-1.63	-1.49	-1.85	-0.97	-1.27	-2.07
3. Location: Congok Dam , Onset: May 2014 , End: Oct 2016, (Said and Hammim, 2016; The Star Online, 2016)											
Nearest Station		2636170				2636170				2237471	
Distance (km)		24.688				24.688				27.950	
1st Onset	02/2014	03/2014	05/2014	02/2014	02/2014	03/2014	05/2014	02/2014	02/2009	07/2008	12/2008
1st End	07/2014	11/2014	11/2014	04/2015	07/2014	11/2014	11/2014	04/2017	03/2017	06/2017	12/2017
2nd Onset	09/2014	03/2015	06/2015	08/2015	09/2014	03/2015	06/2015				
2nd End	10/2014	11/2015	11/2015	02/2017	10/2014	11/2015	12/2016				
3rd Onset	02/2015	03/2016	01/2016		02/2015	03/2016					

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
3rd End	04/2015	10/2016	01/2016		10/2015	10/2016					
4th Onset	06/2015		04/2016		01/2016						
4th End	06/2015		12/2016		01/2016						
5th Onset	09/2015				03/2016						
5th End	10/2015				05/2016						
6th Onset	01/2016				07/2016						
6th End	01/2016				10/2016						
7th Onset	03/2016										
7th End	05/2016										
8th Onset	07/2016										
8th End	10/2016										
Duration (Months)	22	26	23	34	25	26	26	39	98	108	109
Maximum Severity	-2.44	-2.02	-2.04	-1.61	-2.75	-2.75	-1.96	-1.87	-0.61	-0.71	-0.84
4. Location: Johor Bahru, Onset: Feb 2016, End: May 2016, (Utusan Online, 2016)											
Nearest Station		1437116				1437116				1737451	
Distance (km)		2.744				2.744				31.932	
Onset	04/2016	05/2016		08/2015	03/2016	02/2016	05/2016	07/2015	03/2014	02/2014	02/2014
End	04/2016	10/2016		09/2016	09/2016	11/2016	12/2016	07/2017	12/2017	12/2017	12/2017
Duration (Months)	1	6		14	7	10	8	25	46	47	47
Maximum Severity	-0.15	-1.23		-0.75	-1.43	-1.62	-1.94	-1.38	-1.03	-1.25	-1.49
5. Location: Kluang, Onset: Jan 2010, End: Apr 2010, ('El Nino', 2010; Benjamin, 2010)											
Nearest Station		1931003				1931003				2235401	
Distance (km)		15.588				15.588				38.635	
1st Onset	01/2010	06/2009	04/2009	07/2009	12/2009	06/2009	05/2009	06/2009	06/2008	08/2008	03/2001
1st End	02/2010	07/2010	12/2010	03/2011	07/2010	07/2010	11/2010	03/2011	12/2010	12/2017	12/2017

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
2nd Onset	04/2010										
2nd End	06/2010										
Duration (Months)	5	14	21	21	8	14	19	22	31	113	202
Maximum Severity	-1.87	-1.85	-1.77	-2.29	-1.82	-1.63	-1.49	-1.85	-0.90	-1.12	-1.24
6. Location: Kota Tinggi, Onset: Apr 2016, End: Jun 2016, (The San Diego Union-Tribune, 2016; Spykerman, 2016)											
Nearest Station		1737001				1737001				1737451	
Distance (km)		28.003				28.003				25.870	
Onset	06/2016	03/2016	06/2016		06/2016	02/2016	05/2016	09/2014	03/2014	02/2014	02/2014
End	07/2016	04/2016	08/2016		08/2016	09/2016	12/2016	02/2017	12/2017	12/2017	12/2017
Duration (Months)	2	2	3		3	8	8	30	46	47	47
Maximum Severity	-0.43	-0.73	-0.34		-0.91	-1.26	-1.15	-0.96	-1.03	-1.25	-1.49
7. Location: Linggiu Dam, Onset: Apr 2016, End: Jun 2016, (Ewing and Domondon, 2016)											
Nearest Station		1737001				1737001				1737451	
Distance (km)		15.794				15.794				15.490	
Onset	06/2016	03/2016	06/2016		06/2016	02/2016	05/2016	09/2014	03/2014	02/2014	02/2014
End	07/2016	04/2016	08/2016		08/2016	09/2016	12/2016	02/2017	12/2017	12/2017	12/2017
Duration (Months)	2	2	3		3	8	8	30	46	47	47
Maximum Severity	-0.43	-0.73	-0.34		-0.91	-1.26	-1.15	-0.96	-1.03	-1.25	-1.49

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
8. Location: Machap Dam, Onset: Jul 2005, End: Oct 2005, (Hydrology and Water Resources Division Department of Irrigation and Drainage Malaysia, 2005)											
Nearest Station	1931003				1931003				2235401		
Distance (km)	14.002				14.002				52.934		
Onset	06/2005	01/2005	07/2003	11/2003	06/2005	01/2005	07/2003	11/2003	02/2005	02/2005	03/2001
End	08/2005	09/2005	09/2005	08/2007	08/2005	09/2005	10/2005	04/2008	12/2005	12/2006	12/2017
Duration (Months)	3	9	27	46	3	9	28	54	11	23	202
Maximum Severity	-1.87	-4.49	-3.31	-3.2	-1.74	-2.14	-2.06	-2.16	-0.93	-1.06	-1.24
9. Location: Mersing, Onset: Apr 2016, End: Jun 2016, (The San Diego Union-Tribune, 2016; Spykerman, 2016)											
Nearest Station	2235163				2235163				2237471		
Distance (km)	33.228				33.228				21.620		
Onset				03/2015	01/2016	02/2016	02/2016	06/2013	02/2009	07/2008	12/2008
End				05/2016	11/2016	12/2016	02/2017	10/2017	03/2017	06/2017	12/2017
Duration (Months)				15	11	11	13	53	98	108	109
Maximum Severity				-1.08	-2.24	-2.03	-2.16	-2.03	-0.61	-0.71	-0.84
10. Location: Segamat, Onset: Apr 2016, End: Jun 2016, (Today Online, 2016)											
Nearest Station	2330009				2330009				2528414		
Distance (km)	25.805				25.805				0.489		
1st Onset	03/2016	03/2016	06/2016		03/2016	03/2016	04/2016	03/2016	05/2016	06/2016	02/2009
1st End	04/2016	06/2016	12/2016		04/2016	12/2016	12/2016	03/2017	12/2017	12/2017	12/2017
2nd Onset	06/2016				06/2016						
2nd End	06/2016				10/2016						
Duration (Months)	3	4	7		7	10	9	13	20	19	107
Maximum Severity	-1.42, -0.65	-0.84	-0.63		-1.97, -1.02	-1.44	-1.37	-1.19	-1.09	-1.46	-2.07

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
11. Location: Sembrong Dam, Onset: Jul 2005, End: Oct 2005, (Hydrology and Water Resources Division Department of Irrigation and Drainage Malaysia, 2005; The Star Online, 2005)											
Nearest Station		1931003				1931003				2235401	
Distance (km)		1.641				1.641				53.634	
Onset	06/2005	01/2005	07/2003	11/2003	06/2005	01/2005	07/2003	11/2003	02/2005	02/2005	03/2001
End	08/2005	09/2005	09/2005	08/2007	08/2005	09/2005	10/2005	04/2008	12/2005	12/2006	12/2017
Duration (Months)	3	9	27	46	3	9	28	54	11	23	202
Maximum Severity	-1.87	-4.49	-3.31	-3.2	-1.74	-2.14	-2.06	-2.16	-0.93	-1.06	-1.24
12. Location: Sembrong Dam, Onset: Dec 2013, End: Jan 2014, (Astro Awani, 2014)											
Nearest Station		1931003				1931003				2235401	
Distance (km)		1.641				1.641				53.634	
Onset	01/2014	01/2014			01/2014	01/2014		01/2014	04/2011	08/2008	03/2001
End	02/2014	04/2014			02/2014	04/2014		03/2014	12/2017	12/2017	12/2017
Duration (Months)	2	4			2	4		3	81	113	202
Maximum Severity	-1.87	-1.02			-1.56	-0.78		-0.45	-0.96	-1.12	-1.24
13. Location: Sungai Gembut, Onset: Feb 2016, End: May 2016, (Utusan Online, 2016)											
Nearest Station		1737001				1737001				1737451	
Distance (km)		38.973				38.973				36.622	
1st Onset	03/2016	03/2016			03/2016	02/2016	03/2016	09/2014	03/2014	02/2014	02/2014
1st End	03/2016	04/2016			03/2016	09/2016	03/2016	02/2017	12/2017	12/2017	12/2017
2nd Onset							05/2016				
2nd End							12/2016				
Duration (Months)	1	2			1	8	9	30	46	47	47
Maximum Severity	-2.13	-0.73			-2.28	-1.26	-1.15	-0.96	-1.03	-1.25	-1.49

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
14. Location: Sungai Mersing, Onset: Feb 2016, End: May 2016, (Utusan Online, 2016)											
Nearest Station		2235163				2235163				2237471	
Distance (km)		30.207				30.207				18.108	
Onset	03/2016	03/2016		03/2015	01/2016	02/2016	02/2016	06/2013	02/2009	07/2008	12/2008
End	03/2016	03/2016		05/2016	11/2016	12/2016	02/2017	10/2017	03/2017	06/2017	12/2017
Duration (Months)	1	1		15	11	11	13	53	98	108	109
Maximum Severity	-1.40	-0.23		-1.08	-2.24	-2.03	-2.16	-2.03	-0.61	-0.71	-0.84
15. Location: Durian Tunggal Dam, Onset: Jan 1991, End: Feb 1992, (Amin, et al., 2011; Khor and Lee, 1991)											
Nearest Station		2321006				2321006				2322415	
Distance (km)		12.655				12.655				1.824	
1st Onset	11/1990	01/1991	02/1990	06/1989	11/1990	01/1991	11/1990	02/1990	11/1990	09/1990	01/1991
1st End	02/1991	04/1991	10/1991	01/1992	02/1991	04/1991	10/1991	11/1991	03/1993	04/1993	10/1993
2nd Onset	05/1991	06/1991			05/1991	06/1991		01/1992			
2nd End	06/1991	08/1991			06/1991	08/1991		01/1992			
3rd Onset	01/1992				01/1992						
3rd End	01/1992				01/1992						
Duration (Months)	7	1	21	32	7	7	12	22	29	32	34
Maximum Severity	-2.20	-1.26	-1.42	-1.36	-1.75	-1.32	-1.24	-1.15	-1.17	-1.39	-1.41
16. Location: Durian Tunggal Dam, Onset: Jan 2002, End: Mar 2002, (Shaaban and Low, 2003)											
Nearest Station		2321006				2321006				2322415	
Distance (km)		12.655				12.655				1.824	
Onset	12/2001	01/2002	02/2002	01/2002	12/2001	01/2002	02/2002	01/2002	02/2002	05/2001	09/2001
End	02/2002	04/2002	06/2002	02/2002	02/2002	04/2002	06/2002	02/2002	07/2002	02/2002	07/2002
Duration (Months)	3	4	5	2	3	4	5	2	6	10	11
Maximum Severity	-2.30	-2.28	-0.81	-0.55	-1.78	-1.80	-0.95	-0.64	-0.56	-1.09	-0.74

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
17. Location: Asahan Dam, Onset: Apr 2016, End: Jun 2016, (Koh, 2016)											
Nearest Station		2224038				2224038				2528414	
Distance (km)		15.984				15.984				28.145	
1st Onset	02/2016	02/2016	02/2016	09/2013	02/2016	03/2016	04/2016	09/2012	05/2016	02/2009	02/2009
1st End	04/2016	11/2016	12/2016	07/2017	04/2016	07/2016	08/2016	08/2016	12/2017	12/2017	12/2017
2nd Onset	06/2016				06/2016						
2nd End	09/2016				07/2016						
Duration (Months)	7	10	11	47	5	5	5	48	20	107	107
Maximum Severity	-1.92	-1.50	-1.80	-1.81	-1.03	-1.23	-1.15	-1.41	-1.09	-2.07	-2.07
19. Location: Durian Tunggal Dam, Onset: Apr 2016, End: Oct 2016, (The Star Online, 2016)											
Nearest Station		2321006				2321006				2322415	
Distance (km)		12.655				12.655				1.824	
1st Onset	02/2016	02/2016	02/2016	03/2016	12/2015	02/2016	01/2016	11/2015	03/2016	05/2016	
1st End	04/2016	06/2016	10/2016	02/2017	04/2016	11/2016	12/2016	02/2017	07/2016	11/2016	
2nd Onset	07/2016	09/2016			06/2016				10/2016		
2nd End	07/2016	11/2016			07/2016				11/2016		
3rd Onset	09/2016				09/2016						
3rd End	09/2016				10/2016						
Duration (Months)	5	8	9	12	9	10	12	16	7	7	
Maximum Severity	-2.34	-1.92	-1.34	-0.96	-2.17	-2.01	-1.80	-1.67	-0.69	-0.40	
20. Location: Jus Dam, Onset: Apr 2016, End: Jun 2016, (Koh, 2016)											
Nearest Station		2224038				2224038				2322415	
Distance (km)		19.912				19.912				16.630	
1st Onset	02/2016	02/2016	02/2016	09/2013	02/2016	03/2016	04/2016	09/2012	03/2016	05/2016	
1st End	04/2016	11/2016	12/2016	07/2017	04/2016	07/2016	08/2016	08/2016	07/2016	11/2016	

