CLIMATE CHANGE ASSESSMENT ON DROUGHT IN SABAH & SARAWAK

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

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DECLARATION

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

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"CLIMATE CHANGE ASSESSMENT ON DROUGHT IN SABAH & SARAWAK"** was prepared by **NAH KIAN KOK** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Drought is one of the costliest natural disasters that had been troubling human beings for untold years. There are 4 categories of drought such as the agricultural, meteorological, socioeconomic and the hydrological drought. A drought monitoring system had been introduced to monitor the drought characteristics in Sabah and Sarawak. The Standardized Precipitation Index (SPI) is being studied to investigate the drought characteristics in Sabah and Sarawak. The SPI is the only indicator that has been selected in this research due to the full data unavailability. Precipitation data for 1988-2017 (30 years) were acquired from Department of Irrigation and Drainage (DID). Since there were missing data, the four quadrant IDW method was applied for data repairing to get a complete data set, with the aid of the QGIS software. The SPI at timescales of 1-, 3- and 6-months had been utilised to determine the spatial distribution of drought characteristics, including Drought Frequency (DF), Mean Drought Duration (MDD), Mean Drought Severity (MDS), Mean Drought Intensity (MDI) and Mean Drought Peak (MDP). The temporal and spatial variation of drought characteristics in regions of Sabah and Sarawak were obtained and discussed. The droughts could be categorised as mild drought, moderate drought, severe drought and extreme drought. The SPI-1, SPI-3 and SPI-6 all showed multiple results of drought characteristics. For the temporal variation, the lowest, peak and the flow of drought occurrence in six 5-yr sub-periods were examined in the research. In this study, the sub-periods of 1993-1997 and 2008-2012 had the most occurrence of drought, whereas the sub-period 2003-2007 was with the lowest incidence of drought occurrence. Spatial variation was applied to analyse all the 9 regions in East Malaysia. For instance, the regions or areas that have shown relatively higher drought occurrence have been recorded. In this study, the Central (Region 3) and Eastern (Region 1) part of East Malaysia have constantly being facing the most drought occurrence. The results from the spatial and temporal variations were also linked to the factors of El Niño events and mountainous topography of East Malaysia to investigate the cost effect relationship.

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LIST OF SYMBOLS / ABBREVIATIONS

c_0	coefficient for standard normal variable Z calculation
c_1	coefficient for standard normal variable Z calculation
c_2	coefficient for standard normal variable Z calculation
d_1	coefficient for standard normal variable Z calculation
d_2	coefficient for standard normal variable Z calculation
d_3	coefficient for standard normal variable Z calculation
d_i	Distance between x_0 and x_1
i	Monthly heat index
i	Range of observation in uprising sequence
n	Sampled point number used for the estimation
p	Power parameter
q	probability of zero
s	standard deviation of the precipitation
α	Scale parameter
β	Shape parameter
γ	Origin parameter
DID	Department of Irrigation and Drainage
ENSO	El Nino-Southern Oscillation
PDSI	Palmer Drought Severity Index
QGIS	Quantum Geographic Information System
SPI	Standardized Precipitation Index
SPEI	Standardized Precipitation Evapotranspiration Index
Sc-PDSI	Self-calibrating Palmer drought severity index
WMO	World Meteorological Organization

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Drought implicates an environmental, climatic, social, economic and political consequences where the water availability and demands for different uses in the region for specific duration. Criteria of drought characteristics include rainfall amounts, soil moisture, agriculture productivity, reservoirs level, streamflow and so on. Basically, a drought happens when there is lack of moisture availability due to lower volume of rainfall. According to World Disasters Report (1994), it is known that without considering civil strife, droughts have caused more social damage than any other natural or non-natural catastrophe during modern history. It is known that the drought alone has led to half of this out of the overall death toll resulting from natural disasters. Such findings require thorough understanding on the existence of droughts. Drought is therefore the most significant threat to humanity, the climate and the economy.

Drought can be categorized into 4 categories, which are meteorological, agricultural, hydrological and socioeconomic drought. For meteorological drought, it can be termed as the average-to-normal dryness rate where it occurs when the drought impacts are initiated from the dryness of a region. Agricultural drought occurs when the dryness leads to a decrease in soil moisture, a lack of rainfall, an increased disparity between actual and potential evapotranspiration resulting in crop failure. A limitation of surface and subsurface water for residential, irrigational, commercial and other activities due to long periods of decreased rainfall will lead to occurrence of hydrological drought. The combined effects of all these three types of droughts on a region's socio-economic well-being are termed "socio-economic drought." In socio-economic drought, precipitation shortages are directly related to increasing food and service prices, as well as supply reduction. The geographical scale of socio-economic drought may be in wide range of field such as meteorological, agricultural or hydrological droughts, and therefore it is difficult to reliably measure its impacts.

Throughout the twentieth century a variety of indices were created for quantification, monitoring, and analysis of drought. Drought indices were introduced and function as identification of drought characteristic, in term of frequency, duration, intensity and spatial extent. There are various types of drought indices which are useful to estimate the drought characteristics. As part of this study, 3 types of drought indices are being studied. They are Standardized Precipitation Index (McKee, Doesken and Kleist, 1993), Standardized Precipitation Evapotranspiration Index (Vicente-Serrano, et al., 2010) and Palmer Drought Severity Index (Palmer, 1965). SPI is the most popular drought monitoring index, and is recommended as the standard index by the World Meteorological Organization (Tan, et al., 2015). The calculation requires only precipitation data. SPEI is a multivariate index that can clearly detect temporal droughts variability to a greater degree than the SPI index. The calculation is based on data which include precipitation and temperature. The PDSI is function to describe the extent of drought in a specific duration when a region's water supply is consistently below average. The calculation is based on data which include precipitation, temperature and available water content of soil.

Sabah and Sarawak are selected as the areas to be studied in this research. The climate of Sabah and Sarawak is tropical, with little seasonal change. Drought events had occurred in Sabah and Sarawak in the past 30 years. The intensity and frequency of droughts have been rising statistically since the late 1960s. Two severe drought had occurred in in 1877-1915 and 1968-92 in a minimum period of 4 months are known at Sandakan, separated by a near drought-free 52-year period. In the same region, the ecologically damaging 1982-1983 drought was not as long or severe as the drought happened in 1903 and 1915. For Sarawak, drought event had always been a concern for the Sarawak’s government. With the onset of the dry season, the Sarawak water authorities are always on standby to trigger drought contingency plans in case of droughts occurring, especially along the coastal areas. As drought event had always been a concern to the East Malaysia, it leads us to study the drought characteristics in Sabah and Sarawak.

1.2 Importance of the Study

Drought is not just a physical natural event, where it causes big impacts on society which result from the interaction between a natural event and demands towards water supply. There is less precipitation than expected result from normal climate inconstancy. Drought risk can be explained as a combination of the frequency, intensity, and spatial extent of drought, where the degree to which a population is vulnerable to drought effects. The degree of vulnerability of an area depends on the region's environmental and social characteristics, and is calculated by its ability to predict, resist and recover from drought. Drought has enormous impacts on various sectors especially on environment, agriculture, urban water supply and human health. For instance, the most significant agro-climatic conditions for the producer are the lack of humidity. Such effects create the most issues associated with plants and animals, and it is challenging to deal with. Therefore, drought indices play an important character in identifying the drought characteristics. Furthermore, the research aids in characterizing drought is important in evaluating past drought events and includes analysis of severity versus impacts. This helps to better predict on the future drought events. The study also stresses the need for early warning of drought, thus enabling the people to plan and prepare for contingency. For the management of emerging crop losses, early detection of droughts is crucial to avoid or mitigate possible related famines, coping with increased fire risk and so on.

1.3 Problem Statement

Shortage of water has always been a critical issue in Malaysia. Based on the historical drought records, there are different scale of drought happened in the country for the past decades. The drought events that occurred in the years 1983 and 1988 are two severe droughts that hit Malaysia in the recent history. According to the Daily Express reports (2008), the drought in the year 1983 had affected the people for 6 months, and the other drought occurred in the year 1998 in relation to ENSO events. The drought of 1998 literally affected almost two million residents in Kuala Lumpur and affect domestic water supply from April to September 1998 (Shaaban and Sing, 2003).

As for Sabah, from January to April 1998, the state recorded less than 25 per cent of the normal rainfall (Shaaban and Sing, 2003). This practically cut down on Sabah's water supply and affected most sectors of agriculture. By referring to Wada, et al. (2011), the study simulated monthly WSI fits well with Malaysia's two worst drought events that happened in 1983 and 1998. According to the official statement by Sabah government, the state receives about 2500–3500 mm of rainfall annually. The pattern of the rainfall distribution is fully described, where a mean annual rainfall subjected to Sabah's geographic location and topographic features is being studied from 1000 mm to over 3500 mm.

As for Sarawak, extreme droughts occurred in Sarawak in 1998 and 2014 because of the strong El Nino, which had strongly affected water supply and irrigated agriculture. Depending on locality, Sarawak recorded an average rainfall of around 3300-4600 mm per year. Humidity in lowlands ranging from 80% - 90% is consistently high. In addition, according to the study by Aziz (2014), it is known that the decrease in monthly river runoff and drought changes in river basins, such as Limbang and Sadong in Sarawak, Padas and Kinabatangan in Sabah, will literally impact future water supplies.

Findings from this research would be useful for planning and formulating drought strategies to alleviate and reduce the harmful effects of drought.

1.4 Aim and Objectives

This study aims to investigate the Sabah and Sarawak climate change assessment on drought. The aims of the research to achieve the goal are:

(i) To evaluate the difference between Standardized Precipitation Index (SPI) at multiple timescale in drought monitoring system in Sabah and Sarawak.

(ii) To analyze drought characteristics in region of Sabah and Sarawak with the aid of spatial and temporal analysis.

1.5 Scope and Limitation of the Study

The study area of the research is in East Malaysia, which consists of the states of Sabah and Sarawak. The Standardized Precipitation Index (SPI; McKee, Doesken and Kleist, 1993), Standardized Precipitation Evapotranspiration Index (SPEI; Vicente-Serrano, et al., 2010) and Palmer Drought Severity Index (PDSI; Palmer, 1965) were used in the research. The calculation of SPI was based on precipitation data only, whereas the calculation of SPEI was based on precipitation and temperature data; and the calculation of PDSI was based on precipitation, temperature and soil available water content (AWC) data. Unfortunately, temperature and AWC data are both very limited or unavailable for East Malaysia. Hence, only the SPI was chosen and this is one of the limitations faced during the research. Besides, the availability of full sets of raw data is also the limitation for this study. Measurements of meteorological and hydrological data in Malaysia is mostly done by ground-based observations as well as remotely controlled retrieval. Therefore, regarding the topography, remoteness of areas, the dense vegetation, there will be chances that error may be occurred during the measurement, despite all the good planning and intentions.

1.6 Contribution of the Study

Drought events had brought a huge impact to our country in different aspects such as economy, social, environment and so on. By studying different types of drought indices, it allows the researchers to utilize the function and advantages of different drought indices, especially in region of Sabah and Sarawak. An early detection of drought allows citizens in the specific area to plan and minimize their loss caused by drought events. The problem of having insufficient water supply and continuously rising demand for water during drought event will definitely bring inconvenient to the citizens. By understanding the period of drought events, the water management company can constrain the total volume of water supply and evenly supply the water to each household. If a proper integrated water management has been adopted, the non-conventional water resources can be used. Furthermore, field crops can be conserved. For instance, use of saline or brackish water can be used for irrigating field crops. At this point, it is debatable that the research contributes in formulating quick responses to battle water crisis disaster.

1.7 Outline of the Report

The content of each chapter is described as below:

Chapter 1 is the General Introduction of drought and study area in Sabah and Sarawak Malaysia, importance of study, scope and limitation of study, problem statement, aim and objective of study and contribution of study.

Chapter 2 is the Literature Review part. It is about review of the different type of drought indices which might be useful in monitoring the drought characteristics in Sabah and Sarawak. The review is basically in the drought indices, drought characteristic and spatial and temporal analysis of drought. Climate change scenario is being studied to further understand the effects of climate change towards the future economic, social, technological, and environmental conditions.

Chapter 3 shows the methodology of the study. It contains the work flow of this study and methods used to obtain the data. Rainfall data that are obtained from Department of Irrigation and Drainage (DID) have been utilized in SPI-1, SPI-3 and SPI-6. Drought characteristics (Drought Frequency, Mean Drought Duration, Mean Drought Intensity, Mean Drought Severity, Mean Drought Peak) and Drought categories (Mild Drought, Moderate Drought, Severe Drought, Extreme Drought) are generated. Temporal and Spatial analysis are carried out for further studies.

Chapter 4 covers the Results and Discussion. The results are presented and further discussed in this chapter. Results from the Temporal and Spatial analyses were linked to the El Niño events and mountainous topography for further discussion.

Chapter 5 shows the Conclusions and Recommendations for future continuing works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter 2 provides an illustration on the categories of drought, drought indices and spatial and temporal analysis in order to have a better understanding on drought characteristics. Droughts are one of the costliest natural disasters over the years with severe and widespread impacts. Future demand for water supplies to feed the world's increasing population would increase. Drought represents a potentially devastating threat to water supply, agriculture and food production leading to drought and destruction of the environment. However, it is challenging to estimate the onset, extent and end of a drought due to the extreme spatiotemporal variability and complex physical process. Thus, various indices of drought were developed for quantification, monitoring and analysis of drought. Spatial and temporal droughts analysis are important in the study of drought variations and their distribution.

2.2 Type of Drought

A drought is a time range when an area experiences under-normal precipitation. Drought is a regular, natural phenomenon that occurs at several time scales and affects large areas and all facets of the hydrological cycle (Peters, et al., 2006). When the precipitation is abnormal, it will cause reduction of groundwater and soil moisture, decreased stream flow, crop damage and a general water shortage. Drought is different with hurricanes, tornadoes, and thunderstorms, where it is often hard to estimate the period of drought. The beginning and end of a drought is hard to be identified as it may take long periods to identify that a drought has begun. Duration of drought cannot be estimated, which may last for weeks, months, or even years. As the duration of drought getting longer, the greater the harmful effects it will bring to the environment, society, economics and so on. Droughts affects the society in many different ways. Availability of clean drinking water is basic needs for living creatures, and water sources may be affected during droughts. Without presence of water, it brings inconvenient to the society, where people have to obtain clean water from elsewhere to survive. Water is also required for harvests to grow. When the precipitation is insufficient to fall naturally to the crops, they have to be watered by irrigation. During drought, these water sources such as rivers, lakes, groundwater are limited and may even dry up, which act as a huge problem to the people. According to Wilhite and Glantz (1985), there are 4 types of drought, including meteorological, agricultural, hydrological and socio-economic drought. These types of drought may vary due to its own perspectives.

2.2.1 Meteorological Drought

Meteorological drought is considered as the basis of the degree of dryness and the duration of the dry period. The behaviour of atmospheric conditions is important in defining meteorological drought due to the variation of atmosphere from region to region. Precipitation and humidity are the variables that are commonly used as the input parameters to analyse the meteorological drought (Yao, et al., 2018). However, meteorological drought will prompt different sorts of drought and includes extensive areas, where the shortage of precipitation could lead to the extent of lack of water supply failure and moisture content in ground soil.

2.2.2 Agricultural Drought

Agricultural drought happens when water demand of crop is not satisfied or the soil moisture is under minimum requirement for a crop (Zhao, et al., 2017). It is the relationship between climatic conditions and some other factors such as increased water use, land-use variability or low water-use capacity. It would literally affect the major decline in the quality and quantity of agricultural products. Agricultural drought may be considered to be anything greater than climatic drought, as the former could happen due to many besides environmental conditions. There are some linkages between features of agricultural drought and meteorological drought which relate to agricultural impacts, shortages of precipitation, deficits in surface water and decreased amounts of groundwater or reservoir. When available water supplies are unable to satisfy demand of crops at specific time, agricultural drought may happen. This will lead to damages to crop and subsequently reduction of crop yield.

2.2.3 Hydrological Drought

Hydrological drought is explained as a deficient of water in the hydrological system, which shows itself in low stream flow in rivers, lakes, reservoirs and groundwater. Hydrological drought is linked to the effects of precipitation periods on the water supply surface. The frequency and intensity of hydrological drought is also described at a river basin or watershed scale. As a comparison to meteorological and agricultural droughts, hydrological droughts is more challenging to control. Hydrological system elements such as soil moisture, groundwater or reservoir levels take longer period for precipitation deficiencies to turn up. Water is the basic element used for numerous and competing uses in hydrological storage systems. During drought, water in the storage system might be limited, thus competition between water users can be seen significantly.

2.2.4 Socioeconomic Drought

Socioeconomic drought is much related to meteorological, hydrological, and agricultural drought elements, where it connects the supply and demand of economic products. It varies from other forms of drought, where time and space processes of supply and demand is an important element to identify droughts. Socioeconomic drought takes into consideration the effect of drought conditions on the supply and demand of some economic products. Socioeconomic drought occurs when an economic good demand is much more than its supply which will lead to a weather related shortage in water supply.

2.3 Drought Indices

Drought is one of the major natural causes of harm to agriculture, the economy and the environment over the years. Identification and classification of drought are challenging due to different factors such as varying nature, spatiotemporal variability, dynamic physical processes and so on. A great deal of work has been placed into developing methods for assessing and monitoring the drought. Throughout the twentieth century, variety of indices were developed for quantification, monitoring, and analysis of drought (Keyantash and Dracup, 2002). Drought indices are usually treated as a method to monitor changes in conditions of drought. Drought indices were commonly created to capture the physical characteristics of a drought, especially its frequency, duration, intensity, and spatial extent. Therefore, the development of drought indices can be developed in several methods, which are single factor, combining multiple variables or mixing drought indices. Many methodologies are used to measure drought indices by using rainfall, air temperature, soil moisture, evapotranspiration (ET), and flow. Different responses may be presented even for the same area after the input data have been presented.

In order to understand the effects of drought on various components of the hydrological cycle, it is important to research the intensity of drought at various timescales, often over the year. Short time scales can be linked to soil water content or river discharge, whereas medium time scales can be linked to reservoir storage and medium river course, whereas longer time scales are linked to differences in groundwater storage. Hence, various time scales in different hydrological subsystems are useful for tracking drought conditions. The 1–3-month time scale enables short-term precipitation shortfalls to be analysed and sometimes called meteorological or climatological drought. The moisture deficit over the agricultural season accounts for 3-month to 6-month timescale (Vicente-Serrano, et al., 2010). It is known that the 6–12-months timescale show a seasonal to medium term moisture reduction, while the 12–months to 24-months timescale shows information on long term droughts. However, due to limitations in the indicators used, there are still strong uncertainties and a lot of dispute about global drought patterns. For this purpose, more efforts are required to put on for better outcomes of drought indices.

Drought indices that are commonly used includes Standardized precipitation index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI) and Palmer Drought Severity Index (PDSI). There is currently no clear index which can accurately analysing drought conditions for each area and each time span. Consequently, nature of droughts, the area of interest, the objective and the data available to each user are the major elements for the selection of drought indices. In addition, there is challenge in measuring drought in choosing the best indicators to determine drought conditions. There are a few examples of drought indices which was successfully implemented, which are the SPI, SPEI and PDSI.

2.3.1 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI; McKee, Doesken and Kleist, 1993) is an index based on long-term precipitation probability which reflects either abnormal wetness or dryness conditions. The SPI is commonly used in scientific literature, and is recommended as the standard index by the World Meteorological Organization (Tan, et al., 2015). To be useful for monitoring and controlling various available water supplies, drought indices must be correlated with a particular time scale. SPI is widely accepted by the researchers due to its flexibility in time and space. The SPI is eligible to measure precipitation deficits for various time. Therefore, drought characteristics on various timescale can be presented. Shorter timescale SPI is more likely to detect shorter-period drought while certain droughts may not be detected with longer SPI time scale.

Standardized precipitation index (SPI) is able to statistically measures drought conditions in certain regions only from an angle of anomaly in precipitation. The SPI allows the comparison of historical context in term of different location and climate, in order to provide an optimal decision. The outcomes for different areas may show simultaneously in excess or deficit result, depending on different time scale. According to McKee, Doesken and Kleist (1993), SPI values can be classified as table below:

Table 2.1: Classification of SPI values.

SPI value	**Class**
2.0 or greater	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.0 or lesser	Extremely dry

The SPI was used to analyse the spatiotemporal patterns of drought conditions in Huai River Basin (He, Ye and Yang, 2015), The 3-month SPI values were used for the winter, spring, summer, and autumn seasonal pattern analysis respectively. 4 different pattern of outcomes are shown during the four seasons. The classification of drought condition for SPI was done based on the research from McKee, Doesken and Kleist (1993), which consists of four classes to classify a drought. A SPI value between 0 and -0.99 is classified as mild drought; SPI value between -1.00 and -1.49 is classified as moderate drought; SPI value between -1.50 and -1.99 is classified as severe drought; and SPI value less than -2.00 is classified as extreme drought. It is observed that negative trends outcome is recorded in spring and autumn, while positive trends are recorded in the summer and winter. The results are almost same as the research findings. However, there are slightly different patterns observed in summer that are more obvious than in other seasons. The primary reason is the upstream experienced different patterns of shifts in precipitation compared to other Huai River Basin areas. As conclusion for this study, Huai River Basin was vulnerable to both flooding and drought during the study period.

2.3.1.1 Advantages of SPI

SPI's main advantage is that regional drought comparison is possible. SPI is an effective method for identifying drought characteristics regardless of the regions. The potential of the SPI as an instrument for monitoring hydrological conditions and flood risk should be paid attention on, where integrating SPI is eligible to be analysed into a regional climate risk management system (Seiler, Hayes and Bressan, 2002). Other advantages of SPI include time scale flexibility, spatial structure stability, less requirements of input variables and calculation simplicity. SPI is an effective tool to study the spatiotemporal pattern of dry and wet conditions, due to its versatility in temporal scale and ability to represent anomaly of precipitation. The SPI is calculated based on precipitation only, thus it is more sensitive to changes in precipitation than the SPEI. In addition, SPI is accepted more generally because its calculation is simple and it has less input requirements, where only precipitation data is needed.

2.3.1.2 Limitations of SPI

As for disadvantages of SPI, the severity of a drought occurrence is expressed in relative terms only. In addition, only rainfall is included in the SPI index as an input variable, whereas other related variables and meteorological parameters are excluded in the evaluation process. This may due to reported increase in temperature during the research period, where SPI does not include temperature as its input variable. Furthermore, the short-term (1-month SPI) distribution model is varied to the empirical distribution as contrasted with the longer-term (Vicente-Serrano, et al., 2010). One of the reasons is various zero precipitation values are recorded in the SPI's short time scale; therefore, there is a probability that SPI estimation may lead to different outcomes in dry climates.

2.3.2 Standardized Precipitation Evapotranspiration Index (SPEI)

SPEI is an ideal index to analyse the drought pattern which is suitable for drought assessment and even water resource management. As a multivariate index, the SPEI is able to precisely measure the temporal variation of droughts. SPEI is an index that incorporates more than one climatic variable that is better suited to detect droughts than SPI index which is only a single climatic variable. SPEI takes consideration of both precipitation and temperature. Precipitation is the major element that cause temporal variability of droughts, which result in different outcomes. Other than that, rising temperature will cause impact on the region's water stress as well, especially during longer time scales.

In addition, the Standardized Precipitation Evapotranspiration Index (SPEI) defines the degree of variance of regional dry and wet conditions from climate mean conditions. The water balance equation is required to be executed in calculation steps for the evaluation of PET (Vicente-Serrano, et al., 2010). A positive SPEI values indicate wet spells while negative values indicating dry spells. According to Vicente-Serrano, et al. (2010), SPEI values can be classified as table below:

Table 2.2: Classification of SPEI values.

SPEI value	**Class**
2.0 or greater	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0.50 to 0.99	Slightly wet
-0.49 to 0.49	Near normal
-0.99 to 0.50	Mild dry
-1.49 to -1.00	Moderately dry
-1.99 to -1.50	Severely dry
-2.0 or lesser	Extremely dry

As comparison to SPI, SPEI has a higher spatial coverage of the susceptibility to drought than to SPI. By referring to the report by Wang, et al. (2015), the reasons may due to higher rate of evaporation caused by low rainfall and high temperature over a given period. These are the two main factors that influence the drought's evolution, and are both included in the SPEI calculation. Moreover, as a comparison to SPI, SPEI has substantially higher severity and longer drought durations. This may have been attributed to the rise in temperature that contributed to higher water demand for Potential Evapotranspiration (PET) and Real Evapotranspiration (AET), which directly lengthen the frequency of drought at longer time scales.

Another research was done by Zhao, et al. (2017), an analysis of both SPEI and SC-PDSI for 1-48 month timescale was carried out to monitor drought characteristics. The research was carried out in China. The SPEI shows various results depends on different timescale. SPEI-3 has shown a result of most drought periods but with shortest duration, while the SPEI-24, SPEI-36 and SPEI-48 has shown an opposite result of drought periods and duration. The SPEI-6 and SPEI-12 had achieved the lowest points in 2001, in a value of -2.2 and -2.0 respectively. June 2001 recorded a small rise in SPEI-6 and SPEI-12 levels with 45.8mm rise in rainfall. Results showed that SPEI-12 or longer timescales had achieved almost the same result as the historical records. Generally, longer timescale SPEIs and SC-PDSI were both effective in tracking and analysing medium and long-term drought. SPEI had fluctuated more on a monthly basis when being applied for shorter timescale. For instance, in October 2009, the SPEI-1 had captured the extreme drought, while SPEI-3 drought-detection result was generally realistic, with a strong responsiveness to drought initiation, alleviation and relief. The SPEI-6 to SPEI-24 may suggest the initiation and development of drought but it was less effective. The SPEI-24 to SPEI-48 was least sensitive to drought mitigation and thus, this index showed that until December 2010, the area was experiencing moderate drought.

2.3.2.1 Advantages of SPEI

First of all, SPEI is eligible to determine the episode of drought severity clearly, and ability to capture drought characteristics. As a comparison to SPI, the effects of evaporation and rainfall on droughts can be expressed by SPEI (Vicente-Serrano, et al., 2010), whereas the SPI can only consider the impact of rainfall on drought. Besides, temperature factors in influencing drought evolutions was demonstrated at Francistown by Byakatonda, et al. (2018) with SPI shows a positive result while SPEI shows a negative ones. It is proven that SPEI is more effective in monitoring drought characteristics with the current global warming. SPEI is suitable for lower timescale drought analysis and will be an effective tool which will benefit people around the world. It is proven by the research done by Zhao, et al. (2017), where SPEI takes simultaneous precipitation and evapotranspiration into consideration through its versatile time scale option. For example, SPEI-3 shows greater outcomes of the entire cycle from the initiation of drought to elimination, best representing the initiation, aggravation and elimination of droughts.

2.3.2.2 Limitations of SPEI

Thornthwaite algorithm was included together with SPEI in a research by Wang, et al. (2015), where the results only react to air temperature changes to enable the evaporation. Besides, the calculation of potential evapotranspiration (PET) is difficult due to the flexibility of surface temperature, air humidity, water vapor density, and so on. In the same research, only SPI-3 and SPI-6 have successfully tracked the end of drought in July, but SPEI-3 and SPEI-6 did not detect the drought. That is how the SPEI acknowledges the impact on droughts from both precipitation and evaporation. Above are the limitations of SPEI that had been studied during the research, further improvements need to be made in order to enhance the function of SPEI.

2.3.3 Palmer Drought Severity Index (PDSI)

The Palmer Drought Severity Index (PDSI) was commonly treated as a tool to determine drought characteristics. It is more suited for estimating longer time period droughts while this aspect has received little attention. The PDSI is eligible to describe the extent of drought in a specific period when a region is lack in water supply. PDSI was developed based on the supply-and-demand principle of water balance equation using precipitation and temperature for calculating moisture distribution. PDSI has some limitations such as the strong impact of the calibration duration, its minimal utility in different regions and problems of spatial comparability.

Therefore, various researchers have continually developed PDSI. Wells, Goddard and Hayes (2004) introduced the self-calibrating PDSI (SC-PDSI) in order to improve spatial comparability of PDSI. SC-PDSI is more practical for tracking extreme wet and dry events, where temperature is one of the factors in determining drought conditions under current global warming. It has been shown that SC-PDSI has effectively tracked and measured changes in river runoff and groundwater level. A research was done by Zhao, et al. (2017), SC-PDSI was less responsive to short-term drought and optimally associated with SPEI-9 to SPEI-19. These two results indicate that the SC-PDSI is eligible as an index for mid- and long-term drought monitoring and it is functional to track changes in river runoff ad groundwater level. In order to determine the drought characteristics by PDSI, data such as soil water holding capacity, variability of precipitation and evapotranspiration are necessary in the future study.

The PDSI allows wetness and dryness to be calculated on the basis of the water balance equation, which integrates precipitation, moisture availability, runoff, and surface-level evaporation demand. According to Palmer (1965), PDSI values can be classified as table below.

Table 2.3: Classification of PDSI values.

PDSI value	Class
4.0 or greater	Extremely wet
3.00 to 3.99	Severely wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Mild wet
0.50 to 0.99	Incipient wet
0.49 to -0.49	Normal
-0.50 to -0.99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderately drought
-3.00 to -3.99	Severely drought
-4.0 to lesser	Extremely drought

2.3.3.1 Advantages of PDSI

Both agriculture drought and meteorological drought can be assessed by PDSI (Agwata, 2014). Besides, it is known that The PDSI demonstrates better variation in crop production and natural vegetative behavior than the SPI. The application of PDSI is beneficial to wide range of people, including the internal meteorologists, hydrologists, researchers and external policy decision makers, foresters and all the publics.

2.3.3.2 Limitations of PDSI

The disadvantage of PDSI are its fixed time scale, which is between 9 and 12 months, and its autoregressive feature, where past circumstances up to four years can affect the index values of PDSI (Guttman, 1998). PDSI has some issues about its function in tracking and analyzing the drought. The limitations of PDSI on shorter timescale analysis had received less attention and it causes confusion of users on agricultural product. Furthermore, the PDSI lacks of multiscalar character which is important for drought evaluation and comparison of drought. According to the studies by Wang, et al. (2015), the limitations of sc-PDSI had caused the indicator failed to estimate the drought in 1962/1963. It was assumed that runoff cannot occur when soil moisture exceeds the field potential which makes it vary from the mechanism for producing runoffs.

2.4 Climate Change Scenario

Climate change is currently one of the main global issues. Emission of greenhouse gas have significantly affected the weather trends and other variables on the 20th century (Meehl, et al., 2007). It is challenging to estimate the future emissions of greenhouse gaseous and other variables, an indicator which can determine the future scenarios will be useful to benefit the economic, social, environments and so on. Representative Concentration Pathways (RCPs), has been introduced as the basis for both long-term and short-term modeling experiments (Vuuren, et al., 2011).

By utilizing RCP scenarios, it allows researcher to determine the magnitude of anthropogenic forcing, together with the climate change condition by using different model representations. Positive greenhouse gaseous and negative aerosol forcing are the major factor of net forcing, as CO^2 forcing is the dominant influence over the scenarios. As for land-use scenarios, the radiative forcings have less influence compared to greenhouse gaseous forcing, even though deforestation and industrial sectors are the major factors of CO_2 emissions. The major factor that affect atmospheric composition are CO_2, N_2O, CH_4 and CFCs+TG. The four RCPs that can reflect the greenhouse gas radiative forcing values are RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

2.4.1 Representative Concentration Pathways 2.6

Representative Concentration Pathways 2.6 is the lowest forcing level scenario (Vuuren, et al., 2011). It was introduced by the IMAGE modelling team from PBL Netherlands Environmental Assessment Agency. The concentration pathway shows a scenario which lead to low greenhouse gas emissions. Over time, the emissions are substantially decreased in order to meet radiative forcing rates.

The usage of renewables powers, carbon capture and storage, bioenergy will help RCP2.6 in decreasing CO_2 emissions by considering energy conservation. This decrease is moderately offset by a rise in CO_2 related land-use emissions as opposed to the baseline due to land use for bioenergy development. A significant assumption is that modern technology can be rapidly applied and will definitely benefit people around the world. Given the RCP2.6 scenarios, emissions from industrial area are decreased from 20 GtC/yr to marginally negative emissions relative to the baseline. The carbon absorption by natural vegetation is also significantly decreased relative to baseline due to a lower atmospheric CO_2 concentration level. Non- CO_2 gases are strongly reduced in RCP2.6 as well. It is known that most of the remaining greenhouse gas emissions are non-CO_2 gaseous. Further reductions in emissions are heavily hinged on whether further reductions in emissions can be achieved here. Emissions mitigation potential for many main sources of non-CO_2gas emissions is minimal. If non-CO_2 emissions can be decreased gradually, the target to achieve low level of greenhouse gas can be considered as successful also.

Baseline trends play an important role in order to achieve low radiative forcing level, which relate to population growth and development pattern. The rise in global population is expected to increase the baseline emission intensity. The baseline is also predicting a rise in agricultural product production. The growing population would result in following trends such as rising demand for meat and a global change. Besides, development of industry has brought some impact to RCP 2.6. In the IMAGE model, emissions from industrial sources are used to quantify increases in greenhouse gas and air pollutant concentrations. According to Vuuren, et al. (2010), the development of industry has caused the global mean temperature to rise about 4°C above preindustrial levels. In the RCP2.6 scenarios, sea level continues to rise through 2500 due to temperature increase, given temperature recovery to 20th-century values. The thermostatic sea level increases are 19cm to 28 cm for RCP2.6 compared with the ocean level in the year 2100 to the preindustrial (year 1850 – year 1860).

2.4.2 Representative Concentration Pathways 4.5

The Representative Concentration Pathway (RCP) 4.5 is a long-term and global greenhouse gas emission scenario that stabilizes radiative force at 4.5 Wm^{-2} (Thomson, et al., 2011). It was introduced by the GCAM modelling team at the Pacific Northwest National Laboratory in the United States. The goal was to reduce emissions by using lower energy emission technologies, carbon capture and storage, geological storage and so on. Although there are several alternate approaches to obtain a degree of radiative forcing at $4.5\mathrm{Wm}^{-2}$, the RCP4.5 offers a standard basis to investigate the response of the climate system to stabilize the anthropogenic radiative forcing. Radiative forcing is constant in the RCP4.5 from 2080–2100 but greenhouse gas emissions and concentrations remain variable in this scenario.

The population growth will rise in RCP 4.5 scenario. There is also a steady growth in economy, together with effective land-use regulations in such a way that environmental protection is properly assessed. As comparison, population growth has prompted increases in agricultural productivity, increasing cropland in the first half of the century, which lead to higher demand of land-intensive meat. In this scenario, the food demand decrease after 2050 due to the decrease in population. Therefore, cropland and land use emissions will decrease.

According to the research by Nazarenko, et al. (2015), the thermosteric sea level rises are 27cm to 34 cm for RCP4.5 as compared to the preindustrial (year 1850 – year 1860) mean sea level by the year 2100. Industrialization has been shown to have triggered global warming which has raised sea level. Yaduvanshi, et al. (2019) had proved that CMIP 5 models under RCP4.5 scenario had successfully showed the annual rainfall variation at 2°C global warming by 2046, comparing to pre-industrial rates.

2.4.3 Representative Concentration Pathways 6.0

Representative Concentration Pathway 6.0 (RCP6) is a process that defines long-term patterns in global greenhouse gas (GHG) emissions that stabilize radiative force at 6.0 Wm^{-2} (Masui, et al., 2011). It was introduced by the AIM modelling team from the National Institute for Environmental Studies (NIES), Japan. The overall radiative forcing is expected to balance after 2100, by applying variety of technologies and techniques to minimize greenhouse gas emissions, without overshooting.

For RCP6, the limit of CO_2 equivalent concentration is 855 ppm, which making RCP6 excluded from most policy discussion. Although it is not specially modelled in the growth of RCP6, this scenario will be followed by climate change. The climate change is expected to be fluctuate high in year 2100, due to the climate vulnerability and extent of buffering power by oceans. This will provide an input on emission reduction activities across various mechanisms such as preserving and expanding forests, increasing bioenergy to building space conditioning demands and so on. Furthermore, in order to accomplish the goal RCP6, where emission mitigation become modest before 2060, a mitigation of the reference scenario emissions is needed.

As the population rises, RCP6.0 had revealed a result on the increasing demands of cropland but with a decrease in pasture. It shows almost similar pattern as observed for RCP2.6 but with a much stronger execution. Industry growth will definitely cause impacts on global warming. RCP6.0 models experience substantially higher than 2°C warming at 2100, with the surface temperature range rising between 2.4°C and 4.5°C. Temperature increases have caused the ocean level to rise to a maximum of 28cm to 34 cm in 2100 as compared to the pre-industrial (year 1850–year 1860).

2.4.4 Representative Concentration Pathways 8.5

RCP 8.5 is the business-usual or high-end scenario (Riahi, et al., 2011). It was introduced using the MESSAGE model and the IIASA Integrated Evaluation Framework. The RCP 8.5 mainly describe the rise in greenhouse gas emissions with the literature scenarios that cause the high emissions. The socio-economic development direction of RCP 8.5 is characterized by weak economic growth rates with minimal regional convergence, growth in population and a rapidly growing population to comparatively high levels, and a relatively slow technology transition.

New methodologies were used for the development of RCP8.5 such as enhancement of pollutant emission regulations, in order to investigate implications of the RCP and global air pollution. Effective introduction of currently implemented pollutant control policies is shown to substantially decrease the pollutant emissions in short term. For instance, global reductions of about $A = \pi r^2 5\%$ of SO^2 emissions is expected in 2000 to 2030. As long-term, incremental technological changes will definitely reduce the emission of pollutants to very low levels.

In RCP 8.5, the urban demand will increase due to the population growth combined with low economic development, where the community will focus more on development of the area rather than preserving the environment condition (Vuuren, et al., 2011). RCP8.5 shows stronger radiative forcing due to industry development, which will cause energy imbalance by 2100. The RCP6.0 scenario is experiencing a gradual decrease in imbalance with the decreases in CH_4, CFCs, and other gases. However, in the case of RCP8.5 there is no change in the imbalance between 2100 and 2250 which represents a significant increase in the CO_2 concentration. Temperature increases have caused the ocean level to rise to a maximum of 36cm to 45 cm in 2100 as compared to the pre-industrial (year 1850–year 1860).

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Workflow

Chapter 3 outlines the workflows and methods involved in computing the drought analysis with the SPI in East Malaysia, which consists of Sabah and Sarawak. The SPI was selected as the only indicator to monitor drought characteristics due to its computation simplicity, and the availability of input data. Historical daily data of these inputs had been historically recorded at all the meteorological stations distributed in the whole region. The precipitation data that was needed for the SPI was obtained from the Department of Irrigation and Drainage (DID). In this study, all the historical data obtained span from the year 1988 to 2017 (30 years) and used to compute the SPI with 1-, 3- and 6-month timescales. These drought indices were then used to generate the Drought Frequency (DF), Mean Drought Duration (MDD), Mean Drought Severity (MDS), Mean Drought Intensity (MDI) and Mean Drought Peak (MDP) to study the drought characteristics of the study area. Furthermore, the drought occurrences under each drought category indicated by the SPIs were also generated in this study. Finally, these drought characteristics and drought categories were used for both temporal (monthly and six 5-yr sub-periods) and spatial (9 regions) analyses to study the drought pattern in the study area. Figure 3.1 shows the workflow of study.

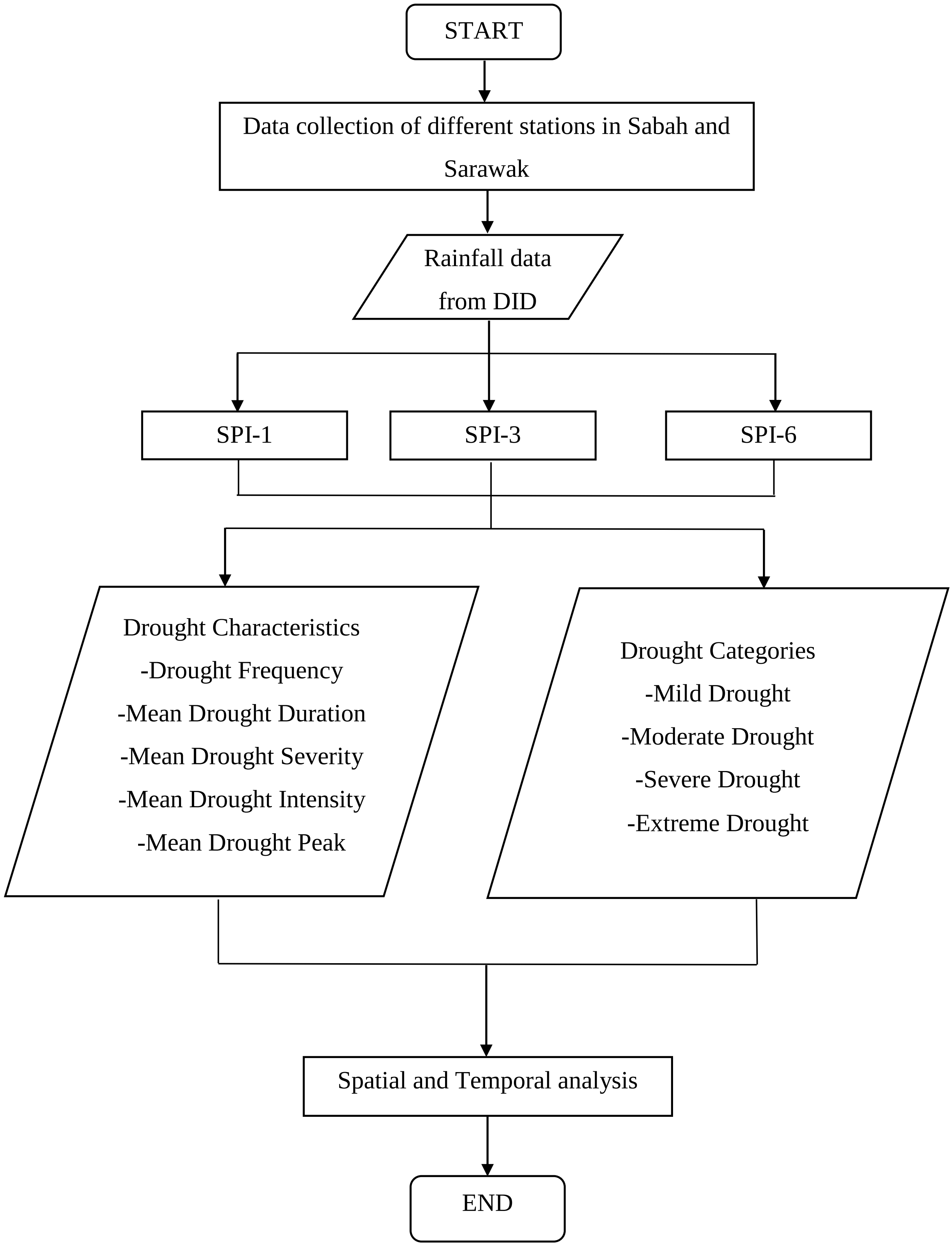

Figure 3.1: Workflow of Study

3.2 Mapping, Location of Study and Data Acquisition

East Malaysia was selected as the study area, which consists of Sabah and Sarawak:

Sabah State is Malaysia's second-largest state after Sarawak, where GPS coordinates of 5 ° 25 '13.4544 "N and 116 ° 47' 48.4188" E. Sabah (73,711km^2) has a long coastline of 1,743 km. The west side is mainly mountainous with three of the highest mountains in Malaysia being a part of it. The Crocker range is the most famous of it, with mountains up to 4,000 meters of height. Mount Kinabalu act as Malaysia's highest mountain, with height of 4.095 meters.

Sabah has a tropical climate with little seasonal change. Temperatures are warm throughout the years but with rarely climb into the middle or upper 90 Fahrenheit degrees. Although the area is subject to seasonal changes in prevailing wind direction, there is no pronounced wet or dry season as in most of Southeast Asia. Therefore, a clear pattern of geographical variation in rainfall can be seen in Sabah. Weather would not normally prevent conventional amphibious operations against Sabah. It could however restrict maritime paramilitary operations using small craft. Air operations would be hindered from time to time by strong winds, turbulence, cloudiness, low ceilings, and poor visibility caused by heavy rain. Strong winds could preclude parachute drops in coastal areas. Such winds be related to typhoons that migrate Northwestward across the Philippine Islands, especially between July and November.

According to official statement by Sabah government, Sabah receives an annual rainfall of 2500–3500 mm. The pattern of the rainfall distribution is clearly defined. With intervals from 1000 mm to over 3500 mm, a relatively consistent trend of mean annual rainfall is found that is subject to Sabah's geographical location and topographical features. Nonetheless, due to coastal influences and in shadow to large land-mass, some localities obtained will not fall within the range.

The state of Sarawak is the largest of Malaysia’s 13 states. It is situated just north of the equator and stretches about 800 km along the northwest coast of the island of Borneo and 600 km from Peninsular Malaysia besides. Sarawak is located at Malaysia in the States place category with the GPS coordinates of

1.5533° N, 110.3592° E. The total land zone of Sarawak is almost 124,451km^2, making up 37.5% of the total territory of Malaysia.

Sarawak comprising of three regions which are coastal lowlands, region of undulating hills and the mountain highlands that are expanded to the Kalimantan border. The longest river in Malaysia, Batang Rajang is located in Sarawak. The Borneo rainforest is known as being among the most species-rich forest in the world. 80 per cent of the total land area of Sarawak is covered by trees, while the remaining include villages, towns, cultivation of agricultural crops and property of customary native rights.

Sarawak has a climate which is equatorial. Throughout the year the temperature is fairly constant with a temperature of 23-32 ° C from the morning to afternoon. Whereas in highlands such as Bario, the temperature is recorded between 16 ° C and 25 ° C during day time and achieved as low as 11 ° C during night time. The northeast monsoon normally brings heavy rain between November and February, whereas for the southwest monsoon, it is generally milder between June and October. Depending on various region of Sarawak, the average rainfall recorded is between 3,300mm and 4,600mm annually. Humidity in lowlands ranging from 80 per cent to 90 per cent is consistently high. Figure 3.2 has been generated to visualize the topography of the study area.

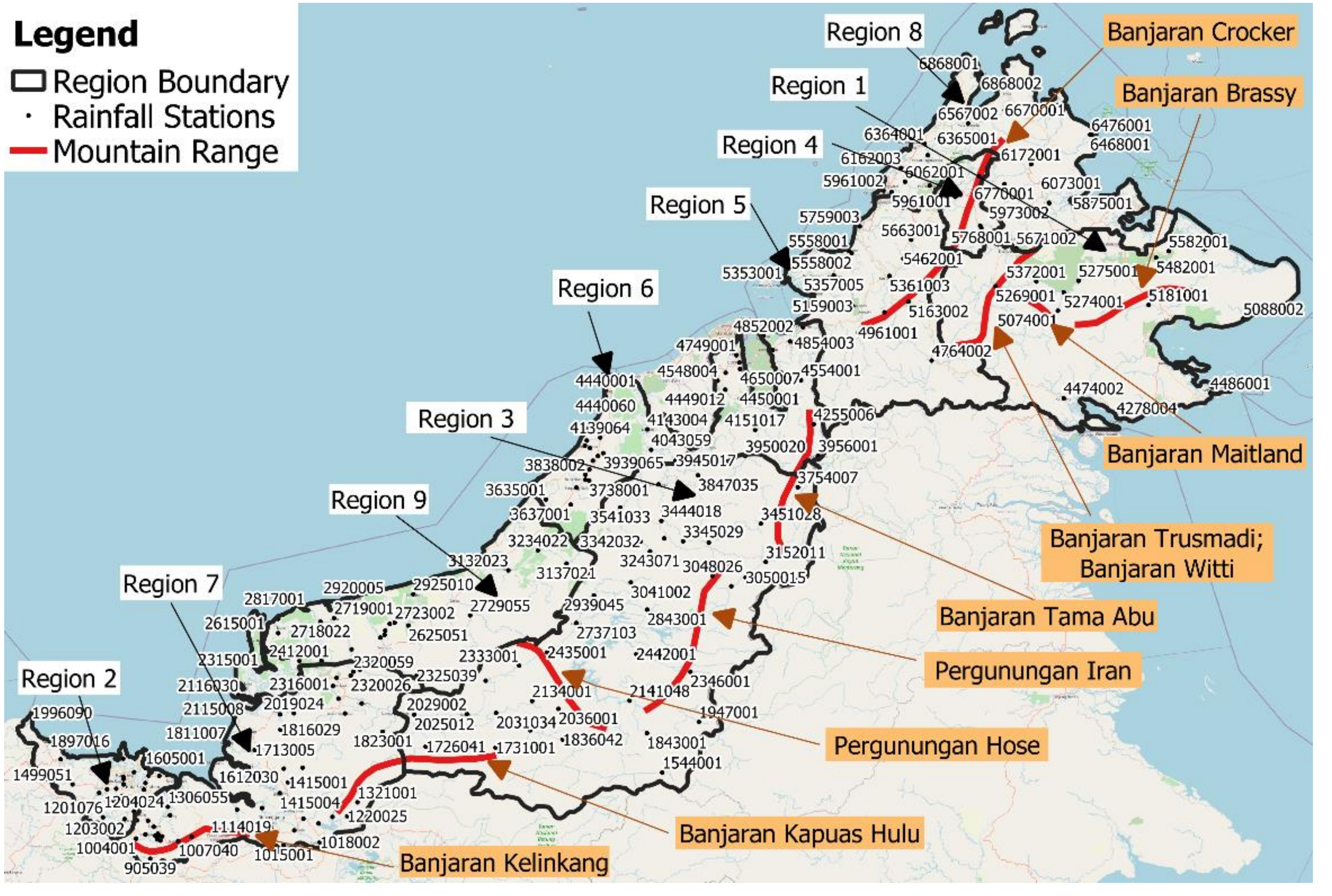

Figure 3.2: Rainfall stations, regional sections and mountain ranges in Sabah and Sarawak.

3.3 Standardized Precipitation Index (SPI)

The SPI is an effective method to estimate the spatial and temporal variations of dryness and wetness in Sabah and Sarawak. The calculation of SPI was conducted by utilizing the rainfall data from 1988-2017 (30 years), at 1-, 3- and 6-months timescales based on the gamma distribution function. A long-term precipitation data is required to undergo this process to develop the probability distribution function, which will result in a normalized numerical values with 0 mean and standard deviation value of 1. The SPI values that is greater than 0 indicate higher level of wetness compared to the SPI values which are less than 0 which indicating lower level of wetness.

The mean of the rainfall is computed by the following equation:

$$\mathrm{Mean} = \overline{\mathrm{X}} = \frac{\sum \mathrm{X}}{\mathrm{N}} \quad (3.1)$$

where

X = Precipitation in mm

N = Number of rainfall stations

The standard deviation for the rainfall was calculated as equation below:

$$\mathrm{Mean} = \overline{\mathrm{X}} = \frac{\sum \mathrm{X}}{\mathrm{N}} \quad (3.2)$$

The skewness of the given rainfall is given as the following equation:

$$\mathrm{Skew} = \frac{\mathrm{N}}{(\mathrm{N}-1)(\mathrm{N}-2)} \sum \left(\frac{\mathrm{X}-\overline{\mathrm{x}}}{\mathrm{s}}\right)^3 \quad (3.3)$$

The SPI was computed based on monthly precipitation data by two parameter gamma distribution functions. First of all, log normal values were found based on the rainfall data provided. Then, U-statistics, shape and scale parameters were computed. By doing this method, the mean was adjusted to 0, standard deviation to 1.0, and skewness of the existing data to 0.

$$\log\text{mean} = \bar{X}_{\ln} = \ln(\bar{X}) \tag{3.4}$$

$$\text{Statistics, U} = \bar{X}_{\ln} - \frac{\sum \ln(X)}{N} \tag{3.5}$$

$$\text{shape parameter} = \beta = \frac{1 + \sqrt{1 + \frac{4U}{3}}}{4U} \tag{3.6}$$

$$\text{scale parameter} = \alpha = \frac{\bar{X}}{\beta} \tag{3.7}$$

Historical rainfall data for different stations are fitted each to gamma probability distribution function as equation below:

$$G(X) = \frac{\int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} dx}{\beta^{\alpha}\Gamma(\alpha)} \tag{3.8}$$

During zero precipitation where undefined x = 0, the cumulative probability equation can be expressed as below:

$$H(x) = q + (1 - q)G(x) \tag{3.9}$$

where
q = Probability of zero

The cumulative probability H(x) is converted to standard normal random variable Z as shown below:

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for } 0 < H(x) \leq 0.5 \tag{3.10}$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for } 0.5 < H(x) \leq 1.0 \quad (3.11)$$

where

$$t = \sqrt{\ln\left(\frac{1}{H(x)^2}\right)} \quad \text{for } 0 < H(x) \leq 0.5 \quad (3.12)$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \quad \text{for } 0.5 < H(x) \leq 1.0 \quad (3.13)$$

where the coefficients in Equation 3.10 and 3.11 are stated below:

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

3.4 Drought Characteristics

Different types of drought indices were performed to identify the characteristics of drought in Sabah and Sarawak. By understanding drought characteristics, it offers early notice to ensure drought preparedness and minimize future impacts. In addition, early detection of droughts is essential to manage potential crop losses in order to avoid or mitigate possible associated famines, and to tackle increased fire risk. Various parameters were considered such as duration, frequency, severity, peak and intensity. Future drought data are obtained to generate future drought map, where the future drought map is used to compare with the historical drought map. Besides, there are others parameters that were computed, which provided another perspective aspect by particular parameter, for example, Mean Drought Duration (MDD), Mean Drought Severity (MDS), Mean Drought Peak (MDP) and Mean Drought Intensity (MDI). The equations to compute the drought characteristics are expressed below:

3.4.1 Drought Frequency

The total number of drought event is the frequency of drought. A drought index with negative values indicate a drought has occurred. The calculation of drought frequency is expressed in the following equation:

$$\text{Drought frequency} = \sum \text{Number of drought event} \qquad (3.26)$$

3.4.2 Mean Drought Duration

The duration of drought is known as period where drought phenomenon occurred. Mean drought duration was computed by averaging the total of drought duration throughout the research period over the drought frequency, which can be expressed in the following equation:

$$\text{Mean drought duration} = \frac{\sum \text{Drought duration}}{\text{Drought frequency}} \qquad (3.27)$$

3.4.3 Mean Drought Severity

Drought severity denotes that the magnitude of the drought event represents the effects caused by rainfall deficiency. The severity of the drought may depend on the rate of moisture deficiency, duration, and size of the study area. According to Guo, et al. (2018), the drought severity is computed based on the drought index value itself and can be expressed in the following equation:

$$\text{Mean drought severity} = \frac{\sum \text{Negative drought index}}{\sum \text{Drought duration}} \qquad (3.28)$$

3.4.4 Mean Drought Intensity

It is known that drought intensity can be explained as the average value of drought magnitude within the drought period, as the equation is expressed in the following equation (Guo, et al., 2018).

$$\text{Drought Intensity} = \frac{\sum \text{Negative drought index of a drought event}}{\text{Drought duration of a drought event}} \quad (3.29)$$

Whereas, the mean drought intensity was computed by averaging the total of drought intensity over drought frequency as the equation is expressed in the following equation.

$$\text{Mean drought intensity} = \frac{\sum \text{Drought intensity}}{\text{Drought frequency}} \quad (3.30)$$

3.4.5 Mean Drought Peak

During a drought event, drought peak can be achieved when the lowest value of drought index is obtained. Mean drought peak is calculated as the ratio of summation of drought peak over drought frequency as the equation is expressed in the following equation:

$$\text{Mean drought peak} = \frac{\sum \text{Drought peak of a drought event}}{\text{Drought frequency}} \quad (3.31)$$

3.5 Drought Categories

From the analysis carried out earlier, the Spatial and Temporal variations were evaluated to compare the drought characteristics in the Regions of East Malaysia. The total of 30 years (1988-2017) research periods were conveniently and arbitrarily and consecutively divided into six 5-yr sub-periods to have the opportunity in order to differentiate the drought characteristics in more comprehensive ways. However, a conclusion on which subareas of the basin were more prone to droughts was difficult to make. Therefore, the drought characteristics were also calculated for and classified as mild, moderate, severe, and extreme drought categories. Under the SPI, SPI values between 0 to -0.99 could be classified as Mild Drought, while SPI values between 1.00 to -1.47 could be classified as Moderate Drought. For Severe Drought, SPI values between -1.50 to -1.99 should be obtained, whereas for Extreme Drought, SPI values less than -2.00 should be obtained (Paulo, 2006). For further understanding of drought categories, graphs have been generated for the total number of stations that showed different drought categories in SPI-1, SPI-3 and SPI-6. The sub-periods that have shown higher drought occurrence have been linked to the El-Niño episodes that had happened over the past 30 years. Besides, maps of each drought category were generated and discussed. The regions or areas that have shown higher occurrence of drought were sorted out and linked ostensibly to the factors of El Niño events and mountainous topography of East Malaysia. For instance, the stations that were located near to seashore might be influenced by those past El Niño events, whereas stations that are located near to mountain ranges could be affected by the mountains which blocked the rainfall from reaching a specific area. Therefore, an improved understanding of relationship of the drought characteristics and drought categories could be achieved.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The Standardized Precipitation Index (SPI) was utilised in order to monitor the drought characteristics from 1988-2017 at timescales of 1-month, 3-months and 6 months respectively, with the precipitation data available. 30 years of rainfall data were divided into six 5-years sub-periods, which were the 1988-1992, 1993-1997, 1998-2002, 2003-2007, 2008-2012 and 2013-2017 sub-periods over the 30-year length of data. There was a total of 5 drought characteristics studied: Drought Frequency (DF), Mean Drought Duration (MDD), Mean Drought Severity (MDS), Mean Drought Intensity (MDI), Mean Drought Peak (MDP). The El-Niño episodes as shown in Table 4.1 and topography of East Malaysia were used to justify the drought characteristics that happened over the 6 sub-periods. During an El Niño event, the occurrence of rainfall will be restricted due to increase in sea surface temperature. Besides, the mountainous topography of East Malaysia could block either South-West Monsoon or North-East Monsoon from reaching a specific area, resulting in drought occurrence.

Table 4.1: El-Niño episodes that happened from year 1951 – 2020 (Oceanic Niño Index, 2020).

El-Niño episodes			
Weak - 12	Moderate - 7	Strong - 5	Very Strong - 3
1952 - 1953	1951 - 1952	1957 – 1958	1982 – 1983
1953 – 1954	1963 - 1964	1956 - 1957	1997 - 1998
1958 - 1959	1968 - 1969	1972 - 1973	2015 - 2016
1969 - 1970	1986 - 1987	1987 - 1988	
1976 - 1977	1994 - 1995	1991 - 1992	
1977 - 1978	2002 - 2003		
1979 - 1980	2009 - 2010		
2004 - 2005			
2006 - 2007			
2014 - 2015			
2018 - 2019			
2019 - 2020			

4.2 Drought Frequency

4.2.1 SPI-1

Drought Frequency (DF) is the number of droughts that had happened in the specific study period. The SPI at 1-month timescale was utilised in order to study the spatial variations of DF as shown in Figure 4.1. The colour depth from lighter yellow to the darker red indicates the level of DF from lowest to highest category.

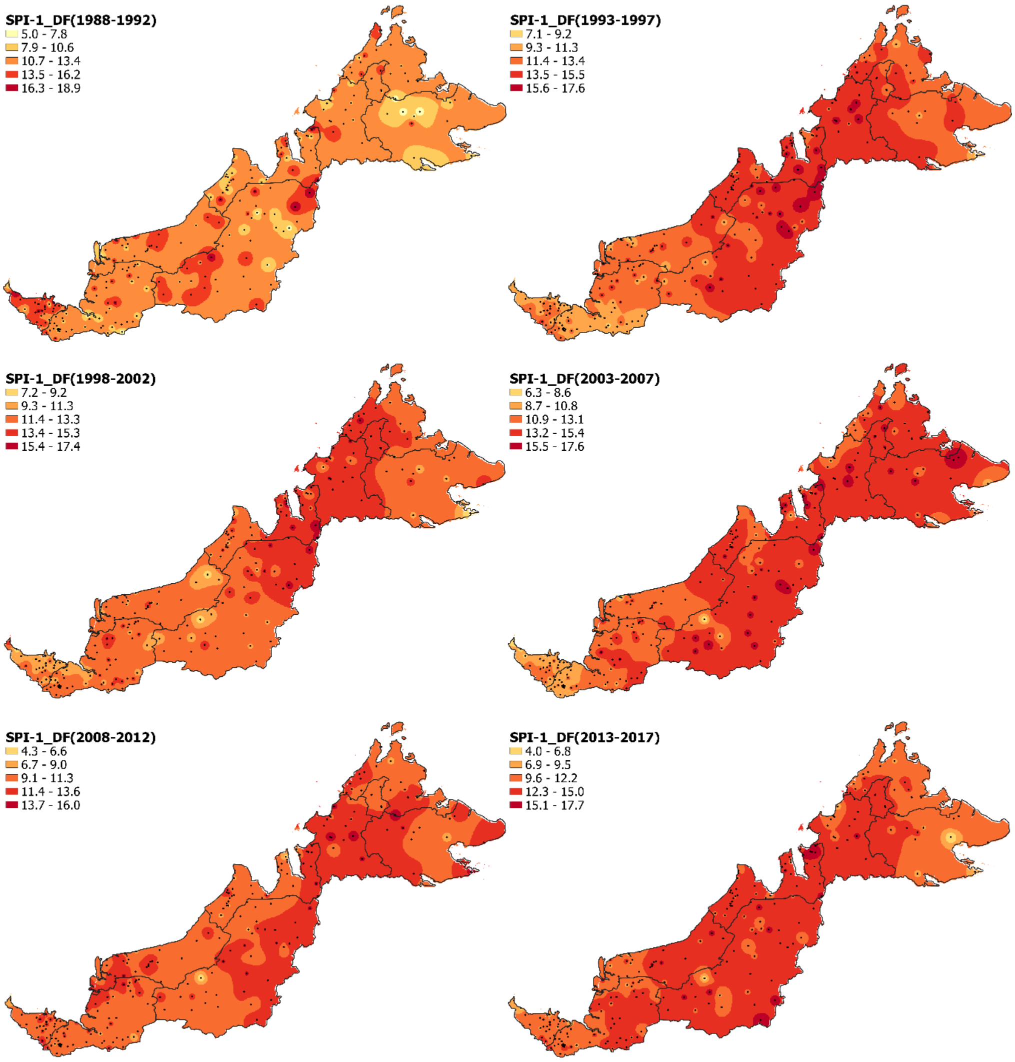

Figure 4.1: Drought Frequency maps of SPI-1 for each 5-years sub-period along 1988-2017.

In **Region 1**, the DF between 5.0-13.4 were observed in sub-period 1988-1992. A majority of the areas had shown DF between 7.9-13.4, whereby the West, Central and Eastern parts of the region had shown higher values of DF. In sub-period of 1993-1997, the DF between 9.3-15.5 were observed. A majority of the areas had shown DF between 11.4-15.5, whereby Western part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 7.2-15.3 were observed. Majority of the areas had shown DF between 11.4-15.3, whereby the Western part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 8.7-17.6 were observed. A majority of the areas had shown DF between 10.9-15.4, whereby the North-East of the region had shown higher values of DF. In sub-period 2008-2012, DF between 6.7-13.6 were observed. A majority of the areas had shown DF between 9.1-13.6, whereby the Western and Eastern parts of the region had shown higher values of DF. In sub-period 2013-2017, DF between 4.0-15.0 were observed. A majority of the areas had shown DF between 9.6-15.0, whereby the Western part of the region had shown higher values of DF.

As it happened over the six sub-periods, it was observed that majority of the areas had shown lowest DF during the sub-period of 1988-1992, which gradually increased and peaked in the sub-period of 1993-1997. The DF have then remained in sub-periods 1998-2002 and 2003-2007. Then, it decreased during sub-period 2008-2012 and maintained in 2013-2017. Besides, the Western part of the region had consistently showed relatively higher DF over the sub-periods, except for sub-period 2003-2007 that has relatively higher DF at station 5482001 and 5582001. Given that the location of these two stations being in the near-coast Kinabatangan district, the high DF could be due to the effect of the El-Niño episodes that had occurred in 2002-2003, 2004-2005, 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, the DF between 7.9-18.9 were observed in sub-period 1988-1992. A majority of the areas had shown DF between 10.7-13.4, whereby the North-West of the region had shown higher values of DF. In sub-period 1993-1997, DF between 7.1-13.4 were observed. A majority of the areas had shown DF between 9.3-13.4, whereby the South-East and East parts of the region had shown higher values of DF. In sub-period 1998-2002, DF between 7.2-13.3 were observed. A majority of the areas had shown DF between 9.3-13.3, whereby the South part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 6.3-13.1 were observed. A majority of the areas had shown DF between 8.7-13.1, whereby the South part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 6.7-13.6 were observed. A majority of the areas had shown DF between 9.1-13.6, whereby the North-East of the region had shown higher values of DF. In sub-period 2013-2017, DF between 6.9-15.0 were observed. A majority of the areas had shown DF between 9.6-12.2, whereby most of the region had shown higher values of DF, except for the North-West.

Therefore, over the six sub-periods, it was observed that majority of the areas had shown peak DF during sub-period 1988-1992, which gradually decreased and maintained in sub-period 1993-1997 and 1998-2002. The DF have then decreased and remained in sub-periods 2003-2007, until lowest DF was observed in 2013-2017. Besides, the Southern part of the region had consistently showed relatively higher DF over the sub-periods, especially at station 1102019 and 1201076. Given that the location of these two stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 1994-1995, 2002-2003, 2004-2005, 2006-2007, 2019-2010, 2014-2014 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, the DF between 5.0-18.9 were observed in sub-period 1988-1992. A majority of the areas had shown DF between 10.7-16.2, whereby the North-East of the region had shown higher values of DF. In sub-period 1993-1997, DF between 9.3-17.6 were observed. A majority of the areas had shown DF between 11.4-15.5, whereby the North-East part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 7.2-17.4 were observed. A majority of the areas had shown DF between 11.4-15.3, whereby the North-East of the region had shown higher values of DF. In sub-period 2003-2007, DF between 10.9-17.6 were observed. A majority of the areas had shown DF between 136.2-15.4, whereby the North-East of the region had shown higher values of DF. In sub-period 2008-2012, DF between 6.7-13.6 were observed. A majority of the areas had shown DF between 9.1-13.6, whereby the Eastern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 4.0-17.7 were observed. A majority of the areas had shown DF between 12.3-15.0, whereby the South-East pf the region had shown higher values of DF. A majority of the areas had shown lowest DF during sub-period 1998-2002, and gradually increased on the following sub-period.

Thus, over the six sub-periods, it was observed that majority of the areas had shown peak DF during sub-period 1988-1992, which gradually decreased and maintained in sub-period 1993-1997. The DF have then remained in sub-periods 1998-2002, 2003-2007 and 2008-2012. Then, it decreased as lowest was observed during sub-period 2008-2012 and increased in 2013-2017. Besides, the Northern-East part consistently showed relatively higher DF over the sub-periods, especially station 3950020 and 3754007. Given the location of these two stations located in inland area, the high DF could be affected by Banjaran Tama Abu which is located near to the stations. Banjaran Tama Abu could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 4**, DF between 10.7-16.2 were observed in sub-period 1988-1992. A majority of the areas had shown DF between 10.7-13.4, whereby the North-East of the region had shown higher values of DF. In sub-period 1993-1997, DF between 11.4-15.5 were observed. The whole region had shown DF between 11.4-15.5, whereby the Central and Western parts of the region had shown higher values of DF. In sub-period 1998-2002, DF between 13.4-15.3 were observed in whole region, whereby the North-East of the region had shown higher values of DF. In sub-period 2003-2007, DF between 13.2-17.6 were observed. A majority of the areas had shown DF between 13.2-15.4, whereby the North-East of the region had shown higher values of DF. In sub-period 2008-2012, DF between 6.7-13.6 were observed. A majority of the areas had shown DF between 9.1-13.6, whereby the Southern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 12.3-15.0 were observed in whole region, whereby the South-East pf the region had shown higher values of DF.

In summary, over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased during sub-period 1988-1992, and peak was observed in sub-period 1993-1997. The DF have then decreased and remained in sub-periods 1998-2002, 2003-2007 and lowest DF was observed in 2008-2012. Then, it increased during sub-period 2013-2017. Besides, since the region is small, almost whole region had shown relatively higher DF over the sub-periods, except for sub-period 1988-1992 and 2008-2012 that has relatively higher DF at station 6168001. Given that the location of these two stations were at the inland area, the high DF could be affected by the Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 5**, the DF between 10.7-16.2 were observed in sub-period 1988-1992. A majority of the areas had shown DF between 10.7-13.4, whereby the North-East of the region had shown higher values of DF. In sub-period 1993-1997, DF between 11.4-15.5 were observed. The whole region had shown DF between 11.4-15.5, whereby the Central and Western part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 13.4-15.3 were observed in whole region, whereby the North-East of the region had shown higher values of DF. In sub-period 2003-2007, DF between 13.2-17.6 were observed. A majority of the areas had shown DF between 13.2-15.4, whereby the North-East of the region had shown higher values of DF. In sub-period 2008-2012, DF between 6.7-13.6 were observed. A majority of the areas had shown DF between 9.1-13.6, whereby the Southern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 12.3-15.0 were observed in whole region, whereby the South-East of the region had shown higher values of DF.

All in all, it was observed that over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased during sub-period 1988-1992, and peak was observed in sub-period 1993-1997. The DF have then decreased and remained in sub-periods 1998-2002, 2003-2007 and lowest DF was observed in 2008-2012. Then, it increased during sub-period 2013-2017.

Besides, the central of the region had shown relatively higher frequency of DF over the sub-periods, except for sub-period 1988-1992 that has relatively higher DF at station 4955002. Given that the location of these two stations being near to seashore, the high DF could have been affected by the El-Niño episodes that had occurred in 1987-1988 and 1991-1992 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 6**, the DF between 7.9-16.2 were observed in sub-period 1988-1992. A majority of the areas had shown DF between 10.7-16.2, whereby the Western and Eastern parts of the region had shown higher values of DF. In sub-period 1993-1997, DF between 11.4-17.6 were observed. The whole region had shown DF between 13.5-17.6, whereby the Eastern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 9.3-17.4 were observed in whole region, whereby the Eastern of the region had shown higher values of DF. In sub-period 2003-2007, DF between 10.9-17.6 were observed. A majority of the areas had shown DF between 10.9-15.4, whereby the North-East of the region had shown higher values of DF. In sub-period 2008-2012, DF between 6.7-13.6 were observed. A majority of the areas had shown DF between 9.1-13.6, whereby the Eastern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 9.6-17.7 were observed in whole region, whereby the North-East of the region had shown higher values of DF.

It was observed that over the six sub-periods, majority of the areas had shown DF gradually increased during sub-period 1988-1992, and peak was observed in sub-period 1993-1997. The DF have then decreased and remained in sub-periods 1998-2002 and peak DF was observed in 1993-1997. Then, it decreased during sub-period 1998-2002 and lowest DF was observed in 2008-2012. Besides, the Eastern part had shown relatively higher frequency of DF over the sub-periods, except for sub-period 1988-1992 that has relatively higher DF at station 4955021. Given that the location of the station being near to seashore, the high DF could be affected by the El-Niño episodes that had taken place in 1987-1988 and 1991-1992 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, the DF between 7.9-16.2 were observed in sub-period 1988-1992. A majority of the areas had shown DF between 10.7-16.2, whereby the Central of the region had shown higher values of DF. In sub-period 1993-1997, DF between 7.1-13.5 were observed. A majority of the areas had shown DF between 9.3-13.4, whereby the Northern and Eastern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 9.3-15.3 were observed. A majority of the areas had shown DF between 9.3-11.3, whereby the Northern part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 8.7-15.4 were observed. A majority of the areas had shown DF between 10.9-15.4, whereby the South-East of the region had shown higher values of DF. In sub-period 2008-2012, DF between 6.7-13.6 were observed. A majority of the areas had shown DF between 9.1-13.6, whereby the Eastern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 6.9-15.0 were observe. A majority of the areas showed DF between 9.6-15.0, whereby the Eastern part of the region had shown higher values of DF.

Thus, it was observed that majority of the areas had shown peak DF during sub-period 1988-1992, and gradually decreased and remained from sub-period 1993-1997. Lowest DF was observed in 2008-2012, and slightly increased in the following period. Besides, the Eastern and northern parts had shown relatively higher frequency of DF over the sub-periods, except for sub-period 1988-1992, that has relatively higher DF at station 1615023 and 1415001. Given that the location of these two stations located in inland area, the high DF could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 8**, the DF between 7.9-16.2 were observed in sub-period 1988-1992. A majority of the areas had shown DF between 10.7-13.4, whereby the North-West of the region had shown higher values of DF. In sub-period 1993-1997, DF between 9.3-15.5 were observed. A majority of the areas had shown DF between 11.4-15.5, whereby the Eastern and Western parts of the region had shown higher values of DF. In sub-period 1998-2002, DF between

11.4-15.3 were observed in whole region, whereby the Western part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 10.9-15.4 were observed in whole region, whereby the Eastern, Southern and Centre of the region had shown higher values of DF. In sub-period 2008-2012, DF between 9.1-16.0 were observed. A majority of the areas had shown DF between 9.1-13.6, whereby the Southern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 6.9-15.0 were observed. A majority of the areas showed DF between 9.6-15.0, whereby the Western part of the region had shown higher values of DF.

For the span of 30 years, it was observed that majority of the areas had shown DF gradually increased during sub-period 1988-1992, and peak was observed in sub-period 1993-1997. DF then decreased in 1998-2002 until lowest DF was observed in 2008-2012, and slightly increased in the following period. Besides, the Western part had shown relatively higher frequency of DF over the sub-periods, except for sub-period 2003-2007 and sub-period 2013-2017, that has relatively higher DF at station 6064001, 6172001 and 6770001. Given that the location of these stations located in inland area, the high DF could be affected by the Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 9**, the DF between 5.0-16.2 were observed in sub-period 1988-1992. A majority of the areas had shown DF between 10.7-16.2, whereby the Eastern and Central parts of the region had shown higher values of DF. In sub-period 1993-1997, DF between 9.3-15.5 were observed. A majority of the areas had shown DF between 11.4-15.5, whereby the Eastern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 7.2-15.3 were observe, majority of the areas showed DF between 9.3-13.3, whereby the Western part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 10.9-15.4 were observed in whole region, whereby the Eastern, Southern and Centre of the region had shown higher values of DF. In sub-period 2008-2012, DF between 6.7-13.6 were observed. A majority of the areas had shown DF between 9.1-13.6, whereby the Western part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 6.9-15.0 were observe. A majority of the areas showed DF between 9.6-15.0, whereby the Central and Eastern parts of the region had shown higher values of DF.

It was observed that majority of the areas had shown peak DF during sub-period 1988-1992, and gradually decreased and remained from sub-period 1993-1997. Lowest DF was observed in 2008-2012, and slightly increased in the following period. Besides, the Eastern part consistently showed relatively higher DF over the sub-periods, except for sub-period 1998-2002 and sub-period 2008-2012, that has relatively higher DF at station 2817001, 2615009, 2520052 and other stations near to it. Given the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes occurring in 1997-1998 and 2009-2010 that inhibited rainfall occurrence due to the increase in sea surface temperature.

4.2.2 SPI-3

The Drought Frequency (DF) is defined as the number of droughts that had happened during the study period. The SPI at 3-month timescale was utilised in order to study the spatial variations of DF as shown in Figure 4.2. The colour depth from yellow to red indicates the level of DF from lowest to highest category.