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
2nd Onset	06/2016				06/2016						
2nd End	09/2016				07/2016						
Duration (Months)	7	10	11	47	5	5	5	48	5	7	
Maximum Severity	-1.92	-1.50	-1.80	-1.81	-1.03	-1.23	-1.15	-1.41	-0.69	-0.40	
21. Location: Lenggeng, Onset: Jan 2002, End: Mar 2002, (Ahsan, 2002)											
Nearest Station		2818110				2818110				2918401	
Distance (km)		9.37				9.37				14.784	
Onset	01/2002	07/2001	10/2001	04/1997	01/2002	07/2001	05/2001	06/1997	01/2001	06/1994	11/1994
End	02/2002	03/2002	03/2002	10/2002	02/2002	03/2002	03/2002	01/2003	02/2007	04/2007	08/2007
Duration (Months)	2	9	6	67	2	9	11	68	74	155	154
Maximum Severity	-2.82	-1.67	-1.70	-2.87	-1.98	-1.51	-1.45	-2.55	-1.52	-1.59	-1.51
22. Location: Rembau, Onset: Jan 2002, End: Mar 2002, (Ahsan, 2002)											
Nearest Station		2719001				2719001				2519421	
Distance (km)		22.354				22.354				21.081	
Onset	12/2001	01/2002	01/2002	01/2002	12/2001	01/2002	01/2002	01/2002	01/2002	11/2001	02/2002
End	03/2002	08/2002	09/2002	01/2003	03/2002	08/2002	10/2002	02/2003	04/2002	10/2002	10/2002
Duration (Months)	4	8	9	13	4	8	10	14	4	12	9
Maximum Severity	-2.78	-3.42	-2.24	-1.15	-2.19	-2.56	-2.26	-1.56	-1.54	-1.00	-0.74

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
23. Location: Seremban, Onset: Apr 2005, End: Jul 2005, (Hydrology and Water Resources Division Department of Irrigation and Drainage Malaysia, 2005; Kong, 2014)											
Nearest Station		2719001				2719001				2519421	
Distance (km)		3.352				3.352				4.972	
1st Onset	06/2005		05/2005		05/2005	01/2005	03/2005	12/2004	07/2005	05/2005	02/2004
1st End	06/2005		06/2005		06/2005	10/2005	02/2006	4/2005	04/2006	10/2006	11/2006
2nd Onset								7/2005			
2nd End								4/2006			
Duration (Months)	1		2		2	10	12	15	10	18	35
Maximum Severity	-0.38		-0.86		-0.99	-1.92	-1.47	-1.51	-1.69	-1.97	-1.74
24. Location: Seremban, Onset: Jan 2010, End: Apr 2010, ('El Nino', 2010; Ahmad, 2010)											
Nearest Station		2719001				2719001				2519421	
Distance (km)		3.352				3.352				4.972	
Onset	10/2009	06/2009	09/2009	11/2009	10/2009	06/2009	08/2009	11/2009	06/2009	06/2009	10/2009
End	02/2010	03/2010	04/2010	05/2010	02/2010	03/2010	04/2010	06/2010	01/2010	02/2010	03/2010
Duration (Months)	5	10	8	7	5	10	9	8	8	9	6
Maximum Severity	-1.55	-1.44	-1.13	-0.77	-1.50	-1.68	-1.29	-1.03	-0.95	-0.92	-0.59
25. Location: Gemencheh Dam, Onset: Jan 2014, End: Apr 2014, (Singh, 2014; Utusan Online, 2014)											
Nearest Station		2725083				2725083				2722413	
Distance (km)		25.985				25.985				22.469	
1st Onset		02/2014	08/2013	11/2013	03/2014	02/2014	01/2014	02/2014	03/2014	08/2013	01/2014
1st End		11/2014	12/2016	03/2017	05/2014	11/2014	02/2014	03/2017	0/2014	02/2014	10/2014
2nd Onset							04/2014				
2nd End							12/2016				
Duration (Months)		10	41	41	2	10	35	38	2	7	10
Maximum Severity		-1.76	-2.55	-2.54	-0.68	-1.56	-2.27	-2.34	-0.28	-0.95	-0.47

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
26. Location: Seremban, Onset: Feb 2014, End: Aug 2014, (The Star Online, 2014)											
Nearest Station		2719001				2719001				2519421	
Distance (km)		3.352				3.352				4.972	
1st Onset	01/2014	01/2014	05/2013	11/2013	01/2014	02/2014	01/2014	11/2013	08/2013	10/2013	02/2014
1st End	03/2014	04/2014	04/2014	07/2014	03/2014	04/2014	04/2014	07/2014	10/2014	08/2016	09/2016
2nd Onset	06/2014	08/2014	06/2014		06/2014	08/2014	06/2014				
2nd End	06/2014	08/2014	06/2014		06/2014	08/2014	07/2014				
Duration (Months)	4	5	13	9	4	4	6	9	15	35	32
Maximum Severity	-2.82	-2.80, -0.04	-1.13	-1.27	-2.06	-1.94	-0.54	-1.16	-0.70	-0.87	-0.90
27. Location: Rembau, Onset: Jan 2015, End: Mar 2015, (The Star Online, 2015)											
Nearest Station		2719001				2719001				2519421	
Distance (km)		22.634				22.634				21.334	
Onset	01/2015	02/2015			01/2015	02/2015			01/2015	10/2013	02/2014
End	02/2015	03/2015			02/2015	03/2015			11/2015	08/2016	09/2016
Duration (Months)	2	2			2	2			11	35	32
Maximum Severity	-1.56	-0.81			-1.22	-0.73			-0.76	-0.87	-0.90
28. Location: Tampin, Onset: Jan 2015, End: Mar 2015, (The Star Online, 2015)											
Nearest Station		2321006				2321006				2322415	
Distance (km)		11.862				11.862				18.127	
Onset	01/2015	02/2015			12/2014	02/2015					10/2008
End	02/2015	03/2015			02/2015	03/2015					01/2015
Duration (Months)	2	2			3	2					76
Maximum Severity	-0.97	-0.78			-0.96	-0.84					-1.28

Drought Index	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
29. Location: Seremban, Onset: Feb 2016, End: Apr 2016, (Azizi, 2016; mStar Online, 2016)											
Nearest Station	2719001				2719001				2519421		
Distance (km)	3.352				3.352				4.972		
1st Onset	01/2016	02/2016		04/2016	01/2016	02/2016	04/2016	04/2016	03/2016	10/2013	02/2014
1st End	02/2016	04/2016		04/2016	04/2016	10/2016	01/2017	02/2017	08/2016	08/2016	09/2016
2nd Onset	04/2016										
2nd End	04/2016										
Duration (Months)	3	3		1	4	9	10	11	6	35	32
Maximum Severity	-0.84, -0.23	-0.66		-0.11	-0.88	-1.24	-1.12	-1.10	-0.41	-0.87	-0.90

Table 4.8: Probability of Detection for SPI, SPEI and SDI Method in Forecasting Drought Events.

Case	**Drought Indices**										
	SPI				**SPEI**				**SDI**		
	1	**3**	**6**	**12**	**1**	**3**	**6**	**12**	**3**	**6**	**12**
1	2	3	-	-	1	3	-	1	46	47	47
2	5	14	21	21	8	14	19	22	29	53	107
3	22	26	23	34	25	26	26	39	98	108	109
4	1	6	-	14	7	10	8	25	46	47	47
5	5	14	21	21	8	14	19	22	31	113	202
6	2	2	3	-	3	8	8	30	46	47	47
7	2	2	3	-	3	8	8	30	46	47	47
8	3	9	27	46	3	9	28	54	11	23	202
9	-	-	-	15	11	11	13	53	98	108	109
10	3	4	7	-	7	10	9	13	20	19	107
11	3	9	27	46	3	9	28	54	11	23	202
12	2	4	-	-	2	4	-	3	81	113	202
13	1	2	-	-	1	8	9	30	46	47	47
14	1	1	-	15	11	11	13	53	98	108	109
15	7	1	21	32	7	7	12	22	29	32	34
16	3	4	5	2	3	4	5	2	6	10	11
17	7	10	11	47	5	5	5	48	20	107	107
18	5	8	9	12	9	10	12	16	7	7	-
19	7	10	11	47	5	5	5	48	5	7	-
20	2	9	6	67	2	9	11	68	74	155	154
21	4	8	9	13	4	8	10	14	4	12	9
22	1	-	2	-	2	10	12	15	10	18	35
23	-	10	41	41	2	10	35	38	2	7	10
24	5	10	8	7	5	10	9	8	8	9	6
25	4	5	13	9	4	4	6	9	15	35	32
26	2	2	-	-	2	2	-	-	11	35	32
27	2	2	-	-	3	2	-	-	-	-	76
28	3	3	-	1	4	9	10	11	6	35	32
Probability of Detection (%)	93	93	68	68	100	100	86	93	96	96	93

Table 4.9: Mean Absolute Error of SPI, SPEI, and SDI in Identification of Drought Duration.

Case	Mean Absolute Error										
	SPI				SPEI				SDI		
	1	3	6	12	1	3	6	12	3	6	12
1	0.33	0.00	1.00	1.00	0.67	0.00	1.00	0.67	14.33	14.67	14.67
2	0.25	2.50	4.25	4.25	1.00	2.50	3.75	4.50	6.25	12.25	25.75
3	0.24	0.10	0.21	0.17	0.14	0.10	0.10	0.34	2.38	2.72	2.76
4	0.67	1.00	1.00	3.67	1.33	2.33	1.67	7.33	14.33	14.67	14.67
5	0.25	2.50	4.25	4.25	1.00	2.50	3.75	4.50	6.75	27.25	49.50
6	0.33	0.33	0.00	1.00	0.00	1.67	1.67	9.00	14.33	14.67	14.67
7	0.33	0.33	0.00	1.00	0.00	1.67	1.67	9.00	14.33	14.67	14.67
8	0.25	1.25	5.75	10.50	0.25	1.25	6.00	12.50	1.75	4.75	49.50
9	1.00	1.00	1.00	4.00	2.67	2.67	3.33	16.67	31.67	35.00	35.33
10	0.00	0.33	1.33	1.00	1.33	2.33	2.00	3.33	5.67	5.33	34.67
11	0.25	1.25	5.75	10.50	0.25	1.25	6.00	12.50	1.75	4.75	49.50
12	0.00	1.00	1.00	1.00	0.00	1.00	1.00	0.50	39.50	55.50	100.00
13	0.75	0.50	1.00	1.00	0.75	1.00	1.25	6.50	10.50	10.75	10.75
14	0.75	0.75	1.00	2.75	1.75	1.75	2.25	12.25	23.50	26.00	26.25
15	0.50	0.93	0.50	1.29	0.50	0.50	0.14	0.57	1.07	1.29	1.43
16	0.00	0.33	0.67	0.33	0.00	0.33	0.67	0.33	1.00	2.33	2.67
17	1.33	2.33	2.67	14.67	0.67	0.67	0.67	15.00	5.67	34.67	34.67
18	0.29	0.14	0.29	0.71	0.29	0.43	0.71	1.29	0.00	0.00	1.00
19	1.33	2.33	2.67	14.67	0.67	0.67	0.67	15.00	0.67	1.33	1.00
20	0.33	2.00	1.00	21.33	0.33	2.00	2.67	21.67	23.67	50.67	50.33
21	0.33	1.67	2.00	3.33	0.33	1.67	2.33	3.67	0.33	3.00	2.00
22	0.75	1.00	0.50	1.00	0.50	1.50	2.00	2.75	1.50	3.50	7.75
23	1.00	1.50	9.25	9.25	0.50	1.50	7.75	8.50	0.50	0.75	1.50
24	0.25	1.50	1.00	0.75	0.25	1.50	1.25	1.00	1.00	1.25	0.50
25	0.43	0.29	0.86	0.29	0.43	0.43	0.14	0.29	1.14	4.00	3.57
26	0.33	0.33	1.00	1.00	0.33	0.33	1.00	1.00	2.67	10.67	9.67
27	0.33	0.33	1.00	1.00	0.00	0.33	1.00	1.00	1.00	1.00	24.33
28	0.00	0.00	1.00	0.67	0.33	2.00	2.33	2.67	1.00	10.67	9.67
Mean	0.45	0.98	1.85	4.16	0.58	1.28	2.10	6.23	8.15	13.15	21.17

Table 4.10: Mean Bias Error of SPI, SPEI and SDI Method in Identification of Drought Duration.

Case	Mean Bias Error										
	SPI				SPEI				SDI		
	1	3	6	12	1	3	6	12	3	6	12
1	-1	0	-3	-3	-2	0	-3	-2	43	44	44
2	1	10	17	17	4	10	15	18	25	49	103
3	-7	-3	-6	5	-4	-3	-3	10	69	79	80
4	-2	3	-3	11	4	7	5	22	43	44	44
5	1	10	17	17	4	10	15	18	27	109	198
6	-1	-1	0	-3	0	5	5	27	43	44	44
7	-1	-1	0	-3	0	5	5	27	43	44	44
8	-1	5	23	42	-1	5	24	50	7	19	198
9	-3	-3	-3	12	8	8	10	50	95	105	106
10	0	1	4	-3	4	7	6	10	17	16	104
11	-1	5	23	42	-1	5	24	50	7	19	198
12	0	2	-2	-2	0	2	-2	1	79	111	200
13	-3	-2	-4	-4	-3	4	5	26	42	43	43
14	-3	-3	-4	11	7	7	9	49	94	104	105
15	-7	-13	7	18	-7	-7	-2	8	15	18	20
16	0	1	2	-1	0	1	2	-1	3	7	8
17	4	7	8	44	2	2	2	45	17	104	104
18	-2	1	2	5	2	3	5	9	0	0	-7
19	4	7	8	44	2	2	2	45	2	4	-3
20	-1	6	3	64	-1	6	8	65	71	152	151
21	1	5	6	10	1	5	7	11	1	9	6
22	-3	-4	-2	-4	-2	6	8	11	6	14	31
23	-4	6	37	37	-2	6	31	34	-2	3	6
24	1	6	4	3	1	6	5	4	4	5	2
25	-3	-2	6	2	-3	-3	-1	2	8	28	25
26	-1	-1	-3	-3	-1	-1	-3	-3	8	32	29
27	-1	-1	-3	-3	0	-1	-3	-3	-3	-3	73
28	0	0	-3	-2	1	6	7	8	3	32	29
Mean	-1.18	1.46	4.68	12.61	0.46	3.68	6.53	21.11	27.39	44.11	70.89

Table 4.11: Summary of Prediction Results for SPI, SPEI, and SDI Method.

Case	**Prediction**										
	SPI				**SPEI**				**SDI**		
	1	**3**	**6**	**12**	**1**	**3**	**6**	**12**	**3**	**6**	**12**
1	Under	Predicted	Under	Under	Under	Predicted	Under	Under	Over	Over	Over
2	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
3	Under	Under	Under	Over	Under	Under	Under	Over	Over	Over	Over
4	Under	Over	Under	Over	Over	Over	Over	Over	Over	Over	Over
5	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
6	Under	Under	Predicted	Under	Predicted	Over	Over	Over	Over	Over	Over
7	Under	Under	Predicted	Under	Predicted	Over	Over	Over	Over	Over	Over
8	Under	Over	Over	Over	Under	Over	Over	Over	Over	Over	Over
9	Under	Under	Under	Over	Over	Over	Over	Over	Over	Over	Over
10	Predicted	Over	Over	Under	Over	Over	Over	Over	Over	Over	Over
11	Under	Over	Over	Over	Under	Over	Over	Over	Over	Over	Over
12	Predicted	Over	Under	Under	Predicted	Over	Under	Over	Over	Over	Over
13	Under	Under	Under	Under	Under	Over	Over	Over	Over	Over	Over
14	Under	Under	Under	Over	Over	Over	Over	Over	Over	Over	Over
15	Under	Under	Over	Over	Under	Under	Under	Over	Over	Over	Over
16	Predicted	Over	Over	Under	Predicted	Over	Over	Under	Over	Over	Over
17	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
18	Under	Over	Over	Over	Over	Over	Over	Over	Predicted	Predicted	Under
19	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Under
20	Under	Over	Over	Over	Under	Over	Over	Over	Over	Over	Over
21	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
22	Under	Under	Under	Under	Under	Over	Over	Over	Over	Over	Over
23	Under	Over	Over	Over	Under	Over	Over	Over	Under	Over	Over

Case	Prediction										
	SPI				SPEI				SDI		
	1	3	6	12	1	3	6	12	3	6	12
24	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
25	Under	Under	Over	Over	Under	Under	Under	Over	Over	Over	Over
26	Under	Under	Under	Under	Under	Under	Under	Under	Over	Over	Over
27	Under	Under	Under	Under	Predicted	Under	Under	Under	Under	Under	Over
28	Predicted	Predicted	Under	Under	Over	Over	Over	Over	Over	Over	Over
Under	18	11	11	11	11	5	7	4	2	1	2
Over	6	15	15	17	12	22	21	24	25	26	26
Predicted	4	2	2	0	5	1	0	0	1	1	0
Total	28	28	28	28	28	28	28	28	28	28	28

Table 4.12: On-Time Detection of Drought Start and End Period Computed by SPI, SPEI and SDI with Historical Drought Events.

Case	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
1	Onset:	01/2014			End:	03/2014					
Onset	01/2014	02/2014			02/2014	02/2014		03/2014	03/2014	02/2014	02/2014
End	02/2014	04/2014			02/2014	04/2014		03/2014	12/2017	12/2014	12/2017
On-time	0	1	N.A	N.A	1	1	N.A	2	2	1	1
Detection	-1	1	N.A	N.A	-1	1	N.A	0	45	9	45
2	Onset:	01/2010			End:	04/2010					
Onset	01/2010	06/2009	04/2009	07/2009	12/2009	06/2009	05/2009	06/2009	07/2008	09/2008	02/2009
End	06/2010	07/2010	12/2010	03/2011	07/2010	07/2010	11/2010	03/2011	11/2010	1/2013	12/2017
On-time	0	-7	-9	-6	-1	-7	-8	-7	-18	-16	-11
Detection	2	3	8	11	3	3	7	11	7	33	92
3	Onset:	05/2014			End:	10/2016					
Onset	02/2014	03/2014	05/2014	02/2014	02/2014	03/2014	05/2014	02/2014	02/2009	07/2008	12/2008
End	10/2016	10/2016	12/2016	02/2017	10/2016	10/2016	12/2016	04/2017	03/2017	06/2017	12/2017
On-time	-3	-2	0	-3	-3	-2	0	-3	-63	-70	-65
Detection	0	0	2	4	0	0	2	6	5	8	14
4	Onset:	02/2016			End:	05/2016					
Onset	04/2016	05/2016		08/2015	03/2016	02/2016	05/2016	07/2015	03/2014	02/2014	02/2014
End	04/2016	10/2016		09/2016	09/2016	11/2016	12/2016	07/2017	12/2017	12/2017	12/2017
On-time	2	3	N.A	-6	1	0	3	-7	-23	-24	-24
Detection	-1	5	N.A	4	4	6	7	14	19	19	19
5	Onset:	01/2010			End:	04/2010					
Onset	01/2010	06/2009	04/2009	07/2009	12/2009	06/2009	05/2009	06/2009	06/2008	08/2008	03/2001
End	06/2010	07/2010	12/2010	03/2011	07/2010	07/2010	11/2010	03/2011	12/2010	12/2017	12/2017
On-time	0	-7	-9	-6	1	-7	-8	-7	-19	-17	-106
Detection	2	3	8	11	4	4	7	11	8	92	92

Case	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
6	Onset:	04/2016			End:	06/2016					
Onset	06/2016	03/2016	06/2016		06/2016	02/2016	05/2016	09/2014	03/2014	02/2014	02/2014
End	07/2016	04/2016	08/2016		08/2016	09/2016	12/2016	02/2017	12/2017	12/2017	12/2017
On-time	2	-1	2	N.A	2	-2	1	-19	-25	-26	-26
Detection	1	2	2	N.A	2	3	6	8	18	18	18
7	Onset:	04/2016			End:	06/2016					
Onset	06/2016	03/2016	06/2016		06/2016	02/2016	05/2016	09/2014	03/2014	02/2014	02/2014
End	07/2016	04/2016	08/2016		08/2016	09/2016	12/2016	02/2017	12/2017	12/2017	12/2017
On-time	2	-1	2	N.A	2	-2	1	-19	-25	-26	-26
Detection	1	-2	2	N.A	2	3	6	8	18	18	18
8	Onset:	07/2005			End:	10/2005					
Onset	06/2005	01/2005	07/2003	11/2003	06/2005	01/2005	07/2003	11/2003	02/2005	02/2005	03/2001
End	08/2005	09/2005	09/2005	08/2007	08/2005	09/2005	10/2005	04/2008	12/2005	12/2006	12/2017
On-time	-1	-6	-24	-20	-1	-6	-24	-20	-5	-5	-52
Detection	-2	-1	-1	13	-2	-1	0	30	2	14	146
9	Onset:	04/2016			End:	06/2016					
Onset				03/2015	01/2016	02/2016	02/2016	06/2013	02/2009	07/2008	12/2008
End				05/2016	11/2016	12/2016	02/2017	10/2017	03/2017	06/2017	12/2017
On-time	N.A	N.A	N.A	-13	-3	-2	-2	-34	-86	-93	-88
Detection	N.A	N.A	N.A	-1	5	6	8	16	9	12	18
10	Onset:	04/2016			End:	06/2016					
Onset	03/2016	03/2016	06/2016		03/2016	03/2016	04/2016	03/2016	05/2016	06/2016	02/2009
End	06/2016	06/2016	12/2016		10/2016	12/2016	12/2016	03/2017	12/2017	12/2017	12/2017
On-time	-1	-1	2	N.A	-1	-1	0	-1	1	2	-86
Detection	0	0	6	N.A	4	6	6	9	18	18	18

Case	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
11	Onset:	07/2005			End:	10/2005					
Onset	06/2005	01/2005	07/2003	11/2003	06/2005	01/2005	07/2003	11/2003	02/2005	02/2005	03/2001
End	08/2005	09/2005	09/2005	08/2007	08/2005	09/2005	10/2005	04/2008	12/2005	12/2006	12/2017
On-time	-1	-6	-24	-20	-1	-6	-24	-20	-5	-5	-52
Detection	-2	-1	-1	22	-2	-1	0	30	2	14	146
12	Onset:	12/2013			End:	01/2014					
Onset	01/2014	01/2014			01/2014	01/2014		01/2014	04/2011	08/2008	03/2001
End	02/2014	04/2014			02/2014	04/2014		03/2014	12/2017	12/2017	12/2017
On-time	1	1	N.A	N.A	1	1	N.A	1	-32	-64	-33
Detection	1	3	N.A	N.A	1	1	N.A	2	47	47	47
13	Onset:	02/2016			End:	05/2016					
Onset	03/2016	03/2016			03/2016	02/2016	03/2016	09/2014	03/2014	02/2014	02/2014
End	03/2016	04/2016			03/2016	09/2016	12/2016	02/2017	12/2017	12/2017	12/2017
On-time	1	1	N.A	N.A	1	0	1	-17	-23	-24	-24
Detection	-2	-1	N.A	N.A	-2	4	7	9	19	19	19
14	Onset:	02/2016			End:	05/2016					
Onset	03/2016	03/2016		03/2015	01/2016	02/2016	02/2016	06/2013	02/2009	07/2008	12/2008
End	03/2016	03/2016		05/2016	11/2016	12/2016	02/2017	10/2017	03/2017	06/2017	12/2017
On-time	1	1	N.A	-11	-1	0	0	-32	-84	-91	-86
Detection	-2	-2	N.A	0	6	7	9	17	10	13	19
15	Onset:	01/1991			End:	02/1992					
Onset	11/1990	01/1991	02/1990	06/1989	11/1990	01/1991	11/1990	02/1990	11/1990	09/1990	01/1991
End	01/1992	08/1991	10/1991	01/1992	01/1992	08/1991	10/1991	01/1992	03/1993	04/1993	10/1993
On-time	-2	0	1	-19	-2	0	-2	1	-2	-4	0
Detection	-1	-6	-4	-1	-1	-6	-4	-1	13	14	20

Case	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
16	Onset:	01/2002			End:	03/2002					
Onset	12/2001	01/2002	02/2002	01/2002	12/2001	01/2002	02/2002	01/2002	02/2002	05/2001	09/2001
End	02/2002	04/2002	06/2002	02/2002	02/2002	04/2002	06/2002	02/2002	07/2002	02/2002	07/2002
On-time	-1	0	1	0	-1	0	1	0	1	-8	-4
Detection	-1	1	3	-1	-1	1	3	-1	4	-1	4
17	Onset:	04/2016			End:	06/2016					
Onset	02/2016	02/2016	02/2016	09/2013	02/2016	03/2016	04/2016	09/2012	05/2016	02/2009	02/2009
End	09/2016	11/2016	12/2016	07/2017	07/2016	07/2016	08/2016	08/2016	12/2017	12/2017	12/2017
On-time	-2	-2	-2	-31	-2	-1	0	-43	1	-86	-86
Detection	3	5	6	13	1	1	2	2	18	18	18
18	Onset:	04/2016			End:	10/2016					
Onset	02/2016	02/2016	02/2016	03/2016	12/2015	02/2016	01/2016	11/2015	03/2016	05/2016	
End	09/2016	11/2016	10/2016	02/2017	10/2016	11/2016	12/2016	02/2017	11/2016	11/2016	
On-time	-2	-2	-2	-1	-4	-2	-3	-5	-1	1	N.A
Detection	-1	1	0	4	0	1	2	4	1	1	N.A
19	Onset:	04/2016			End:	06/2016					
Onset	02/2016	02/2016	02/2016	09/2013	02/2016	03/2016	04/2016	09/2012	03/2016	05/2016	
End	09/2016	11/2016	12/2016	07/2017	07/2016	07/2016	08/2016	08/2016	07/2016	11/2016	
On-time	-2	-2	-2	-31	-2	-1	0	-43	-1	1	N.A
Detection	3	5	6	13	1	1	2	2	1	5	N.A
20	Onset:	01/2002			End:	03/2002					
Onset	01/2002	07/2001	10/2001	04/1997	01/2002	07/2001	05/2001	06/1997	01/2001	06/1994	11/1994
End	02/2002	03/2002	03/2002	10/2002	02/2002	03/2002	03/2002	01/2003	02/2007	04/2007	08/2007
On-time	0	-6	-3	-57	0	-6	-8	-55	-12	-91	-86
Detection	-1	0	0	7	-1	0	0	-2	59	61	65