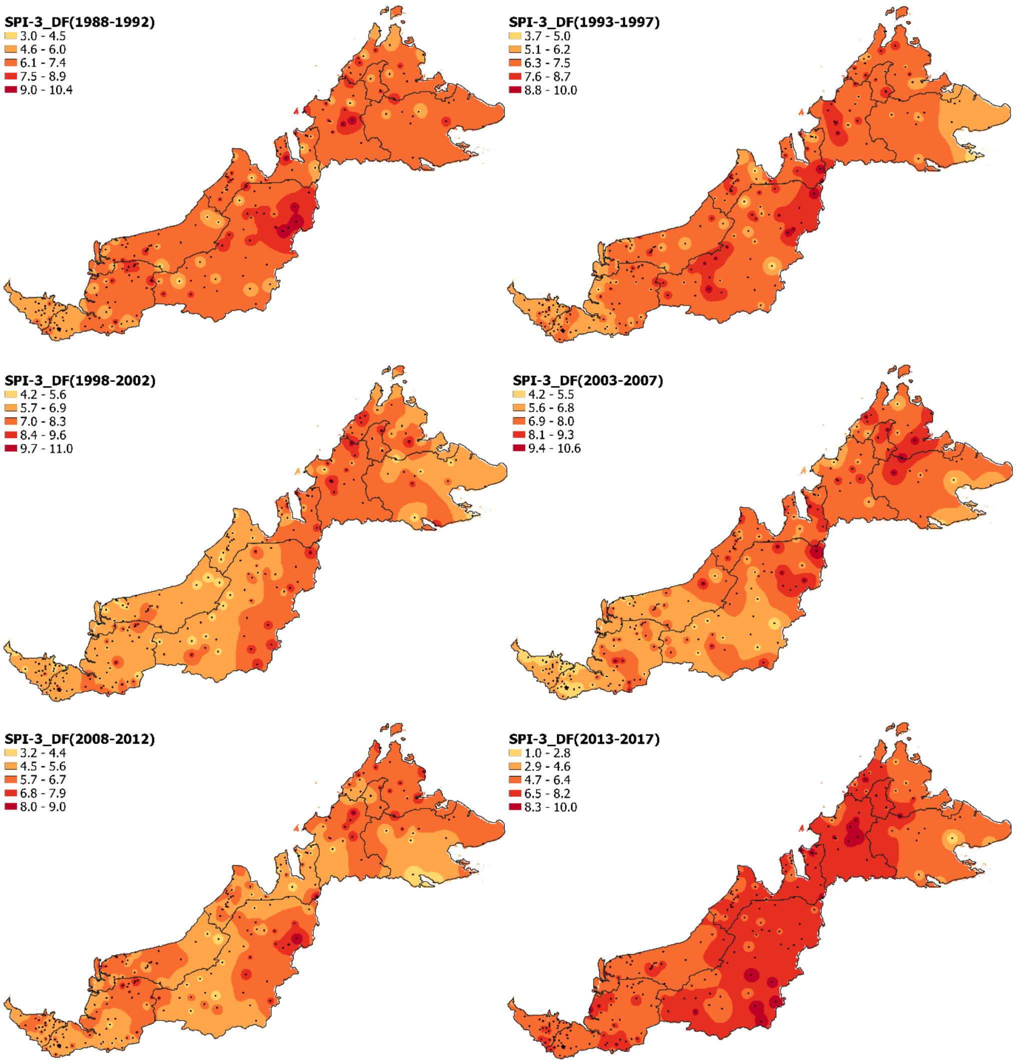

Figure 4.2: Drought Frequency maps of SPI-3 for each 5-years sub-period along 1988-2017.

In **Region 1**, the DF between 4.6-8.9 were observed in the sub-period 1988-1992. A majority of the areas had shown DF between 6.1-7.4, whereby the Central part of the region had shown higher values of DF. In the sub-period 1993-1997, DF between 3.7-7.5 were observed. A majority of the areas had shown DF between 5.1-7.5, whereby the Western and Central parts of the region had shown higher values of DF. In sub-period 1998-2002, DF between 4.2-8.3 were observed. Majority of the areas had shown DF between 5.7-8.3, whereby the Western part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 5.6-10.6 were observed. A majority of the areas had shown DF between 5.6-8.0, whereby the Northern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 3.2-6.7 were observed. A majority of the areas had shown DF between 4.5-6.7, whereby the Northern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 1.0-8.2 were observed. A majority of the areas had shown DF between 2.9-6.4, whereby the Western part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased during sub-period 1988-1992 and peak was observed in 1998-2002. DF then decreased and remained from sub-period 2003-2007 and lowest DF was observed in 2013-2017. Besides, the Western and Northern part had relatively shown high DF over the sub-periods, except 1988-1992, that has relatively higher DF at station 5181001. Given that the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 1987-1998 and 1991-1992 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, DF between 4.6-7.4 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 4.6-6.0, whereby the Southern part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 5.1-7.5 were observed. Majority of the areas had shown DF between 5.1-6.2, whereby the Southern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 4.2-6.9 were observed. A majority of the areas had shown DF between 5.7-6.9, whereby whole part of the region had shown higher values of DF, except for the Northern part. In sub-period 2003-2007, DF between 4.2-6.8 were observed. A majority of the areas had shown DF between 4.2-6.8, whereby the Southern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 3.2-5.6 were observed. A majority of the areas had shown DF between 4.5-5.6, whereby the Central part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 4.7-8.2 were observed. A majority of the areas had shown DF between 4.7-6.4, whereby the Southern part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased during sub-period 1988-1992 and peak was observed in 1998-2002. Lowest DF was observed in 2003-2007 and remained for the following periods. Besides, the Southern part had relatively shown high DF over the sub-periods, except 2008-2012, that has relatively higher DF at station 1402047, 1402001, 1402047. Given the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 2009-2010 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, DF between 3.0-10.4 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 6.1-8.9, whereby the North-East part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 3.7-10.0 were observed. Majority of the areas had shown DF between 6.3-8.7, whereby the North-East part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 4.2-6.9 were observed. Majority of the areas had shown DF between 5.7-8.3, whereby the Eastern part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 4.2-10.6 were observed. Majority of the areas had shown DF between 5.6-8.0, whereby the North-East part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 3.2-9.0 were observed. Majority of the areas had shown DF between 4.5-6.7, whereby the North-East part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 4.7-10.0 were observed. Majority of the areas had shown DF between 4.7-8.2, whereby the Eastern part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown peak DF was observed during sub-period 1988-1992 and decreased in 1993-1997. DF then decreased in 1998-2002 and remained for the following periods. Besides, the North-East part had relatively shown high DF over the sub-periods, except 1998-2002 and 2013-2017, that has relatively higher DF at station 1947001, 1544001 and 2346001. Given the location of these stations located in inland area, the high DF could be affected by the mountain ranges Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, DF between 4.6-8.9 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 6.1-7.4, whereby the Southern part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 5.1-8.7 were observed. Majority of the areas had shown DF between 6.3-7.5, whereby the Southern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 5.7-9.6 were observed. Majority of the areas had shown DF between 7.0-8.3, whereby the Northern part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 6.9-9.3 were observed. Majority of the areas had shown DF between 6.9-9.3, whereby the Northern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 4.5-6.7 were observed. Majority of the areas had shown DF between 4.5-6.7, whereby Northern and Southern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 6.5-8.2 were observed. Majority of the areas had shown DF between 6.5-8.2, whereby the whole part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased during sub-period 1988-1992. DF then decreased and remained in 1998-2002 and lowest DF was observed in 2008-2012. DF then increased in the following period. Besides, the Northern and Southern part had relatively shown high DF over the sub-periods, especially at station 6168001 and 5768001. Given the location of these stations located in inland area, the high DF could be affected by the Banjaran Crocker range which is located near to the stations. The Banjaran Crocker range could block North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 5**, DF between 4.6-8.9 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 6.1-7.4, whereby the Central part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 5.1-8.7 were observed. Majority of the areas had shown DF between 6.3-7.5, whereby Western part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 5.7-9.6 were observed. Majority of the areas had shown DF between 7.0-8.3, whereby the Northern and Central parts of the region had shown higher values of DF. In sub-period 2003-2007, DF between 5.6-9.3 were observed.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased since sub-period 1988-1992. DF then decreased in 2003-2007 and lowest DF was observed in 2008-2012. DF then increased in the following period and peak was observed in 2013-2017. Besides, the Central part had relatively shown high DF over the sub-periods, except 1993-1997 and 2008-2012, that relatively showed high DF at station 5158001, 4959001, 5361003, 5462001 and other stations near to it. Given the location of these stations located in inland area, the high DF could be affected by the Banjaran Crocker range which is located near to the stations. The Banjaran Crocker range could block North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 6**, DF between 4.6-8.9 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 6.1-7.4, whereby the Central part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 5.1-10.0 were observed. Majority of the areas had shown DF between 6.3-8.7, whereby the Eastern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 5.7-9.6 were observed. Majority of the areas had shown DF between 7.0-8.3, whereby the Northern and Central part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 5.6-9.3 were observed. Majority of the areas had shown DF between 5.6-8.0, whereby the Northern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 4.5-7.9 were observed. Majority of the areas had shown DF between 4.5-6.7, whereby the Eastern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 4.7-8.2 were observed. Majority of the areas had shown DF between 4.7-8.2, whereby the Central, Northern and Southern part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased since sub-period 1988-1992 and peak was observed in 1993-1997. DF then decreased and remained in 1998-2002 and

2003-2007 and lowest DF was observed in 2008-2012. DF then increased in the following period. Besides, the Eastern and Northern part had relatively shown high DF over the sub-periods, except 1988-1992, that relatively showed high DF at station 4450001 and 4449012. Given the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 1987-1988 and 1991-1992 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, DF between 3.0-7.4 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 3.0-6.0, whereby the Northern part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 5.1-7.5 were observed. Majority of the areas had shown DF between 5.1-7.5, whereby the Eastern and Central parts of the region had shown higher values of DF. In sub-period 1998-2002, DF between 4.2-8.3 were observed. Majority of the areas had shown DF between 5.7-6.9, whereby the Central part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 4.2-9.3 were observed. Majority of the areas had shown DF between 5.6-8.0, whereby the Central part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 3.2-7.9 were observed. Majority of the areas had shown DF between 4.5-6.7, whereby the Northern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 4.7-8.2 were observed. Majority of the areas had shown DF between 4.7-8.2, whereby the Northern and Southern part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased since sub-period 1988-1992 and peak was observed in 1993-1997. DF then decreased and remained in 1998-2002 and 2003-2007 and lowest DF was observed in 2008-2012. DF then increased in the following period. Besides, the Northern part had relatively shown high DF over the sub-periods, except 1993-1997, 1998-2002, 2003-2007 that relatively showed high DF at station 1105027, 1616021, 1015001 and other stations near to it. Given the location of these stations located in inland area, the high DF could be affected by the Banjaran Kelinkang range which is located near to the stations. The Banjaran Kelinkang could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 8**, DF between 4.6-8.9 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 6.1-7.4, whereby the Western part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 5.1-8.7 were observed. Majority of the areas had shown DF between 6.3-7.5, whereby the Northern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 4.2-9.6 were observed. Majority of the areas had shown DF between 5.7-8.3, whereby the Western part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 5.6-10.6 were observed. Majority of the areas had shown DF between 5.6-8.0, whereby the Southern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 3.2-7.9 were observed. Majority of the areas had shown DF between 4.5-7.9, whereby the Southern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 2.9-8.2 were observed. Majority of the areas had shown DF between 4.7-8.2, whereby the Western part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased since sub-period 1988-1992 and peak was observed in 1998-2002. DF then decreased and remained in 1998-2002 and lowest DF was observed in 2008-2012. DF then increased in the following period. Besides, the Western and Southern part had relatively shown high DF over the sub-periods, except 1993-1997 that relatively showed high DF at station 6567002 and 6670001. Given the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, DF between 4.6-8.9 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 4.6-7.4, whereby the South-West part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 5.1-8.7 were observed. Majority of the areas had shown DF between 6.3-7.5, whereby the South-West part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 4.2-8.3 were observed. Majority of the areas had shown DF between 5.7-6.9, whereby the South-West part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 4.2-9.3 were observed. Majority of the areas had shown DF between 5.6-8.0, whereby the Northern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 3.2-6.7 were observed. Majority of the areas had shown DF between 4.5-6.7, whereby the Western part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 4.7-8.2 were observed. Majority of the areas had shown DF between 4.7-8.2, whereby the South-West and Northern part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased since sub-period 1988-1992. DF then decreased and remained in 2008-2012 as lowest DF was observed in 2008-2012. DF then increased and peak was observed in 2013-2017. Besides, the Western part had relatively shown high DF over the sub-periods, except for 2003-2007 and 2013-2017 that relatively showed high DF at station 3132023 and 3137021. Given the location of these stations located in inland area, the high DF could be affected by Banjaran Kapuas Hulu range which is located near to the stations. The Banjaran Kapuas Hulu could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

4.2.3 SPI-6

Drought Frequency (DF) is the number of droughts that had happened in the specific study period. The SPI at 6-month timescale was utilised in order to study the spatial variations of DF as shown in Figure 4.3. The colour depth from lighter yellow to darker red indicates the level of DF from lowest to highest category.

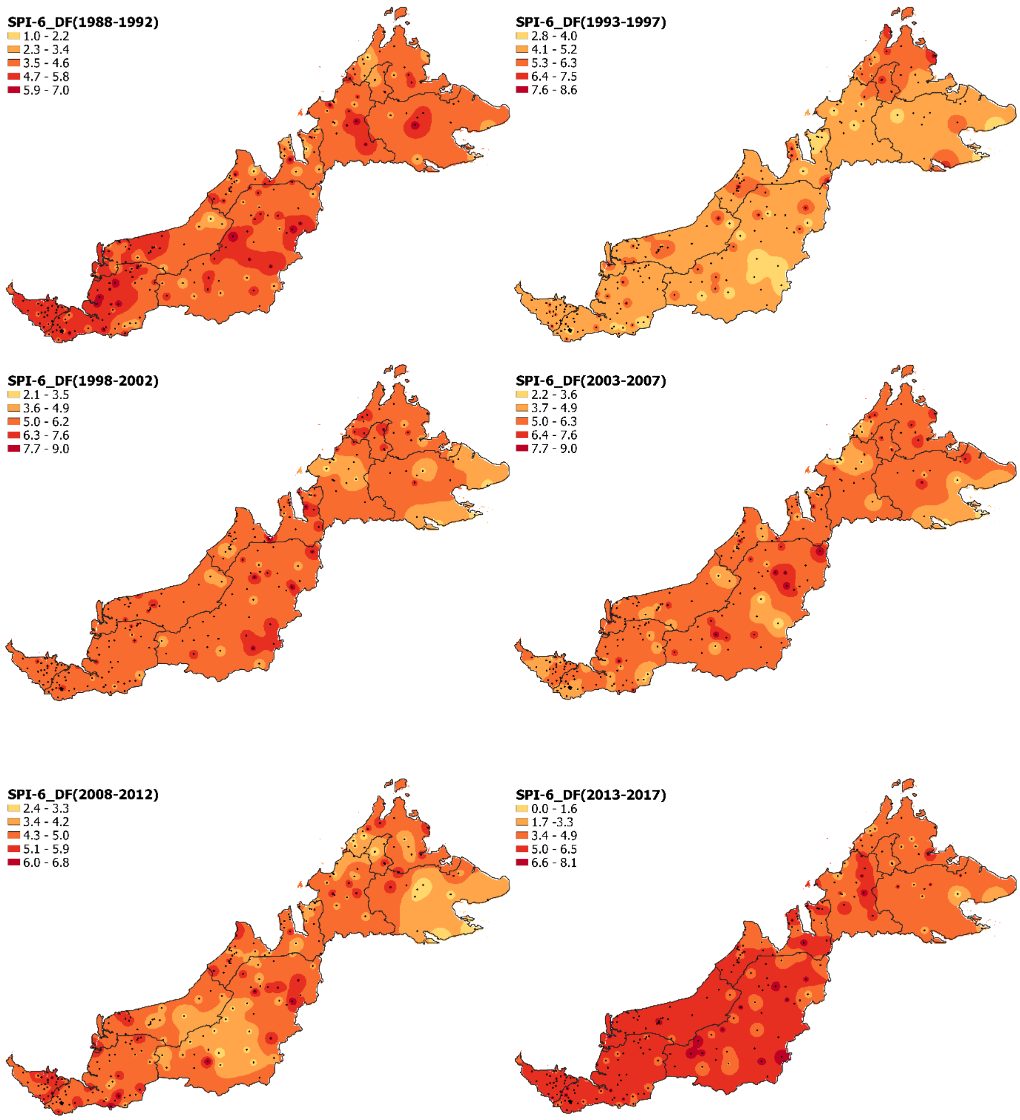

Figure 4.3: Drought Frequency maps of SPI-6 for each 5-years sub-period along 1988-2017.

In **Region 1**, DF between 2.3-7.0 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 3.5-5.8, whereby the Central part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 2.8-7.5 were observed. Majority of the areas had shown DF between 4.1-6.3, whereby the Southern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 2.1-6.2 were observed. Majority of the areas had shown DF between 3.6-6.2, whereby the Western and Central part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 2.2-7.6 were observed. Majority of the areas had shown DF between 3.7-6.3, whereby the Northern and Western part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 2.4-5.9 were observed. Majority of the areas had shown DF between 3.4-5.0, whereby the Western part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 0.0-4.9 were observed. Majority of the areas had shown DF between 3.4-4.9, whereby the whole region had shown higher values of DF, except for the Eastern part.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased since sub-period 1988-1992, and peak was observed in 1993-1997. DF then decreased and remained since 1998-1992 as lowest DF was observed in 2008-2012. Besides, the Western part had relatively shown high DF over the sub-periods, except 1988-1992, 1993-1997 that relatively showed high DF at station 5074001 and 4278004. Given that the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, DF between 3.5-5.8 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 4.7-5.8, whereby the whole region had shown higher values of DF. In sub-period 1993-1997, DF between 4.1-5.2 were observed. Majority of the areas had shown DF between 4.1-5.2, whereby the whole region had shown higher values of DF. In sub-period 1998-2002, DF between 5.0-7.6 were observed. Majority of the areas had shown DF between 5.0-6.2, whereby the whole region had shown higher values of DF. In sub-period 2003-2007, DF between 3.7-6.3 were observed. Majority of the areas had shown DF between 3.7-6.3, whereby the North-West and Eastern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 4.3-5.9 were observed. Majority of the areas had shown DF between 4.3-5.9, whereby the Northern and Southern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 3.4-6.5 were observed. Majority of the areas had shown DF between 5.0-6.5, whereby the whole region had shown higher values of DF, except for the North-West part.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually decreased since sub-period 1988-1992, and lowest DF was observed in 2003-2007. DF then increased and remained since 2008-2012, and highest DF was observed in 2013-2017. Besides, most part of the region had relatively shown high DF over the sub-periods, except 2003-2007, 2008-2012 that relatively showed high DF at station 1506034, 1405001, 1102019, 1201076 and other stations near to it. Given the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 2002-2003, 2004-2005, 2006-2007 and 2009-2010 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, DF between 2.3-7.0 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 3.5-5.8, whereby the Eastern and Western part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 2.8-6.3 were observed. Majority of the areas had shown DF between 4.1-5.2, whereby the Western and Northern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 3.6-7.6 were observed. Majority of the areas had shown DF between 5.0-7.6, whereby the Eastern part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 2.2-9.0 were observed. Majority of the areas had shown DF between 3.7-7.6, whereby the Northern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 2.4-6.8 were observed. Majority of the areas had shown DF between 3.4-5.9, whereby the Eastern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 1.7-8.1 were observed. Majority of the areas had shown DF between 3.4-6.5, whereby the Eastern and Western part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased since sub-period 1988-1992, and peak DF was observed in 1998-2002. DF then decreased and remained since 2003-2007, and lowest DF was observed in 2008-2012. Besides, the Eastern part of the region had relatively shown high DF over the sub-periods, except 1993-1997, 2003-2007 that relatively showed high DF at station 3754007, 3048026 and 3347003. Given the location of these stations located in inland area, the high DF could be affected by Banjaran Tama Abu range which is located near to the stations. The Banjaran Tama Abu could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 4**, DF between 2.3-4.6 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 3.5-4.6, whereby the Eastern and Southern part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 5.3-7.5 were observed. Majority of the areas had shown DF between 5.3-6.3, whereby the Western part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 5.0-7.6 were observed. Majority of the areas had shown DF between 5.0-6.2, whereby the Northern and South-East part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 5.0-7.6 were observed. Majority of the areas had shown DF between 5.0-6.3, whereby the whole region had shown higher values of DF. In sub-period 2008-2012, DF between 2.4-5.9 were observed. Majority of the areas had shown DF between 3.4-5.0, whereby the South-East part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 3.4-4.9 were observed. Majority of the areas had shown DF between 3.4-4.9, whereby the whole region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased since sub-period 1988-1992, and peak DF was observed in 1993-1997. DF then decreased and remained since 1998-2002, and lowest DF was observed in 2013-2017. Besides, the Eastern part of the region had relatively shown high DF over the sub-periods, except 1993-1997 that relatively showed high DF at station 5966001 and 5966003. Given that the location of these stations located in inland area, the high DF could be affected by Banjaran Crocker range which is located near to the stations. The Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 5**, DF between 2.3-5.8 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 3.5-5.8, whereby the Eastern part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 2.8-5.2 were observed. Majority of the areas had shown DF between

4.1-5.2, whereby the whole region had shown higher values of DF, except for the Central part. In sub-period 1998-2002, DF between 2.1-6.2 were observed. Majority of the areas had shown DF between 3.6-6.2, whereby the North-East and Southern part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 2.2-6.3 were observed. Majority of the areas had shown DF between 3.7-6.3, whereby the Western, Southern and Central parts of the region had shown higher values of DF. In sub-period 2008-2012, DF between 3.4-5.9 were observed. Majority of the areas had shown DF between 3.4-5.0, whereby the Central part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 1.7-6.5 were observed. Majority of the areas had shown DF between 3.4-6.5, whereby the Eastern part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased and remained since sub-period 1988-1992, DF then decreased during 1998-2002, and lowest DF was observed in 2008-2012. DF then increased and peak was observed in 2013-2017. Besides, the Eastern part of the region had relatively shown high DF over the sub-periods, except 2003-2007, 2008-2012 that relatively showed high DF at station 5361003, 5163002 and 5061001. Given the location of these stations located in inland area, the high DF could be affected by the Banjaran Crocker range which is located near to the stations. The Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 6**, DF between 1.0-4.6 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 2.3-3.4, whereby the Western part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 2.8-6.3 were observed. Majority of the areas had shown DF between 4.1-5.2, whereby the Western part of the region had shown higher values of DF, except for the Central part. In sub-period 1998-2002, DF between 3.6-7.2 were observed. Majority of the areas had shown DF between 5.0-6.2, whereby the Eastern part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 3.7-6.3 were observed. Majority of the areas had shown DF between 5.0-6.3, whereby the whole part of the region had shown higher values of DF, except for the Central part. In sub-period 2008-2012, DF between 3.4-5.9 were observed. Majority of the areas had shown DF between 3.4-5.0, whereby the Western part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 3.4-8.1 were observed. Majority of the areas had shown DF between 3.4-6.5, whereby the Western and Eastern part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown lowest DF in sub-period 1988-1992, DF then increased and remained for the following periods until peak was observed in 2013-2017. Besides, the Western part of the region had relatively shown high DF over the sub-periods, except 1998-2002, 2003-2007 that relatively showed high DF at station 3946001, 3945017, 4653001. Given the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 1997-1998, 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, DF between 2.3-7.0 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 3.5-5.8, whereby the Western part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 2.8-6.3 were observed. Majority of the areas had shown DF between 4.1-5.2, whereby the Central and Northern part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 3.6-6.2 were observed. Majority of the areas had shown DF between 5.0-6.2, whereby the Western part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 3.7-6.3 were observed. Majority of the areas had shown DF between 5.0-6.3, whereby the Central part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 3.4-6.8 were observed. Majority of the areas had shown DF between 4.3-5.0, whereby the Southern part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 3.4-6.5 were observed. Majority of the areas had shown DF between 5.0-6.5, whereby the whole region had shown higher values of DF, except for the Eastern part.

Over the six sub-periods, it was observed that majority of the areas had shown lowest DF in sub-period 1988-1992, DF then increased and remained for the following periods until peak was observed in 2013-2017. Besides, the Western and Central parts of the region had relatively shown high DF over the sub-periods, except 2008-2012 that relatively showed high DF at station 1018002, 1118002. Given the location of these stations located in inland area, the high DF could be affected by the Banjaran Kelinkang range which is located near to the stations. The Banjaran Kelinkang range could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high DF in a specific area.

In **Region 8**, DF between 2.3-5.8 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 3.5-4.6, whereby the Central part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 4.1-8.6 were observed. Majority of the areas had shown DF between 4.1-6.3, whereby the Eastern and Northern parts of the region had shown higher values of DF. In sub-period 1998-2002, DF between 3.6-7.6 were observed. Majority of the areas had shown DF between 5.0-6.2, whereby the Western part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 3.7-6.3 were observed. Majority of the areas had shown DF between 5.0-6.3, whereby the Eastern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 2.4-5.9 were observed. Majority of the areas had shown DF between 3.4-5.0, whereby the Eastern and Western part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 1.7-6.5 were observed. Majority of the areas had shown DF between 3.4-4.9, whereby the Eastern part of the region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased in sub-period 1988-1992 and peak was observed in 1993-1997, DF then decreased and remained for the following periods until lowest was observed in 2013-2017. Besides, the Eastern part of the region had relatively shown high DF over the sub-periods, except 1988-1992, 1998-2002 that relatively showed high DF at station 6062001, 6162003 and 5973001. Given the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1997-1998 and 2002-2003 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, DF between 1.0-5.8 were observed in sub-period 1988-1992. Majority of the areas had shown DF between 3.5-5.8, whereby the Western part of the region had shown higher values of DF. In sub-period 1993-1997, DF between 2.8-6.3 were observed. Majority of the areas had shown DF between 4.1-5.2, whereby the Western part of the region had shown higher values of DF. In sub-period 1998-2002, DF between 3.6-7.6 were observed. Majority of the areas had shown DF between 5.0-6.2, whereby the Western part of the region had shown higher values of DF. In sub-period 2003-2007, DF between 3.7-7.6 were observed. Majority of the areas had shown DF between 5.0-6.3, whereby the Western, Centre and Eastern part of the region had shown higher values of DF. In sub-period 2008-2012, DF between 3.4-5.9 were observed. Majority of the areas had shown DF between 3.4-5.0, whereby the Western part of the region had shown higher values of DF. In sub-period 2013-2017, DF between 5.0-8.1 were observed. Majority of the areas had shown DF between 5.0-6.5, whereby the whole region had shown higher values of DF.

Over the six sub-periods, it was observed that majority of the areas had shown DF gradually increased in sub-period 1988-1992 and peak was observed in 2003-2007, DF then decreased and lowest was observed in 2008-2012. Besides, the Western part of the region had relatively shown high DF over the sub-periods, especially station 2614004, 2712001, 2817001. Given the location of the stations being near to seashore, the high DF could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992 that inhibited rainfall occurrence due to the increase in sea surface temperature.

4.2.4 Summary

According to the study with the SPI-1, the occurrence of the DF was the least in the sub-period of 1988-1992 as compared to other sub-periods. The peak DF with the range of 16.3-18.9 had occurred in Region 3 of East Malaysia, and it was predicted that the high DF was caused by mountainous topography due to the location of drought events. As for sub-period 1993-1997, the occurrence of

DF was considered high among the sub-periods. The peak DF with the range of 15.6-17.6 also occurred in Region 3 of East Malaysia. By referring to the location of drought events, it was predicted that high DF was caused by mountainous topography as well. On average, the occurrence of DF was considered low in the sub-period 1998-2002. Peak DF with the range of 15.4-17.4 had occurred in Region 6 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, the occurrence of DF was the highest among sub-periods. Peak DF with the range of 15.5-17.6 was observed in Region 1 of East Malaysia, and it was predicted that the high DF was caused by El-Niño episodes that had happened in the past, due to its location being near to seashore. For sub-period, 2008-2012, peak DF with the range of 13.7-16.0 was observed in Region 1 of East Malaysia. However, it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak DF with the range of 15.1-17.7 was observed in Region 6 of East Malaysia, and it could be caused by past occurrence of El-Niño episodes due to its location being near to seashore. Overall, the SPI-1 had shown that the peak DF had occurred often in the Eastern and Central part of East Malaysia. Besides, Region 1 and Region 3 had both twice showed peak DF. Regarding the location of the DF, peak DF were mostly caused by mountainous topography rather than due to previous El-Niño episodes.

As for SPI-3, the occurrence of DF was considered high during the sub-period 1988-1992 as compared to other sub-periods. Peak DF with the range of 9.0-10.4 had occurred in Region 3 of East Malaysia, and it was predicted that the high DF was caused by mountainous topography due to the location of drought events. As for sub-period 1993-1997, the occurrence of DF was considered high as well. Peak DF with the range of 8.8-10.0 had occurred in Region 3 of East Malaysia. By referring to the location of drought events, it was predicted that high DF was caused by mountainous topography. Averagely speaking, the occurrence of DF was considered low in sub-period 1998-2002. Peak DF with the range of 9.7-11.0 had occurred in Region 5 of East Malaysia, and it was caused by El-Niño episodes due to its location being near to seashore. For sub-period 2003-2007, peak DF with the range of 9.4-10.6 was observed in Region 3 of East Malaysia, and it was predicted that the high DF was caused by mountainous topography. For sub-period, 2008-2012, peak DF with the range of 8.0-9.0 was observed in Region 3 of East Malaysia. However, it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak DF with the range of 8.3-10.0 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. In overall, SPI-3 had shown that peak DF had occurred often in Central part of East Malaysia. Besides, Region 3 had shown most occurrence peak DF. Regarding the location of DF, peak DF were mostly caused by mountainous topography rather than El-Niño episodes.

For SPI-6, the occurrence of DF was high in sub-period 1988-1992 as compared to other sub-periods. Peak DF with the range of 5.9-7.0 had occurred in Region 7 of East Malaysia, and it was predicted that the high DF was caused by mountainous topography due to the location of drought events. As for sub-period 1993-1997, the occurrence of DF was the lowest among the sub-periods. Peak DF with the range of 7.6-8.6 had occurred in Region 8 of East Malaysia. By referring to the location of drought events, it was predicted that high DF was caused by El-Niño episodes due to its location being near to seashore. Averagely, the occurrence of DF was considered high in sub-period 1998-2002. Peak DF with the range of 7.7-9.6 had occurred in Region 3 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, peak DF with the range of 7.7-9.0 was observed in Region 3 of East Malaysia, and it was predicted that the high DF was caused by mountainous topography. For sub-period, 2008-2012, peak DF with the range of 6.0-6.8 was observed in Region 3 of East Malaysia, and it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, the occurrence of DF is the highest among the sub-periods. Peak DF with the range of 6.6-8.1 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography due to its location. In overall, SPI-6 had shown that peak DF had occurred often in Central part of East Malaysia. Besides, Region 3 had shown most occurrence of peak DF. Regarding the location of DF, peak DF were mostly caused by mountainous topography rather than the El-Niño episodes.

4.3 Mean Drought Duration

4.3.1 SPI-1

The Mean Drought Duration, MDD is determined by averaging the total of drought duration of all drought events in the study period. The SPI at 1-month timescale was utilised in order to study the spatial variations of MDD as shown in Figure 4.4. The colour depth from yellow to red indicates the level of MDD from lowest to highest category.

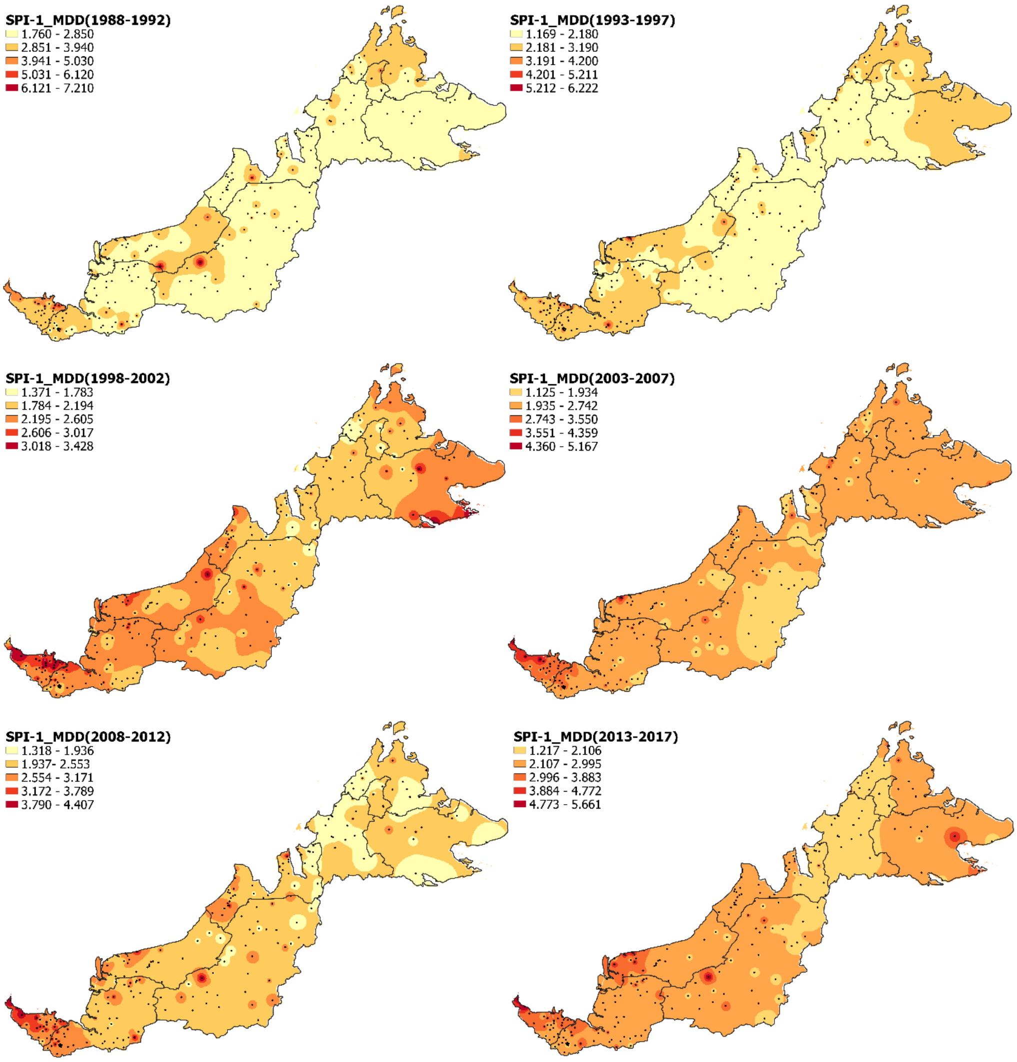

Figure 4.4: Mean Drought Duration maps of SPI-1 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDD between 1.760-3.940 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 1.760-2.850, whereby the South-East of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 1.169-3.190 were observed. Majority of the areas had shown MDD between 1.169-2.180, whereby the Eastern and Central part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 1.371-3.428 were observed, majority of the areas showed MDD between1.784-2.605, whereby the South-East of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.125-3.550 were observed. Majority of areas had shown MDD between 1.935-2.742, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 1.318-3.171 were observed. Majority of the areas had shown MDD between 1.318-2.553, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 1.217-4.772 were observed. Majority of the areas showed MDD between 1.217-2.995, whereby the Central part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown MDD gradually decreased in sub-period 1988-1992 and lowest was observed in 1993-1997, MDD then increased and remained for the following periods, with a slight decreased in 2008-2012. Peak MDD was observed in 2013-2017. Besides, the Eastern part consistently showed relatively higher MDD over the sub-periods, except for sub-period 2008-2012 that relatively showed high MDD at station 5269001. Given the location of these stations located in inland area, the high MDD could be affected by Banjaran Trusmadi which is located near to the stations. Banjaran Trusmadi could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

In **Region 2**, MDD between 2.851-6.120 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 2.851-5.030, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 1.169-4.200 were observed. Majority of the areas had shown MDD between 20181-3.190, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.195-3.428 were observed, majority of the areas showed MDD between 2.195-3.017, whereby the Eastern and Western parts of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.935-5.167 were observed. Majority of areas had shown MDD between 2.743-4.359, whereby the Western part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 1.937-4.407 were observed. Majority of the areas had shown MDD between 2.554-3.789, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 2.107-4.772 were observed. Majority of the areas showed MDD between 2.107-4.772, whereby the Western part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992 and gradually decreased in 1993-1997, MDD then increased and remained for the following periods, with a slight decreased in 2008-2012. MDD then decreased in 2008-2012 and lowest was observed in 2013-2017. Besides, the Western part consistently showed relatively higher MDD over the sub-periods, except for sub-period 1988-1992 and sub-period 1993-1997 that relatively showed high MDD at station 1506034, 1506001 and 1505081. Given that the location of these stations located in inland area, the high MDD could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

In **Region 3**, MDD between 1.760-7.210 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 1.760-3.940, whereby the Western part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 1.371-3.017 were observed. Majority of the areas had shown MDD between 1.169-2.180, whereby the Western part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 1.371-3.017 were observed, majority of the areas showed MDD between 1.784-2.605, whereby the Western of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.935-4.359 were observed. Majority of areas had shown MDD between 1.935-3.550, whereby the Western part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 1.318-4.407 were observed. Majority of the areas had shown MDD between 1.937-2.553, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 2.107-5.661 were observed. Majority of the areas showed MDD between 2.107-3.883, whereby the Western part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992 and decreased to lowest in 1993-1997, MDD then increased and remained for the following periods. MDD then decreased and maintained in the following periods. Besides, the Western part consistently showed relatively higher MDD over the sub-periods especially at station 2333001. Given that the location of these stations located in inland area, the high MDD could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDD between 1.760-5.030 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 1.760-3.940, whereby the North-East part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 1.169-3.190 were observed. Majority of the areas had shown MDD between 1.169-2.180, whereby the North-West part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 1.371-2.605 were observed, majority of the areas showed MDD between 1.784-2.605, whereby the Central, Northern and Western parts of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 2.743-3.550 were observed in whole region. In sub-period 2008-2012, MDD between 1.318-2.553 were observed. Majority of the areas had shown MDD between 1.937-2.553, whereby most parts of the region had shown higher values of MDD, except for the Northern part. In sub-period 2013-2017, MDD between 2.107-3.883 were observed. Majority of the areas showed MDD between 2.107-2.995, whereby the most of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992 and decreased to lowest in 1993-1997, MDD then increased and remained for the following periods, with a slight decreased in 2008-2012. Besides, the Northern part had shown relatively higher MDD, especially at station 5966001 and 5966003. Given the location of these stations located in inland area, the high MDD could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

In **Region 5**, MDD between 1.760-3.940 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 1.760-2.850, whereby the North-West part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 1.169-3.190 were observed. Majority of the areas had shown MDD between 1.169-2.180, whereby the South-East part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 1.371-2.605 were observed, majority of the areas showed MDD between 1.784-2.194, whereby the North-East part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.125-3.550 were observed, majority of the areas showed MDD between 1.935-2.742, whereby the North-West part of the region had shown higher value of MDD. In sub-period 2008-2012, MDD between 1.318-2.553 were observed in the whole region. In sub-period 2013-2017, MDD between 2.107-3.883 were observed. Majority of the areas showed MDD between 2.107-2.995, whereby most of the region had shown higher values of MDD, except for the South-East part.