Case	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
21	Onset:	01/2002			End:	03/2002					
Onset	12/2001	01/2002	01/2002	01/2002	12/2001	01/2002	01/2002	01/2002	01/2002	11/2001	02/2002
End	03/2002	08/2002	09/2002	01/2003	03/2002	08/2002	10/2002	02/2003	04/2002	10/2002	10/2002
On-time	-1	0	0	0	-1	0	0	0	0	-2	1
Detection	0	5	6	-2	0	5	7	-1	1	7	7
22	Onset:	04/2005			End:	07/2005					
Onset	06/2005		05/2005		05/2005	01/2005	03/2005	12/2004	07/2005	05/2005	02/2004
End	06/2005		06/2005		06/2005	10/2005	02/2006	4/2006	04/2006	10/2006	11/2006
On-time	2	N.A	1	N.A	1	-3	-1	-4	3	1	-14
Detection	-1	N.A	-1	N.A	-1	3	7	9	9	15	16
23	Onset:	01/2010			End:	04/2010					
Onset	10/2009	06/2009	09/2009	11/2009	10/2009	06/2009	08/2009	11/2009	06/2009	06/2009	10/2009
End	02/2010	03/2010	04/2010	05/2010	02/2010	03/2010	04/2010	06/2010	01/2010	02/2010	03/2010
On-time	-3	-7	-4	-2	-3	-7	-5	-2	-7	-7	-3
Detection	-2	-1	0	1	-2	-1	0	2	-3	-2	-1
24	Onset:	01/2014			End:	04/2014					
Onset		02/2014	08/2013	11/2013	03/2014	02/2014	01/2014	02/2014	03/2014	08/2013	01/2014
End		11/2014	12/2016	03/2017	05/2014	11/2014	12/2016	03/2017	05/2014	02/2014	10/2014
On-time	N.A	1	-5	-2	2	1	0	1	2	-5	0
Detection	N.A	-5	-4	35	1	7	8	35	1	-2	6
25	Onset:	02/2014			End:	08/2014					
Onset	01/2014	01/2014	05/2013	11/2013	01/2014	02/2014	01/2014	11/2013	08/2013	10/2013	02/2014
End	06/2014	08/2014	06/2014	07/2014	06/2014	08/2014	07/2014	07/2014	10/2014	08/2016	09/2016
On-time	-1	-1	-9	-3	-1	0	-1	-3	-6	-4	0
Detection	-2	0	-2	-1	-2	0	-1	-1	2	24	25

Case	SPI-1	SPI-3	SPI-6	SPI-12	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SDI-3	SDI-6	SDI-12
26	Onset:	01/2015			End:	03/2015					
Onset	01/2015	02/2015			01/2015	02/2015			01/2015	10/2013	02/2014
End	02/2015	03/2015			02/2015	03/2015			11/2015	08/2016	09/2016
On-time	0	1	N.A	N.A	0	1	N.A	N.A	0	-15	-11
Detection	-1	0	N.A	N.A	-1	0	N.A	N.A	8	5	18
27	Onset:	01/2015			End:	03/2015					
Onset	01/2015	02/2015			12/2014	02/2015					10/2008
End	02/2015	03/2015			02/2015	03/2015					01/2015
On-time	0	1	N.A	N.A	-1	1	N.A	N.A	N.A	N.A	-75
Detection	-1	0	N.A	N.A	-1	0	N.A	N.A	N.A	N.A	-2
28	Onset:	02/2016			End:	04/2016					
Onset	01/2016	02/016		04/2016	01/2016	02/2016	04/2016	04/2016	03/2016	10/2013	02/2014
End	04/2016	04/2016		04/2016	04/2016	10/2016	01/2017	02/2017	08/2016	08/2016	09/2016
On-time	-1	0	N.A	2	-1	0	2	2	1	-28	-24
Detection	0	0	N.A	0	0	6	9	10	4	4	5

Table 4.13: Comparison of Onset Detection Between Historical Drought and Computed Results from SPI, SPEI and SDI Method.

Case	Onset Detection (Month)										
	SPI				**SPEI**				**SDI**		
	1	**3**	**6**	**12**	**1**	**3**	**6**	**12**	**3**	**6**	**12**
1	0	1	N.A	N.A	1	1	N.A	2	2	1	1
2	0	-7	-9	-6	-1	-7	-8	-7	-18	-16	-11
3	-3	-2	0	-3	-3	-2	0	-3	-63	-70	-65
4	2	3	N.A	-6	1	0	3	-7	-23	-24	-24
5	0	-7	-9	-6	1	-7	-8	-7	-19	-17	-106
6	2	-1	2	N.A	2	-2	1	-19	-25	-26	-26
7	2	-1	2	N.A	2	-2	1	-19	-25	-26	-26
8	-1	-6	-24	-20	-1	-6	-24	-20	-5	-5	-52
9	N.A	N.A	N.A	-13	-3	-2	-2	-34	-86	-93	-88
10	-1	-1	2	N.A	-1	-1	0	-1	1	2	-86
11	-1	-6	-24	-20	-1	-6	-24	-20	-5	-5	-52
12	1	1	N.A	N.A	1	1	N.A	1	-32	-64	-33
13	1	1	N.A	N.A	1	0	1	-17	-23	-24	-24
14	1	1	N.A	-11	-1	0	0	-32	-84	-91	-86
15	-2	0	1	-19	-2	0	-2	1	-2	-4	0
16	-1	0	1	0	-1	0	1	0	1	-8	-4
17	-2	-2	-2	-31	-2	-1	0	-43	1	-86	-86
18	-2	-2	-2	-1	-4	-2	-3	-5	-1	1	N.A
19	-2	-2	-2	-31	-2	-1	0	-43	-1	1	N.A
20	0	-6	-3	-57	0	-6	-8	-55	-12	-91	-86
21	-1	0	0	0	-1	0	0	0	0	-2	1
22	2	N.A	1	N.A	1	-3	-1	-4	3	1	-14
23	-3	-7	-4	-2	-3	-7	-5	-2	-7	-7	-3
24	N.A	1	-5	-2	2	1	0	1	2	-5	0
25	-1	-1	-9	-3	-1	0	-1	-3	-6	-4	0
26	0	1	N.A	N.A	0	1	N.A	N.A	0	-15	-11
27	0	1	N.A	N.A	-1	1	N.A	N.A	N.A	N.A	-75
28	-1	0	N.A	2	-1	0	2	2	1	-28	-24
Mean	-0.43	-1.48	-6.33	-9.00	-0.68	-1.68	-2.67	-12.91	-16.54	-26.92	-38.17

Table 4.14: Comparison of End Detection Between Historical Drought and Computed Results from SPI, SPEI and SDI Method.

Case	End Detection (Month)										
	SPI				**SPEI**				**SDI**		
	1	**3**	**6**	**12**	**1**	**3**	**6**	**12**	**3**	**6**	**12**
1	-1	1	N.A	N.A	-1	1	N.A	0	45	9	45
2	2	3	8	11	3	3	7	11	7	33	92
3	0	0	2	4	0	0	2	6	5	8	14
4	-1	5	N.A	4	4	6	7	14	19	19	19
5	2	3	8	11	4	4	7	11	8	92	92
6	1	2	2	N.A	2	3	6	8	18	18	18
7	1	-2	2	N.A	2	3	6	8	18	18	18
8	-2	-1	-1	13	-2	-1	0	30	2	14	146
9	N.A	N.A	N.A	-1	5	6	8	16	9	12	18
10	0	0	6	N.A	4	6	6	9	18	18	18
11	-2	-1	-1	22	-2	-1	0	30	2	14	146
12	1	3	N.A	N.A	1	1	N.A	2	47	47	47
13	-2	-1	N.A	N.A	-2	4	7	9	19	19	19
14	-2	-2	N.A	0	6	7	9	17	10	13	19
15	-1	-6	-4	-1	-1	-6	-4	-1	13	14	20
16	-1	1	3	-1	-1	1	3	-1	4	-1	4
17	3	5	6	13	1	1	2	2	18	18	18
18	-1	1	0	4	0	1	2	4	1	1	N.A
19	3	5	6	13	1	1	2	2	1	5	N.A
20	-1	0	0	7	-1	0	0	-2	59	61	65
21	0	5	6	-2	0	5	7	-1	1	7	7
22	-1	N.A	-1	N.A	-1	3	7	9	9	15	16
23	-2	-1	0	1	-2	-1	0	2	-3	-2	-1
24	N.A	-5	-4	35	1	7	8	35	1	-2	6
25	-2	0	-2	-1	-2	0	-1	-1	2	24	25
26	-1	0	N.A	N.A	-1	0	N.A	N.A	8	5	18
27	-1	0	N.A	N.A	-1	0	N.A	N.A	N.A	N.A	-2
28	0	0	N.A	0	0	6	9	10	4	4	5
Mean	-0.30	0.78	4.17	8.50	0.68	2.08	4.05	7.87	13.38	18.63	31.43

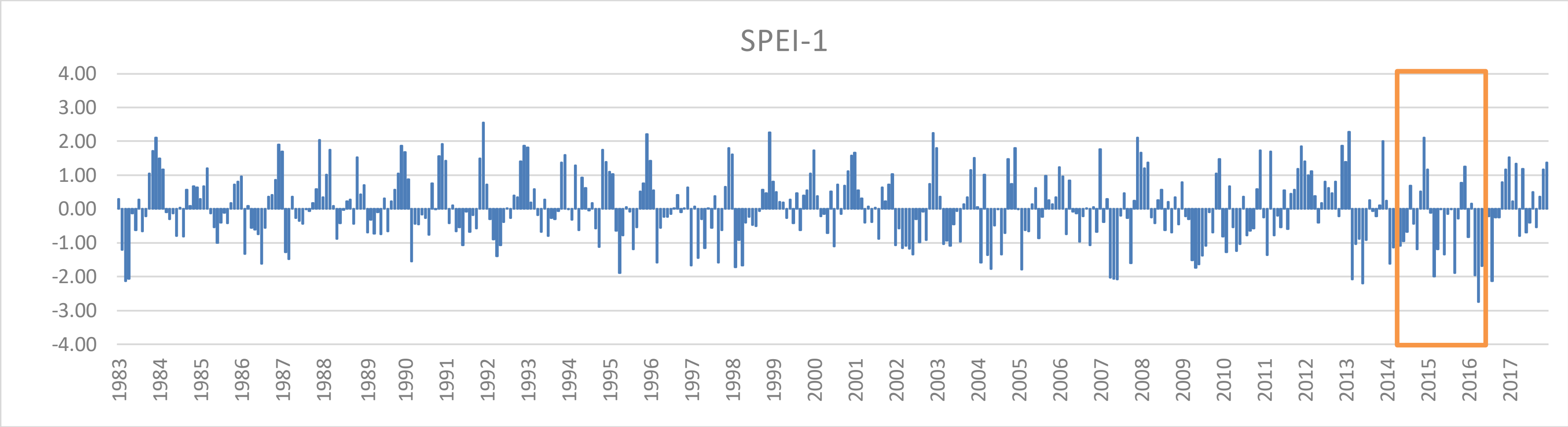

Figure 4.31: SPEI-1 Index for Congok Dam (Case 3).

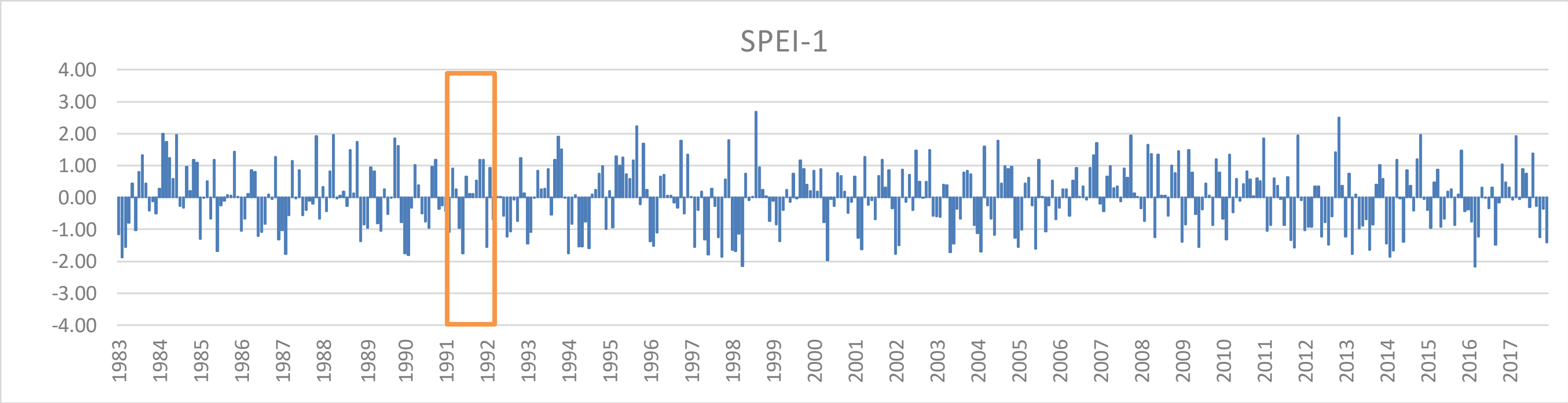

Figure 4.32: SPEI-1 Index for Durian Tunggal Dam (Case 15).

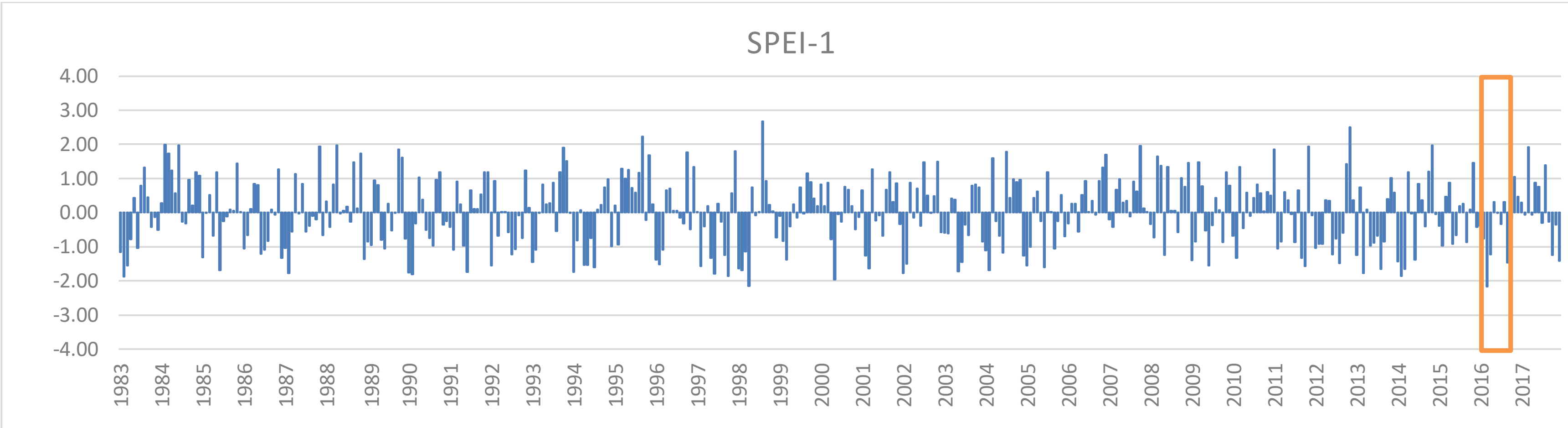

Figure 4.33: SPEI-1 Index for Durian Tunggal Dam (Case 18).

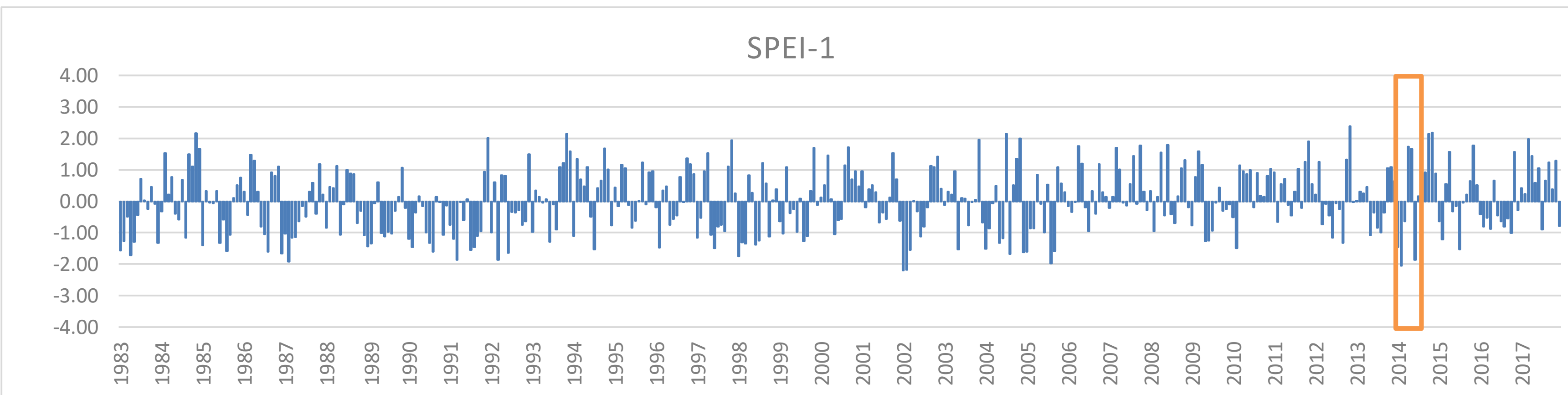

Figure 4.34: SPEI-1 Index for Seremban (Case 25).

4.3 Average Moving Range

The average moving range utilizes the difference between 2 data and measure how these 2 variations change over the 35 years from 1983 to 2017 given that monthly data are collected as individual measurements rather than in subgroups.

From the Table 4.15, findings show that as time scale elongates, the AMR will become lesser. For the SPEI, the AMR for 1-month time scale has value of generally above 0.90 for all stations. For the case of the 3-month time scale, the AMR drops to 0.60, continuing with 0.40 until 0.30 for 6- and 12-month time scale, respectively. All indexes have shown the same properties of getting lesser fluctuation in values.

As Malaysia is located at the equatorial zone, it has dry and humid weather throughout the year, with the rainy day almost equivalent to non-rainy day, not to say that the weather and atmospheric condition is affected by monsoons and inter-monsoons period. As short time scale is applied in computation, the monthly data for streamflow and rainfall will typically fluctuate due to the reasons stated above. However, if longer time-scale is applied, the fluctuation will become lesser since the monthly data is accumulated which could cover up to cross-monsoon season interval.

Nonetheless, short time-scale computation is not necessarily applicable for other countries. For instance, if the deserts are to be treated as the study area, then the short time-scale cumulative rainfall computation is said to be meaningless. This is due to the deserts commonly having dry and hot weather, thus leading to less fluctuation in short time-scale computation. In this case, the AMR for deserts will only significant fluctuate if measured in longer time-scale. In conclusion, a shorter time-scale computation method is more applicable in this study, and the rainfall data should represent a significant and meaningful parameter compared to other data.

Table 4.15: The Average Moving Range (AMR) Determined by SPEI for 16 Stations.

Station No.	State	SPEI-1	SPEI-3	SPEI-6	SPEI-12
1437116	Johor	0.99	0.58	0.41	0.26
1534002	Johor	0.98	0.55	0.40	0.27
1541139	Johor	0.98	0.56	0.36	0.20
1732004	Johor	0.97	0.55	0.41	0.26
1737001	Johor	0.99	0.55	0.38	0.23
1931003	Johor	0.96	0.52	0.34	0.19

Station No.	State	SPEI-1	SPEI-3	SPEI-6	SPEI-12
2025001	Johor	0.99	0.56	0.38	0.23
2231001	Johor	0.96	0.52	0.36	0.21
2235163	Johor	0.94	0.49	0.35	0.20
2330009	Johor	0.96	0.53	0.35	0.24
2636170	Johor	0.87	0.50	0.38	0.23
2224038	Malacca	1.05	0.60	0.43	0.25
2321006	Malacca	1.00	0.63	0.41	0.28
2719001	Negeri Sembilan	0.94	0.58	0.38	0.24
2725083	Negeri Sembilan	1.02	0.55	0.39	0.24
3020016	Negeri Sembilan	0.97	0.55	0.37	0.20

4.4 Trend Analysis

The trend analysis of monthly SPEI-1 at various rainfall stations from 1983 to 2017 are listed in Table 4.16 to Table 4.17. SPEI-1 had shown decreasing trend in February, June, July, and August.

In general, as shown in figure 4.35 to 4.37 all stations in the SPEI- 1 computation has shown increasing trend indicating that even though the dry weather occurred throughout the year, the weather in the southern region of Peninsular Malaysia is still generally wet. All the stations have shown wet tendencies towards the end of the year along the study period (year 1983 to 2017). Figure 4.38 showed the trends for all rainfall station over the 35 years. From the SPEI-1 method which is in 1-month time scale, the line started to decline to the negative value at June. This decline in the graph will continue until it reaches September, where the graph will start to invert back to the normal condition (above 0). Based on the table 4.17, the high magnitude of trend decreases is frequently observed in June (Stations 2719001, 1732004, 1437116 and 3020016), while the increasing trend can be found commonly in November and December (Stations 1541139, 2224038, 2231001, 2235163, 2321006, 2636170, 2725083 and 3020016).

As the north-east monsoon usually commenced from early November until middle of March, it is the major rainy season in Malaysia. As it constantly brings rainfall from South China Sea, the humid weather in the southern region is supposed to cool down the hot temperature. However, as the north-east monsoon is coming to the last phase and entering inter-monsoon season (February), the temperature will be rising due to lesser rainfall. This drop of rainfall at 20% to 60% at the southern region caused the weather to shift from humid back to hot again, and the temperature will rise by 0.5 to 2.0 degree Celsius.

Typically, the south-west monsoon season starts from late May until September and this monsoon is also a major hot season in Malaysia. As the south-west monsoon originates from the deserts of Australia, it brings extremely less rainfall as well as dry and hot air to the southern region. All stations exhibited a decreasing trend in June, July and August as it were part of the period where the south-west monsoon occurs. In September, most of the station gives an increasing trend as when the south-west monsoon season comes to an end, the atmosphere will start to cool down and enter inter-monsoon period.

Based on the results in Table 4.17, more drought monitoring and attention should be concentrated on the stations' region with decreasing trend during February, June, July, and August. Furthermore, the location of stations with high decreasing trend, which are: the northern region of Negeri Sembilan and the southern and the south-west of Johor, required more mitigation plan for the better sake of water resources management to cope with the water shortage issues during dry spells.

Table 4.16: Summary of Trend Analysis for 16 Stations in Southern Region of Peninsular Malaysia Along 35 Years.

Station	Trend	Magnitude (Slope)
1437116	Increasing	0.013
1534002	Increasing	0.016
1541139	Increasing	0.067
1732004	Increasing	0.032
1737001	Increasing	0.027
1931003	Increasing	0.030
2025001	Increasing	0.049
2231001	Increasing	0.065
2235163	Increasing	0.095
2330009	Increasing	0.021
2636170	Increasing	0.086
2224038	Increasing	0.054
2321006	Increasing	0.123
2719001	Increasing	0.088
2725083	Increasing	0.090
3020016	Increasing	0.050

Figure 4.35: Trend Analysis for Station 1437116, 1534002, 1541139, 1732004, 1737001 and 1931003 Along 35 Years.

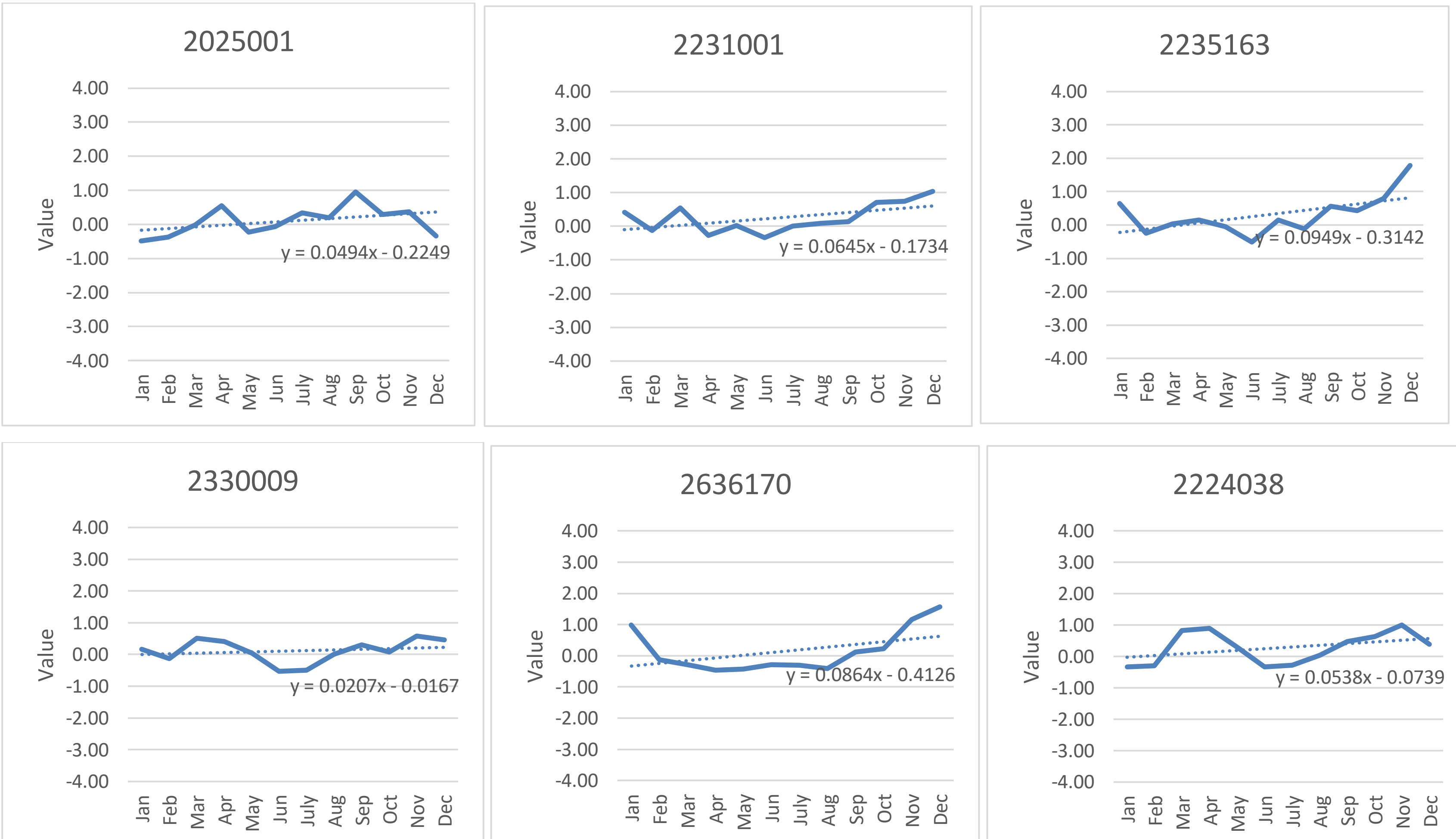

Figure 4.36: Trend Analysis for Station 2025001, 2231001, 2235163, 2330009, 2636170 and 2224038 Along 35 Years.