Over the six sub-periods, it was observed that majority of the areas had shown MDD gradually decreased in sub-period 1988-1992 and lowest was observed in 1993-1997. MDD then increased and remained for the following periods, and peak MDD was observed in 2013-2017. Besides, the Northern part had shown relatively higher MDD except for sub-period 1993-1997 and sub-period 2013-2017 that relatively showed high MDD at station 4764002. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 1994-1995, 1997-1998, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 6**, MDD between 1.760-5.030 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 1.760-2.850, whereby the Central of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 1.169-3.190 were observed. Majority of the areas had shown MDD between 1.169-2.180, whereby the South-East part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 1.371-3.017 were observed, majority of the areas showed MDD between 1.784-2.605, whereby the Northern part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.935-4.359 were observed, majority of the areas showed MDD between 1.935-3.550, whereby the North-East of the region had shown higher value of MDD. In sub-period 2008-2012, MDD between 1.318-3.789 were observed. Majority of the areas showed that MDD occurred between 1.318-2.553, whereby the Northern part had shown higher value of MDD. In sub-period 2013-2017, MDD between 2.107-3.883 were observed in whole region, whereby the Western and Central parts had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown MDD gradually decreased in sub-period 1988-1992 and lowest was observed in 1993-1997. MDD then increased and remained for the following periods, and peak MDD was observed in 2013-2017. Besides, the Northern part had shown relatively higher MDD except for sub-period 1988-1992, 1993-1997 and sub-period 2013-2017 that relatively showed high MDD at station 3946001, 4955002 and other stations near to it. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had happened in 1987-1988, 1991-1992, 1994-1995, 1997-1998, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDD between 1.760-5.030 were observed in sub-period 1. Majority of the areas had shown MDD between 1.760-3.940, whereby the South-East of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 1.169-4.200 were observed. Majority of the areas had shown MDD between 1.169-3.190, whereby the South-East part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between

1.748-3.017 were observed, majority of the areas showed MDD between 1.784-2.605, whereby the Western part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.935-4.359 were observed, majority of the areas showed MDD between 1.935-3.550, whereby the Western of the region had shown higher value of MDD. In sub-period 2008-2012, MDD between 1.318-3.789 were observed. Majority of the areas showed MDD occurred between 1.937-3.171, whereby the Western part had shown higher value of MDD. In sub-period 2013-2017, MDD between 2.107-4.772 were observed. Majority areas had shown MDD between 2.107-2.995, whereby the Western part had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown MDD gradually decreased in sub-period 1988-1992 and lowest was observed in 1993-1997. MDD then increased and remained, peak MDD was observed in 2003-2007. MDD then decreased and remained in the following periods. Besides, the Western part had shown relatively higher MDD except for sub-period 1988-1992, 1993-1997 that relatively showed high MDD at station 1220025, 1018002. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1994-1995, 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 8**, MDD between 1.760-3.940 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 1.760-3.940, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 1.169-4.200 were observed. Majority of the areas had shown MDD between 2.181-3.190, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 1.371-3.017 were observed, majority of the areas showed MDD between 1.784-2.605, whereby the Northern part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.935-4.359 were observed, majority of the areas showed MDD between 2.743-3.550, whereby the Northern part of the region had shown higher value of MDD. In sub-period 2008-2012, MDD between 1.318-3.171 were observed. Majority of the areas showed that MDD occurred between 1.318-3.2.553, whereby the Northern part had shown higher values of MDD. In sub-period 2013-2017, MDD between 2.107-4.772 were observed. Majority areas had shown MDD between 2.107-3.883, whereby the Northern part had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD was observed in sub-period 1988-1992. MDD then decreased and remained, lowest MDD was observed in 2008-2012. MDD then increased in the following periods. Besides, the Northern part had relatively shown relatively higher MDD, especially at station 6670001, 6868001, 6868002. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1994-1995, 1997-1998, 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDD between 1.169-4.200 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 1.169-3.190, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 1.784-4.428 were observed. Majority of the areas had shown MDD between 1.784-2.605, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 1.784-4.428 were observed, majority of the areas showed MDD between 1.784-2.605, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.935-4.359 were observed, majority of the areas showed MDD between 2.743-3.550, whereby the Western part of the region had shown higher value of MDD. In sub-period 2008-2012, MDD between 1.318-3.789 were observed. Majority of the areas showed that MDD occurred between 1.937-2.553, whereby the Western part had shown higher MDD value. In sub-period 2013-2017, MDD between 1.217-4.772 were observed. Majority areas had shown MDD between 2.107-3.883, whereby the Western part had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD was observed in sub-period 1988-1992. MDD then decreased and remained, lowest MDD was observed in 1993-1997. MDD then increased and remained in the following periods. Besides, the Western part had shown relatively higher MDD, except for sub-period 1993-1997 and 1998-2002 that relatively showed high MDD at station 3234022 and 2920005. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 1994-1995, 1997-1998, 2002-2003 that inhibited rainfall occurrence due to the increase in sea surface temperature.

4.3.2 SPI-3

Mean drought duration is determined by averaging the total of drought duration of all drought events in the study period. SPI at 3-month timescale was utilised in order to study the spatial variations of MDD as shown in Figure 4.5. The colour depth from yellow to red indicates the level of MDD from lowest to highest category.

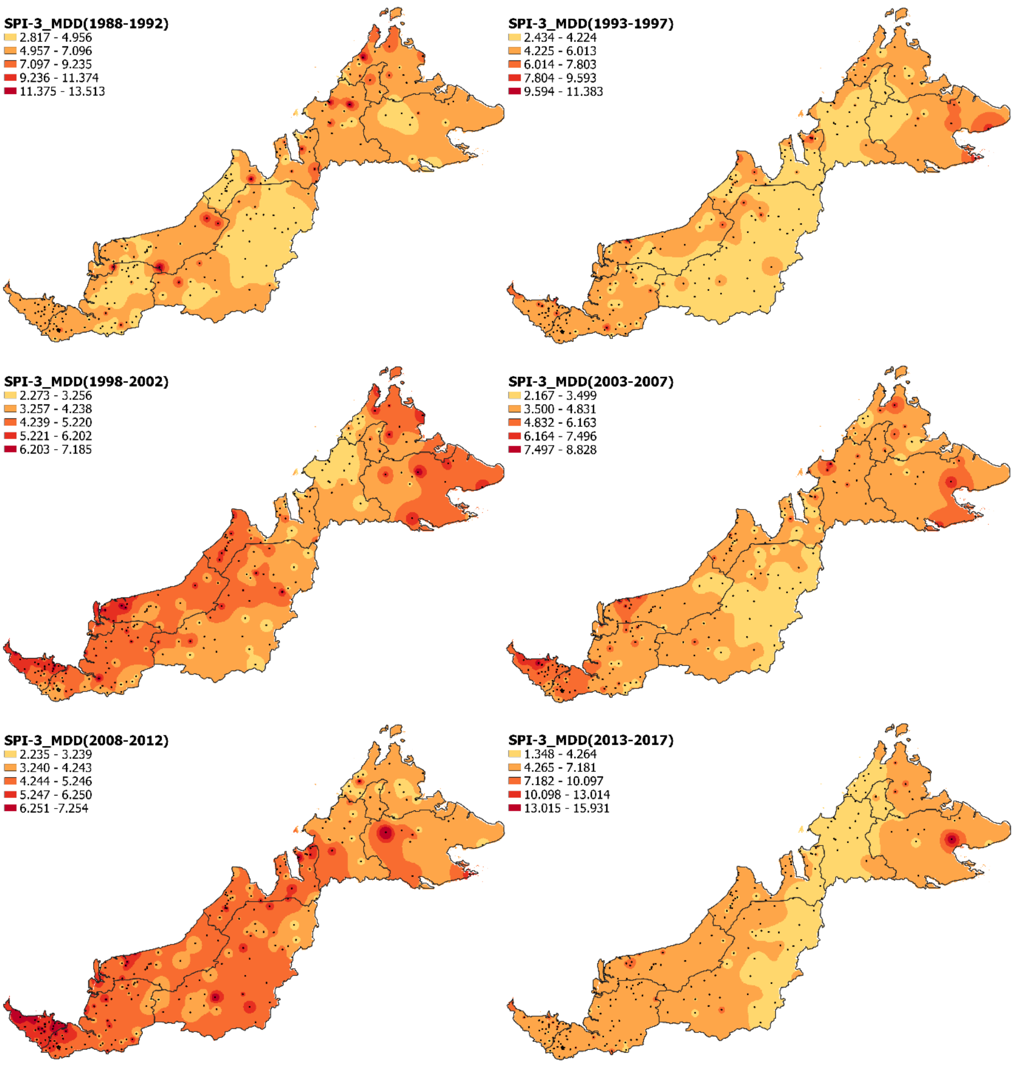

Figure 4.5: Mean Drought Duration maps of SPI-3 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDD between 2.817-7.096 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 2.817-7.096, whereby the Eastern, Western and Southern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.434-9.593 were observed. Majority of the areas had shown MDD between 2.434-6.013, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.273-7.185 were observed. Majority of the areas had shown MDD between 3.257-5.220, whereby the Central part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 2.167-7.496 were observed. Majority of the areas had shown MDD between 3.500-6.163, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.235-7.254 were observed. Majority of the areas had shown MDD between 3.240-5.246, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 1.348-15.931 were observed. Majority of the areas had shown MDD between1.348-7.181, whereby the Eastern part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown MDD decreased in sub-period 1988-1992. MDD then decreased and remained since sub-period 1998-2002, peak and lowest MDD was observed in 2013-2017. Besides, the Eastern part had relatively shown higher MDD over the sub-periods, except for 2003-2007 and 2008-2012 that relatively showed high MDD at station 5181001 and 5269001. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 2002-2003, 2004-2005, 2006-2007 and 2009-2010 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, MDD between 4.597-7.096 were observed in sub-period 1988-1992. The whole region had shown MDD between 2.817-7.096. In sub-period 1993-1997, MDD between 4.225-7.803 were observed. Majority of the areas had shown MDD between 4.225-6.013, whereby the North-West part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 4.239-6.202 were observed. Majority of the areas had shown MDD between 4.239-6.202, whereby the Northern part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 3.500-7.496 were observed. Majority of the areas had shown MDD between 4.832-7.496, whereby the Northern part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 4.244-7.254 were observed. Majority of the areas had shown MDD between 5.247-7.254, whereby the Northern part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 4.265-10.097 were observed. Majority of the areas had shown MDD between 4.265-7.181, whereby the Northern part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown MDD decreased in sub-period 1988-1992. Lowest MDD was observed in 1993-1997, MDD then increased as Peak MDD was observed in 2003-2007. MDD then decreased and remained in the following periods. Besides, the Eastern part had relatively shown higher MDD over the sub-periods, especially at station 1996090 and 1897016. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1994-1995, 1997-1998, 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDD between 2.817-9.235 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 2.187-7.096, whereby the Southern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.434-4.224 were observed. Majority of the areas had shown MDD between 2.434-4.224, whereby the Eastern and Western parts of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.273-6.202 were observed. Majority of the areas had shown MDD between 3.257-5.220, whereby the Western part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 2.167-6.163 were observed. Majority of the areas had shown MDD between 2.167-4.831, whereby the Southern and Northern parts of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.235-7.254 were observed. Majority of the areas had shown MDD between 4.244-6.250, whereby the Southern part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 1.348-10.097 were observed. Majority of the areas had shown MDD between 4.265-7.181, whereby the Southern and Western parts of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown MDD decreased and remained since sub-period 1988-1992. Lowest MDD was observed in 2003-2007. MDD then increased and remained in the following periods. Besides, the Western and Southern parts had relatively shown higher MDD over the sub-periods. Given that the location of these stations located in inland area, the high MDD could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDD between 2.817-9.235 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 4.957-7.096, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.434-6.013 were observed. Majority of the areas had shown MDD between 2.434-4.224, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.273-5.220 were observed. Majority of the areas had shown MDD between 3.257-4.238, whereby the Centre part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 3.500-6.163 were observed. Majority of the areas had shown MDD between 3.500-4.831, whereby the whole region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.235-5.246 were observed. Majority of the areas had shown MDD between 4.244-5.246, whereby the whole region had shown higher values of MDD, except Northern part. In sub-period 2013-2017, MDD between 1.348-7.181 were observed. Majority of the areas had shown MDD between 1.348-4.264, whereby the Western part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD was observed in sub-period 1988-1992. MDD then decreased and maintained in 1993-1997. Lowest MDD was observed in 2013-2017. Besides, the Northern part had relatively shown higher MDD over the sub-periods, except for 1998-2002, 2008-2012 and 2013-2017 that had relatively shown higher MDD at station 5966001 and 5966003. Given the location of these stations located in inland area, the high MDD could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

In **Region 5**, MDD between 2.817-11.374 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 4.957-7.096, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.434-6.013 were observed. Majority of the areas had shown MDD between 2.434-4.224, whereby the Northern and South-East part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.273-4.238 were observed. Majority of the areas had shown MDD between 3.257-4.238, whereby the Centre and Southern part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 3.500-6.163 were observed. Majority of the areas had shown MDD between 3.500-4.831, whereby the North-West part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.235-5.246 were observed. Majority of the areas had shown MDD between 4.244-5.246, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 1.348-7.181 were observed. Majority of the areas had shown MDD between 1.348-4.264, whereby the South-East part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD was observed in sub-period 1988-1992. MDD then decreased and maintained in 1993-1997. Lowest MDD was observed in 2013-2017. Besides, the Southern and Northern parts had relatively shown higher MDD over the sub-periods, except for 2008-2012 that had relatively shown higher MDD at station 4959001. Given the location of these stations located in inland area, the high MDD could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

In **Region 6**, MDD between 2.817-11.374 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 2.817-7.096, whereby the Central part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.434-7.803 were observed. Majority of the areas had shown MDD between 2.434-6.013, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.273-6.202 were observed. Majority of the areas had shown MDD between 3.257-4.238, whereby the Western part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 2.167-6.163 were observed. Majority of the areas had shown MDD between 2.167-4.831, whereby the Northern part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 3.240-6.250 were observed. Majority of the areas had shown MDD between 4.244-5.246, whereby the Northern part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 1.348-7.181 were observed. Majority of the areas had shown MDD between 1.348-7.181, whereby the Western and Northern part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown MDD gradually decreased since sub-period 1988-1992. MDD then increased and maintained in 2008-2012. Peak and lowest MDD was observed in 2013-2017. Besides, the Northern part had relatively shown higher MDD over the sub-periods, except for 1988-1992, 1998-2002 that had relatively shown higher MDD at station 3945017 and 3637001. Given that the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1997-1998, 2002-2003 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDD between 2.817-7.096 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 2.817-7.096, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.434-7.803 were observed. Majority of the areas had shown MDD between 2.434-6.013, whereby the Southern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.273-6.202 were observed. Majority of the areas had shown MDD between 3.257-5.220, whereby the Central part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 2.167-6.163 were observed. Majority of the areas had shown MDD between 2.167-4.831, whereby the Western part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 3.240-6.250 were observed. Majority of the areas had shown MDD between 4.244-5.246, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 1.348-7.181 were observed. Majority of the areas had shown MDD between 4.265-7.181, whereby the whole region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown MDD gradually decreased since sub-period 1988-1992, and lowest was observed in 2003-2007. MDD then increased and maintained in 2008-2012. Peak MDD was observed in 2013-2017. Besides, the Western part had relatively shown higher MDD over the sub-periods, except for 1988-1992, 1993-1997, 1998-2002 that had relatively shown higher MDD at station 1007040 and 1313006. Given that the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1997-1998, 2002-2003 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 8**, MDD between 2.817-11.374 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 4.957-9.235, whereby the Western part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.434-7.803 were observed. Majority of the areas had shown MDD between 2.434-6.013, whereby the Northern, Western and Eastern parts of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.273-6.202 were observed. Majority of the areas had shown MDD between 3.257-5.220, whereby the Central and Eastern parts of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 2.167-6.163 were observed. Majority of the areas had shown MDD between 2.167-4.831, whereby the Northern and Central parts of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.235-5.246 were observed. Majority of the areas had shown MDD between 2.235-4.243, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 1.348-10.097 were observed. Majority of the areas had shown MDD between 1.348-7.181, whereby the Central, Eastern and Northern parts of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 2013-2017. Besides, the Western and Eastern parts had relatively shown higher MDD over the sub-periods, except for 2003-2007 that had relatively shown higher MDD at station 6670001 and 6770001. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDD between 2.817-13.513 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 2.817-7.096, whereby the Southern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.434-7.803 were observed. Majority of the areas had shown MDD between 2.434-6.013, whereby the Northern, Western and Eastern parts of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 4.239-7.185 were observed. Majority of the areas had shown MDD between 4.239-6.202, whereby the Western part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 2.167-6.163 were observed. Majority of the areas had shown MDD between 2.167-4.831, whereby the Western part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 3.240-6.250 were observed. Majority of the areas had shown MDD between 3.240-5.246, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 4.265-10.097 were observed. Majority of the areas had shown MDD between 4.265-7.181, whereby the Western part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 1993-1997. MDD then increased and maintained in the following periods. Besides, the Western part had relatively shown higher MDD over the sub-periods, except for 1988-1992 that had relatively shown higher MDD at station 2325039. Given the location of these stations located in inland area, the high MDD could be affected by Banjaran Kapuas Hulu which is located near to the stations. Banjaran Kapuas Hulu could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

4.3.3 SPI-6

Mean drought duration is determined by averaging the total of drought duration of all drought events in the study period. SPI at 6-month timescale was utilised in order to study the spatial variations of MDD as shown in Figure 4.6. The colour depth from yellow to red indicates the level of MDD from lowest to highest category.

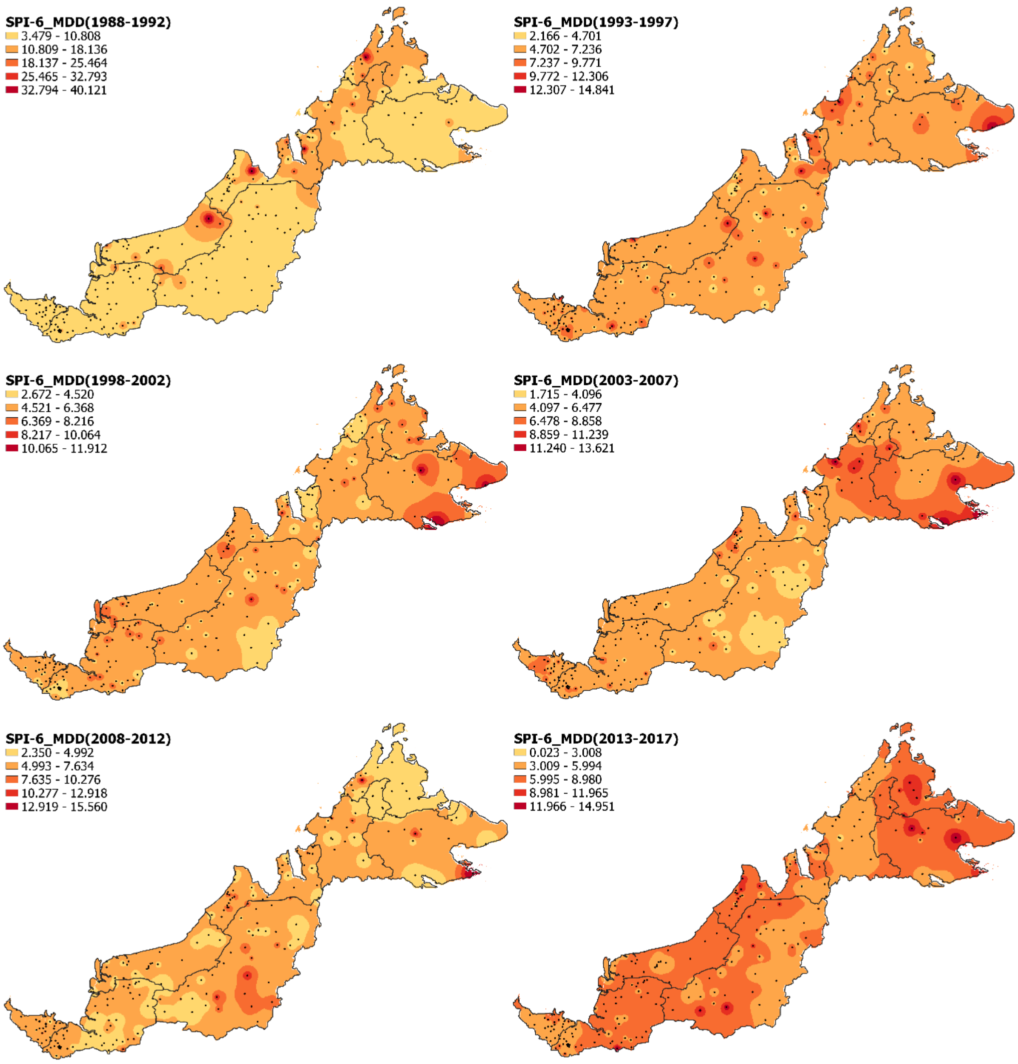

Figure 4.6: Mean Drought Duration maps of SPI-6 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDD between 3.479-18.136 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 3.479-10.808, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 4.702-14.841 were observed. Majority of the areas had shown MDD between 4.702-9.771, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 4.521-11.912 were observed. Majority of the areas had shown MDD between 4.521-8.216, whereby the Eastern and Southern parts of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 4.097-13.621 were observed. Majority of the areas had shown MDD between 4.097-8.858, whereby the Southern and Eastern parts of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.350-15.560 were observed. Majority of the areas had shown MDD between 2.350-7.634, whereby the South-East part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 3.009-14.951 were observed. Majority of the areas had shown MDD between 3.009-8.980, whereby the Eastern part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 2008-2012. MDD then increased in the following period. Besides, the Eastern part of the region had relatively shown high MDD over the sub-periods, especially at station 4486001 and 5181001. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 2009-2010 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, MDD between 3.479-10.808 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 3.479-10.808, whereby the whole region had shown higher values of MDD. In sub-period 1993-1997, MDD between 4.702-7.236 were observed. Majority of the areas had shown MDD between 4.702-7.236, whereby the whole region had shown higher values of MDD. In sub-period 1998-2002, MDD between 4.521-6.368 were observed. Majority of the areas had shown MDD between 4.521-6.368, whereby the whole region had shown higher values of MDD. In sub-period 2003-2007, MDD between 4.097-8.858 were observed. Majority of the areas had shown MDD between 4.097-8.858, whereby the Central part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 4.993-7.634 were observed. Majority of the areas had shown MDD between 4.993-7.634, whereby the whole region had shown higher values of MDD. In sub-period 2013-2017, MDD between 3.009-8.980 were observed. Majority of the areas had shown MDD between 3.009-5.994, whereby the Northern and North-West parts of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 2013-2017. Besides, whole part of the region had relatively shown high MDD over the sub-periods, except for 2003-2007, 2013-2017 that had relatively shown high MDD at station 1603058, 1704013 and 1201076. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 2002-2003, 2004-2005, 2006-2007, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDD between 3.479-18.136 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 3.479-10.808, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.166-9.771 were observed. Majority of the areas had shown MDD between 4.702-7.236, whereby the Central, Eastern and Western parts of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.672-8.216 were observed. Majority of the areas had shown MDD between 4.521-6.368, whereby the Central part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.715-8.858 were observed. Majority of the areas had shown MDD between 4.097-6.477, whereby the Southern part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.350-12.918 were observed. Majority of the areas had shown MDD between 2.350-10.276, whereby the Central part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 3.009-11.965 were observed. Majority of the areas had shown MDD between 3.009-8.980, whereby the Southern part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 2008-2012. MDD then increased in the following period. Besides, the Central and Southern parts of the region had relatively shown high MDD over the sub-periods, except for 1988-1992 that had relatively shown high MDD at station 3754007. Given the location of these stations located in inland area, the high MDD could be affected by Banjaran Tama Abu which is located near to the stations. Banjaran Tama Abu could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

In **Region 4**, MDD between 3.479-18.136 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 3.479-10.808, whereby the whole region had shown higher values of MDD, except for the Southern part. In sub-period 1993-1997, MDD between 2.166-7.236 were observed. Majority of the areas had shown MDD between 4.702-7.236, whereby the whole region had shown higher values of MDD, except for the Eastern part. In sub-period 1998-2002, MDD between 2.672-6.368 were observed. Majority of the areas had shown MDD between 4.521-6.368, whereby the whole region had shown higher values of MDD, except for the Northern part. In sub-period 2003-2007, MDD between 4.097-8.858 were observed. Majority of the areas had shown MDD between 4.097-8.858, whereby the Southern part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.350-4.992 were observed. Majority of the areas had shown MDD between 2.350-4.992, whereby the whole region had shown higher values of MDD. In sub-period 2013-2017, MDD between 5.995-8.980 were observed. Majority of the areas had shown MDD between 5.995-8.980, whereby the whole region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 2008-2012. MDD then increased in the following period. Besides, the Southern part of the region had relatively shown high MDD over the sub-periods, except for 1988-1992 that had relatively shown high MDD at station 6168001, 5966001 and 5966003. Given the location of these stations located in inland area, the high MDD could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

In **Region 5**, MDD between 3.479-18.136 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 3.479-18.136, whereby the Northern and Western parts of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 4.702-9.771 were observed. Majority of the areas had shown MDD between 4.702-7.236, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.672-8.216 were observed. Majority of the areas had shown MDD between 4.521-6.368, whereby the Central part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 4.097-11.239 were observed. Majority of the areas had shown MDD between 4.097-8.858, whereby the Northern part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.350-10.276 were observed. Majority of the areas had shown MDD between 2.350-7.634, whereby the Northern and Southern parts of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 0.023-8.980 were observed. Majority of the areas had shown MDD between 3.009-8.980, whereby the South-East part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 2008-2012. MDD then increased in the following period. Besides, the Northern part of the region had relatively shown high MDD over the sub-periods, except for 1998-2002, 2013-2017 that had relatively shown high MDD at station 5061001, 5163002 and 4764002. Given the location of these stations located in inland area, the high MDD could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

In **Region 6**, MDD between 3.479-40.121 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 3.479-25.464, whereby the Central part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.166-9.771 were observed. Majority of the areas had shown MDD between 4.702-9.771, whereby the Eastern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.672-8.216 were observed. Majority of the areas had shown MDD between 2.672-6.368, whereby the Western part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.715-8.858 were observed. Majority of the areas had shown MDD between 4.097-6.477, whereby the Western part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.350-10.276 were observed. Majority of the areas had shown MDD between 4.993-7.634, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 3.009-8.980 were observed. Majority of the areas had shown MDD between 3.009-8.980, whereby the Western part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 1998-2002. MDD then increased and maintained in the following periods. Besides, the Western part of the region had relatively shown high MDD over the sub-periods, except for 1988-1992, 1993-1997 that had relatively shown high MDD at station 4143004, 4151017 and 4255006. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDD between 3.479-18.136 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 3.479-10.808, whereby the whole region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.166-9.771 were observed. Majority of the areas had shown MDD between 4.702-7.236, whereby the Southern part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 2.672-8.216 were observed. Majority of the areas had shown MDD between 4.521-6.368, whereby the Southern part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 4.097-8.858 were observed. Majority of the areas had shown MDD between 4.097-6.477, whereby the Southern part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.350-7.634 were observed. Majority of the areas had shown MDD between 4.993-7.634, whereby the Western and Northern parts of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 3.009-8.980 were observed. Majority of the areas had shown MDD between 5.995-8.980, whereby the whole region had shown higher values of MDD, except for the Western part.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 2003-2007. MDD then increased and maintained in the following periods. Besides, the Southern part of the region had relatively shown high MDD over the sub-periods, except for 2008-2012, 2013-2017 that had relatively shown high MDD at Western and Southern part of the region. Given the location of these stations located in inland area, the high MDD could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDD in a specific area.

In **Region 8**, MDD between 3.479-32.793 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 3.479-18.136, whereby the Western part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 2.166-9.771 were observed. Majority of the areas had shown MDD between 4.702-7.236, whereby the whole region had shown higher values of MDD, except for the Eastern part. In sub-period 1998-2002, MDD between 2.672-8.216 were observed. Majority of the areas had shown MDD between 4.521-6.368, whereby the whole part of the region had shown higher values of MDD, except Eastern. In sub-period 2003-2007, MDD between 4.097-8.858 were observed. Majority of the areas had shown MDD between 4.097-6.477, whereby the Western part of the region had shown higher values of MDD. In sub-period 2008-2012, MDD between 2.350-10.276 were observed. Majority of the areas had shown MDD between 2.350-7.634, whereby the Western part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 3.009-11.965 were observed. Majority of the areas had shown MDD between 3.009-8.980, whereby the Eastern part of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 2008-2012. MDD then increased in the following period. Besides, the Western part of the region had relatively shown high MDD over the sub-periods, except for 2013-2017 that had relatively shown high MDD at station 6172001 and 6073001. Given the location of the stations being near to seashore, the high MDD could be affected by the El-Niño episodes that had occurred in 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDD between 3.479-40.121 were observed in sub-period 1988-1992. Majority of the areas had shown MDD between 3.479-18.136, whereby the Northern part of the region had shown higher values of MDD. In sub-period 1993-1997, MDD between 7.237-12.306 were observed. Majority of the areas had shown MDD between 7.327-9.771, whereby the North-East part of the region had shown higher values of MDD. In sub-period 1998-2002, MDD between 4.521-8.216 were observed. Majority of the areas had shown MDD between 4.521-6.368, whereby the Western part of the region had shown higher values of MDD. In sub-period 2003-2007, MDD between 1.715-6.477 were observed. Majority of the areas had shown MDD between 4.097-6.477, whereby the whole region had shown higher values of MDD, except for the Eastern part. In sub-period 2008-2012, MDD between 2.350-10.276 were observed. Majority of the areas had shown MDD between 2.350-7.634, whereby the Western, Centre and Eastern part of the region had shown higher values of MDD. In sub-period 2013-2017, MDD between 3.009-8.980 were observed. Majority of the areas had shown MDD between 4.993-7.634, whereby the Eastern, Western and Central parts of the region had shown higher values of MDD.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDD in sub-period 1988-1992. MDD then decreased and maintained, as lowest MDD was observed in 2003-2007. MDD then increased and maintained in the following periods. Besides, the Western part of the region had relatively shown high MDD over the sub-periods, except for 1988-1992, 1993-1997 that had relatively shown high MDD at station 3234022 and 3137021. Given the location of the stations being near to seashore, the high

MDD could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

4.3.4 Summary

According to the study with SPI-1, the occurrence of MDD was the lowest in sub-period 1988-1992 as compared to other sub-periods. Peak MDD with the range of 6.121 – 7.210 had occurred in Region 3 of East Malaysia, and it was predicted that the high MDD was caused by mountainous topography due to the location of drought events. As for sub-period 1993-1997, the occurrence of MDD was considered low among the sub-periods. Peak MDD with the range of 5.212 – 6.222 had occurred in Region 7 of East Malaysia. By referring to the location of drought events, it was predicted that high MDD was caused by mountainous topography as well. Averagely, the occurrence of MDD was the highest in sub-period 1998-2002. Peak MDD with the range of 3.018 – 3.428 had occurred in Region 2 of East Malaysia, and it was caused by El-Niño episodes due to its location being near to seashore. For sub-period 2003-2007, the occurrence of MDD was high among the sub-periods. Peak MDD with the range of 4.360 – 5.167 was observed in Region 2 of East Malaysia, and it was predicted that the high MDD was caused by El-Niño episodes due to its location being near to seashore. For sub-period, 2008-2012, peak MDD with the range of 3.790 – 4.407 was observed in Region 2 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. For sub-period 2013-2017, peak MDD with the range of 4.773-5.661 was observed in Region 1 of East Malaysia, and it could be caused by both mountainous topography and El-Niño episodes due to its specific location. In overall, SPI-1 had shown that peak MDD had occurred often in South-West part of East Malaysia. Besides, Region 2 had shown the most occurrence of peak MDD. Regarding the location of MDD, peak MDD were mostly caused by El-Niño episodes rather than mountainous topography.

As for SPI-3, the occurrence of MDD was low in sub-period 1988-1992 as compared to other sub-periods. Peak MDD with the range of 11.375 – 13.513 had occurred in Region 9 of East Malaysia, and it was predicted that the high MDD was caused by mountainous topography due to the location of drought events. As for sub-period 1993-1997, the occurrence of MDD was considered low among the sub-periods. Peak MDD with the range of 9.594 – 11.383 had occurred in Region 1 of East Malaysia. By referring to the location of drought events, it was predicted that high MDD was caused by El-Niño episodes due to its location being near to seashore. Averagely, the occurrence of MDD was considered high in sub-period 1998-2002. Peak MDD with the range of 6.203 – 7.185 had occurred in Region 9 of East Malaysia, and it was El-Niño episodes due to its location being near to seashore. For sub-period 2003-2007, peak MDD with the range of 7.497 – 8.828 was observed in Region 2 of East Malaysia, and it was predicted that the high MDD was caused by El-Niño episodes due to its location being near to seashore. For sub-period, 2008-2012, peak MDD with the range of 6.251 – 7.254 was observed in Region 2 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. For sub-period 2013-2017, peak MDD with the range of 13.015 – 15.931 was observed in Region 1 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. Overall, the SPI-3 had shown that peak MDD had occurred often in South-West and North-East part of East Malaysia. Besides, Region 2 had shown most occurrence of peak MDD. Regarding the location of MDD, peak MDD were mostly caused by El-Niño episodes rather than mountainous topography.

For SPI-6, the occurrence of MDD was low in sub-period 1988-1992 as compared to other sub-periods. Peak MDD with the range of 32.794 – 45.121 had occurred in Region 9 of East Malaysia, and it was predicted that the high MDD was caused by El-Niño episodes due to its location being near to seashore. As for sub-period 1993-1997, the occurrence of MDD was considered high among the sub-periods. Peak MDD with the range of 12.307 – 14.841 had occurred in Region 1 of East Malaysia. By referring to the location of drought events, it was predicted that high MDD was caused by El-Niño episodes due to its location being near to seashore. Averagely, the occurrence of MDD was considered high in sub-period 1998-2002. Peak MDD with the range of 10.065 – 11.912 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, peak MDD with the range of 11.240 – 13.621 was observed in Region 1 of East Malaysia, and it was predicted that the high MDD was caused by mountainous topography. For sub-period, 2008-2012, peak MDD with the range of 12.919 – 15.560 was observed in Region 1 of East Malaysia. However, it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak MDD with the range of 11.966 – 14.951 was observed in Region 1 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. Overall, the SPI-6 had shown that peak MDD had occurred often in the Eastern part of East Malaysia. Besides, Region 1 had shown most occurrence of peak MDD. Regarding the location of MDD, peak MDD were mostly caused by mountainous topography rather than El-Niño episodes.

4.4 Mean Drought Severity

4.4.1 SPI-1

Mean drought severity is a measurement of the magnitude of drought events. SPI at 1-month timescale was utilised in order to study the spatial variations of MDS as shown in Figure 4.7. The colour depth from yellow to red indicates the level of MDS from lowest to highest category.