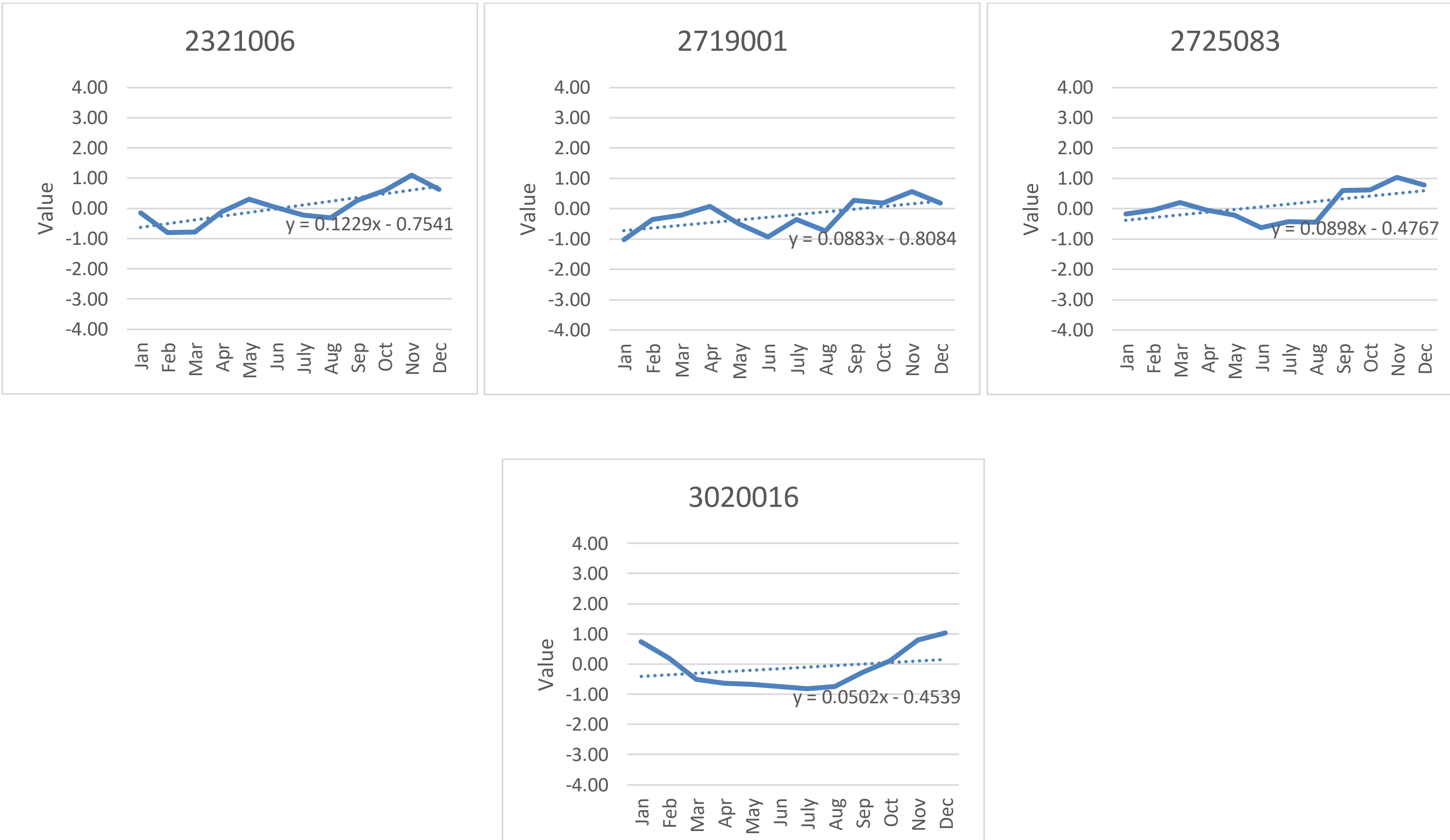

Figure 4.37: Trend Analysis for Station 2321006, 2719001 2725083 and 3020016 Along 35 Years.

Table 4.17: SPEI-1 Average Trend Analysis at 16 Rainfall Stations over 35 Years (1983 to 2017).

	SPEI-1											
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1437116	0.01	-0.31	0.36	0.08	0.37	-0.84	-0.15	0.03	0.24	0.00	0.05	0.24
1534002	-0.10	-0.09	0.50	0.07	0.08	-0.46	-0.14	-0.33	0.53	0.30	0.56	-0.22
1541139	1.23	-0.76	0.18	0.03	0.49	0.13	0.25	0.14	0.26	0.24	0.85	1.60
1732004	0.16	-0.27	0.64	0.36	-0.48	-0.28	-0.11	-0.23	0.55	0.29	0.43	0.48
1737001	0.12	-0.31	0.43	0.26	0.03	-0.77	-0.15	0.03	0.14	0.07	0.39	0.48
1931003	0.30	-0.10	0.89	0.74	0.13	-0.04	0.06	0.36	0.17	0.68	0.68	0.77
2025001	-0.49	-0.37	-0.02	0.54	-0.22	-0.06	0.33	0.19	0.95	0.30	0.36	-0.34
2224038	-0.33	-0.30	0.83	0.90	0.29	-0.34	-0.27	0.03	0.47	0.64	1.00	0.39
2231001	0.41	-0.12	0.54	-0.27	0.02	-0.33	0.01	0.08	0.13	0.70	0.75	1.04
2235163	0.65	-0.25	0.03	0.15	-0.04	-0.52	0.15	-0.12	0.57	0.43	0.79	1.79
2321006	-0.16	-0.80	-0.78	-0.11	0.30	0.03	-0.22	-0.31	0.27	0.59	1.10	0.63
2330009	0.17	-0.14	0.52	0.41	0.05	-0.54	-0.50	0.02	0.31	0.07	0.58	0.45
2636170	0.98	-0.12	-0.29	-0.46	-0.42	-0.29	-0.30	-0.41	0.12	0.23	1.17	1.58
2719001	-1.03	-0.36	-0.21	0.09	-0.50	-0.93	-0.35	-0.74	0.27	0.19	0.56	0.19
2725083	-0.17	-0.05	0.21	-0.04	-0.21	-0.62	-0.42	-0.45	0.60	0.61	1.03	0.78
3020016	0.75	0.19	-0.51	-0.63	-0.68	-0.75	-0.82	-0.75	-0.28	0.11	0.80	1.03
Average	0.16	-0.26	0.21	0.13	-0.05	-0.41	-0.16	-0.15	0.33	0.34	0.69	0.68

Table 4.18: 35 Years Trend Summary for All Stations in SPI, SPEI and SDI Method.

Method	**Time-scale**	**Trend**	**Magnitude (Slope)**
SPEI	1	Increasing	0.0566

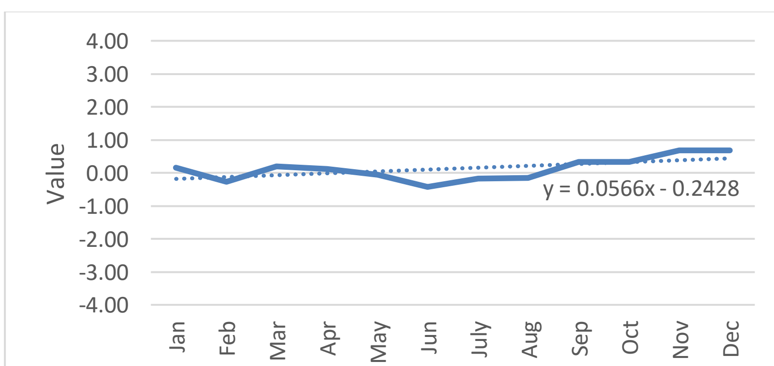

Figure 4.38: Average Trend Determined by SPEI under Different Time Scale over 35 Years Along Each Month for 16 Rainfall Stations.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

4.5 Conclusion

Based on the study of the dry spells in the southern region of Peninsular Malaysia, it shows that from identifying the occurrence of drought events, the north part of the southern region tends to have agricultural or meteorological drought events more frequently, while south part and the Negeri Sembilan are prone to the hydrological drought events with longer duration. In determining the magnitude of droughts over in the southern region of Peninsular Malaysia, the dry spells normally will only be “moderately or slightly dry” with overall -1.0 in the SPI, the SPEI and the SDI computations.

The SPEI-1 has the highest probability of detection which is 100% amongst other methods or time-scales with mean absolute error of 0.58 in determining drought duration. The SPEI-1 model has shown promising results in which it would over-predict the drought duration in most optimal way, which in other words, it would not over-predict too much on the drought duration to the extent of affecting the mean absolute error for computation. Other than that, the onset and end detection computed by the SPEI-1 shows that the drought to be commenced 1 month earlier and end approximately by 1 month later. This would help the researcher or authorities to get fully prepared for the upcoming drought as it gives a margin to adjust the response plan to drought.

In general, the trend analysis computed using the SPEI-1 showed an increasing slope over the 35 years throughout the year. This indicates that in spite of the fact that drought occurred in the southern region of Peninsular Malaysia, the region is still under wet conditions throughout the year. The SPEI-1 has an average moving range of close to 1.0 in which the study has shown that since the SPEI-1 has a shorter time-scale computation method, it could best describe the drought condition more precisely and accurately as for Peninsular Malaysia which is located near the equator, the weather condition changes are drastic throughout the year.

4.6 Recommendations

This study shows that the SPEI-1 is feasible to apply in identifying drought characteristics as well as dry condition, but further study is required to assure a more suitable interpretation of drought conditions in the southern region of Peninsular Malaysia. Thus, a few possible improvements are suggested herein, for future research and computation analysis of drought conditions in the southern region of Peninsular Malaysia.

There are only 3 indices which are adopted in this study. Among these 3 indices, the SPI and the SPEI are using rainfall data; while the SDI is merely applying streamflow data. Additional studies with different indices with same input hydrology parameters should be carried out in order to compare the results of drought condition in the southern region of Peninsular Malaysia in a more effective and precise way. Indices such as PDSI, or CMI can be applied to differentiate the distinguish results between each drought index.

Time-scales for each drought indices were set to 1-month, 3-month, 6-month and 12-month. This however, could not completely govern the general drought or dry condition in the southern region of Peninsular Malaysia. Thus, indices with more different time-scales such as 2-month and 4-month should be developed to describe the condition in the southern region of Peninsular Malaysia. Since Malaysia rarely has prolonged drought period to the extent of 1 year, studies should iterate more on the agricultural or meteorological droughts that occurred in the southern region of Peninsular Malaysia as in this area, plantations sector hold more land than other general usage, which further emphasize on how important the monitoring of the short-term drought was to the southern region of Peninsular Malaysia.

Since Malaysia is located between the Indian Ocean and Pacific Ocean, more studies on the relationship between the sea surface temperature could be carried out in order to link the climatology study of Peninsular Malaysia with the global temperature changing factor. Climate variations phenomena caused by ocean variations such as ENSO Modoki and Indian Ocean Dipole (IOD) which affects the Asian monsoon system could be adopted to compare with the data changes in precipitation or temperature in Peninsular Malaysia.

REFERENCES

ABC News, 2016. Drought forces Malaysia to expand water rationing around Kuala Lumpur. *ABC News*, [online] 1 Mar. Available at: <https://www.abc.net.au/news/2014-02-28/an-drought-forces-malaysia-to-expand-water-rationing-around-kua/5292466> [Accessed 30 December 2018].

Abramowitz, M. and Stegun, I.A., 1965. *Handbook of mathematical functions with formulas, graphs, and mathematical tables.* New York: Dover Publications Inc.

Ahmad, H. F., 2010. Peritnya dilanda kemarau. *Utusan Online*, [online] 11 Mar. Available at: <http://ww1.utusan.com.my/utusan/info.asp?y=2010&dt=0311&pub=Utusan_Malaysia&sec=Timur&pg=wt_01.htm> [Accessed 11 Jan 2019].

Ahsan, A. A., 2002. Paras air di beberapa sungai turun, pengunna hadapi masalah. *Utusan Online*, [online] 17 Feb. Available at: <http://ww1.utusan.com.my/utusan/info.asp?y=2002&dt=0217&pub=Utusan_Malaysia&sec=Muka_Hadapan&pg=mh_03.htm> [Accessed 11 Jan 2019].

Ahsan, A. A., 2002. Paras air di beberapa sungai turun, pengunna hadapi masalah. *Utusan Online*, [online] 17 Feb. Available at: <http://ww1.utusan.com.my/utusan/info.asp?y=2002&dt=0217&pub=Utusan_Malaysia&sec=Muka_Hadapan&pg=mh_03.htm> [Accessed 11 Jan 2019].

Alley, W.M., 1984. The Palmer drought severity index: Limitations and assumptions. *Journal of Applied Meteorology*, 23, pp. 1100-1109. [online] Available at: <https://www.researchgate.net/publication/51997439_The_Palmer_Drought_Severity_Index_Limitations_and_Assumptions> [Accessed 12 August 2018].

American Meteorological Society, 2013. *Drought*. [online] Available at: <https://www.ametsoc.org/ams/index.cfm/about-ams/ams-statements/statements-of-the-ams-in-force/drought/> [Accessed 10 August 2018].

Amin, A. Q., Leal, W., Trinxeria, J. M., Jaafar, A. H. and Ghani, Z. A., 2011. Assessing the impacts of climate change in the Malaysian agriculture sector and its influences in investment decision. *Middle-East Journal of Scientific Research*. [online] Available at: <https://www.idosi.org/mejsr/mejsr7(2)11/17.pdf> [11 Jan 2019].

Astro Awani, 2014. Water at Sembrong Dam in Batu Pahat drops to lowest levels. *Astro Awani*, [online] 24 Feb. Available at: <http://english.astroawani.com/malaysia-news/water-sembrong-dam-batu-pahat-drops-lowest-levels-30733> [Accessed 11 Jan 2019].

Ayantobo, O., Li, Y., Song, S. and Yao, N., 2017. Spatial comparability of drought characteristics and related return periods in mainland China over 1961-2013. *Journal of*

Hydrology, 550. [online] Available at: <https://www.researchgate.net/publication/316924951_Spatial_Comparability_of_Drought_Characteristics_and_Related_Return_Periods_in_Mainland_China_over_1961_-_2013> [Accessed 10 August 2018].

Azizi, N. A., 2016. Negri Sembilan may consider water rationing in two weeks, if dry spells continues: MB. *New Straits Times*, [online] 9 Mar. Available at: <https://www.nst.com.my/news/2016/03/131888/negri-sembilan-may-consider-water-rationing-two-weeks-if-dry-spell-continues-mb> [Accessed 11 Jan 2019].

Bagheri, F., 2016. Mapping drought hazard using SPI index and GIS (A case study: Fars province, Iran). *International Journal of Environment and Geoinformatics*. [online] Available at: <http://dergipark.gov.tr/download/article-file/291682> [Accessed 2 November 2018].