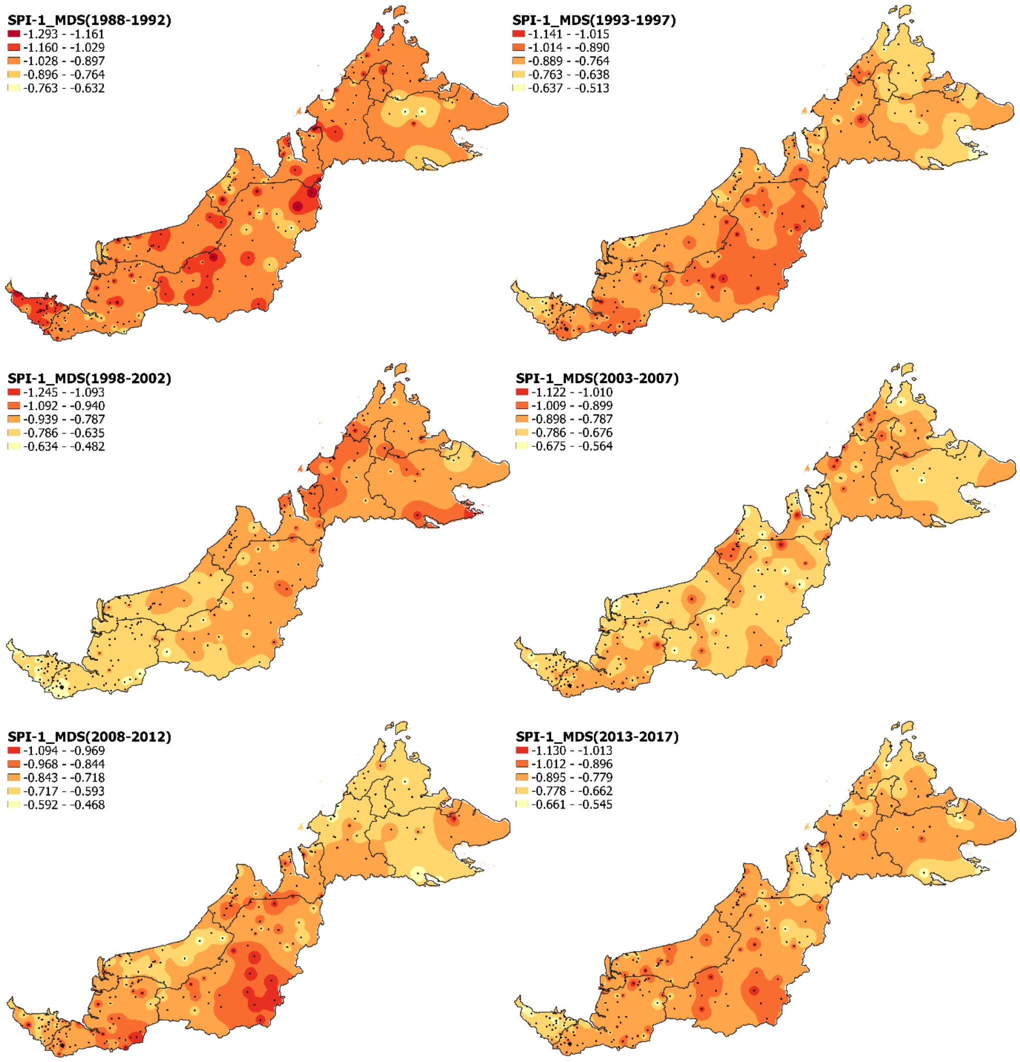

Figure 4.7: Mean Drought Severity maps of SPI-1 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDS between -1.160- -0.632 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.028- -0.764, whereby the Centre part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.889- - 0.513 were observed. Majority of the areas had shown MDS between -0.889 - -0.638, whereby the Eastern, Centre and Western parts of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.245 - -0.482 were observed, majority of the areas showed MDS between 0.939 - -0.635, whereby the South-East part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -0.898 - -0.564 were observed, majority of the areas showed MDS between -0.898 - -0.676, whereby the Eastern and Western parts of the region had shown higher value of MDS. In sub-period 2008-2012, MDS between -0.968 - -0.468 were observed. Majority of the areas showed that MDS occurred between -0.843 - -0.593, whereby the Western part had shown higher MDS value. In sub-period 2013-2017, MDS between -1.012 - -0.545 were observed. Majority areas had shown MDS between -0.895 - -0.662, whereby the Centre part had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDS in sub-period 1988-1992. MDS then decreased and maintained, as lowest MDS was observed in 2008-2012. MDS then increased in the following periods. Besides, the Eastern and centre part had shown relatively higher MDS, especially at station 5088002. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1994-1995, 1997-1998, 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015, 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, MDS between -1.293 - -0.764 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.160- -0.897, whereby the North-West of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.889- -0.513 were observed. Majority of the areas had shown MDS between -0.763 - -0.513, whereby the Centre part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -0.786 - -0.482 were observed, majority of the areas showed MDS between -0.786 - -0.635, whereby the Centre, Eastern and Western parts of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -0.898 - -0.564 were observed, majority of the areas showed MDS between -0.898 - -0.676, whereby the Southern part of the region had shown higher value of MDS. In sub-period 2008-2012, MDS between -1.904 - -0.593 were observed. Majority of the areas showed that MDS occurred between -0.968 - -0.718, whereby the Western part had shown higher MDS value. In sub-period 2013-2017, MDS between -0.895 - -0.545 were observed. Majority areas had shown MDS between -0.895 - -0.662, whereby the Southern part had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDS in sub-period 1988-1992. MDS then decreased and maintained, as lowest MDS was observed in 1993-1997. MDS then increased and maintained in the following periods. Besides, the Southern, Western and Central parts had relatively shown higher MDS, especially at station 1203002, 1102019 and 1204024. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes that had happened in 1987-1988, 1991-1992, 1994-1995, 1997-1998, 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015, 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDS between -1.293 - -0.632 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.160- -0.897, whereby the North-East of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.141- -0.638 were observed. Majority of the areas had shown MDS between -1.014 - -0.764, whereby the Eastern and Centre parts of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.092 - -0.482 were observed, majority of the areas showed MDS between –0.939 - -0.635, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.009 - -0.564 were observed, majority of the areas showed MDS between -0.898 - -0.676, whereby the Southern part of the region had shown higher value of MDS. In sub-period 2008-2012, MDS between -1.904 - -0.593 were observed. Majority of the areas showed that MDS occurred between -0.968 - -0.718, whereby the South-East part had shown higher MDS value. In sub-period 2013-2017, MDS between --1.012 - -0.545 were observed. Majority areas had shown MDS between -0.895 - -0.662, whereby the South-East part had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDS in sub-period 1988-1992. MDS then decreased and maintained, as lowest MDS was observed in 1998-2002. MDS then increased and maintained in the following periods. Besides, the Southern part had relatively shown higher MDS, except for sub-period 1988-1992, 1993-1997, 1998-2002 that relatively showed higher MDS at station 3754007, 3451028 and

3347003. Given the location of these stations located in inland area, the high MDS could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block the North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDS between -1.160 - -0.897 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.028- -0.897, whereby the North-East of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.889 - -0.638 were observed. Majority of the areas had shown MDS between -0.763 - -0.638, whereby the Northern part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.092 - -0.787 were observed, majority of the areas showed MDS between –0.939 - -0.787, whereby the Southern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.009 - -0.676 were observed, majority of the areas showed MDS between -0.898 – 0.787, whereby the Western part of the region had shown higher value of MDS. In sub-period 2008-2012, MDS between -0.717- -0.593 were observed in whole region. In sub-period 2013-2017, MDS between -0.895 - -0.662 were observed. Majority areas had shown MDS between -0.895 - -0.662, whereby the Centre and Southern parts had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDS in sub-period 1988-1992. MDS then decreased and maintained, as lowest MDS was observed in 2008-2012. MDS then increased and maintained in the following periods. Besides, the Northern, Southern and Western part of the region had relatively shown higher MDS, especially at station 6168002 and 5768001. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 5**, MDS between -1.160 - -0.764 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.028- -0.897, whereby the Western part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.141 - -0.638 were observed. Majority of the areas had shown MDS between -0.889 - -0.764, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.092 - -0.635 were observed, majority of the areas showed MDS between -1.092 - -0.787, whereby the Western part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.009 - -0.676 were observed, majority of the areas showed MDS between -0.898 – 0.676, whereby the Western part of the region had shown higher value of MDS. In sub-period 2008-2012, MDS between -0.843 - -0.468 were observed. Most of the areas showed MDS between -0.843 - -0.593, whereby the Southern and Centre parts had shown higher MDS. In sub-period 2013-2017, MDS between -0.895 - -0.662 were observed. Majority of the areas had shown MDS between -0.895 - -0.662, whereby the Eastern part had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDS in sub-period 1988-1992. MDS then decreased and maintained, as lowest MDS was observed in 2008-2012. MDS then increased and maintained in the following periods. Besides, the Western part had relatively shown higher MDS, except sub-period 2008-2012 and 2013-2017 that relatively showed high MDS at station 4764002, 5061001 and 5163002. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Crocker, which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 6**, MDS between -1.160 - -0.764 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.028- -0.897, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.014 - -0.638 were observed. Majority of the areas had shown MDS between -0.889 - -0.638, whereby the South-East part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.092 - -0.635 were observed, majority of the areas showed MDS between -1.092 - -0.787, whereby the Northern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.122 - -0.564 were observed, majority of the areas showed MDS between -0.898 – 0.676, whereby the Eastern part of the region had shown higher value of MDS. In sub-period 2008-2012, MDS between -0.968 - -0.593 were observed. Most of the areas showed MDS between -0.968 - -0.718, whereby the Southern part had shown higher MDS. In sub-period 2013-2017, MDS between -1.012 - -0.662 were observed. Majority areas had shown MDS between -0.895 - -0.662, whereby the Northern and Western parts had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown lowest MDS in sub-period 1988-1992. MDS then increased and maintained, as peak MDS was observed in 1993-1997. MDS then decreased and maintained in the following periods. Besides, the Western part had relatively shown higher MDS, except sub-period 2008-2012 and 2013-2017 that relatively showed high MDS at station 4650007, 4955002 and other stations near to it. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes that had occurred in 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDS between -1.160 - -0.764 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.028- -0.897, whereby the Centre part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.014 - -0.638 were observed. Majority of the areas had shown MDS between -1.014 - -0.764, whereby the Centre part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -0.939 - -0.482 were observed, majority of the areas showed MDS between -0.786 - -0.635, whereby the Centre part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.122 - -0.676 were observed, majority of the areas showed MDS between -0.898 – 0.676, whereby the Eastern part of the region had shown higher value of MDS. In sub-period 2008-2012, MDS between -1.094 - -0.593 were observed. Most of the areas showed MDS between -0.968 - -0.718, whereby the South-East part had shown higher MDS. In sub-period 2013-2017, MDS between -1.012 - -0.545 were observed. Majority areas had shown MDS between -0.895 - -0.662, whereby the Northern part had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually increased in sub-period 1988-1992, and peak MDS was observed in 1993-1997. MDS then decreased and maintained, as lowest MDS was observed in 1998-2002. MDS then increased and maintained in the following periods. Besides, the Central and Eastern parts had relatively shown higher MDS, except sub-period 2013-2017 that relatively showed high MDS at station 1015001, 1321001 and 2320026. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 8**, MDS between -1.014 - -0.638 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.014- -0.764, whereby the Western part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.092 - -0.635 were observed. Majority of the areas had shown MDS between -1.092 - -0.787, whereby the Western part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.092 - -0.635 were observed, majority of the areas showed MDS between -1.092 - -0.787, whereby the Western part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.009 - -0.564 were observed, majority of the areas showed MDS between -0.898 – 0.676, whereby the Western part of the region had shown higher value of MDS. In sub-period 2008-2012, MDS between -0.843 - -0.468 were observed. Most of the areas showed MDS between -0.717 - -0.593, whereby the Northern part had shown higher MDS. In sub-period 2013-2017, MDS between -0.895 - -0.545 were observed. Majority areas had shown MDS between -0.895 - -0.662, whereby the Southern and Western parts had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually increased in sub-period 1988-1992, and peak MDS was observed in 1993-1997. MDS then decreased and maintained, as lowest MDS was observed in 2008-2012. MDS then increased and maintained in the following period. Besides, the West and North part had relatively shown higher MDS, except sub-period 2013-2017 that relatively showed high MDS at station 5671002, 5973001, 6264001 and stations near to it. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes that had occurred in 2014-2015, 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDS between -1.160 - -0.764 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.160- -0.897, whereby the Eastern and Centre parts of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.014 - -0.638 were observed. Majority of the areas had shown MDS between -1.014 - -0.764, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -0.939 - -0.635 were observed in whole region, whereby the Centre and North-East parts of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.009 - -0.564 were observed, majority of the areas showed MDS between -0.898 – 0.676, whereby the Centre part of the region had shown higher value of MDS. In sub-period 2008-2012, MDS between -0.843 - -0.468 were observed. Most of the areas showed MDS between -0.843 - -0.593, whereby the Southern part had shown higher MDS. In sub-period 2013-2017, MDS between -1.012 - -0.662 were observed. Majority areas had shown MDS between -0.895 - -0.779, whereby the Centre part had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually increased in sub-period 1988-1992, and peak MDS was observed in 1993-1997. MDS then decreased and maintained, as lowest MDS was observed in 2008-2012. MDS then increased and maintained in the following period. Besides, the Eastern and Centre parts had relatively shown higher MDS, except sub-period 2008-2012 that relatively showed high MDS at station 2920005, 2818001, 2817001. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes that had occurred in 2009-2010 that inhibited rainfall occurrence due to the increase in sea surface temperature.

4.4.2 SPI-3

Mean drought severity is magnitude of drought events. SPI at 3-month timescale was utilised in order to study the spatial variations of MDS as shown in Figure 4.8. The colour depth from yellow to red indicates the level of MDS from lowest to highest category.

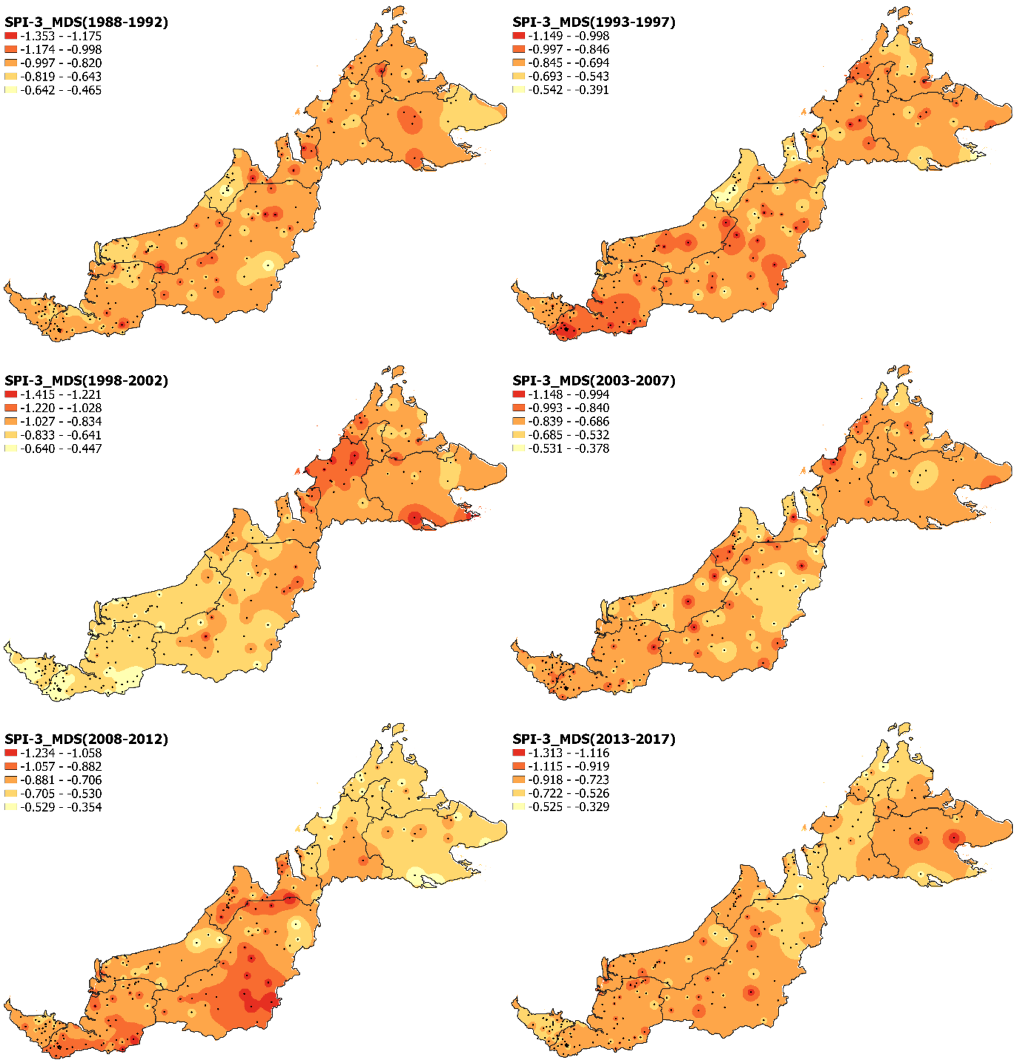

Figure 4.8: Mean Drought Severity maps of SPI-3 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDS between -1.174- -0.643 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -0.997- -0.643, whereby the Central part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.997- -0.391 were observed. Majority of the areas had shown MDS between -0.845 - -0.543, whereby the Central part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.415 - -0.641 were observed. Majority of the areas had shown MDS between -1.027- -0.641, whereby the Southern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -0.993 - -0.532 were observed. Majority of the areas had shown MDS between -0.839 - -0.532, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -0.881 - -0.354 were observed. Majority of the areas had shown MDS between -0.705 - -0.530, whereby the Central part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -1.313 - -0.329 were observed. Majority of the areas had shown MDS between -0.918 - -0.526, whereby the Central part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually decreased in sub-period 1988-1992, and lowest MDS was observed in 1998-2002. MDS then increased and maintained, as peak MDS was observed in 2013-2017. Besides, the Central part had relatively shown higher MDS over the sub-periods, except for 1998-2002, 2003-2007 that relatively showed high MDS at station 4474002 and 5088002. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes that had occurred in 1997-1998, 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, MDS between -0.997- -0.643 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -0.997- -0.820, whereby the Central, Southern and Western parts of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.845 - -0.543 were observed. Majority of the areas had shown MDS between -0.845 - -0.694, whereby the whole region had shown higher values of MDS. In sub-period 1998-2002, MDS between –0.833 - -0.447 were observed. Majority of the areas had shown MDS between -0.833 - -0.641, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -

0.993 - -0.532 were observed. Majority of the areas had shown MDS between -0.993 - -0.686, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -0.881 - -0.354 were observed. Majority of the areas had shown MDS between -0.705 - -0.530, whereby the Western part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -0.918 - -0.329 were observed. Majority of the areas had shown MDS between -0.918 - -0.526, whereby the North-West and Northern parts of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown lowest MDS in sub-period 1988-1992. MDS then increased and maintained, as peak MDS was observed in 2013-2017. Besides, the Western part had relatively shown higher MDS over the sub-periods, except for 1998-2002, 2003-2007 that relatively showed high MDS at station 1204024 and 1203002. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes that had occurred in 1997-1998, 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDS between -1.353- -0.465 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -0.997- -0.643, whereby the Northern part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.997 - -0.391 were observed. Majority of the areas had shown MDS between -0.845 - -0.543, whereby the Eastern and Western parts of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between –1.220 - -0.447 were observed. Majority of the areas had shown MDS between -1.027 - -0.641, whereby the Northern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -0.993 - -0.378 were observed. Majority of the areas had shown MDS between -0.839 - -0.532, whereby the Eastern and Western parts of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -1.234 - -0.354 were observed. Majority of the areas had shown MDS between -1.057 - -0.706, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -1.115 - -0.526 were observed.

Majority of the areas had shown MDS between -0.918 - -0.723, whereby the Central part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown lowest MDS in sub-period 1988-1992. MDS then increased and maintained in the following periods, as peak MDS was observed in 2013-2017. Besides, the Northern and Western parts had relatively shown higher MDS over the sub-periods, except for 2008-2012, 2013-2017 that relatively showed high MDS at the Eastern part of the region. Given that the location of these stations located in inland area, the high MDS could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block the North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDS between -1.174 - -0.820 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -0.997- -0.820, whereby the Northern part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.997 - -0.694 were observed. Majority of the areas had shown MDS between -0.845 - -0.694, whereby the Northern part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between –1.027 - -0.641 were observed. Majority of the areas had shown MDS between -1.027 - -0.834, whereby the whole region had shown higher values of MDS, except for the Northern part. In sub-period 2003-2007, MDS between -0.839 - -0.532 were observed. Majority of the areas had shown MDS between -0.839 - -0.686, whereby the whole region had shown higher values of MDS, except for the Northern part. In sub-period 2008-2012, MDS between -0.705 - -0.354 were observed. Majority of the areas had shown MDS between -0.705 - -0.530, whereby the whole region had shown higher values of MDS, except for the Northern part. In sub-period 2013-2017, MDS between -0.918 - -0.526 were observed. Majority of the areas had shown MDS between -0.918 - -0.526, whereby the Southern part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually decreased in sub-period 1988-1992 and lowest MDS was observed in 1998-2002. MDS then increased and maintained in the following periods, as peak MDS was observed in 2013-2017. Besides, the Southern part had relatively shown higher MDS over the sub-periods, except for 1988-1992, 1993-1997 that relatively showed high MDS at station 6168001. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 5**, MDS between -1.174 - -0.643 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -0.997- -0.820, whereby the Northern, Southern and Western parts of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.997 - -0.543 were observed. Majority of the areas had shown MDS between -0.845 - -0.694, whereby the Central part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between –1.415 - -0.641 were observed. Majority of the areas had shown MDS between -1.220 - -0.834, whereby the Northern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -0.993 - -0.532 were observed. Majority of the areas had shown MDS between -0.839 - -0.686, whereby the whole region had shown higher values of MDS, except for the Northern part. In sub-period 2008-2012, MDS between -0.881 - -0.354 were observed. Majority of the areas had shown MDS between -0.881 - -0.530, whereby the Central and Southern parts of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -0.918 - -0.526 were observed. Majority of the areas had shown MDS between -0.918 - -0.526, whereby the North-West and South-East parts of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually decreased in sub-period 1988-1992 and lowest MDS was observed in 1998-2002. MDS then increased and maintained in the following periods, as peak MDS was observed in 2013-2017. Besides, the Southern part had relatively shown higher MDS over the sub-periods, except for 1993-1997, 1998-2002 that relatively showed high MDS at station 5663001 and 5462001. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Crocker which is located near to the stations. Banjaran

Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 6**, MDS between -1.353 - -0.465 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.174- -0.643, whereby the Central and Eastern parts of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.845- -0.391 were observed. Majority of the areas had shown MDS between -0.845 - -0.543, whereby the Eastern and Central parts of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between –1.220 - -0.641 were observed. Majority of the areas had shown MDS between -1.027 - -0.641, whereby the Western part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.148 - -0.532 were observed. Majority of the areas had shown MDS between -0.993 - -0.686, whereby the Western part of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -1.234 - -0.530 were observed. Majority of the areas had shown MDS between -1.057 - -0.706, whereby the Western part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -0.918 - -0.329 were observed. Majority of the areas had shown MDS between -0.918 - -0.526, whereby the Western part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown lowest MDS in sub-period 1988-1992. MDS then increased and maintained in the following periods, as peak MDS was observed in 2013-2017. Besides, the Western part had relatively shown higher MDS over the sub-periods, except for 1988-1992, 1993-1997 that relatively showed high MDS at station 4554001, 4151017 and 3945017. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDS between -1.174 - -0.643 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -0.997- -0.643, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.149 - -0.694 were observed. Majority of the areas had shown MDS between -0.997 - -0.694, whereby the South-West part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between –0.883 - -0.447 were observed. Majority of the areas had shown MDS between –0.883 - -0.447, whereby the Western, Northern and Southern parts of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -0.993 - -0.532 were observed. Majority of the areas had shown MDS between -0.839 - -0.686, whereby the North-East part of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -1.234 - -0.530 were observed. Majority of the areas had shown MDS between -1.057 - -0.706, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -1.115 - -0.526 were observed. Majority of the areas had shown MDS between -0.918 - -0.723, whereby the Northern part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually increased in sub-period 1988-1992. Peak MDS was observed in the 1998-2002. MDS gradually decreased and maintained in the following periods, as lowest MDS was observed in 2008-2012. Besides, the Northern part had relatively shown higher MDS over the sub-periods, except for 1988-1992, 1993-1997, 2008-2012 that relatively showed high MDS at station 1018002, 1003031, 1018002. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 8**, MDS between -1.174 - -0.643 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -0.997- -0.643, whereby the whole region had shown higher values of MDS, except for the Central part. In sub-period 1993-1997, MDS between -0.997 - -0.543 were observed. Majority of the areas had shown MDS between -0.845 - -0.543, whereby the Western part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between –1.220 - -0.641 were observed. Majority of the areas had shown MDS between –1.027 - -0.641, whereby the Western part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -0.993 - -0.532 were observed. Majority of the areas had shown MDS between -0.839 - -0.532, whereby the Western part of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -0.881 - -0.354 were observed. Majority of the areas had shown MDS between -0.705 - -0.530, whereby the whole region had shown higher values of MDS, except for the Western part. In sub-period 2013-2017, MDS between -0.918 - -0.329 were observed. Majority of the areas had shown MDS between -0.918 - -0.526, whereby the Southern part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually decreased in sub-period 1988-1992. Lowest MDS was observed in the 1998-2002. MDS gradually increased and maintained in the following periods, as peak MDS was observed in 2013-2017. Besides, the Western part had relatively shown higher MDS over the sub-periods, except for 2008-2012, 2013-2017 that relatively showed high MDS at station 5671002, 5973001 and other stations near to it. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes that had occurred in 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDS between -1.353 - -0.643 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -0.997- -0.643, whereby the Southern part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.149 - -0.543 were observed. Majority of the areas had shown MDS between -0.845 - -0.543, whereby the Northern part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between –1.027 - -0.447 were observed. Majority of the areas had shown MDS between -0.883 - -0.641, whereby the Northern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.148 - -0.378 were observed. Majority of the areas had shown MDS between -0.839 - -0.532, whereby the Northern and Central parts of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -0.881 - -0.354 were observed. Majority of the areas had shown MDS between -0.881 - -0.530, whereby the Central, Eastern and Western parts of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -1.115 - -0.526 were observed. Majority of the areas had shown MDS between -0.918 - -0.526, whereby the South-West part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown lowest MDS in sub-period 1988-1992. MDS gradually increased and maintained since 1993-1997. Peak MDS was observed in 2013-2017. Besides, the Northern part had relatively shown higher MDS over the sub-periods, except for 1988-1992, 2008-2012, 2013-2017 that relatively showed high MDS at station 2325039, 2520052 and other stations near to it. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Kapuas Hulu which is located near to the stations. Banjaran Kapuas Hulu could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

4.4.3 SPI-6

Mean drought severity is magnitude of drought events. SPI at 6-month timescale was utilised in order to study the spatial variations of MDS as shown in Figure 4.9. The colour depth from yellow to red indicates the level of MDS from lowest to highest category.

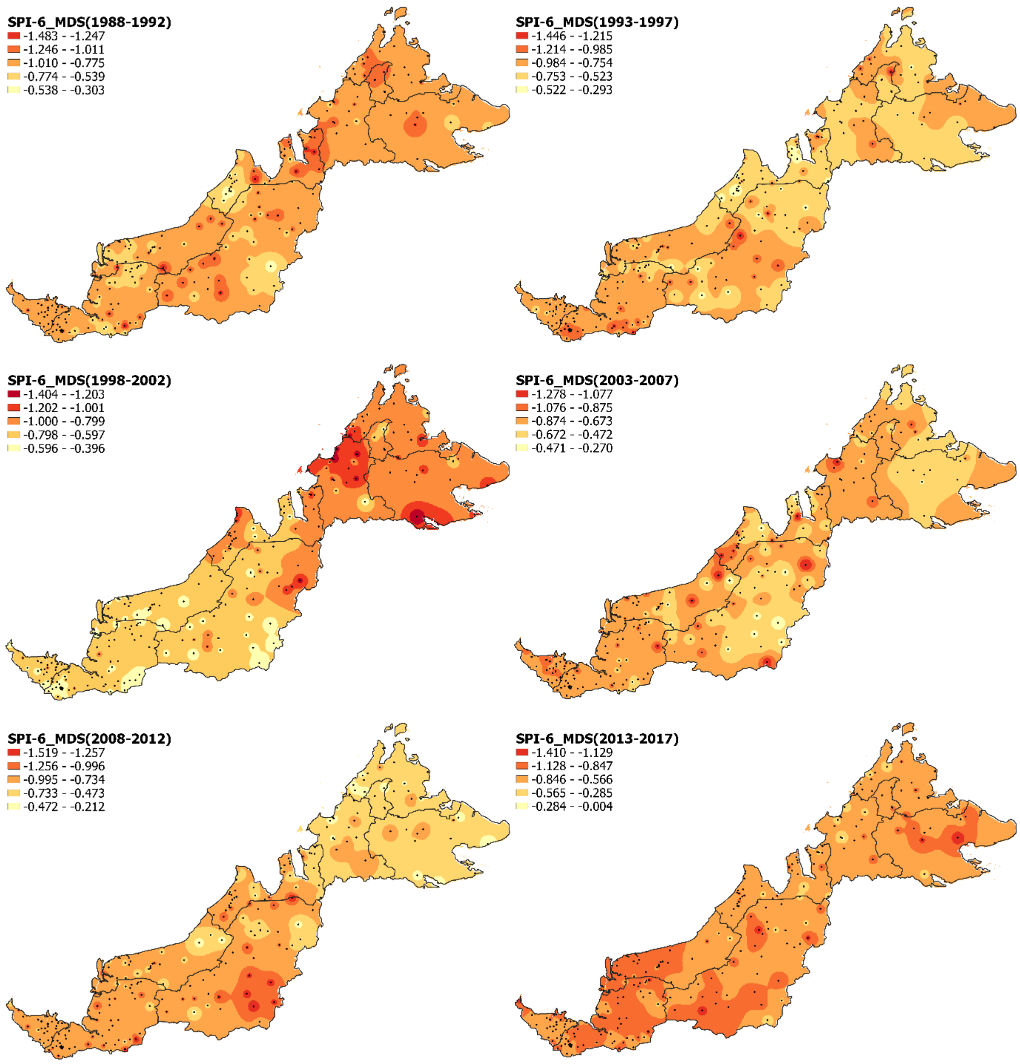

Figure 4.9: Mean Drought Severity maps of SPI-6 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDS between -1.246- -0.539 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.010 - -0.775, whereby the Central part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.984 - -0.523 were observed. Majority of the areas had shown MDS between -0.984 - -0.523, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.404 - -0.597 were observed. Majority of the areas had shown MDS between -1.000 - -0.799, whereby the Southern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -0.874 - -0.472 were observed. Majority of the areas had shown MDS between -0.874 - -0.472, whereby the Eastern and Western parts of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -0.995 - -0.212 were observed. Majority of the areas had shown MDS between -0.733 - -0.473, whereby the Western part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -1.128 - -0.004 were observed. Majority of the areas had shown MDS between -0.846 - -0.285, whereby the Eastern part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDS in sub-period 1988-1992. MDS gradually decreased and maintained since 1993-1997. Lowest MDS was observed in 2013-2017. Besides, the Eastern part of the region had relatively shown high MDS over the sub-periods, except for 1988-1992, 1998-2002, 2008-2012 that relatively showed high MDS at station 5269001 and 5372001. Given that the location of these stations located in inland area, the high MDS could be affected by Banjaran Maitland and Banjaran Brassy which are located near to the stations. Banjaran Maitland and Banjaran Brassy could both block the North-East Monsoon from reaching the stations.

In **Region 2**, MDS between -1.246- -0.775 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.010 - -0.775, whereby the whole region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.984 - -0.523 were observed. Majority of the areas had shown MDS between -0.984 - -0.754, whereby the whole region had shown higher values of MDS, except for the Western part. In sub-period 1998-2002, MDS between -0.798 - -0.396 were observed. Majority of the areas had shown MDS between -0.798 - -0.597, whereby the Northern, Eastern and Western parts of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.076 - -0.673 were observed. Majority of the areas had shown MDS between -1.076 - -0.673, whereby the Central part of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -1.256 - -0.473 were observed. Majority of the areas had shown MDS between -0.995 - -0.734, whereby the whole region had shown higher values of MDS, except for the North-West. In sub-period 2013-2017, MDS between -1.128 - -0.566 were observed. Majority of the areas had shown MDS between -0.846 - -0.285, whereby the North-West and Northern parts of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually increased in sub-period 1988-1992, and peak MDS was observed in 2003-2007. MDS gradually decreased and maintained in the following periods, and lowest MDS was observed in 2013-2017. Besides, the Northern part of the region had relatively shown high MDS over the sub-periods, except for 2003-2007 that relatively showed high MDS at station 1897016 and 1996090. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes of 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDS between -1.246- -0.303 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.010 - -0.539, whereby the South-West part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.446 - -0.293 were observed. Majority of the areas had shown MDS between -0.984 - -0.523, whereby the Western part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.202 - -0.396 were observed. Majority of the areas had shown MDS between -1.000 - -0.597, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.278 - -0.270 were observed. Majority of the areas had shown MDS between -0.874 - -0.472, whereby the Northern and South-East parts of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -1.519 - -0.212 were observed. Majority of the areas had shown MDS between -1.256 - -0.473, whereby the South-East part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -1.410 - -0.285 were observed. Majority of the areas had shown MDS between -1.128 - -0.566, whereby the Southern part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually decreased in sub-period 1988-1992, and lowest MDS was observed in 2003-2007.MDS then increased and peak MDS was observed in 2008-2012. Besides, the Southern part of the region had relatively shown high

MDS over the sub-periods, except for 1993-1997, 1998-2002 that relatively showed high MDS at station 1947001, 2346001 and 3754007. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Tama Abu which is located near to the stations. Banjaran Tama Abu could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 4**, MDS between -1.246- -0.775 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.246 - -0.775, whereby the Northern part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.446 - -0.523 were observed. Majority of the areas had shown MDS between -0.984 - -0.523, whereby the North-East part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.000 - -0.597 were observed. Majority of the areas had shown MDS between -1.000 - -0.799, whereby the Southern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -0.874 - -0.472 were observed. Majority of the areas had shown MDS between -0.874 - -0.673, whereby the whole region had shown higher values of MDS, except for the North-East. In sub-period 2008-2012, MDS between -0.733 - -0.212 were observed. Majority of the areas had shown MDS between -0.733 - -0.473, whereby the whole region had shown higher values of MDS, except for the North-East. In sub-period 2013-2017, MDS between -0.846 - -0.566 were observed. Majority of the areas had shown MDS between -0.846 - -0.566, whereby the whole region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDS in sub-period 1988-1992. MDS decreased and lowest MDS was observed in 1993-1997. MDS then gradually increased on the following periods. Besides, the Northern part of the region had relatively shown high MDS over the sub-periods, except for 1998-2002 that relatively showed high MDS at station 6168001 and 5768001. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 5**, MDS between -1.246- -0.539 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.010 - -0.775, whereby the Western part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.214 - -0.523 were observed. Majority of the areas had shown MDS between -0.984 - -0.523, whereby the North-East and South-East parts of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.404 - -0.396 were observed. Majority of the areas had shown MDS between -1.202 - -0.799, whereby the Northern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.076 - -0.472 were observed. Majority of the areas had shown MDS between -0.874 - -0.673, whereby the North-West part of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -0.9995 - -0.212 were observed. Majority of the areas had shown MDS between -0.995 - -0.473, whereby the Southern part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -0.846 - -0.285 were observed. Majority of the areas had shown MDS between -0.846 - -0.566, whereby the Eastern part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually increased in sub-period 1988-1992, and peak MDS was observed in 1998-2002. MDS decreased and lowest MDS was observed in 2008-2012. MDS then increased in the following period. Besides, the Northern and Eastern parts of the region had relatively shown high MDS over the sub-periods, except for 1988-1992, 2008-2012 that relatively showed high MDS at station 5163002, 4764002 and 4959001. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 6**, MDS between -1.483- -0.303 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.246 - -0.539, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -0.984 - -0.293 were observed. Majority of the areas had shown MDS between -0.753 - -0.523, whereby the Northern part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.202 - -0.597 were observed. Majority of the areas had shown MDS between -1.000 - -0.597, whereby the Western and Eastern parts of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.278 - -0.472 were observed. Majority of the areas had shown MDS between -1.076 - -0.673, whereby the Central part of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -1.256 - -0.473 were observed. Majority of the areas had shown MDS between -0.995 - -0.473, whereby the Western and Central parts of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -0.846 - -0.285 were observed. Majority of the areas had shown MDS between -0.846 - -0.566, whereby the whole region had shown higher values of MDS, except for the Central part.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDS in sub-period 1988-1992. MDS then decreased gradually and lowest MDS was observed in 2008-2012. MDS then increased in the following period. Besides, the Western part of the region had relatively shown high MDS over the sub-periods, except for 1988-1992, 1993-1997, 2003-2007 that relatively showed high MDS at station 3635001, 4449012 and 4548004. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes of 1991-1992, 1987-1988, 1994-1995, 1997-1998, 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDS between -1.246- -0.539 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.010 - -0.775, whereby the South-East part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.214 - -0.523 were observed. Majority of the areas had shown MDS between -0.984 - -0.754, whereby the Southern part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.000 - -0.396 were observed. Majority of the areas had shown MDS between -0.798 - -0.396, whereby the whole region had shown higher values of MDS, except for the Southern part. In sub-period 2003-2007, MDS between -1.076 - -0.472 were observed. Majority of the areas had shown MDS between -0.874 - -0.673, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -1.256 - -0.473 were observed. Majority of the areas had shown MDS between -0.995 - -0.734, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -1.128 - -0.566 were observed. Majority of the areas had shown MDS between -1.128 - -0.566, whereby the Central, Western and Northern parts of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually decreased in sub-period 1988-1992, and lowest MDS was observed in 1998-2002. MDS then increased in the following periods, and peak MDS was observed in 2013-2017. Besides, the Eastern part of the region had relatively shown high MDS over the sub-periods, except for 1993-1997 that relatively showed high MDS at station 1415001, 1816029. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

In **Region 8**, MDS between -1.246- -0.775 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.010 - -0.775, whereby the Western part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.214 - -0.523 were observed. Majority of the areas had shown MDS between -0.984 - -0.523, whereby the Western part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -1.202 - -0.597 were observed. Majority of the areas had shown MDS between -1.000 - -0.799, whereby the Eastern part of the region had shown higher values of MDS. In sub-period 2003-2007, MDS between -1.076 - -0.472 were observed. Majority of the areas had shown MDS between -0.874 - -0.472, whereby the Western and Central parts of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -0.995 - -0.212 were observed. Majority of the areas had shown MDS between -0.733 - -0.473, whereby the Southern part of the region had shown higher values of MDS. In sub-period 2013-2017, MDS between -0.846 - -0.285 were observed. Majority of the areas had shown MDS between -0.846 - -0.566, whereby the whole region had shown higher values of MDS, except for the North-West.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDS in sub-period 1988-1992. MDS then decreased gradually in the following periods, and lowest MDS was observed in 2003-2007. MDS then increased in the following periods. Besides, the Western part of the region had relatively shown high MDS over the sub-periods, except for 1998-2002, 2008-2012 that relatively showed high MDS at station 6062001, 6264001, 6365001. Given the location of the stations being near to seashore, the high MDS could be affected by the El-Niño episodes of 1997-1998, 2002-2003 and 2009-2010 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDS between -1.246- -0.539 were observed in sub-period 1988-1992. Majority of the areas had shown MDS between -1.010 - -0.775, whereby the Southern part of the region had shown higher values of MDS. In sub-period 1993-1997, MDS between -1.214 - -0.523 were observed. Majority of the areas had shown MDS between -0.984 - -0.754, whereby the North-East part of the region had shown higher values of MDS. In sub-period 1998-2002, MDS between -0.789 - -0.396 were observed. Majority of the areas had shown MDS between -0.798 - -0.597, whereby the whole region had shown higher values of MDS, except for the Southern and Central part. In sub-period 2003-2007, MDS between -1.076 - -0.270 were observed. Majority of the areas had shown MDS between -0.874 - -0.472, whereby the Northern and Central parts of the region had shown higher values of MDS. In sub-period 2008-2012, MDS between -0.995 - -0.212 were observed. Majority of the areas had shown MDS between -0.995 - -0.473, whereby the whole region had shown higher values of MDS, except for the Northern part. In sub-period 2013-2017, MDS between -1.128 - -0.566 were observed. Majority of the areas had shown MDS between -1.128 - -0.566, whereby the Western part of the region had shown higher values of MDS.