Benjamin, N., 2010. Water rationing in Kluang to be affected from today to March 13. The Star Online, [online] 13 Feb. Available at: <https://www.thestar.com.my/news/community/2010/02/13/water-rationing-in-kluang-to-be-affected-from-today-to-march-13/> [Accessed 11 Jan 2019].

Benjamin, N., 2010. Water rationing in Kluang to be affected from today to March 13. *The Star Online*, [online] 13 Feb. Available at: <https://www.thestar.com.my/news/community/2010/02/13/water-rationing-in-kluang-to-be-affected-from-today-to-march-13/> [Accessed 11 Jan 2019].

Brown, J.F., Wardlow, B.D., Tadesse, T., Hayes, M.J. and Reed, B.C., 2013. The vegetation drought response index (VegDRI): A new integrated approach for monitoring drought stress in vegetation. *GIScience and Remote Sensing*, 45(1), pp. 16-46. [online] Available at: <https://www.researchgate.net/publication/228665132_The_Vegetation_Drought_Response_Index_VegDRI_A_New_Integrated_Approach_for_Monitoring_Drought_Stress_in_Vegetation> [Accessed 7 August 2018].

Carlowicz, M., 2015. *Europe and Pacific Northwest face record heat*. NASA's Earth observatory. [online] 14 Jul. The National Aeronautics and Space Administration. Available at: < https://climate.nasa.gov/news/2309/europe-and-pacific-northwest-face-record-heat/> [Accessed 4 August 2018].

Ching, O.T., 2017. Plantation commodity exports rise to RM122b. New Straits Times, [online] 23 Feb. Available at: >https://www.nst.com.my/news/2017/02/214692/plantation-commodity-exports-rise-rm122b> [Accessed 4 August 2018].

Chuah, B.K., 2016. Congok dam water level dropping, necessitating scheduled water supply for Mersing. New Straits Times, [online] 25 Aug. Available at: <https://www.nst.com.my/news/2016/08/168355/congok-dam-water-level-depleting-necessitating-scheduled-water-supply-mersing> [Accessed 2 February 2019].

Crausbay, S.D. and Ramirez, A.R., Carter, S.L., Cross, M.S., Hall, K.R., Bathke, D.J., Betancourt, J., Colt, S., Cravens, A., Dalton, M.S., Dunham, J., Hay, L.E., Hayes, M.J., McEvoy, J., McNutt, C.A., Moritz, M.A., Nislow, K.H., Raheem, N., Sanford, T., 2018. Defining ecological drought for the twenty-first century. *Bulletin of the American Meteorological Society*, 98(12), pp. 2543-2550. [online] Available at: <https://www.researchgate.net/publication/329642850_Defining_Ecological_Drought_for_the_Twenty-First_Century/citations> [Accessed 8 August 2018].

Department of Statistics Malaysia, 2010. *Preliminary count report 2010*. [online] Available at: <https://mycensus.gov.my/banci/www/admin/uploads/penerbitan52/mobile/index.html#p=1> [Accessed 2 October 2018].

Department of Statistics Malaysia, 2017. *Current population estimates, Malaysia, 2016-2017*. [online]. Available at: <https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=155&bul_id=a1d1UTFZazd5ajJiRWFHNDduOXFFQT09&menu_id=L0pheU43NWJwRWVSZklWdzQ4TlhUUT09> [Accessed 4 August 2018].

Doesken, N.J., McKee, T.B. and Kleist, J., 1991. *Development of surface water supply index for the western United States*. [online] Colorado: Colorado State University. Available at: <http://www.droughtmanagement.info/literature/CSU_Development_SWSI_Western_United_States_1991.pdf> [Accessed 14 August 2018].

Doorenbos, J. and Pruitt, W.O., 1977. Guidelines for predicting crop water requirements. *FAO Irrigation and Drainage Paper 24 (Revised)*. [online] Available at: <http://www.fao.org/3/a-f2430e.pdf> [Accessed 28 December 2018].

Esfahanian, E., Nejadhashemi, A.P., Mohammad Abouali, Adhikari, U., Zhang, Z., Daneshvar, F., Herman, M.R., 2016. Development and evaluation of a comprehensive drought index. *Journal of Environmental Management, 185*. [online] Available at: <https://www.researchgate.net/publication/309545497_Development_and_evaluation_of_a_comprehensive_drought_index> [Accessed 10 August 2018].

Ewing, J. and Domondon, K., 2016. *Drought, pollution and Johor's growing water needs*. [pdf] Available at: <https://www.iseas.edu.sg/images/pdf/ISEAS_Perspective_2016_47.pdf> [Accessed 4 January 2019].

Ganguli, P., Ganguly, A.R., 2015. Space-time trends in U.S. meteorological droughts. Journal of Hydrology: Regional Studies, [e-journal] 8, pp. 235-259. Available through: Universiti Tunku Abdul Rahman Library website <http://library.utar.edu.my/> [Accessed 5 August 2018].

GISgeography, 2018. Kriging interpolation-The prediction is strong in this one. [online] Available at: < https://gisgeography.com/kriging-interpolation-prediction/> [Accessed 21 September 2018].

Guttman, N.B., 1998. Comparing the Palmer drought index and the standardized precipitation index. *Journal of The American Water Resources Association*. [online] Available at: <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1752-1688.1998.tb05964.x> [Accessed 13 September 2018].

Halim Said, 2016. Congok dam, Mersing's main source of water, has completely dried up. New Straits Times, [online] 28 Aug. Available at: <https://www.nst.com.my/news/2016/08/168851/congok-dam-mersings-main-source-water-has-completely-dried> [Accessed 2 February 2019].

Hayes, M.J., 2006. *Drought indices*. Van Nostrand's Scientific Encyclopedia. John Wiley & Sons, Inc. [e-book] Available at: Wiley Online Library < https://onlinelibrary.wiley.com/ > [Accessed 2 September 2018].

Hayes, M.J., Svoboda, M., Wall, N.A. and Widhalm, M., 2011. The Lincoln Declaration on Drought Indices: Universal Meteorological Drought Index Recommended. *Bulletin of the American Meteorological Society*, 92(4), pp. 485-488. [online] Available at: <https://www.researchgate.net/publication/234530250_The_Lincoln_Declaration_on_Drought_Indices_Universal_Meteorological_Drought_Index_Recommended> [Accessed 12 August 2018].

Hayes, M.J., Svoboda, M.D. and Wilhite, D.A., 2000. Monitoring drought using the standardized precipitation index. In D.A. Wilhite, ed. *Drought: A Global Assessment.* London: Routledge. pp. 168-180.

Hayes, M.J., Svoboda, M.D., Wilhite, D.A. and Vanyarkho, O.V., 1999. Monitoring the 1996 drought using the standardized precipitation index. *Bulletin of American Meteorological Society*. [online] Available at: <http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1030&context=droughtfacpub> [Accessed 20 September 2018].

Heim, R.R., 2002. A review of twentieth-century drought indices used in the Unites States. *Bulletin of American Meteorological Society*. [online] Available at: <https://pdfs.semanticscholar.org/8790/277954cd5985b244a7522333263789ff242c.pdf> [Accessed 22 September 2018].

Hydrology and Water Resources Division Department of Irrigation and Drainage Malaysia, 2005. *Drought report of Peninsular Malaysia*. [pdf] Malaysia: Department of Irrigation and Drainage Malaysia. Available at: <infokemarau.water.gov.my/report/Drought%20ReporL_21Oct05.pdf> [Accessed 5 January 2019].

Jailan Simon, 2015. El-Nino: Current progress, possibility and severity of occurrence in 2015. In: Malaysian Meteorological Department, *El-Nino: The good, the bad and the ugly of 2015*. Kuala Lumpur, 22 September 2015. Available at: < http://www.mpoc.org.my/upload/Paper-1-Jailan-Simon.pdf> [Accessed 22 August 2018].
Johnston, K., 2004. *ArcGIS 9: Using ArcGIS geostatistical analyst*. [e-book] Esri Press. Available at: Google Books <books.google.com. [Accessed 23 September 2018].

Karamouz, M., Rasouli, K. and Nazif, S., 2009. Development of a hybrid index for drought prediction: Case study. *Journal of Hydrologic Engineering*, 14, pp. 617-627. [online] Available at: <https://www.researchgate.net/publication/245287563_Development_of_a_Hybrid_Index_for_Drought_Prediction_Case_Study> [Accessed 2 September 2018].

Karl, T.R. and Koscielny, A.J., 1982. Drought in the United States:1895-1981. *International Journal of Climatology*, 2(4), pp. 313-329. [online] Available at: <https://www.researchgate.net/publication/227557216_Drought_in_the_United_States_1895-1981> [Accessed 14 August 2018].

Katsanos, D., Retalis, A., Tymvios, F. and Michaelides, S., 2018. Study of extreme wet and dry periods in Cyprus using climatic indices. *Atmospheric Research*, [e-journal] 208, pp. 88-93. Available through: Universiti Tunku Abdul Rahman Library website <http://library.utar.edu.my/> [Accessed 5 August 2018].

Keyantash, J.A. and Dracup, J.A., 2002. The Quantification of Drought: An Evaluation of Drought Indices. *Bulletin of American Meteorological Society*. [online] Available at: <http://www.droughtmanagement.info/literature/AMS_Quantification_of_Drought_Evaluation_of_Drought_Indices_2002.pdf> [Accessed 18 August 2018].

Keyantash, J.A. and Dracup, J.A., 2004. An aggregate drought index: Assessing drought severity based on fluctuations in the hydrologic cycle and surface water storage. *Water Resources Research*, 40(9). [online] Available at: <https://www.researchgate.net/publication/228531410_An_aggregate_drought_index_Assessing_drought_severity_based_on_fluctuations_in_the_hydrologic_cycle_and_surface_water_storage> [Accessed 18 August 2018].

Kis, I.M., 2016. Comparison of ordinary kriging and universal kriging interpolation techniques on a depth variable (A case of linear spatial trend), case study of the Sandrovac field. The Mining-Geology-Petroleum Engineering Bulletin. [online] Available at: <https://www.researchgate.net/publication/301788692_Comparison_of_Ordinary_and_Universal_Kriging_interpolation_techniques_on_a_depth_variable_a_case_of_linear_spatial_trend_case_study_of_the_Sandrovac_Field> [Accessed17 October 2018].

Kogan, F.N., 1995. Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research*, [e-journal] 15(11), pp. 91-100. Available through: < Universiti Tunku Abdul Rahman Library website <http://library.utar.edu.my/> [Accessed 14 August 2018].

Koh, K. (2016). Enough water in Malacca dams to last 50 days without rain. *New Straits Times*, [online] 16 Apr. Available at: <https://www.nst.com.my/news/2016/04/139565/enough-water-malacca-dams-last-50-days-without-rain> [Accessed 19 Jan 2019].

Koh, K. (2016). Enough water in Malacca dams to last 50 days without rain. *New Straits Times*, [online] 16 Apr. Available at: <https://www.nst.com.my/news/2016/04/139565/enough-water-malacca-dams-last-50-days-without-rain> [Accessed 19 Jan 2019].

Kong, L., 2014. Negeri Sembilan declares water crisis. *Asia One*, [online] 21 Feb. Available at: <http://www.asiaone.com/malaysia/negeri-sembilan-declares-water-crisis?nopaging=1> [Accessed 11 Jan 2019].

Lefohn, A.S., Knudsen, H.P., Shadwick, D.S., 2005. Using ordinary kriging to estimate the seasonal W126, and N100 24-h concentrations for the year 2000 and 2003. A.S.L. Associates. Available at: <https://webcam.srs.fs.fed.us/impacts/ozone/spatial/2000/contractor_2000_2003.pdf> [Accessed 24 September 2018].

Low, P.S. and Tangang, F., 2016. *El-Nino- A review of scientific understanding and the impacts of 1997/98 event in Malaysia*. [online] Academy of Sciences Malaysia. Available at: <https://www.akademisains.gov.my/download/El%20Nino%20-%20A%20Review%20of%20Scientific%20Understanding%20and%20the%20Impacts%20of%201997-98%20Event%20in%20Malaysia%20(final%20version)%2030%20April%202017.pdf> [Accessed 22 August 2018].

Massachusetts Executive Office of Energy and Environmental Affairs and Massachusetts Emergency Management Agency, 2013. *Massachusetts Drought Management Plan*. [online] Available at: < https://drought.unl.edu/archive/plans/drought/state/MA_2013.pdf > [Accessed 11 August 2018].

McGuire, J.K. and Palmer, W.C., 1957. The 1957 drought in the eastern united states. In: Office of Climatology, US Weather Bureau, *Monthly Weather Review*. Washington DC. [pdf] Available at: <https://journals.ametsoc.org/doi/abs/10.1175/1520-0493%281957%29085%3C0305%3ATDITEU%3E2.0.CO%3B2> [Accessed 5 August 2018].

McKee, T.B., Doesken, N.J. and Kleist, J., 1993. The relationship of drought frequency and duration to time scales. In: *Eighth Conference on Applied Climatology*. California, 17-22 January 1993. Anaheim. Available at: <http://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf> [Accessed 3 August 2018].

Mishra, A.K. and Singh, V.P., 2010. A review of drought concepts. *Journal of Hydrology*, [e-journal] 391 (2010) pp. 202-216. Available through: Universiti Tunku Abdul Rahman Library website < http://library.utar.edu.my/> [Accessed 5 August 2018].

Mitigation Center, 2018. *Types of drought*. [online] Available at: <https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx> [Accessed 10 August 2018].

Monzonis, M.P., Solera, A., Ferrer, J., Estrela, T. and Arquiola, J.P., 2015. A review of water scarcity and drought indices in water resources planning and management. Journal of Hydrology. [online] Available at: <https://www.researchgate.net/publication/276458897_A_Review_of_Water_Scarcity_and_Drought_Indexes_in_Water_Resources_Planning_and_Management> [Accessed 21 September 2018].