Over the six sub-periods, it was observed that majority of the areas had shown MDS gradually increased in sub-period 1988-1992, and peak MDS was achieved in 2003-2007. MDS then decreased in the following periods and lowest MDS was observed in 2013-2017. Besides, the Northern and Western parts of the region had relatively shown high MDS over the sub-periods, except for 1988-1992 that relatively showed high MDS at station 2615009, 2719001, 27118022 and other stations near to it. Given the location of these stations located in inland area, the high MDS could be affected by Banjaran Kapuas Hulu which is located near to the stations. Banjaran Kapuas Hulu could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDS in a specific area.

4.4.4 Summary

According to the study with SPI-1, the occurrence of MDS was the highest among the sub-periods. Peak MDS with the range of -1.293 - -1.161 had occurred in Region 3 of East Malaysia, and it was predicted that the high MDS was caused by mountainous topography due to the location of drought events. As for sub-period 1993-1997, the occurrence of MDS was considered high among the sub-periods. Peak MDS with the range of -1.141 - -1.015 had occurred in Region 5 of East Malaysia. By referring to the location of drought events, it was predicted that high MDS was caused by mountainous topography as well. On average, the occurrence of MDS was considered low in sub-period 1998-2002. Peak MDS with the range of -1.245 - -1.093 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, the occurrence of MDS was low among the sub-periods. Peak MDS with the range of -1.122 - -1.010 was observed in Region 6 of East Malaysia, and it was predicted that the high MDS was caused by El-Niño episodes due to its location being near to seashore. For sub-period, 2008-2012, peak MDS with the range of -1.094 - -0.969 was observed in Region 3 of East Malaysia. However, it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak MDS with the range of -1.130 - -1.013 was observed in Region 3 of East Malaysia, and it could be caused by the mountainous topography due to its location. In overall, the SPI-1 analysis had shown that peak MDS had occurred often in the Eastern and Central parts of East Malaysia. Besides, Region 3 had shown the most occurrence of peak MDS. Regarding the location of MDS, peak MDS were mostly caused by mountainous topography rather than El-Niño episodes.

As for SPI-3, the occurrence of MDS was high in sub-period 1988-1992 as compared to other sub-periods. Peak MDS with the range of -1.333 - -1.175 had occurred in Region 4 of East Malaysia, and it was predicted that the high MDS was caused by mountainous topography due to the location of drought events. In sub-period 1993-1997, the occurrence of MDS was the highest among the sub-periods. Peak MDS with the range of -1.149 - -0.998 had occurred in Region 7 of East Malaysia. By referring to the location of drought events, it was predicted that high MDS was caused by mountainous topography as well. On average, the occurrence of MDS was considered low in sub-period 1998-2002. Peak MDS with the range of -1.415 - -1.221 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, peak MDS with the range of -1.148 - -0.994 was observed in Region 9 of East Malaysia, and it was predicted that the high MDS was caused by El-Niño episodes due to its location being near to seashore. For sub-period, 2008-2012, peak MDS with the range of -1.234 - -1.058 was observed in Region 3 of East Malaysia. However, it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak MDS with the range of -1.313 - -1.116 was observed in Region 1 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. In overall, SPI-3 had shown that peak MDS had occurred often in the Eastern and Central parts of East Malaysia. Besides, Region 1 showed the most occurrence of peak MDS. Regarding the location of MDS, peak MDS were mostly caused by mountainous topography rather than El-Niño episodes.

For SPI-6, the occurrence of MDS was high in sub-period 1988-1992 as compared to other sub-periods. Peak MDS with the range of -1.483 - -1.247 had occurred in Region 6 of East Malaysia, and it was predicted that the high MDS was caused by mountainous topography due to the location of drought events. In sub-period 1993-1997, the occurrence of MDS was considered high among the sub-periods. Peak MDS with the range of -1.496 - -1.215 had occurred in Region 3 of East Malaysia. By referring to the location of drought events, it was predicted that high MDS was caused by mountainous topography as well. On average, the occurrence of MDS was the highest in sub-period 1998-2002. Peak MDS with the range of -1.404 - -1.203 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, the occurrence of MDS was high among the sub-periods. Peak MDS with the range of -1.278 - -1.077 was observed in Region 3 of East Malaysia, and it was predicted that the high MDS was caused by mountainous topography. For sub-period, 2008-2012, peak MDS with the range of -1.519 - -1.257 was observed in Region 3 of East Malaysia, and it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak MDS with the range of -1.410 - -1.129 was observed in Region 1 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. In overall, SPI-6 had shown that peak MDS had occurred often in Eastern and Central part of East Malaysia. Besides, Region 3 had shown most occurrence of peak MDS. Regarding the location of MDS, peak MDS were mostly caused by mountainous topography rather than El-Niño episodes.

4.5 Mean Drought Intensity

4.5.1 SPI-1

Mean drought intensity is the mean of drought magnitude within a study period. SPI at 1-month timescale was utilised in order to study the spatial variations of MDI as shown in Figure 4.10. The colour depth from yellow to red indicates the level of MDI from lowest to highest category.

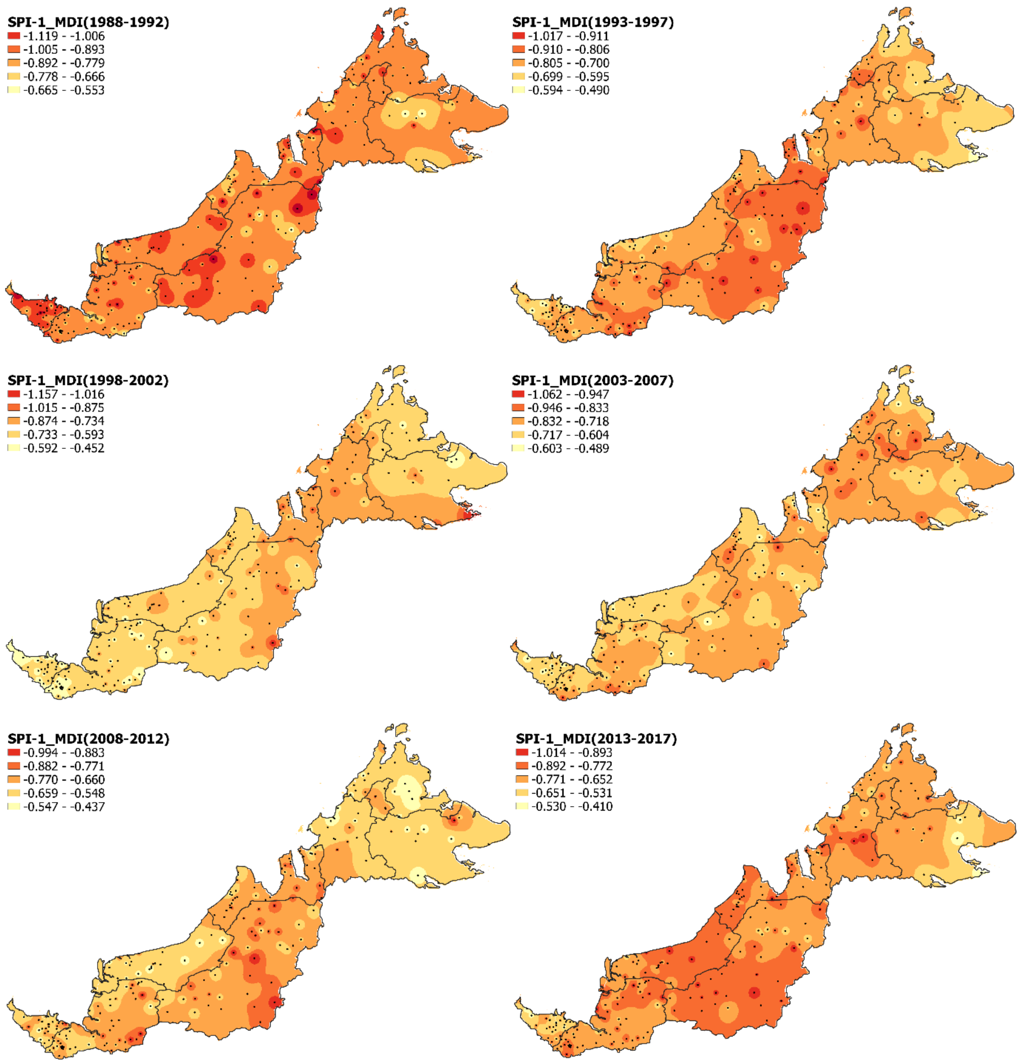

Figure 4.10: Mean Drought Intensity maps of SPI-1 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDI between -1.005 - -0.553 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.892 - -0.666, whereby the Centre part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.805 - -0.490 were observed. Majority of the areas had shown MDI between -0.805 - -0.490, whereby the West and Centre parts of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -1.157 - -0.452 were observed. Majority of the area had shown MDI between -0.874- -0.593 whereby the South-East part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.946 - -0.604 were observed, majority of the areas showed MDI between -0.832 – 0.604, whereby the Southern part of the region had shown higher value of MDI.

In sub-period 2008-2012, MDI between -0.882 - -0.437 were observed. Most of the areas showed MDI between -0.770 - -0.548, whereby the North-East had shown higher MDI. In sub-period 2013-2017, MDI between -0.892 - -0.410 were observed. Majority areas had shown MDI between -0.771 - -0.531, whereby the Centre part had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI gradually decreased since 1993-1997, and lowest MDI was achieved in 2013-2017. Besides, Eastern and Centre part had relatively shown higher MDI, except sub-period 2003-2007 that relatively showed high MDI at station 4474002. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes of 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, MDI between -1.005 - -0.779 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -1.005 - -0.779, whereby the Centre, North and West parts of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.805 - -0.490 were observed. Majority of the areas had shown MDI between -0.805 - -0.595, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.733 - -0.452 were observed. Majority of the area had shown MDI between -0.733 - -0.452 whereby the Centre and Eastern parts of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.832 - -0.489 were observed, majority of the areas showed MDI between -0.717 – 0.604, whereby the North-West part of the region had shown higher value of MDI. In sub-period 2008-2012, MDI between -0.882 - -0.437 were observed. Most of the areas showed MDI between -0.770 - -0.548, whereby the Western part had shown higher MDI. In sub-period 2013-2017, MDI between -0.892 - -0.410 were observed. Majority areas had shown MDI between -0.771 - -0.410, whereby the Centre part had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI gradually decreased since 1993-1997, and lowest MDI was observed in 1998-2002. MDI then slowly increased in the following periods. Besides, the Eastern, Western and Central parts had relatively shown higher MDI, especially at station 1102019, 1203002, 1201076 and other stations near to it. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes happened of 1987-1988, 1991-1992, 1994-1995, 1997-1998, 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDI between -1.119 - -0.553 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -1.005 - -0.779, whereby the North-East of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -1.017 - -0.595 were observed. Majority of the areas had shown MDI between -0.910 - -0.700, whereby the North-East of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -1.015 - -0.452 were observed. Majority of the area had shown MDI between -0.874 - -0.593 whereby the South-East of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.946 - -0.489 were observed, majority of the areas showed MDI between -0.832 – 0.604, whereby the South-East part of the region had shown higher value of MDI. In sub-period 2008-2012, MDI between -0.994 - -0.548 were observed. Most of the areas showed MDI between -0.882 - -0.660, whereby the South-East part had shown higher MDI. In sub-period 2013-2017, MDI between -1.014 - -0.531 were observed. Majority areas had shown MDI between -0.892 - -0.652, whereby the Centre part had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI gradually decreased since 1993-1997, and lowest MDI was observed in 1998-2002. MDI then slowly increased in the following periods. Besides, the South-East and North-East parts had relatively shown higher MDI, except for sub-period 2013-2017 that relatively showed high MDI at station 2141048. Given the location of these stations located in inland area, the high MDI could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block the North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDI between -1.005 - -0.779 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.892 - -0.779, whereby the North-East part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.805 - -0.595 were observed. Majority of the areas had shown MDI between -0.805 - -0.700, whereby the Northern, Western and Centre parts of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.874 - -0.593 were observed. Majority of the area had shown MDI between -0.733 - -0.593 whereby the Western of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.946 - -0.718 were observed, majority of the areas showed MDI between -0.946 – 0.718, whereby the South-East and Centre parts of the region had shown higher value of MDI. In sub-period 2008-2012, MDI between -0.770 - -0.548 were observed. Most of the areas showed MDI between -0.770 - -0.660, whereby the Centre part had shown higher MDI. In sub-period 2013-2017, MDI between -0.892 - -0.652 were observed. Majority areas had shown MDI between -0.771 - -0.652, whereby the Western part had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually decreased since sub-period 1988-1992. Lowest MDI gradually was observed in 1998-2002. MDI then slowly increased in the following periods and peak MDI was observed in 2003-2007. Besides, the Western and Centre parts had relatively shown higher MDI, except for sub-period 1988-1992 that relatively showed high MDI at station 6168001. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

In **Region 5**, MDI between -1.005 - -0.666 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.892 - -0.779, whereby the Western of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.910 - -0.595 were observed. Majority of the areas had shown MDI between -0.805 - -0.700, whereby the Eastern of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -1.015 - -0.593 were observed. Majority of the area had shown MDI between -0.874 - -0.734 whereby the Western of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -1.062 - -0.718 were observed, majority of the areas showed MDI between -1.062 – 0.833, whereby the Western and Centre parts of the region had shown higher value of MDI. In sub-period 2008-2012, MDI between -0.882 - -0.548 were observed. Most of the areas showed MDI between -0.882 - -0.660, whereby the South-West part had shown higher MDI. In sub-period 2013-2017, MDI between -1.014 - -0.531 were observed. Majority areas had shown MDI between -0.892 - -0.652, whereby the Centre part had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually increased since sub-period 1988-1992. Peak MDI gradually was observed in 2003-2007. MDI then slowly decreased in the following periods and lowest MDI was observed in 2013-2017. Besides, the Western and Centre parts had relatively shown higher MDI, except for sub-period 1993-1997 that relatively showed high MDI at station 5163002. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

In **Region 6**, MDI between -1.005 - -0.666 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.892 - -0.779, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.910 - -0.595 were observed. Majority of the areas had shown MDI between -0.910 - -0.700, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -1.015 - -0.593 were observed. Majority of the area had shown MDI between -0.874 - -0.593, whereby the Eastern of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.946 - -0.489 were observed, majority of the areas showed MDI between -0.832 – 0.604, whereby the South-West part of the region had shown higher value of MDI. In sub-period 2008-2012, MDI between -0.882 - -0.548 were observed. Most of the areas showed MDI between -0.882 - -0.660, whereby the South-East part had shown higher MDI. In sub-period 2013-2017, MDI between -0.892 - -0.531 were observed. Majority areas had shown MDI between -0.892 - -0.652, whereby the Western part had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually increased since sub-period 1988-1992. Peak MDI gradually was observed in 1993-1997. MDI then slowly decreased in the following periods and lowest MDI was observed in 1998-2002. MDI then increased and maintained in the following periods. Besides, the Western and Eastern part had relatively shown higher MDI over the sub-periods, especially station 4151017 and 4450001. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes of 1987-1988, 1991-1992, 1994-1995, 1997-1998, 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDI between -1.005 - -0.666 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.892 - -0.779, whereby the Centre of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.910 - -0.595 were observed. Majority of the areas had shown MDI between -0.910 - -0.700, whereby the Southern of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.874 - -0.452 were observed. Majority of the area had shown MDI between -0.733 - -0.593, whereby the most of the region had shown higher values of MDI, except for the Western part. In sub-period 2003-2007, MDI between -0.946 - -0.604 were observed, majority of the areas showed MDI between -0.832 - -0.604, whereby the Southern part of the region had shown higher value of MDI. In sub-period 2008-2012, MDI between -0.882 - -0.548 were observed. Most of the areas showed MDI between -0.770 - -0.545, whereby the South-East part had shown higher MDI. In sub-period 2013-2017, MDI between -0.892 - -0.531 were observed. Majority areas had shown MDI between -0.892 - -0.652, whereby the Northern and Western parts had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually increased since sub-period 1988-1992. Peak MDI gradually was observed in 1993-1997. MDI then slowly decreased in the following periods and lowest MDI was observed in 2008-2012. MDI then increased and maintained in the following periods. Besides, the Southern part had relatively shown higher MDI over the sub-periods, except for sub-periods 1988-1992 and 2013-2017 that relatively showed high MDI at station 1415001, 1615023 and 905039. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

In **Region 8**, MDI between -1.005 - -0.666 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.892 - -0.779, whereby the Northern of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.910 - -0.595 were observed. Majority of the areas had shown MDI between -0.805 - -0.595, whereby the Western of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.874 - -0.452 were observed. Majority of the area had shown MDI between -0.733 - -0.593, whereby the Western part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -1.062 - -0.604 were observed, majority of the areas showed MDI between -0.946 - -0.718, whereby the Southern and Western parts of the region had shown higher value of MDI. In sub-period 2008-2012, MDI between -0.770 - -0.437 were observed. Most of the areas showed MDI between -0.659 - -0.437, whereby the Northern part had shown higher MDI. In sub-period 2013-2017, MDI between -0.892 - -0.531 were observed. Majority areas had shown MDI between -0.771 - -0.652, whereby almost the whole region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually increased since sub-period 1988-1992. Peak MDI gradually was observed in 2003-2007. MDI then decreased and maintained in the following periods. Besides, the Western and Northern parts had relatively shown higher MDI over the sub-periods. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes of 1987-1988, 1991-1992, 1994-1995, 1997-1998, 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDI between -1.005 - -0.666 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.892 - -0.779, whereby the Northern and Eastern parts of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.910 - -0.595 were observed. Majority of the areas had shown MDI between -0.805 - -0.595, whereby the Southern of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.874 - -0.452 were observed. Majority of the area had shown MDI between -0.733 - -0.593, whereby the Centre part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.946 - -0.604 were observed, majority of the areas showed MDI between -0.946 - -0.718, whereby the Eastern and Centre parts of the region had shown higher value of MDI. In sub-period 2008-2012, MDI between -0.770 - -0.437 were observed. Most of the areas showed MDI between -0.659 - -0.437, whereby the South-East part had shown higher MDI. In sub-period 2013-2017, MDI between -1.014 - -0.652 were observed. Majority areas had shown MDI between -0.892 - -0.652, whereby the Centre, Northern and Southern parts had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually increased since sub-period 1988-1992. Peak MDI gradually was observed in 2003-2007. MDI then slowly decreased in the following periods and lowest MDI was observed in 2008-2012. MDI then increased and maintained in the following period. Besides, the Central and Eastern part had relatively shown higher MDI over the sub-periods, except for sub-period 1993-1997 that relatively showed high MDI at station 2325039. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Kapas Hulu which is located near to the stations. Banjaran Kapas Hulu could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

4.5.2 SPI-3

Mean drought intensity is the mean of drought magnitude within a study period. SPI at 3-month timescale was utilised in order to study the spatial variations of MDI as shown in Figure 4.11. The colour depth from yellow to red indicates the level of MDI from lowest to highest category.

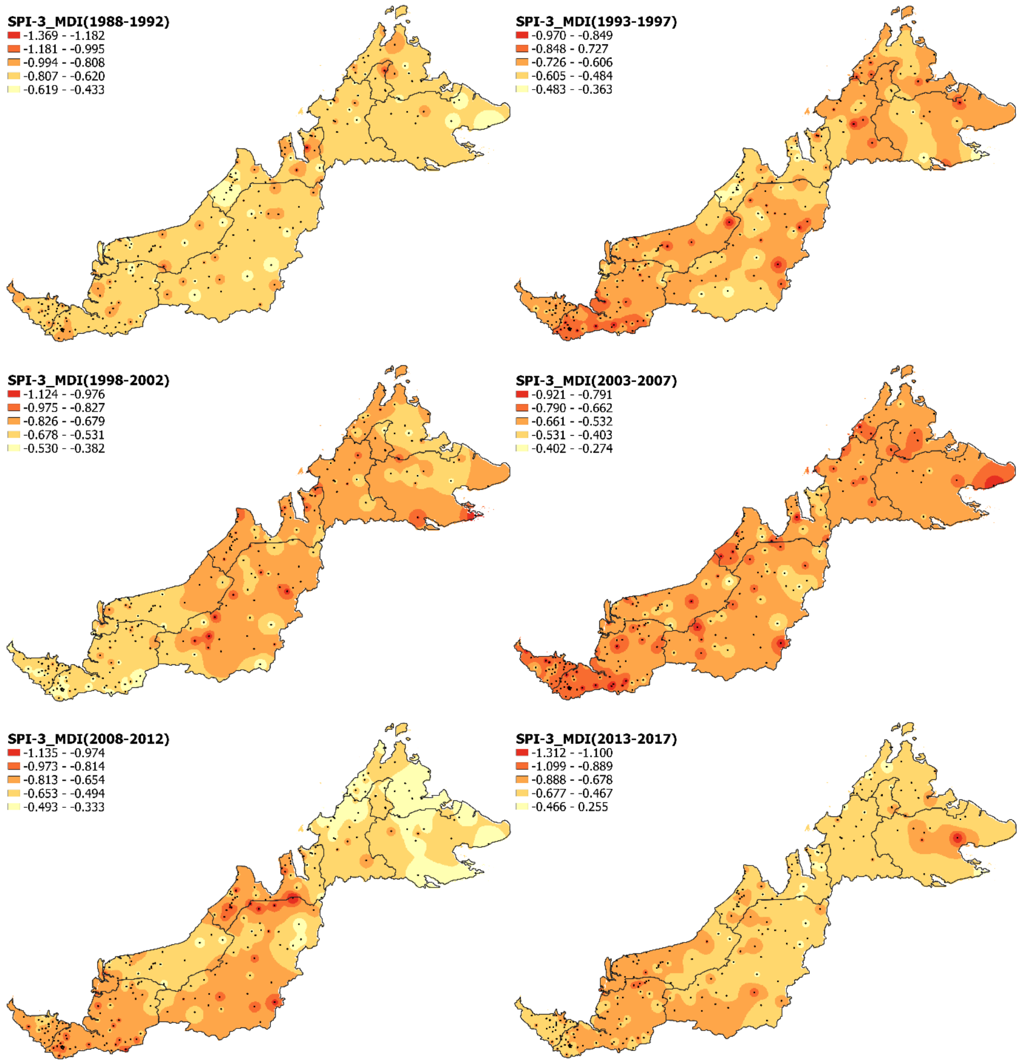

Figure 4.11: Mean Drought Intensity maps of SPI-3 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDI between -0.994 - -0.433 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.807 - -0.620, whereby the Central part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.848 - -0.363 were observed. Majority of the areas had shown MDI between -0.726 - -0.484, whereby the Northern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.975 - -0.531 were observed. Majority of the areas had shown MDI between -0.826 - -0.531, whereby the South-East part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.921 - -0.403 were observed. Majority of the areas had shown MDI between -0.661 - -0.532, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.813 - -0.333 were observed. Majority of the areas had shown MDI between -0.653 - -0.333, whereby the Central and Western parts of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -1.312 - -0.467 were observed. Majority of the areas had shown MDI between -1.099 - -0.678, whereby the Eastern part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually decreased since sub-period 1988-1992. Lowest MDI was observed in 2008-2012. MDI then increased and peak MDI was observed in 2013-2017. Besides, the Eastern and Central parts had relatively shown higher MDI over the sub-periods, except for 1993-1997 that relatively showed high MDI at station 5482001 and 5582001. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes of 1994-1995, 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, MDI between -0.994 - -0.620 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.807 - -0.620, whereby the North-West part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.726 - -0.484 were observed. Majority of the areas had shown MDI between -0.726 - -0.606, whereby the whole region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.678 - -0.382 were observed. Majority of the areas had shown MDI between -0.678 - -0.382, whereby the Northern and Eastern parts of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.790 - -0.403 were observed. Majority of the areas had shown MDI between -0.790 - -0.532, whereby the Northern, Eastern and North-West parts of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.813 - -0.494

were observed. Majority of the areas had shown MDI between -0.813 - -0.494, whereby the Western, Southern and Eastern parts of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -0.888 - -0.467 were observed. Majority of the areas had shown MDI between -0.888- -0.467, whereby the Northern part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually decreased since sub-period 1988-1992. Lowest MDI was observed in 1998-2002. MDI then gradually increased and peak MDI was observed in 2013-2017. Besides, the Eastern part had relatively shown higher MDI over the sub-periods, except for 1988-1992 and 2013-2017 that relatively showed high MDI at station 1996090, 1897016 and 1698007. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDI between -0.994 - -0.433 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.807 - -0.620, whereby the Northern and South-West parts of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.970 - -0.363 were observed. Majority of the areas had shown MDI between -0.726 - -0.484, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.978 - -0.382 were observed. Majority of the areas had shown MDI between -0.826- -0.531, whereby the Western part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.921 - -0.274 were observed. Majority of the areas had shown MDI between -0.661 - -0.403, whereby the Eastern and Western parts of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -1.135 - -0.333 were observed. Majority of the areas had shown MDI between -0.813 - -0.494, whereby the Northern part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -0.888 - -0.255 were observed. Majority of the areas had shown MDI between -0.888- -0.467, whereby the Northern part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually decreased since sub-period 1988-1992.Lowest MDI was observed in 2003-2007. MDI then gradually increased and peak MDI was observed in 2013-2017. Besides, the Western part had relatively shown higher MDI over the sub-periods, except for 1993-1997, 2008-2012, 2013-2017 that relatively showed high MDI at station 2346001,1947001, 3850020 and 3847035. Given the location of these stations located in inland area, the high MDI could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block the North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDI between -1.369 - -0.808 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.994 - -0.808, whereby the Northern part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.726 - -0.484 were observed. Majority of the areas had shown MDI between -0.726 - -0.484, whereby the Eastern, Northern and Western parts of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.826 - -0.382 were observed. Majority of the areas had shown MDI between -0.826- -0.531, whereby the Western and Southern parts of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0790 - -0.532 were observed. Majority of the areas had shown MDI between -0.661 - -0.532, whereby the South-East part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.653 - -0.333 were observed. Majority of the areas had shown MDI between -0.653- -0.494, whereby the whole region had shown higher values of MDI, except for the Northern part. In sub-period 2013-2017, MDI between -0.888 - -0.467 were observed. Majority of the areas had shown MDI between -0.888- -0.467, whereby the Southern part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI then decreased and lowest MDI was observed in 1993-1997. MDI then gradually increased and remained in the following periods. Besides, the Southern part had relatively shown higher

MDI over the sub-periods, except for 1988-1992, 1993-1997 that relatively showed high MDI at station 6168001. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

In **Region 5**, MDI between -0.994 - -0.433 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.807 - -0.620, whereby the whole region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.970 - -0.484 were observed. Majority of the areas had shown MDI between -0.726 - -0.484, whereby the Central part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.975 - -0.531 were observed. Majority of the areas had shown MDI between -0.826- -0.679, whereby the Northern, Western and Southern parts of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0790 - -0.403 were observed. Majority of the areas had shown MDI between -0.661 - -0.532, whereby the Northern and Central parts of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.831 - -0.333 were observed. Majority of the areas had shown MDI between -0.653- -0.333, whereby the South-East part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -0.677 - -0.255 were observed. Majority of the areas had shown MDI between -0.677- -0.467, whereby the whole region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually increased in sub-period 1988-1992, and peak MDI was observed in 1998-2002. MDI then decreased and lowest MDI was observed in 2008-2012. MDI then gradually increased and remained in the following periods. Besides, the Northern part had relatively shown higher MDI over the sub-periods, except for 1993-1997, 2008-2012 that relatively showed high MDI at station 5061001 and 4764002. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Trusmadi which is located near to the stations. Banjaran Trusmadi could block the North-East

Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

In **Region 6**, MDI between -1.181 - -0.433 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.807 - -0.433, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.848 - -0.363 were observed. Majority of the areas had shown MDI between -0.605 - -0.363, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.975 - -0.531 were observed. Majority of the areas had shown MDI between -0.826- -0.679, whereby the Northern and Eastern parts of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.790 - -0.403 were observed. Majority of the areas had shown MDI between -0.661 - -0.532, whereby the Western part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -1.135 - -0.494 were observed. Majority of the areas had shown MDI between -0.973- -0.654, whereby the Southern part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -0.888 - -0.255 were observed. Majority of the areas had shown MDI between -0.677- -0.467, whereby the Western part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually decreased since sub-period 1988-1992, and lowest MDI was observed in 1993-1997. MDI then increased and peak MDI was observed in 2008-2012. MDI then decreased and remained in the following period. Besides, the Eastern part had relatively shown higher MDI over the sub-periods, except for 2003-2007, 2008-2012, 2013-2017 that relatively showed high MDI at station 4450001 and 3950020. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes that had occurred in 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDI between -0.994 - -0.433 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.807 - -0.620, whereby the Western part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.848 - -0.484 were observed. Majority of the areas had shown MDI between -0.848 - -0.606, whereby the Southern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.826 - -0.382 were observed. Majority of the areas had shown MDI between -0.678 - -0.531, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.921 - -0.532 were observed. Majority of the areas had shown MDI between -0.790 - -0.532, whereby the Southern part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.973 - -0.494 were observed. Majority of the areas had shown MDI between -0.813- -0.494, whereby the Southern part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -1.099 - -0.467 were observed. Majority of the areas had shown MDI between -0.888- -0.467, whereby the Northern part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually decreased since sub-period 1988-1992, and lowest MDI was observed in 2008-2012. MDI then increased and peak MDI was observed in 2013-2017. Besides, the Southern part had relatively shown higher MDI over the sub-periods, except for 1988-1992, 1998-2002, 2013-2017 that relatively showed high MDI at station 905039, 2320026 and 2024001. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

In **Region 8**, MDI between -0.994 - -0.433 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.994 - -0.808, whereby the Northern part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.848 - -0.484 were observed. Majority of the areas had shown MDI between -0.726 - -0.484, whereby the Western part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.826 - -0.382 were observed. Majority of the areas had shown MDI between -0.826- -0.531, whereby the Northern and Western parts of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.790 - -0.403 were observed. Majority of the areas had shown MDI between -0.790 - -0.532, whereby the Southern and Western parts of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.653 - -0.333 were observed. Majority of the areas had shown MDI between -0.653- -0.333, whereby the Southern part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -0.888 - -0.255 were observed. Majority of the areas had shown MDI between -0.677- -0.467, whereby the Eastern part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI gradually decreased in 1993-1997 and lowest MDI observed in 2008-2012. MDI then increased in the following period. Besides, the Western and Southern parts had relatively shown higher MDI over the sub-periods, except for 1988-1992, 2013-2017 that relatively showed high MDI at station 6670001 and 5875001. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes of 1987-1988, 1991-1992, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDI between -0.994 - -0.433 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.807 - -0.620, whereby the South-West part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.970 - -0.606 were observed. Majority of the areas had shown MDI between -0.848 - -0.606, whereby the North-East part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.826 - -0.382 were observed. Majority of the areas had shown MDI between -0.826- -0.531, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.790 - -0.274 were observed. Majority of the areas had shown MDI between -0.661 - -0.403, whereby the Central part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.813 - -0.333 were observed. Majority of the areas had shown MDI between -0.813- -0.494, whereby the Western part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -0.888 - -0.255 were observed. Majority of the areas had shown MDI between -0.888- -0.467, whereby the Northern and Western parts of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually decreased since sub-period 1988-1992 and lowest MDI was observed in 2003-2007. MDI then gradually increased and peak MDI was observed in 2013-2017. Besides, the Western and Southern part had relatively shown higher MDI over the sub-periods, except for 1988-1992, 2013-2017 that relatively showed high MDI at station 2325039 and 2520052. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Kapuas Hulu which is located near to the stations. Banjaran Kapuas Hulu could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

4.5.3 SPI-6

Mean drought intensity is the mean of drought magnitude within a study period. SPI at 6-month timescale was utilised in order to study the spatial variations of MDI as shown in Figure 4.12. The colour depth from yellow to red indicates the level of MDI from lowest to highest category.

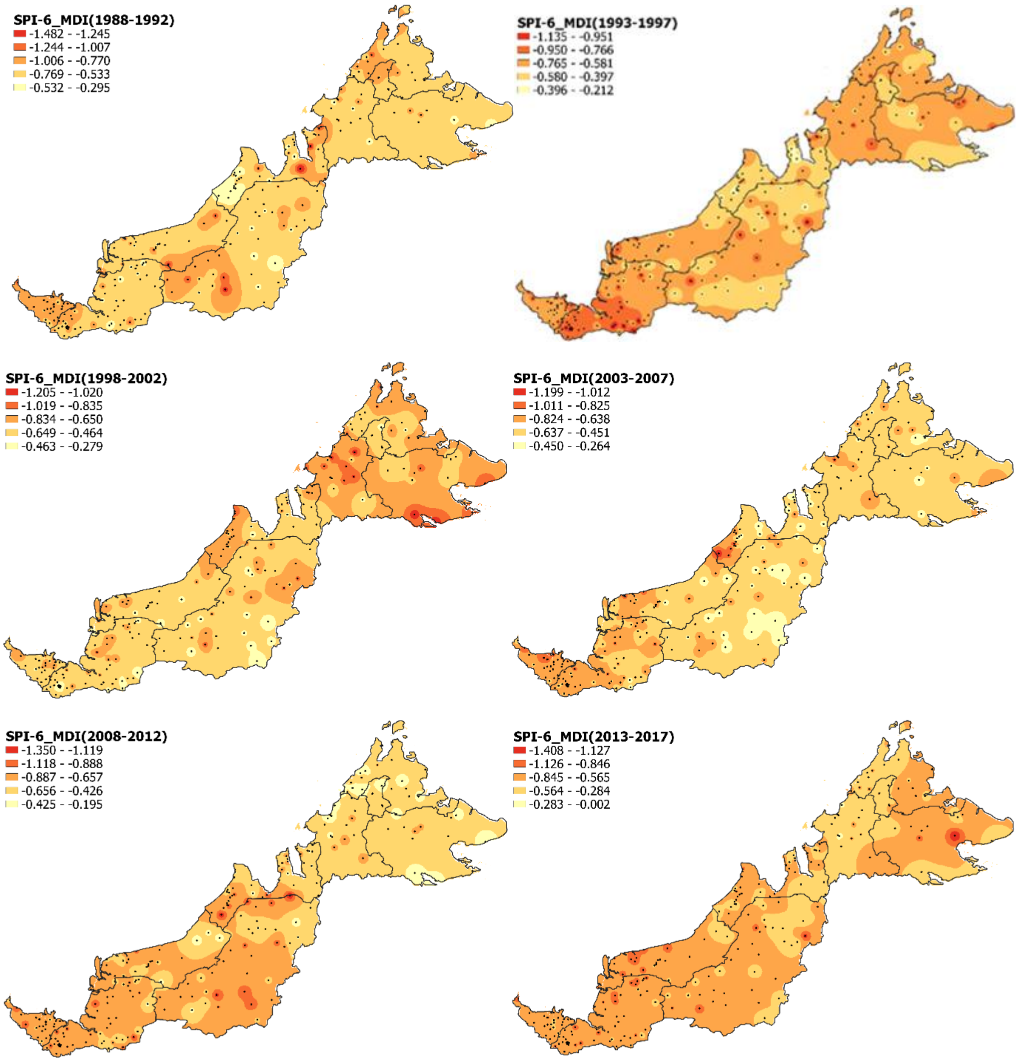

Figure 4.12: Mean Drought Intensity maps of SPI-6 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDI between -1.006- -0.295 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.769 - -0.535, whereby the whole region had shown higher values of MDI, except for the South-East. In sub-period 1993-1997, MDI between -0.950 - -0.212 were observed. Majority of the areas had shown MDI between -0.765- -0.397, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -1.205 - -0.464 were observed. Majority of the areas had shown MDI between -0.834 - -0.464, whereby the Southern part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.824 - -0.264 were observed. Majority of the areas had shown MDI between -0.637 - -0.451, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.887 - -0.195 were observed. Majority of the areas had shown MDI between -0.656 - -0.426, whereby the Central part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -1.408 - -0.284 were observed. Majority of the areas had shown MDI between -0.845- -0.284, whereby the Central part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI then gradually decreased in 1993-1997 and lowest MDI was observed in 2013-2017. Besides, the Central and Eastern part of the region had relatively shown high MDI over the sub-periods, except for 1998-2002 that relatively showed high MDI at station 4474002. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes that had occurred in 1997-1998, 2002-2003 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, MDI between -1.006- -0.533 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -1.006 - -0.770, whereby the whole region had shown higher values of MD. In sub-period 1993-1997, MDI between -0.950 - -0.581 were observed. Majority of the areas had shown MDI between -0.765- -0.581, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.834 - -0.464 were observed. Majority of the areas had shown MDI between -0.834 - -0.464, whereby the Western and Eastern parts of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -1.011 - -0.638 were observed. Majority of the areas had shown MDI between -0.824 - -0.638, whereby the Northern part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -1.118 - -0.657 were observed. Majority of the areas had shown MDI between -0.887 - -0.657, whereby the Western part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -0.845 - -0.284 were observed. Majority of the areas had shown MDI between -0.845- -0.565, whereby the whole region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI then gradually decreased since 1993-1997 and lowest MDI was observed in 1998-2002. MDI then gradually increased in the following periods. Besides, the Western part of the region had relatively shown high MDI over the sub-periods, except for 1993-1997, 2003-2007 that relatively showed high MDI at station 1506001, 1507093, 1603058. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes that had occurred in 1994-1995, 1997-1998, 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDI between -1.244 - -0.295 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -1.006 - -0.533, whereby the Southern part of the region had shown higher values of MD. In sub-period 1993-1997, MDI between -0.950 - -0.212 were observed. Majority of the areas had shown MDI between -0.765- -0.397, whereby the Eastern and Western parts of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.834 - -0.279 were observed. Majority of the areas had shown MDI between -0.834 - -0.464, whereby the Eastern part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.824 - -0.264 were observed. Majority of the areas had shown MDI between -0.637 - -0.264, whereby the Southern part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -1.118 - -0.195 were observed. Majority of the areas had shown MDI between -0.887 - -0.426, whereby the Central part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -1.126 - -0.284 were observed. Majority of the areas had shown MDI between -0.845- -0.284, whereby the Eastern and Southern parts of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI then gradually decreased and lowest MDI was observed in 2003-2007. MDI then increased in the following periods. Besides, the Southern and Eastern parts of the region had relatively shown high MDI over the sub-periods, except for 2008-2012 that relatively showed high MDI at station 2141048 and 1843001. Given the location of these stations located in inland area, the high MDI could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block the North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDI between -1.006 - -0.533 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -1.006 - -0.533, whereby the Northern part of the region had shown higher values of MD. In sub-period 1993-1997, MDI between -0.950 - -0.397 were observed. Majority of the areas had shown MDI between -0.765- -0.397, whereby the North-East part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.834 - -0.279 were observed. Majority of the areas had shown MDI between -0.649 - -0.464, whereby the South-West part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.637 - -0.451 were observed. Majority of the areas had shown MDI between -0.637 - -0.451, whereby the whole region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.656 - -0.195 were observed. Majority of the areas had shown MDI between -0.656 - -0.426, whereby the whole region had shown higher values of MDI, except for the Northern part. In sub-period 2013-2017, MDI between -0.845 - -0.284 were observed. Majority of the areas had shown MDI between -0.564- -0.284, whereby the whole region had shown higher values of MDI, except South-East.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI gradually in sub-period 1988-1992. MDI then gradually decreased and lowest MDI was observed in 2013-2017. Besides, the Northern part of the region had relatively shown high MDI over the sub-periods, except for 1998-2002, 2008-2012 that relatively showed high MDI at station 5966001, 6168002 and other stations near to it. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

In **Region 5**, MDI between -1.006 - -0.295 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.769 - -0.533, whereby the Northern part of the region had shown higher values of MD. In sub-period 1993-1997, MDI between -0.950 - -0.397 were observed. Majority of the areas had shown MDI between -0.765- -0.581, whereby the North-East part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -1.019- -0.464 were observed. Majority of the areas had shown MDI between -1.019 - -0.464, whereby the South-West part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.824 - -0.451 were observed. Majority of the areas had shown MDI between -0.637 - -0.451, whereby the whole region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.887 - -0.195 were observed. Majority of the areas had shown MDI between -0.656 - -0.426, whereby the whole region had shown higher values of MDI, except Northern part. In sub-period 2013-2017, MDI between -0.845 - -0.002 were observed. Majority of the areas had shown MDI between -0.845- -0.284, whereby the whole region had shown higher values of MDI, except for the South-East part.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually increased in sub-period 1988-1992, and peak MDI was observed in 1998-2002. MDI then gradually decreased and lowest MDI was observed in 2013-2017. Besides, the Northern part of the region had relatively shown high MDI over the sub-periods, except for 1998-2002, 2008-2012 that relatively showed high MDI at station 5163002, 5361003 and 5462001. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

In **Region 6**, MDI between -1.482 - -0.295 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -1.244 - -0.533, whereby the Central part of the region had shown higher values of MD. In sub-period 1993-1997, MDI between -0.950 - -0.212 were observed. Majority of the areas had shown MDI between -0.765- -0.397, whereby the Northern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -1.019- -0.279 were observed. Majority of the areas had shown MDI between -0.834 - -0.464, whereby the Western part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -1.011 - -0.264 were observed. Majority of the areas had shown MDI between -0.637 - -0.451, whereby the Western part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -1.118 - -0.426 were observed. Majority of the areas had shown MDI between -0.887 - -0.426, whereby the Western part of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -0.845 - -0.284 were observed. Majority of the areas had shown MDI between -0.845- -0.284, whereby the Western and Northern parts of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI then gradually decreased and lowest MDI was observed in 2013-2017. Besides, the Western part of the region had relatively shown high MDI over the sub-periods, except for 1988-1992, 1993-1997 that relatively showed high MDI at station 4450001, 4752022 and 4653001. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes of 1987-1988, 1991-1992, 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDI between -1.006 - -0.295 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.769 - -0.533, whereby the Western part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -1.135 - -0.397 were observed. Majority of the areas had shown MDI between -0.950- -0.581, whereby the Southern part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.834 - -0.297 were observed. Majority of the areas had shown MDI between -0.649- -0.464, whereby the Western part of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.824 - -0.451 were observed. Majority of the areas had shown MDI between -0.824 - -0.451, whereby the Western, Southern and Northern parts of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -1.118 - -0.426

were observed. Majority of the areas had shown MDI between -0.887 - -0.426, whereby the Western and Eastern parts of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -1.126 - -0.284 were observed. Majority of the areas had shown MDI between -0.845- -0.565, whereby the Northern part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually increased in sub-period 1988-1992, and peak MDI was observed in 1993-1997. MDI then gradually decreased and lowest MDI was observed in 2003-2007. MDI then increased and remained for the following periods. Besides, the Western part of the region had relatively shown high MDI over the sub-periods, except for 1993-1997, 2013-2017 that relatively showed high MDI at station 1018002, 1015001 and 2219016. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

In **Region 8**, MDI between -1.006 - -0.533 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -0.769 - -0.533, whereby the Western part of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.950 - -0.581 were observed. Majority of the areas had shown MDI between -0.950- -0.766, whereby the Southern and Western parts of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.834 - -0.464 were observed. Majority of the areas had shown MDI between -0.834- -0.464, whereby the Northern and Eastern parts of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.824 - -0.264 were observed. Majority of the areas had shown MDI between -0.824 - -0.264, whereby the Central part of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.656 - -0.195 were observed. Majority of the areas had shown MDI between -0.656 - -0.426, whereby the Northern, Eastern and Southern parts of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -0.845 - -0.284

were observed. Majority of the areas had shown MDI between -0.845- -0.284, whereby the Eastern part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown MDI gradually increased in sub-period 1988-1992, and peak MDI was observed in 1993-1997. MDI then gradually decreased and lowest MDI was observed in 2003-2007. MDI then increased and remained for the following periods. Besides, the Western and Eastern part of the region had relatively shown high MDI over the sub-periods, except for 2003-2007 that relatively showed high MDI at station 6770001 and 6172001. Given the location of the stations being near to seashore, the high MDI could be affected by the El-Niño episodes of 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDI between -1.244 - -0.533 were observed in sub-period 1988-1992. Majority of the areas had shown MDI between -1.006 - -0.533, whereby the Southern and Northern parts of the region had shown higher values of MDI. In sub-period 1993-1997, MDI between -0.950 - -0.397 were observed. Majority of the areas had shown MDI between -0.950- -0.397, whereby the Western part of the region had shown higher values of MDI. In sub-period 1998-2002, MDI between -0.834 - -0.279 were observed. Majority of the areas had shown MDI between -0.649- -0.464, whereby the Northern and Western parts of the region had shown higher values of MDI. In sub-period 2003-2007, MDI between -0.824 - -0.264 were observed. Majority of the areas had shown MDI between -0.824 - -0.451, whereby the Western and Northern parts of the region had shown higher values of MDI. In sub-period 2008-2012, MDI between -0.887 - -0.195 were observed. Majority of the areas had shown MDI between -0.887 - -0.426, whereby the Western, Central and Southern parts of the region had shown higher values of MDI. In sub-period 2013-2017, MDI between -1.126 - -0.284 were observed. Majority of the areas had shown MDI between -0.845- -0.284, whereby the Western part of the region had shown higher values of MDI.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDI in sub-period 1988-1992. MDI then gradually decreased and lowest MDI was observed in 2013-2017. Besides, the Western part of the region had relatively shown high MDI over the sub-periods, except for 1988-1992 that relatively showed high MDI at station 2325039. Given the location of these stations located in inland area, the high MDI could be affected by Banjaran Kapuas Hulu which is located near to the stations. Banjaran Kapuas Hulu could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDI in a specific area.

4.5.4 Summary

According to the analysis with the SPI-1, the occurrence of MDI was the highest in sub-period 1988-1992 as compared to other sub-periods. Peak MDI with the range of -1.119 - -1.006 had occurred in Region 3 of East Malaysia, and it was predicted that the high MDI was caused by mountainous topography due to the location of drought events. In sub-period 1993-1997, the occurrence of MDI was considered high among the sub-periods. Peak MDI with the range of -1.017 - -0.911 had occurred in Region 3 of East Malaysia. By referring to the location of drought events, it was predicted that high MDI was caused by mountainous topography as well. On average, the occurrence of MDI was considered low in sub-period 1998-2002. Peak MDI with the range of -1.157 - -1.016 had occurred in Region 1 of East Malaysia, and it was caused by El-Niño episodes due to its location being near to seashore. For sub-period 2003-2007, the occurrence of MDI was low among the sub-periods. Peak MDI with the range of -1.062 - -0.947 was observed in Region 8 of East Malaysia, and it was predicted that the high MDI was caused by mountainous topography. For sub-period, 2008-2012, peak MDI with the range of -0.994 - -0.883 was observed in Region 3 of East Malaysia, and it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak MDI with the range of -1.014 - -0.893 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. In overall, SPI-1 had shown that peak MDI had occurred often in Central part of East Malaysia. Besides, Region 3 had shown most occurrence of peak MDI. Regarding the location of MDI, peak MDI were mostly caused by mountainous topography rather than El-Niño episodes.

As for the SPI-3 analysis, the occurrence of MDI was low in sub-period 1988-1992 as compared to other sub-periods. Peak MDI with the range of -1.369

- -1.182 had occurred in Region 4 of East Malaysia, and it was predicted that the high MDI was caused by mountainous topography due to the location of drought events. In sub-period 1993-1997, the occurrence of MDI was considered high among the sub-periods. Peak MDI with the range of -0.970 - -0.849 had occurred in Region 7 of East Malaysia. By referring to the location of drought events, it was predicted that high MDI was caused by mountainous topography as well. On average, the occurrence of MDI was considered low in sub-period 1998-2002. Peak MDI with the range of -1.124 - -0.976 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, the occurrence of MDI was the highest among sub-periods. Peak MDI with the range of -0.921 - -0.791 was observed in Region 1 of East Malaysia, and it was predicted that the high MDI was caused by El-Niño episodes due to its location being near to seashore. For sub-period, 2008-2012, peak MDI with the range of -1.135 - -0.974 was observed in Region 6 of East Malaysia. However, it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak MDI with the range of -1.312 - -1.100 was observed in Region 1 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. In overall, SPI-3 had shown that peak MDI had occurred often in the Eastern part of East Malaysia. Besides, Region 1 had most showed most occurrence of peak MDI. Regarding the location of MDI, peak MDI were mostly caused by mountainous topography rather than El-Niño episodes.

For the SPI-6 scenario, the occurrence of MDI was low in sub-period 1988-1992 as compared to other sub-periods. Peak MDI with the range of -1.482 - -1.245 had occurred in Region 6 of East Malaysia, and it was predicted that the high MDI was caused by El-Niño episodes due to its location being near to seashore. In sub-period 1993-1997, the occurrence of MDI was the highest among the sub-periods. Peak MDI with the range of -1.135 - -0.951 had occurred in Region 7 of East Malaysia. By referring to the location of drought events, it was predicted that high MDI was caused by mountainous topography. On average, the occurrence of MDI was considered low in sub-period 1998-2002. Peak MDI with the range of -1.205 - -1.020 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, the occurrence of MDI was the lowest among sub-periods. Peak

MDI with the range of -1.199 - -1.012 was observed in Region 6 of East Malaysia, and it was predicted that the high MDI was caused by El-Niño episodes due to its location being near to seashore. For sub-period, 2008-2012, peak MDI with the range of -1.330 - -1.119 was observed in Region 6 of East Malaysia. However, it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak MDI with the range of 1.408 - -1.127 was observed in Region 1 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. In overall, SPI-6 had shown that peak MDI had occurred often in the Central part of East Malaysia. Besides, Region 6 had shown most occurrence of peak MDI. Regarding the location of MDI, peak MDI were mostly due to the mountainous topography rather than El-Niño episodes.

4.6 Mean Drought Peak

4.6.1 SPI-1

Mean drought peak is the mean of lowest drought index value within a study period. SPI at 1-month timescale was utilised in order to study the spatial variations of MDP as shown in Figure 4.13. The colour depth from yellow to red indicates the level of MDP from lowest to highest category.

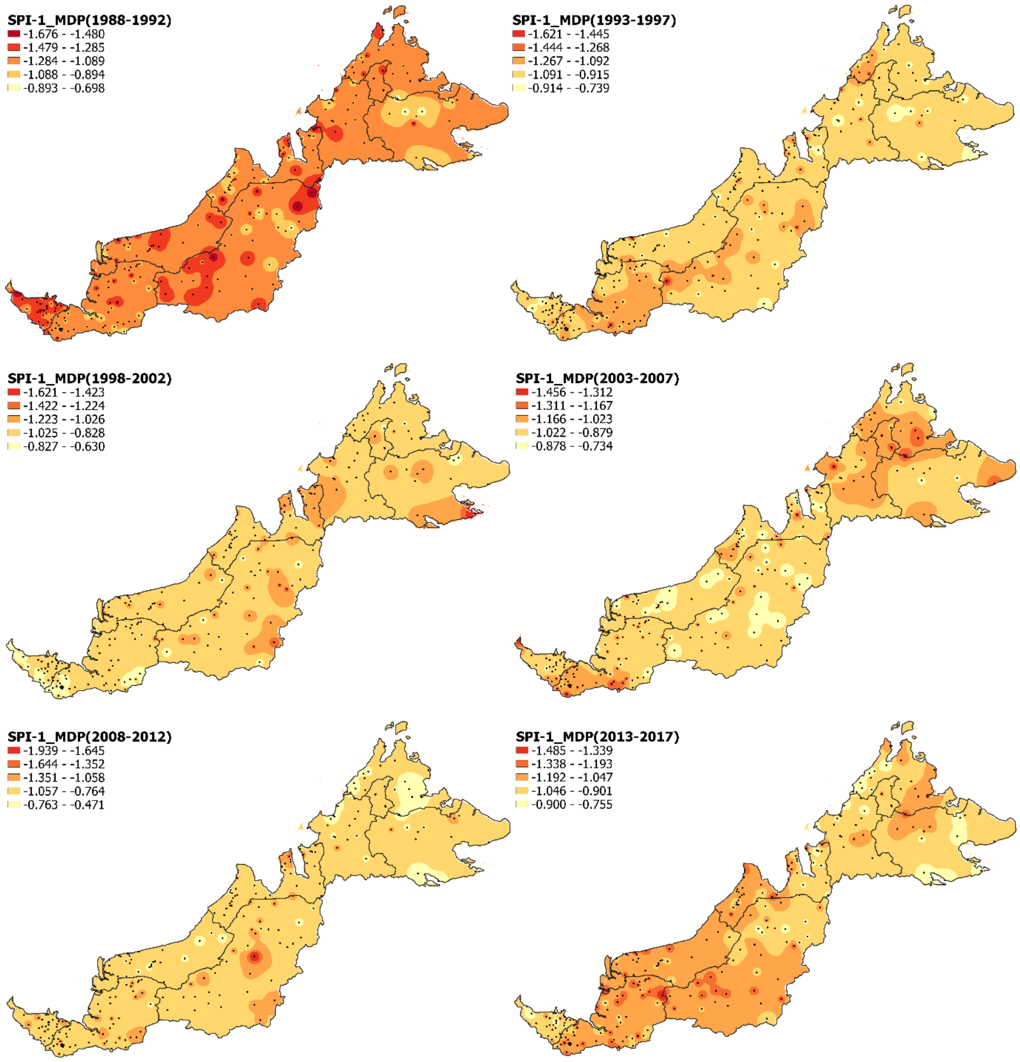

Figure 4.13: Mean Drought Peak maps of SPI-1 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDP between -1.479 - -0.698 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.284 - -0.894, whereby the Centre part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.267 - -0.739 were observed. Majority of the areas had shown MDP between -1.091 - -0.739, whereby the Centre of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.621 - -0.630 were observed. Majority of the area had shown MDP between -0.733 - -0.593, whereby the South-East part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.311 - -0.734 were observed, majority of the areas showed MDP between -1.166 - -0.879, whereby the Eastern part of the region had shown higher value of MDP. In sub-period 2008-2012, MDP between -1.351 - -0.471 were observed. Most of the areas showed MDP between -1.057 - -0.764, whereby the South-East part had shown higher MDP. In sub-period 2013-2017, MDP between -1.192 - -0.755 were observed. Majority areas had shown MDP between -1.192 - -0.901, whereby the Northern part had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then gradually decreased and lowest MDP was observed in 1993-1997. MDP then increased and remained for the following periods. Besides, the Central and Eastern parts had relatively shown higher MDP over the sub-periods, except for sub-period 2013-2017 that relatively showed high MDP at station 5671002. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Trusmadi which is located near to the stations. Banjaran Trusmadi could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 2**, MDP between -1.479 - -0.894 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.479 - -1.089, whereby the Centre and Northern parts of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.267 - -0.739 were observed. Majority of the areas had shown MDP between -1.091 - -0.739, whereby the Southern of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.025 - -0.630 were observed. Majority of the area had shown MDP between -1.025 - -0.630 whereby the Eastern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.311 - -0.734 were observed, majority of the areas showed MDP between -1.166 - -0.879, whereby the North-West part of the region had shown higher value of MDP. In sub-period 2008-2012, MDP between -1.351 - -0.764 were observed. Most of the areas showed MDP between -1.057 - -0.764, whereby the Western part had shown higher MDP. In sub-period 2013-2017, MDP between -1.192 - -0.755 were observed. Majority areas had shown MDP between -1.046 - -0.901, whereby the Northern part had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then gradually decreased and lowest MDP was observed in 1998-2002. MDP then increased and remained for the following periods. Besides, the Northern and Western parts had relatively shown higher MDP over the sub-periods, except for sub-period 1993-1997 and 1998-2002 that relatively showed high MDP at station 1204024, 1404049 and stations near to it. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes as had happened in 1994-1995, 1997-1998 and 2002-2003 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDP between -1.676 - -0.698 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.479 - -1.089, whereby the North-East part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.444 - -0.739 were observed. Majority of the areas had shown MDP between -1.267 - -0.915, whereby the Western of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.422 - -0.630 were observed. Majority of the area had shown MDP between -1.223 - -0.828 whereby the Eastern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.166 - -0.734 were observed, majority of the areas showed MDP between -1.022 - -0.879, whereby the Northern part of the region had shown higher value of MDP. In sub-period 2008-2012, MDP between -1.393 - -0.764 were observed. Most of the areas showed MDP between -1.644 - -1.058, whereby the Centre part had shown higher MDP. In sub-period 2013-2017, MDP between -1.338- -0.755 were observed. Majority areas had shown MDP between -1.192 - -0.901, whereby the Western part had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown MDP gradually decreased since sub-period 1988-1992 and lowest MDP was observed in 1998-2002. MDP then increased and remained, as peak MDP was observed in 2008-2012. Besides, the Northern and Western parts had relatively shown higher MDP over the sub-periods, except for sub-period 1998-2002 and 2008-2012 that relatively showed high MDP at station 1947001 and 2442001. Given the location of these stations located in inland area, the high

MDP could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block the North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDP between -1.479 - -1.089 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.284 - -1.089, whereby the North-East part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.267 - -0.915 were observed. Majority of the areas had shown MDP between -1.091 - -0.915, whereby the North-West of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.223 - -0.630 were observed. Majority of the area had shown MDP between -1.025 - -0.828 whereby the Western part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.311 - -0.879 were observed, majority of the areas showed MDP between -1.311 - -1.023, whereby the Southern part of the region had shown higher value of MDP. In sub-period 2008-2012, MDP between -1.057 - -0.764 were observed. The whole region had shown MDP between -1.057 - -0.764, whereby the Southern part had shown higher MDP. In sub-period 2013-2017, MDP between -1.192- -0.901 were observed. Majority areas had shown MDP between -1.046 - -0.901, whereby the Western part had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown MDP gradually increased since sub-period 1988-1992 and peak MDP was observed in 2003-2007. MDP then decreased and remained, as lowest MDP was observed in 2008-2012. Besides, the Northern and Western part had relatively shown higher MDP over the sub-periods, except for sub-period 2003-2007 that relatively showed high MDP at station 5768001 and 6168002. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 5**, MDP between -1.479 - -0.894 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.284 - -1.089, whereby the Western part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.267 - -0.739 were observed. Majority of the areas had shown MDP between -1.091 - -0.915, whereby the Eastern of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.223 - -0.828 were observed. Majority of the area had shown MDP between -1.223 - -0.828 whereby the Western part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.311 - -0.879 were observed, majority of the areas showed MDP between -1.166 - -0.879, whereby the Western part of the region had shown higher value of MDP. In sub-period 2008-2012, MDP between -1.351- -0.471 were observed. Majority of the region had shown MDP between -1.057 - -0.764, whereby the Western part had shown higher MDP. In sub-period 2013-2017, MDP between -1.192- -0.755 were observed. Majority areas had shown MDP between -1.046 - -0.901, whereby the Central part had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then decreased and remained, as lowest MDP was observed in 2008-2012. MDP then increased in the following period. Besides, the Western part had relatively shown higher MDP over the sub-periods, except for sub-period 1993-1997 and 2013-2017 that relatively showed high MDP at station 5163002 and 5061001. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 6**, MDP between -1.479 - -0.894 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.284 - -1.089, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.267 - -0.739 were observed. Majority of the areas had shown MDP between -1.091 - -0.915, whereby the Eastern of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.223 - -0.828 were observed. Majority of the area had shown MDP between -1.223 - -0.828 whereby the Eastern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.311 - -0.734 were observed, majority of the areas showed MDP between -1.166 - -0.879, whereby the Western part of the region had shown higher value of MDP. In sub-period 2008-2012, MDP between -1.351- -0.764 were observed. Majority of the region had shown MDP between -1.057 - -0.764, whereby the Northern part had shown higher MDP. In sub-period 2013-2017, MDP between -1.338- -0.755 were observed. Majority areas had shown MDP between -1.192 - -0.901, whereby the Centre part had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then decreased and remained, as lowest MDP was observed in 2008-2012. MDP then increased in the following period. Besides, the Eastern part had relatively shown higher MDP over first 3 sub-periods. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes as had happened in 1987-1988, 1991-1992, 1994-1995, 1997-1998 and 2002-2003 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDP between -1.479 - -0.894 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.284 - -1.089, whereby the Central part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.267 - -0.739 were observed. Majority of the areas had shown MDP between -1.091 - -0.915, whereby the South-East of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.223 - -0.630 were observed. Majority of the area had shown MDP between -1.025 - -0.630 whereby the Central, Northern and Eastern parts of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.311 - -0.734 were observed, majority of the areas showed MDP between -1.166 - -0.879, whereby the Southern part of the region had shown higher value of MDP. In sub-period 2008-2012, MDP between -1.351- -0.471 were observed. Majority of the region had shown MDP between -1.057 - -0.764, whereby the Central part had shown higher MDP. In sub-period 2013-2017, MDP between -1.338- -0.755 were observed. Majority areas had shown MDP between -1.192 - -0.901, whereby the Eastern part had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then decreased and remained, as lowest MDP was observed in 1998-2002. MDP then increased in the following period. Besides, the Eastern and Centre part had relatively shown higher MDP over first 3 sub-periods, except 2003-2007 that relatively showed high MDP at station 1015001 and 1018002. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 8**, MDP between -1.479 - -0.894 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.284 - -1.089, whereby the Northern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.267 - -0.739 were observed. Majority of the areas had shown MDP between -1.091 - -0.915, whereby the Western of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.025 - -0.630 were observed. Majority of the area had shown MDP between -1.025 - -0.828 whereby the whole region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.311 - -0.734 were observed, majority of the areas showed MDP between -1.166 - -0.879, whereby the Southern part of the region had shown higher value of MDP. In sub-period 2008-2012, MDP between -1.057- -0.471 were observed. Majority of the region had shown MDP between -1.057 - -0.471, whereby the Northern part had shown higher MDP. In sub-period 2013-2017, MDP between -1.192- -0.755 were observed. Majority areas had shown MDP between -1.192 - -0.901, whereby the South-East part had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then decreased and remained, as lowest MDP was observed in 2008-2012. MDP then increased in the following period. Besides, the Northern and Southerns part had relatively shown higher MDP over sub-periods, except 1993-1997 that relatively showed high MDP at station 5961002, 6062001, 6162003 and stations near to it. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes of 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDP between -1.479 - -0.894 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.479 - -0.894, whereby the Central and Eastern parts of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.267 - -0.739 were observed. Majority of the areas had shown MDP between -1.091 - -0.915, whereby the Southern of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.223 - -0.630 were observed. Majority of the area had shown MDP between -1.025 - -0.828 whereby the North-East of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.166 - -0.734 were observed, majority of the areas showed MDP between -1.022 - -0.734, whereby the Western part of the region had shown higher value of MDP. In sub-period 2008-2012, MDP between -1.057- -0.471 were observed. The whole region had shown MDP between -1.057 - -0.471. In sub-period 2013-2017, MDP between -1.338- -0.901 were observed. Majority areas had shown MDP between -1.192 - -0.901, whereby the North-West part had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then decreased and remained, as lowest MDP was observed in 2008-2012. MDP then increased in the following period. Besides, the Western and Eastern parts had relatively shown higher MDP over sub-periods, except 1993-1997 that relatively showed high MDP at station 2817001 and 2818001. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes as had happened in 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

4.6.2 SPI-3

Mean drought peak is the mean of lowest drought index value within a study period. SPI at 3-month timescale was utilised in order to study the spatial variations of MDP as shown in Figure 4.14. The colour depth from yellow to red indicates the level of MDP from lowest to highest category.

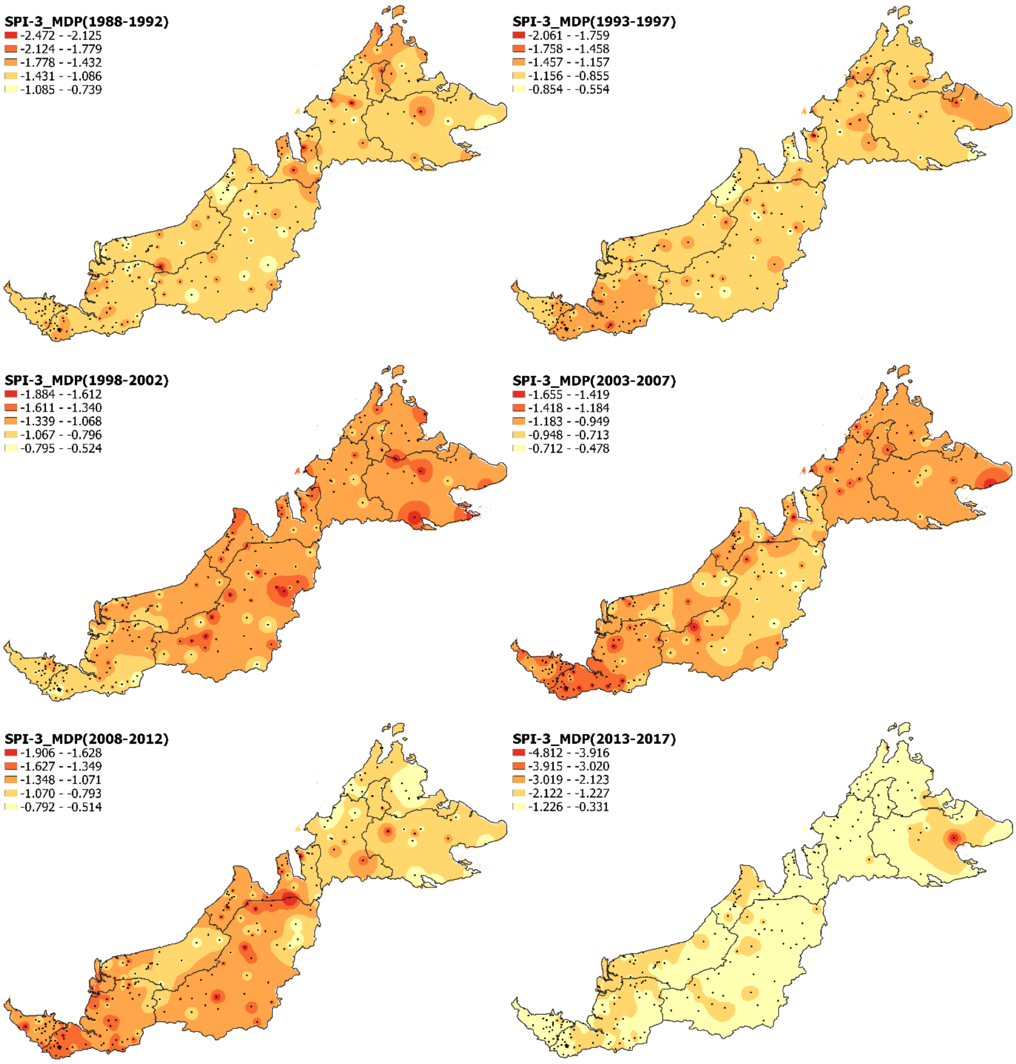

Figure 4.14: Mean Drought Peak maps of SPI-3 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDP between -2.124 - -0.739 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.778 - -1.086, whereby the Northern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.758 - -0.554 were observed. Majority of the areas had shown MDP between -1.457 - -0.855, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.884 - -0.796 were observed. Majority of the areas had shown MDP between –1.611 - -1.068, whereby the Southern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.655 - -0.713 were observed. Majority of the areas had shown MDP between -1.183 - -0.949, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.627 - -0.514 were observed. Majority of the areas had shown MDP between -1.070 - -0.793, whereby the Western part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -4.812 - -0.331 were observed. Majority of the areas had shown MDP between -2.122 - -0.331, whereby the Eastern part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then decreased and remained, as lowest MDP was observed in 2013-2017. Besides, the Eastern part had relatively shown higher MDP over the sub-periods, except for 1988-1992, 1998-1992, 2008-2012 that relatively showed high MDP at station 5274001, 5275001, 4474002 and 5269001. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Trusmadi which is located near to the stations. Banjaran Trusmadi could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 2**, MDP between -1.431 - -1.086 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.431 - -1.086, whereby the whole region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.457 - -0.855 were observed. Majority of the areas had shown MDP between -1.457 - -0.855, whereby the Eastern, North-West parts of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.339 - -0.796 were observed. Majority of the areas had shown MDP between –1.339 - -0.796, whereby the Northern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.418 - -0.949 were observed. Majority of the areas had shown MDP between -1.183 - -0.949, whereby the Northern and Eastern parts of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.627 - -0.793 were observed. Majority of the areas had shown MDP between -1.627 - -1.071, whereby the Western part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.122 - -0.331 were observed. Majority of the areas had shown MDP between -1.226 - -0.331, whereby the North-East part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown MDP gradually increased since sub-period 1988-1992, and peak MDP was observed in 2008-2012. MDP then decreased as lowest was observed in 2013-2017. Besides, the Eastern part had relatively shown higher MDP over the sub-periods, except for, 1988-1992, 2008-2012 that relatively showed high MDP at station 1499051. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the South-West Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 3**, MDP between -1.778 - -0.739 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.431 - -1.086, whereby the Northern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.457 - -0.554 were observed. Majority of the areas had shown MDP between -1.156 - -0.855, whereby the Eastern, North-West parts of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.884 - -0.524 were observed. Majority of the areas had shown MDP between –1.884 - -0.796, whereby the Eastern and Western parts of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.418 - -0.478 were observed. Majority of the areas had shown MDP between -1.183 - -0.713, whereby the Western part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.906 - -0.514 were observed. Majority of the areas had shown MDP between -1.627 - -0.793, whereby the Northern part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.122 - -0.331 were observed. Majority of the areas had shown MDP between -2.122 - -0.331, whereby the Southern and Western parts of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown MDP gradually decreased since sub-period 1988-1992, and lowest MDP was observed in 2003-2007. MDP then increased as peak was observed in 2013-2017. Besides, the Western part had relatively shown higher MDP over the sub-periods, except for 1988-1992, 2008-2012 that relatively showed high MDP at station 3950020 and 3754007. Given the location of these stations located in inland area, the high MDP could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block the North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDP between -2.124 - -1.086 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.778 - -1.086, whereby the North-East part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.457 - -0.554 were observed. Majority of the areas had shown MDP between -1.156 - -0.855, whereby the North-East part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.611 - -0.796 were observed. Majority of the areas had shown MDP between –1.339 - -0.796, whereby the whole region had shown higher values of MDP, except for the North-East. In sub-period 2003-2007, MDP between -1.418 - -0.713 were observed. Majority of the areas had shown MDP between -1.183 - -0.949, whereby the South-East part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.348 - -0.793 were observed. Majority of the areas had shown MDP between -1.070 - -0.793, whereby the whole region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.122 - -0.331 were observed. Majority of the areas had shown MDP between -1.226 - -0.331, whereby the South-East part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP was observed in sub-period 1988-1992. MDP then gradually decreased as lowest was observed in 2013-2017. Besides, the Eastern part had relatively shown higher MDP over the sub-periods, except for 1998-2002 that relatively showed high MDP at station 5768001, 6168002, 5966003 and 5966001. Given the location of these stations located in inland area, the high

MDP could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 5**, MDP between -2.124 - -0.739 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.778 - -1.086, whereby the Northern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.457 - -0.554 were observed. Majority of the areas had shown MDP between -1.457 - -0.855, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.611 - -0.796 were observed. Majority of the areas had shown MDP between –1.339 - -1.068, whereby the North-West and North-East parts of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.418 - -0.713 were observed. Majority of the areas had shown MDP between -1.183 - -0.949, whereby the Northern and Central parts of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.627 - -0.514 were observed. Majority of the areas had shown MDP between -1.348 - -0.793, whereby the South-East part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.122 - -0.331 were observed. Majority of the areas had shown MDP between -1.226 - -0.331, whereby the South-East part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP was observed in sub-period 1988-1992. MDP then gradually decreased as lowest was observed in 2013-2017. Besides, the Eastern part had relatively shown higher MDP over the sub-periods, except for 1988-1992, 2003-2007 that relatively showed high MDP at station 5462001, 5364002 and 5361003. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 6**, MDP between -2.124 - -0.739 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.778 - -1.086, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -2.061 - -0.554 were observed. Majority of the areas had shown MDP between -1.457 - -0.855, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.611 - -0.796 were observed. Majority of the areas had shown MDP between –1.611 -1.068, whereby the Northern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.418 - -0.478 were observed. Majority of the areas had shown MDP between -1.183 - -0.713, whereby the Central part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.906 - -0.793 were observed. Majority of the areas had shown MDP between -1.348 - -0.793, whereby the Southern part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.122 - -0.331 were observed. Majority of the areas had shown MDP between -2.122- -0.331, whereby the Western part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP was observed in sub-period 1988-1992. MDP then gradually decreased as lowest was observed in 2013-2017. Besides, the Eastern part of the region had shown higher MDP over the sub-periods, especially at station 4554001 and 4854001. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes as had happened in 1987-1988, 1991-1992, 1994-1995, 1997-1998, 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDP between -1.778 - -0.739 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.778 - -1.086, whereby the Southern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.758 - -0.855 were observed. Majority of the areas had shown MDP between -1.457 - -0.855, whereby the Southern part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.339 - -0.524 were observed. Majority of the areas had shown

MDP between –1.339 -0.796, whereby the Northern and Central parts of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.655 - -0.713 were observed. Majority of the areas had shown MDP between -1.418 - -0.949, whereby the Southern and Western parts of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.906 - -0.793 were observed. Majority of the areas had shown MDP between -1.348 - -0.793, whereby the Southern part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.122 - -0.331 were observed. Majority of the areas had shown MDP between -2.122- -0.331, whereby the Northern and Southern parts of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP was observed in sub-period 1988-1992. MDP then gradually decreased as lowest was observed in 2013-2017. Besides, the Southern part of the region had shown higher MDP over the sub-periods, except 1998-2002 that relatively showed high MDP in Northern part of the region. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes that had occurred in 1997-1998, 2002-2003 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 8**, MDP between -2.124 - -0.739 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.778 - -1.086, whereby the Northern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.457 - -0.855 were observed. Majority of the areas had shown MDP between -1.457 - -0.855, whereby the Eastern and Western parts of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.611 - -0.796 were observed. Majority of the areas had shown MDP between –1.611 -1.068, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.418 - -0.713 were observed. Majority of the areas had shown MDP between -1.183 - -0.949, whereby the Western part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.070 - -0.514 were observed. Majority of the areas had shown MDP between -1.070 - -0.514, whereby the Northern and Western parts of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.122 - -0.331 were observed. Majority of the areas had shown MDP between -1.226 - -0.331, whereby the Eastern part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP was observed in sub-period 1988-1992. MDP then gradually decreased as lowest was observed in 2013-2017. Besides, the Western and Eastern part of the region had shown higher MDP over the sub-periods, except 1988-1992 that relatively showed high MDP at station 6868001 and 6868002. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes as had happened in 1987-1988, 1991-1992 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDP between -2.472 - -0.739 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.778 - -1.086, whereby the Southern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.457 - -0.855 were observed. Majority of the areas had shown MDP between -1.156 - -0.855, whereby the Eastern and Central parts of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.611 - -0.796 were observed. Majority of the areas had shown MDP between –1.339 -0.796, whereby the whole region had shown higher values of MDP, except for the South-West. In sub-period 2003-2007, MDP between -1.418 - -0.478 were observed. Majority of the areas had shown MDP between -1.183 - -0.713, whereby the Western and Central parts of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.348 - -0.514 were observed. Majority of the areas had shown MDP between -1.348 - -0.793, whereby the Western part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.122 - -0.331 were observed. Majority of the areas had shown MDP between -2.122 - -0.331, whereby the Western part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP was observed in sub-period 1988-1992. MDP then gradually decreased as lowest was observed in 2013-2017. Besides, the Western part of the region had shown higher MDP over the sub-periods, except 1988-1992, 1993-1997 that relatively showed high MDP at station 3137021 and 3234022. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes that had occurred in 1987-1988, 1991-1992, 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

4.6.3 SPI-6

Mean drought peak is the mean of lowest drought index value within a study period. SPI at 6-month timescale was utilised in order to study the spatial variations of MDP as shown in Figure 4.15. The colour depth from yellow to red indicates the level of MDP from lowest to highest category.