Nagler, P.L., Scott, R.L., Westenburg, C., Cleverly, J.R., Glenn, E.P. and Huete, A.R., 2005. Evapotranspiration on western US rivers estimated using the enhanced vegetation index from MODIS and data from eddy covariance and Bowen ratio flux towers. *Remote Sensing of Environment*, [e-journal] 97(3), pp. 337-351. Available through: < Universiti Tunku Abdul Rahman Library website <http://library.utar.edu.my/> [Accessed 5 August 2018].

Nalbantis, I. and Tsakiris, G., 2009. Assessment of hydrological drought revisited. *Water Resources Management*, 23(5), pp. 881-897. [online] Available at: <https://www.researchgate.net/publication/226680805_Assessment_of_Hydrological_Drought_Revisited> [Accessed 15 August 2018].

Niemeyer, S., 2008. New drought indices. *Options Mediterraneennes, Series A, No. 80*, pp. 267-274. [online] Available at: <http://projects.iamz.ciheam.org/medroplan/a-80_OPTIONS/Sesion%203/(267-274)%2037%20Niemeyer%20GS3.pdf> [Accessed 8 August 2018].

Olaniyi, A.O., Abdullah, A.M., Ramli, M.F. and Sood, A.M., 2012. Agricultural land use in Malaysia: An historical overview and implications for food security. *Bulgarian Journal of Agricultural Science*, 19(1), pp. 60-69. [online] Available at: <http://www.agrojournal.org/19/01-08.pdf> [Accessed 1 September 2018].

Palmer, W.C., 1965. Meteorological drought. In: Office of Climatology, US Weather Bureau, *Research paper no. 45*. Washington DC, 58p. 16 June. Available at: <https://www.ncdc.noaa.gov/temp-and-precip/drought/docs/palmer.pdf> [Accessed 3 August 2018].

Palmer, W.C., 1968. Keeping track of moisture conditions, nationwide: The new crop moisture index. *Weatherwise*. 21:4, pp156-161. Available at: <https://doi.org/10.1080/00431672.1968.9932814> [Accessed 3 August 2018].

Rouse, J.W., Haas, R.H., Schell, J.A. and Deering, D.W., 1974. Monitoring vegetation systems in the great plains with ERTS. *Third Earth Resources Technology Satellite-1 Symposium*, 1, pp. 309-317. [online] Available at: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19740022614.pdf> [Accessed 14 August 2018].

Safavi, H.R. and Ahmadi, K.M., 2015. Prediction and assessment of drought effects on surface water quality using artificial neural networks: Case study of Zayandehrud River, Iran. Journal of Environmental Health Science and Engineering. [online] Available at: <https://www.researchgate.net/publication/282702658_Prediction_and_assessment_of_drought_effects_on_surface_water_quality_using_artificial_neural_networks_Case_study_of_Zayandehrud_River_Iran> [Accessed 12 October 2018].

Said, H, and Hammim, R., 2016. Johor water woes critical. New Straits Times, [online] 4 Sep. Available at: <https://www.nst.com.my/news/2016/09/170635/johor-water-woes-critical> [Accessed 11 Jan 2019].

Salas, J.D., 1993. Analysis and modeling of hydrological time series. In: Maidment, D.R., Ed., *Handbook of Hydrology*, McGraw-Hill, New York.

Shaaban, A. J. and Low, K. S., 2003. Drought in Malaysia: A look at its characteristics, impacts, related policies and management strategies. In: *Water and Drainage 2003 Conference*. Kuala Lumpur, 28-29 April 2003. Kuala Lumpur: NAHRIM. Available at: <http://www.nahrim.gov.my/images/LampiranPDF/KertasTeknikal/drought_in_malaysia.pdf> [Accessed 29 December 2018].

Shafer, B.A. and Dezman, L.E., 1982. Development of a surface water supply index (SWSI) to assess the severity of drought conditions in snowpack runoff areas. In: *Western Snow Conference 1982*. Colorado: Colorado Division of Water Resources. Available at: <https://westernsnowconference.org/sites/westernsnowconference.org/PDFs/1982Shafer.pdf> [Accessed 13 August 2018].

Singh, S., 2014. Water levels at four dams continue to drop. *The Star Online*, [online] 21 Feb. Available at: <https://www.thestar.com.my/news/nation/2014/02/21/water-levels-at-four-dams-continue-to-drop-authorities-scrambling-to-restore-supply-to-affected-are/> [Accessed 11 Jan 2019].

Stagge, J.H., Tallaksen, L.M., Xu, C.Y. and Van Lanen, H.A.J, 2014. Standardized precipitation-evapotranspiration index (SPEI): Sensitivity to potential evapotranspiration model and parameters. Hydrology in A Changing World: Environmental and Human Dimensions, [online] Available at: <https://iahs.info/uploads/dms/16617.66-367-373-363-55-Paper-213-Stagge.pdf > [Accessed 23 September 2018].

Svoboda, M., LeComte, D., Hayes, M., Heim, R., Gleason, K., Angel, J., Rippey, B., Tinker, R., Palecki, M., Stooksbury D., Miskus, D. and Stephens, S., 2002. *The drought monitor*. Massachusetts: Bulletin of American Meteorological Society.

The San Diego Union-Tribune, 2016. Rains partially ease drought in Malaysia but water rationing persists. *The San Diego Union-Tribune*, [online] 22 May. Available at: <https://www.sandiegouniontribune.com/hoy-san-diego/sdhoy-rains-partially-ease-drought-in-malaysia-but-2016may22-story.html> [Accessed 19 January 2019].

The San Diego Union-Tribune, 2016. Rains partially ease drought in Malaysia but water rationing persists. *The San Diego Union-Tribune*, [online] 22 May. Available at: <https://www.sandiegouniontribune.com/hoy-san-diego/sdhoy-rains-partially-ease-drought-in-malaysia-but-2016may22-story.html> [Accessed 19 January 2019].

The Star Online, 2005. Projects to tackle Johor water woes. *The Star Online*, [online] 1 Oct. Available at: <https://www.thestar.com.my/news/nation/2005/10/01/projects-to-tackle-johor-water-woes/> [Accessed 12 January 2019].

The Star Online, 2014. Negri bracing for water crisis. *The Star Online*, [online] 20 Feb. Available at: <https://www.thestar.com.my/news/nation/2014/02/20/negri-bracing-for-water-crisis-our-administration-will-exhaust-all-options-to-replenish-our-dams-say/> [Accessed 12 January 2019].

The Star Online, 2015. Water rationing extended in Tampin and Rembau. *The Star Online*, [online] 28 Feb. Available at: <https://www.thestar.com.my/news/nation/2015/02/28/water-rationing-extended-in-tampin-and-rembau/> [Accessed 11 Jan 2019].

The Star Online, 2015. Water rationing extended in Tampin and Rembau. *The Star Online*, [online] 28 Feb. Available at: <https://www.thestar.com.my/news/nation/2015/02/28/water-rationing-extended-in-tampin-and-rembau/> [Accessed 11 Jan 2019].

The Star Online, 2016. Water woes loom in Malacca with three dams critical. *The Star Online*, [online] 25 Oct. Available at: <https://www.thestar.com.my/news/nation/2016/10/25/water-woes-loom-in-malacca-with-three-dams-critical/> [Accessed 11 Jan 2019].

Tobler, W.R., 1970. A computer movie simulating urban growth in the Detroit region. *Economic Geography*, 46, pp. 234-240. [online] Available at: <https://dds.cepal.org/infancia/guia-para-estimar-la-pobreza-infantil/bibliografia/capitulo-IV/Tobler%20Waldo%20(1970)%20A%20computer%20movie%20simulation%20urban%20growth%20in%20the%20Detroit%20region.pdf> [Accessed 23 September 2018].

Today Online, 2016. Malaysia warns of continuing drought as Malacca sounds water shortage alarm. *Today Online*, [online] 28 Apr. Available at: <https://www.todayonline.com/world/asia/second-death-heatstroke-malaysia> [Accessed 12 January 2019].

Tsakiris, G. and Vangelis, H., 2005. Establishing a drought index incorporating evapotranspiration. European Water Publications, 9/10: 3-11. [online]. Available at: <https://www.ewra.net/ew/pdf/EW_2005_9-10_01.pdf> [Accessed 4 August 2018].

Tsakiris, G., Nalbantis, I., Vangelis, H., Verbeiren, B., Huysmans, M., Tychon, B., Jacquemin, I., Canters, F., Vanderhaegen, S., Engelen, G., Poelmans, L., Becker, P. De, Batelaan, O., 2013. A system-based paradigm of drought analysis for operational management. *Water Resources Management*, 27(15), pp. 5281-5297. [online] Available at: < https://orbi.uliege.be/bitstream/2268/197342/1/Tsakiris%202013.pdf> [Accessed 8 August 2018].

Tsakiris, G., Pangalou, D. and Vangelis, H., 2007. Regional drought assessment based on the reconnaissance drought index (RDI). *Water Resources Management*, 21(5), pp. 821-833. [online] Available at: <https://www.researchgate.net/publication/225940023_Regional_Drought_Assessment_Based_on_the_Reconnaissance_Drought_Index_RDI> [Accessed 9 August 2018].

Utusan Online, 2016. El Nino: Enam negeri catat penurunan bekalan air terawat. *Utusan Online*, [online] 14 Apr. Available at: <http://www.utusan.com.my/berita/nasional/el-nino-enam-negeri-catat-penurunan-bekalan-air-terawat-1.259746> [Accessed 11 Jan 2019].

Utusan Online, 2016. El Nino: Enam negeri catat penurunan bekalan air terawat. *Utusan Online*, [online] 14 Apr. Available at: <http://www.utusan.com.my/berita/nasional/el-nino-enam-negeri-catat-penurunan-bekalan-air-terawat-1.259746> [Accessed 11 Jan 2019].

Utusan Online, 2016. El Nino: Enam negeri catat penurunan bekalan air terawat. *Utusan Online*, [online] 14 Apr. Available at: <http://www.utusan.com.my/berita/nasional/el-nino-enam-negeri-catat-penurunan-bekalan-air-terawat-1.259746> [Accessed 11 Jan 2019].

Van Lanen, H.A., Peters, E., 2000. Definition, effects and assessment of groundwater droughts. *Drought and Drought Mitigation in Europe pp.49-61*. [online] Available at: <https://www.researchgate.net/publication/40191877_Definition_Effects_and_Assessment_of_Groundwater_Droughts> [Accessed 10 August 2018].

Vincente-Serrano, S.M., Begueria, S., Lopez-Moreno, J.I., 2010. A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate*, vol 23. [online]. Available at: <https://journals.ametsoc.org/doi/pdf/10.1175/2009JCLI2909.1> [Accessed 3 August 2018].

Vogel, R.M. and Kroll, C.N., 1992. Regional geohydrologic-geomorphic relationships for the estimation of low-flow statistics. *Water Resources Research*, 28(9), pp. 2451-2458. [online] Available at: <https://www.researchgate.net/publication/264322455_Regional_Geohydrologic-

Geomorphic_Relationships_for_the_Estimation_of_Low-Flow_Statistics> [Accessed 5 August 2018].

Wan Hazdy Azad Wan Abdul Majid, Brown, E., Sazali Osman, Gapar Asan, Ab Qahar Osman, Rosham Kadiman Samsudin, Boelee, L. and Faizah Ahmad, 2017. Food forecasting and warning for Muar river: Non-structural measures for flood mitigation. In: *37th International Association for Hydro-Environment Engineering and Research World Congress*. Malaysia, 13-18 August 2017. Kuala Lumpur, Malaysia: HR Wallingford. Available at: <https://pdfs.semanticscholar.org/6150/f5b83ce04d8727cc8bd0ac184cd4e19807ba.pdf> [Accessed 17 October 2018].

Wessels, K.J., Prince, S.D., Frost, P.E. and Zyl, D., 2004. Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series. Remote Sensing of Environment, [e-journal] 91(1), pp. 47-67. Available through: Universiti Tunku Abdul Rahman Library website <http://library.utar.edu.my/> [Accessed 24 August 2018].

Wilhite, D.A. and Glantz, M., 1985. Understanding the drought phenomenon: The role of definitions. *Water International,* 10(3), pp. 111-120. [online] Available at: <https://www.researchgate.net/publication/240371212_Understanding_the_Drought_Phenomenon_The_Role_of_Definitions> [Accessed 5 August 2018].

Wilhite, D.A., Svoboda, M. and Hayes, M.J., 2007. Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness. *Water Resources Management,* 21(5), pp763-774. [online] Available at: <https://www.researchgate.net/publication/225339430_Understanding_the_Complex_Impacts_of_Drought_A_Key_to_Enhancing_Drought_Mitigation_and_Preparedness> [Accessed 3 August 2018].

World Meteorological Organization and Global Water Partnership, 2016. *Handbook of drought indicators and indices*. [online] Available at: <http://www.droughtmanagement.info/literature/GWP_Handbook_of_Drought_Indicators_and_Indices_2016.pdf> [Accessed 10 August 2018].

Yao, J., Zhao, Y., Chen, Y., Yu, X., and Zhang, R., 2018. Multi-scale assessments of droughts: A case study in Xinjiang, China. *Science of The Total Environment,* [e-journal] 630, pp. 444-452. Available through: Universiti Tunku Abdul Rahman Library website <http://library.utar.edu.my/> [Accessed 5 August 2018].

Yun, C.C., Lee, Y.H. and Mohd Ekhwan Toriman, 2015. Effect of big flood events on the water quality of the Muar River, Malaysia. Sustainable Water Resources Management. [online] Available at: <https://www.researchgate.net/publication/279155725_Effect_of_the_big_flood_events_on_the_water_quality_of_the_Muar_River_Malaysia> [Accessed 28 October 2018].

Zargar, A., Sadiq R., Naser, B. and Khan, F.I., 2011. A review of drought indices. *Environmental Reviews*, 19, pp. 333-349. Canada: NRC Research Press.