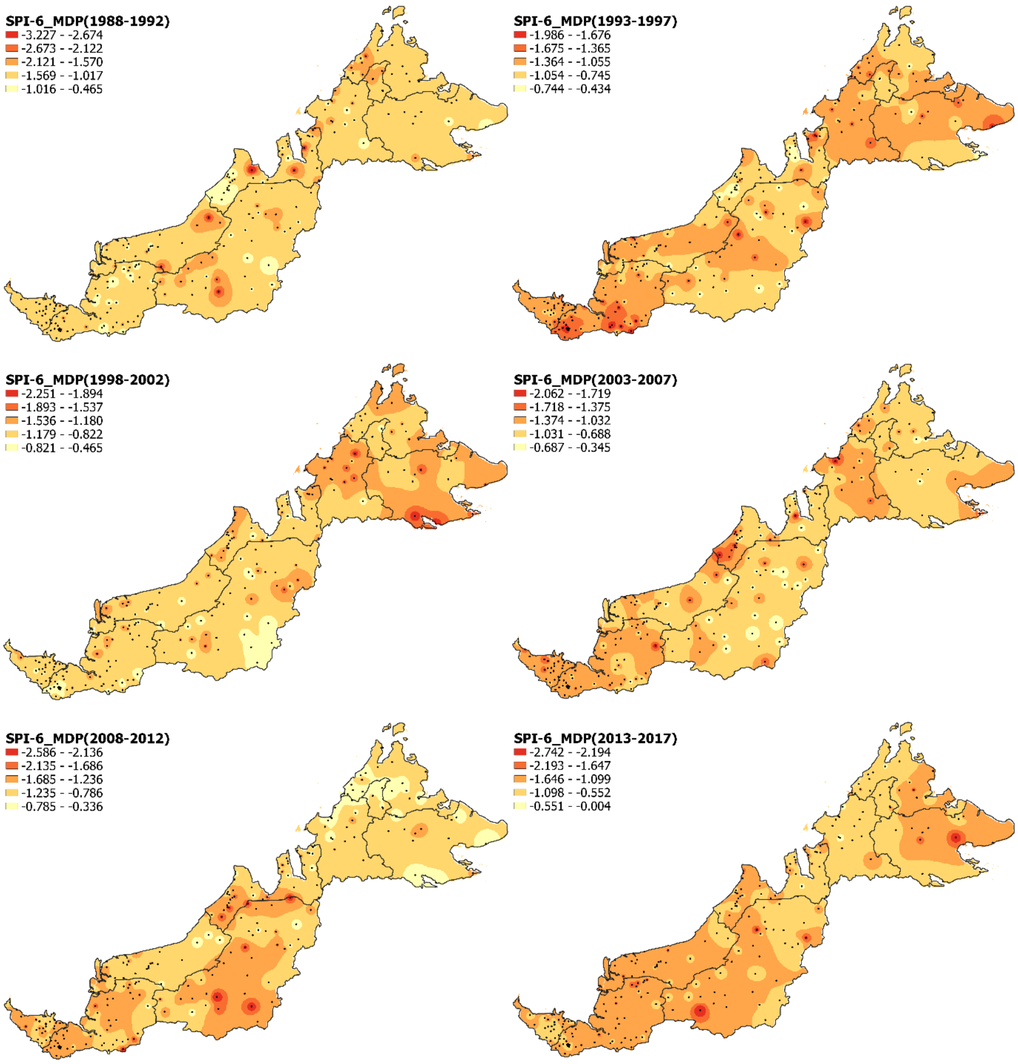

Figure 4.15: Mean Drought Peak maps of SPI-6 for each 5-years sub-period along 1988-2017.

In **Region 1**, MDP between -2.121 - -0.465 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.569 - -1.017, whereby the whole region had shown higher values of MDP, except for the Eastern part. In sub-period 1993-1997, MDP between -1.675 - -0.434 were observed. Majority of the areas had shown MDP between -1.364 - -0.745, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -2.251 - -0.822 were observed. Majority of the areas had shown MDP between -1.536 - -0.822, whereby the Southern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.374 - -0.345 were observed. Majority of the areas had shown MDP between -1.374 - -0.688, whereby the Western and Eastern parts of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.685 - -0.336 were observed. Majority of the areas had shown MDP between -1.235 - -0.786, whereby the Central part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.742 - -0.552 were observed. Majority of the areas had shown MDP between -1.646 - -0.552, whereby the Eastern part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP was observed in sub-period 1988-1992. MDP then gradually decreased as lowest was observed in 2013-2017. Besides, the Eastern part of the region had relatively shown high MDP over the sub-periods, except for 1988-1992, 1998-2002, 2008-2012 that relatively showed high MDP at station 4474002 and 5274001. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes as had happened in 1987-1988, 1991-1992, 1994-1995 and 1997-1998 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 2**, MDP between -2.121 - -1.017 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.569 - -1.017, whereby the whole region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.364 - -0.745 were observed. Majority of the areas had shown MDP between -1.364 - -1.055, whereby the whole region had shown higher values of MDP, except for the Central part. In sub-period 1998-2002, MDP between -1.536 - -0.465 were observed. Majority of the areas had shown

MDP between -1.179 - -0.822, whereby the North-West part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.718 - -1.032 were observed. Majority of the areas had shown MDP between -1.374 - -1.032, whereby the Central part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.685 - -0.786 were observed. Majority of the areas had shown MDP between -1.685 - -0.786, whereby the Western part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -1.646 - -0.552 were observed. Majority of the areas had shown MDP between -1.646 - -0.552, whereby the Western and Northern parts of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown MDP gradually decreased since sub-period 1988-1992. MDP then increased in sub-period 2003-2007, as peak was observed in 2008-2012. MDP decreased in the following period, as lowest MDP was observed in 2013-2017. Besides, the Western part of the region had relatively shown high MDP over the sub-periods, except for 2003-2007 that relatively showed high MDP at station 1502001 and 1402001. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes that had occurred in 2002-2003, 2004-2005 and 2006-2007 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 3**, MDP between -2.673 - -0.465 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -2.121- -1.017, whereby the Southern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.675 - -0.434 were observed. Majority of the areas had shown MDP between -1.364 - -0.745, whereby the Eastern and Western parts of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.536 - -0.465 were observed. Majority of the areas had shown MDP between -1.179 - -0.465, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.374 - -0.345 were observed. Majority of the areas had shown MDP between -1.031 - -0.688, whereby the Northern and South-East parts of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -2.586 - -0.336 were observed. Majority of the areas had shown MDP between -1.685 -

-0.786, whereby the Central part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.742 - -0.552 were observed. Majority of the areas had shown MDP between -1.646 - -0.552, whereby the Southern part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then decreased gradually in sub-period 1993-1997, as lowest was observed in 1998-2002. MDP then increased and remained in the following period. Besides, the Eastern and Southern part of the region had relatively shown high MDP over the sub-periods, except for 2008-2012 that relatively showed high MDP at station 2141048 and 2036001. Given the location of these stations located in inland area, the high MDP could be affected by Pergunungan Iran and Pergunungan Hose which are located near to the stations. Pergunungan Iran could block the North-East Monsoon, whereas Pergunungan Hose could block the South-West Monsoon from reaching those stations.

In **Region 4**, MDP between -2.121 - -1.017 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -2.121- -1.017, whereby the Northern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.364 - -0.745 were observed. Majority of the areas had shown MDP between -1.054 - -0.745, whereby the Northern part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.536 - -0.465 were observed. Majority of the areas had shown MDP between -1.179 - -0.822, whereby the South-West part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.374 - -0.688 were observed. Majority of the areas had shown MDP between -1.031 - -0.688, whereby the whole region had shown higher values of MDP, except for the Southern part. In sub-period 2008-2012, MDP between -1.235 - -0.336 were observed. Majority of the areas had shown MDP between -1.235 - -0.336, whereby the Southern part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -1.098 - -0.552 were observed. Majority of the areas had shown MDP between -1.098 - -0.552, whereby the whole region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then decreased gradually in sub-period 1993-1997, as lowest was observed in 2008-2012. MDP then increased in the following period. Besides, the Northern part of the region had relatively shown high MDP over the sub-periods, except for 1998-2002, 2008-2012 that relatively showed high MDP at station 6168002 and 5768001. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 5**, MDP between -2.121 - -0.465 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.569- -1.017, whereby the Western part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.675 - -0.745 were observed. Majority of the areas had shown MDP between -1.364 - -1.055, whereby the South-East part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.893 - -0.465 were observed. Majority of the areas had shown MDP between -1.536 - -0.822, whereby the Northern part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -2.062 - -0.345 were observed. Majority of the areas had shown MDP between -1.031 - -0.345, whereby the Northern part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.685 - -0.336 were observed. Majority of the areas had shown MDP between -1.685 - -0.786, whereby the whole region had shown higher values of MDP, except for the Northern part. In sub-period 2013-2017, MDP between -1.646 - -0.004 were observed. Majority of the areas had shown MDP between -1.098 - -0.552, whereby the South-East part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown MDP gradually decreased in sub-period 1988-1992, and lowest was observed in 2003-2007. MDP then increased in the following periods and peak MDP was observed in 2008-2012. Besides, the Northern and South-East parts of the region had relatively shown high MDP over the sub-periods, except for

1988-1992 that relatively showed high MDP at station 5158001 and 5159003. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Crocker which is located near to the stations. Banjaran Crocker could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 6**, MDP between -3.227 - -0.465 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.569- -0.465, whereby the Central part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.675 - -0.434 were observed. Majority of the areas had shown MDP between -1.364 - -0.745, whereby the Northern part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.536 - -0.465 were observed. Majority of the areas had shown MDP between -1.536 - -0.822, whereby the Northern and Western parts of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -2.062 - -0.345 were observed. Majority of the areas had shown MDP between -1.374 - -0.688, whereby the Western part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -2.135 - -0.336 were observed. Majority of the areas had shown MDP between -1.685 - -0.786, whereby the Southern part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -1.646 - -0.004 were observed. Majority of the areas had shown MDP between -1.646 - -0.552, whereby the Western part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown lowest MDP was observed in sub-period 1988-1992. MDP then gradually increased in the following periods and peak MDP was observed in 2008-2012. Besides, the Western part of the region had relatively shown high MDP over the sub-periods, except for 1988-1992, 1993-1997, 2008-2012 that relatively showed high MDP at station 3946001, 4752022 and other stations near to it. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes as had happened in 1987-1988, 1991-1992, 1994-1995, 1997-1998 and 2009-2010 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 7**, MDP between -2.121 - -0.465 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.569- -1.017, whereby the Western, Eastern and Central parts of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.986 - -0.745 were observed. Majority of the areas had shown MDP between -1.675 - -1.055, whereby the Southern part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.536 - -0.465 were observed. Majority of the areas had shown MDP between -1.179 - -0.822, whereby the Western part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.718 - -0.688 were observed. Majority of the areas had shown MDP between -1.374 - -0.688, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -2.135 - -0.336 were observed. Majority of the areas had shown MDP between -1.685 - -0.786, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -2.193 - -0.552 were observed. Majority of the areas had shown MDP between -1.646 - -1.099, whereby the Northern part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown MDP gradually decreased in sub-period 1988-1992, and lowest was observed in 2003-2007. MDP then gradually increased and peak MDP was observed in 2008-2012. Besides, the Western and Eastern parts of the region had relatively shown high MDP over the sub-periods, except for 1993-1997, 2013-2017 that relatively showed high MDP at station 1005079 and 1015001. Given the location of these stations located in inland area, the high MDP could be affected by Banjaran Kelinkang which is located near to the stations. Banjaran Kelinkang could block the North-East Monsoon from reaching the stations, whereby one side of a mountain range may be rainy and the other side may be a dry area, which lead to high MDP in a specific area.

In **Region 8**, MDP between -2.121 - -0.465 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -1.016- -0.465, whereby the Western part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.675 - -0.434 were observed. Majority of the areas had shown MDP between -1.364 - -0.745, whereby the Western and

South-East parts of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.536 - -0.882 were observed. Majority of the areas had shown MDP between -1.536 - -0.822, whereby the Northern and South-East parts of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.374 - -0.345 were observed. Majority of the areas had shown MDP between -1.031 - -0.688, whereby the Western part of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.235 - -0.336 were observed. Majority of the areas had shown MDP between -1.235 - -0.336, whereby the Northern and Eastern parts of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -1.646 - -0.552 were observed. Majority of the areas had shown MDP between -1.646 - -0.552, whereby the Eastern part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown MDP gradually increased in sub-period 1988-1992, and peak MDP was observed in 1998-2002. MDP then gradually decreased and lowest MDP was observed in 2008-2012. Besides, the Western part of the region had relatively shown high MDP over the sub-periods, except for 1998-2002, 2008-2012, 2013-2017 that relatively showed high MDP at station 6670001, 6868001, 5875001 and other stations near to it. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes that had occurred in 1997-1998, 2002-2003, 2009-2010, 2014-2015 and 2015-2016 that inhibited rainfall occurrence due to the increase in sea surface temperature.

In **Region 9**, MDP between -2.673 - -0.465 were observed in sub-period 1988-1992. Majority of the areas had shown MDP between -2.121 - -1.017, whereby the Northern part of the region had shown higher values of MDP. In sub-period 1993-1997, MDP between -1.675 - -0.745 were observed. Majority of the areas had shown MDP between -1.364 - -0.745, whereby the Eastern part of the region had shown higher values of MDP. In sub-period 1998-2002, MDP between -1.536 - -0.465 were observed. Majority of the areas had shown MDP between -1.179- -0.822, whereby the Western part of the region had shown higher values of MDP. In sub-period 2003-2007, MDP between -1.718 - -0.345 were observed. Majority of the areas had shown MDP between -1.374 - -0.688, whereby the Northern and Centre parts of the region had shown higher values of MDP. In sub-period 2008-2012, MDP between -1.685 - -0.336 were observed. Majority of the areas had shown MDP between -1.235 - -0.786, whereby the Southern part of the region had shown higher values of MDP. In sub-period 2013-2017, MDP between -1.646 - -0.552 were observed. Majority of the areas had shown MDP between -1.646 - -0.552, whereby the Western part of the region had shown higher values of MDP.

Over the six sub-periods, it was observed that majority of the areas had shown peak MDP in sub-period 1988-1992. MDP then gradually decreased and lowest MDP was observed in 2013-2017. Besides, the Western and Northern parts of the region had relatively shown high MDP over the sub-periods, except for 1993-1997, 2008-2012 that relatively showed high MDP at station 3137021 and 2615021. Given the location of the stations being near to seashore, the high MDP could be affected by the El-Niño episodes of 1994-1995, 1997-1998 and 2009-2010 that inhibited rainfall occurrence due to the increase in sea surface temperature.

4.6.4 Summary

According to the SPI-1 analysis, the occurrence of MDP was the highest in sub-period 1988-1992 as compared to other sub-periods. Peak MDP with the range of -1.676 - -1.480 had occurred in Region 3 of East Malaysia, and it was predicted that the high MDP was caused by mountainous topography due to the location of drought events. In sub-period 1993-1997, the occurrence of MDP was considered low among the sub-periods. Peak MDP with the range of -1.621 - -1.445 had occurred in Region 3 of East Malaysia. By referring to the location of drought events, it was predicted that high MDP was caused by mountainous topography as well. On average, the occurrence of MDP was considered low in sub-period 1998-2002. Peak MDP with the range of -1.621 - -1.423 had occurred in Region 1 of East Malaysia, and it was caused by El-Niño episodes due to its location being near to seashore. For sub-period 2003-2007, the occurrence of MDP was the high among the sub-periods. Peak MDP with the range of -1.456 - -1.312 was observed in Region 8 of East Malaysia, and it was predicted that the high MDP was caused by mountainous topography due to its location. For sub-period, 2008-2012, peak MDP with the range of -1.393 - -1.645 was observed in Region 3 of East Malaysia, and it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak MDP with the range of -1.485 - -1.339 was observed in Region 7 of East Malaysia, and it could be caused by mountainous topography. Overall, SPI-1 had shown that peak MDP had occurred often in Eastern part of East Malaysia. Besides, Region 3 had shown most occurrence of peak MDP. Regarding the location of MDP, peak MDP were mostly caused by mountainous topography rather than El-Niño episodes.

As for SPI-3 analysis, the occurrence of MDP was low in sub-period 1988-1992 as compared to other sub-periods. Peak MDP with the range of -2.472 - -2.125 had occurred in Region 9 of East Malaysia, and it was predicted that the high MDP was caused by mountainous topography due to the location of drought events. In sub-period 1993-1997, the occurrence of MDP was considered low among the sub-periods. Peak MDP with the range of -2.061 - -1.759 had occurred in Region 7 of East Malaysia. By referring to the location of drought events, it was predicted that high MDP was caused by mountainous topography as well. On average, the occurrence of MDP was the highest in sub-period 1998-2002. Peak MDP with the range of -1.804 - -1.612 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, the occurrence of MDP was high among the sub-periods. Peak MDP with the range of -1.655 - -1.419 was observed in Region 1 of East Malaysia, and it was predicted that the high MDP was caused by El-Niño episodes due to its location being near to seashore. For sub-period, 2008-2012, peak MDP with the range of -1.906 - -1.628 was observed in Region 3 of East Malaysia. However, it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, the occurrence of MDP was the lowest among the sub-periods. Peak MDP with the range of -4.812 - -3.916 was observed in Region 1 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. Overall, the SPI-3 had shown that peak MDP had occurred often in Eastern part of East Malaysia. Besides, Region 1 had shown most occurrence of peak MDP. Regarding the location of MDP, peak MDP were mostly caused by mountainous topography rather than El-Niño episodes.

For SPI-6, the occurrence of MDP was high in sub-period 1988-1992 as compared to other sub-periods. Peak MDP with the range of -3.227 - -2.674 had occurred in Region 6 of East Malaysia, and it was predicted that the high MDP was caused by El-Niño episodes due to its location being near to seashore. In sub-period 1993-1997, the occurrence of MDP was the highest among the sub-periods. Peak MDP with the range of -1.906 - -1.676 had occurred in Region 7 of East Malaysia. By referring to the location of drought events, it was predicted that high MDP was caused by mountainous topography. On average, the occurrence of MDP was considered high in sub-period 1998-2002. Peak MDP with the range of -2.251 - -1.894 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, peak MDP with the range of -2.062 - -1.719 was observed in Region 5 of East Malaysia, and it was predicted that the high MDP was caused by El-Niño episodes due to its location being near to seashore. For sub-period, 2008-2012, peak MDP with the range of -2.506 - -2.136 was observed in Region 3 of East Malaysia. However, it could be caused by the mountainous topography due to its location. For sub-period 2013-2017, peak MDP with the range of -2.742 - -2.194 was observed in Region 1 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. Overall, SPI-6 had shown that peak MDP had occurred often in Eastern and Central parts of East Malaysia. Besides, Region 1 had shown most occurrence of peak MDP. Regarding the location of MDP, peak MDP were mostly caused by El-Niño episodes rather than mountainous topography.

4.7 Drought Categories

In order to differentiate the differences between drought categories (Mild Drought, Moderate Drought, Severe Drought, Extreme Drought), a table had been constructed as shown in Table 4.2. The number of stations that had been grouped into each drought category had been recorded with respect to Standardized Precipitation Index in 1-, 3- and 6-months timescales. A total of 251 stations in East Malaysia were chosen to be studied from year 1988 to year 2017. For further description of drought categories, graphs had been produced for clearer view of the differences between drought categories, as shown in Figure 4.16, Figure 4.17 and Figure 4.18.

Table 4.2: Number of stations in each drought category.

	SPI-1				SPI-3				SPI-6			
Years	Mild	Moderate	Severe	Extreme	Mild	Moderate	Severe	Extreme	Mild	Moderate	Severe	Extreme
1988	245	122	85	48	251	93	42	29	251	57	26	21
1989	249	154	83	59	248	137	80	55	240	143	56	34
1990	250	196	128	98	247	191	110	81	245	185	112	59
1991	251	191	149	109	249	201	160	99	239	195	122	67
1992	251	170	136	88	247	160	92	95	242	169	99	58
1993	249	177	102	55	247	143	70	33	244	130	54	22
1994	246	155	127	108	248	174	94	60	243	143	77	34
1995	245	123	67	28	238	76	39	13	220	72	29	16
1996	249	148	71	28	236	97	37	19	200	76	27	12
1997	250	183	161	129	250	194	146	93	247	193	145	94
1998	245	120	83	112	243	117	82	117	239	148	116	98
1999	250	136	59	21	243	101	26	7	233	76	27	7
2000	248	152	79	29	247	108	40	9	233	84	32	8
2001	248	168	102	38	248	146	73	20	236	111	42	9
2002	250	171	98	40	251	180	87	41	247	171	62	21
2003	248	167	86	58	248	164	74	37	245	153	53	19
2004	248	177	129	80	249	165	94	32	244	139	55	18
2005	250	163	75	47	249	128	61	38	236	115	57	17
2006	248	155	115	61	246	148	96	60	235	126	90	47
2007	249	98	48	16	234	60	23	19	213	39	14	14
2008	247	76	16	13	218	45	9	14	191	39	15	14
2009	246	179	115	61	250	177	115	68	238	170	107	56
2010	239	90	54	80	224	77	56	46	207	73	42	26
2011	250	139	90	41	245	144	61	28	236	119	54	23
2012	247	155	114	75	246	160	80	48	238	159	101	49
2013	250	143	71	50	246	124	57	22	234	129	49	23
2014	248	172	147	120	243	186	106	59	238	174	113	78
2015	248	185	121	92	250	182	115	54	241	175	105	48
2016	249	144	120	80	250	159	87	71	248	160	81	44
2017	245	104	49	25	232	56	18	11	208	63	24	9

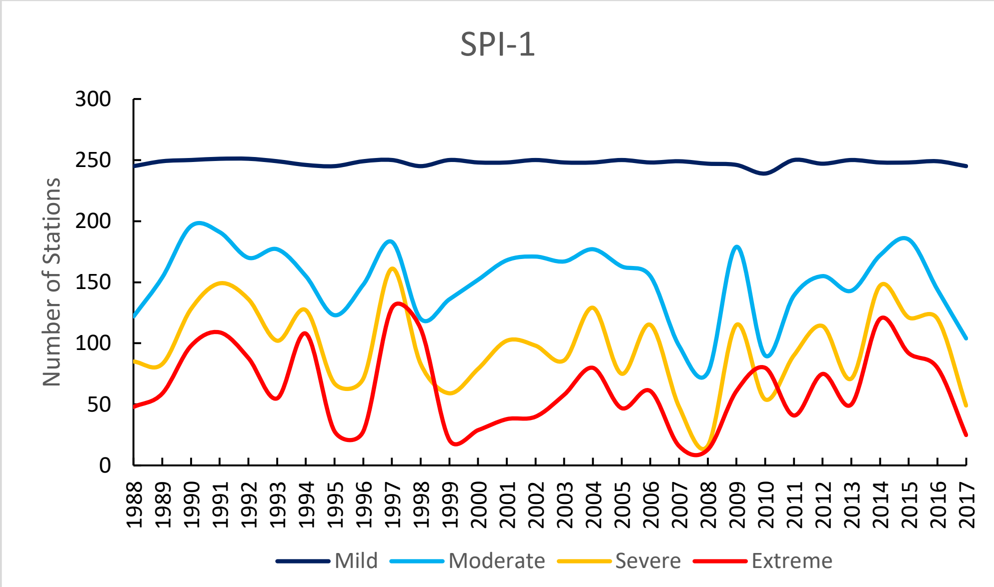

Figure 4.16: Number of stations that showed different drought categories in SPI-1.

In SPI-1, the numbers of stations had shown the highest occurrence of Mild Drought, followed by Moderate, Severe and Extreme Drought. Almost all of the stations being studied (251) had relatively shown consistent trend for Mild Drought category. For Moderate Drought, the number of stations were fluctuating in the range of 76-196 stations, whereas for Severe Drought, the number of stations were fluctuating in the range of 16-161 stations. All of the number of stations for the categories above did not overtake each other throughout the 30 years, except for Extreme Drought. For Extreme Drought, the number of stations were fluctuating in the range of 13-129 stations. However, it was observed that the number of stations for extreme drought had overtaken severe drought in year 1997-1998 and 2009-2010. The phenomenon could be explained by the very strong El-Niño episodes that happened in year 1997-1998 and 2009-2010, in which rainfall occurrence had been inhibited due to the increase in sea surface temperature, resulting in Extreme Drought.

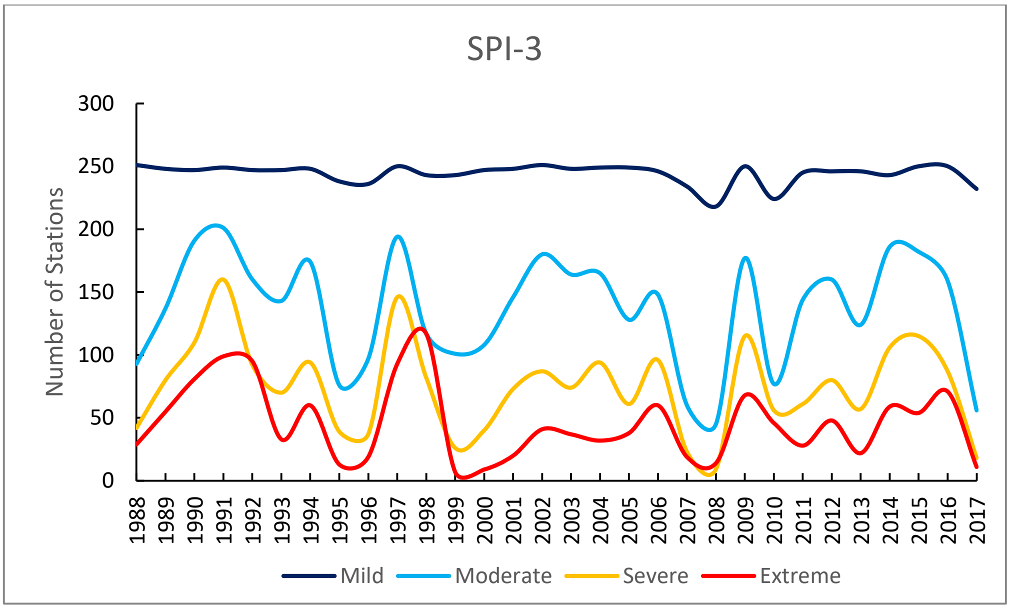

Figure 4.17: Number of stations that showed different drought categories in SPI-3.

In SPI-3, the graph had shown relatively higher fluctuation of number of stations as compared to SPI-1. However, an almost similar trend had been recorded, whereby the the numbers of stations had shown the highest occurrence of mild drought, followed by Moderate, Severe and Extreme drought. For Mild Drought, the number stations had shown a consistent trend in the range of 218-251. For Moderate Drought and Severe Drought, the number of stations were fluctuating in the range of 45-201 stations and 9-160 respectively. All of the number of stations for the categories above did not overtake each other throughout the 30 years, except for Extreme Drought. For Extreme Drought, the number of stations were fluctuating in the range of 7-117 stations. However, it was observed that the number of stations for Extreme Drought had overtaken severe drought in year 1997-1998 and 2007-2008. The phenomenon could be explained by the very strong El-Niño episodes that happened in year 1997-1998 and weak El-Niño episodes in 2006-2007, in which rainfall occurrence had been inhibited due to the increase in sea surface temperature, resulting in Extreme Drought.

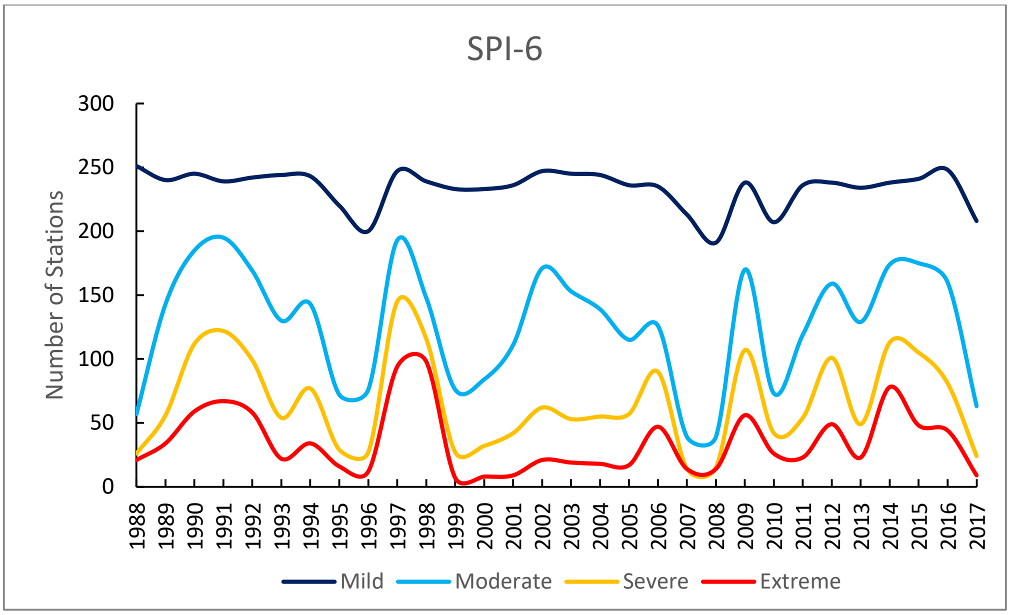

Figure 4.18: Number of stations that showed different drought categories in SPI-6.

In SPI-6, the graph had shown even higher fluctuation of the number of stations as compared to SPI-1 and SPI-3. However, an almost similar trend had been recorded, whereby the the numbers of stations had shown the highest occurrence of mild drought, followed by Moderate, Severe and Extreme drought. For Mild Drought, the number of stations had shown a trend in the range of 191-251. For Moderate Drought and Severe Drought, the number of stations were fluctuating in the range of 39-195 stations and 14-122 respectively. All of the number of stations for the categories above did not overtake each other throughout the 30 years, except for the case of the Extreme Drought. For Extreme Drought, the number of stations were fluctuating in the range of 7-98 stations. However, it was observed that the number of stations for Extreme Drought had overtaken severe drought in year 2007-2008. The phenomenon could be explained by the weak El-Niño episodes in 2006-2007, in which rainfall occurrence had been inhibited due to the increase in sea surface temperature, resulting in Extreme Drought. As an explanation, the SPI-6 did not show the results of Extreme Drought overtaken Severe Drought in 1997-1998 as shown in SPI-1 and SPI-3, it might due to the sensitivity of SPI-6, which was considered to be less accurate representation of monthly precipitation for a given location. In order to further study the Spatial Variation, maps of different drought categories had been produced as shown in Figure 4.19.

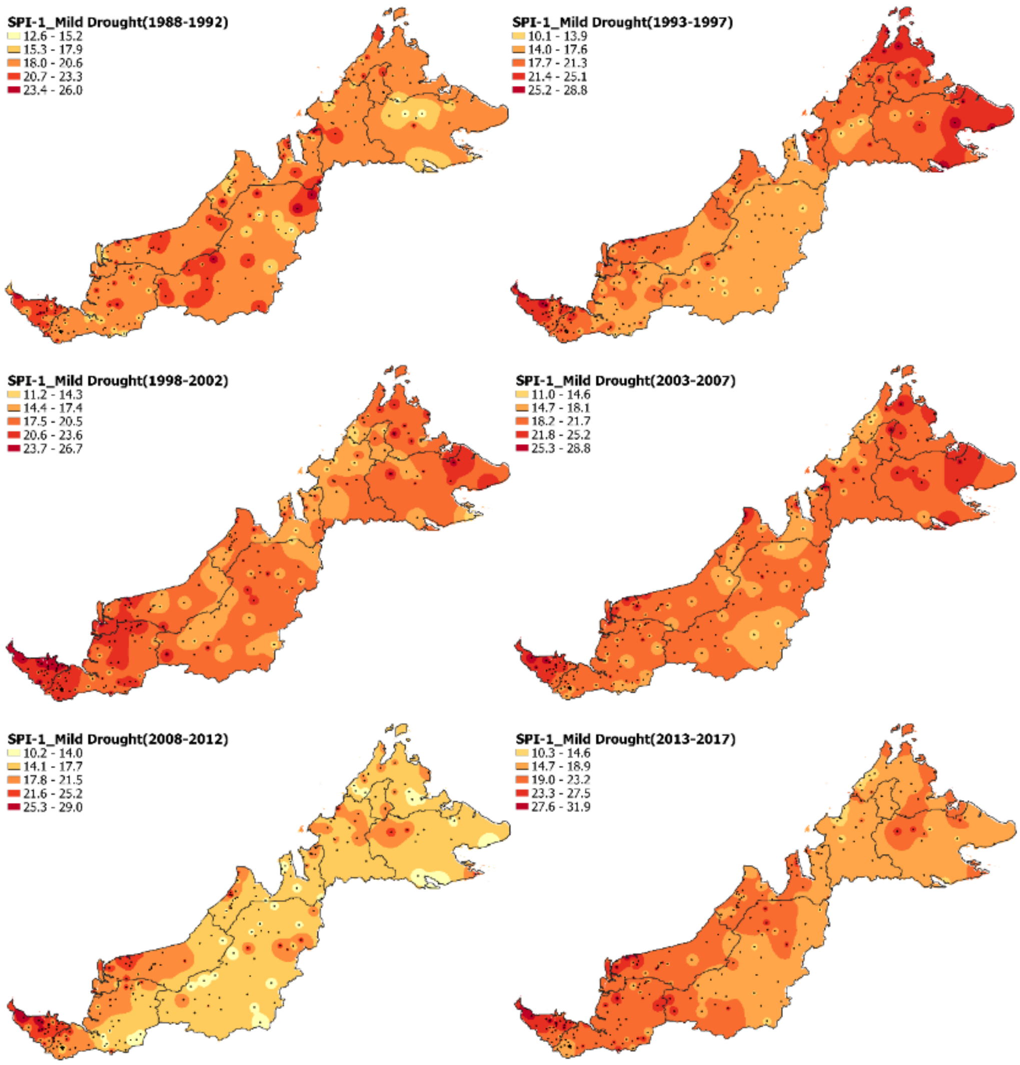

Figure 4.19: Mild Drought maps of SPI-1 for each 5-years sub-period along 1988-2017.

According to the study with SPI-1, the occurrence of Mild Drought was high in sub-period 1988-1992 as compared to other sub-periods. Peak Mild Drought with the range of 3.4-26.0 had occurred in Region 3 of East Malaysia, and it was predicted that the high Mild Drought was caused by mountainous topography due to the location of drought events. In sub-period 1993-1997, the occurrence of Mild Drought was considered high as well. Peak Mild Drought with the range of 25.2-28.8 had occurred in Region 4 of East Malaysia. By referring to the location of drought events, it was predicted that high Mild Drought was caused by El-Niño episodes due to its location being near to seashore. On average, the occurrence of Mild Drought was considered high in sub-period 1998-2002. Peak Mild Drought with the range of 23.7-26.7 had occurred in Region 2 of East Malaysia, and it was caused by El-Niño episodes due to its location being near to seashore. For sub-period 2003-2007, the occurrence of Mild Drought was low among the sub-periods. Peak Mild Drought with the range of 25.3-28.8 was observed in Region 1 of East Malaysia, and it was predicted that the high Mild Drought was caused by mountainous topography due to its location. For sub-period, 2008-2012, peak Mild Drought with the range of 25.3-29.0 was observed in Region 2 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. For sub-period 2013-2017, peak Mild Drought with the range of 27.6-31.9 was observed in Region 7 of East Malaysia, and it could be caused by El-Niño episodes too. In overall, SPI-1 had shown that peak Mild Drought had occurred often in Eastern and South-West parts of East Malaysia. Besides, Region 2 had shown most occurrence of peak Mild Drought. Regarding the location of Mild Drought, peak Mild Drought could both caused by mountainous topography and El-Niño episodes.

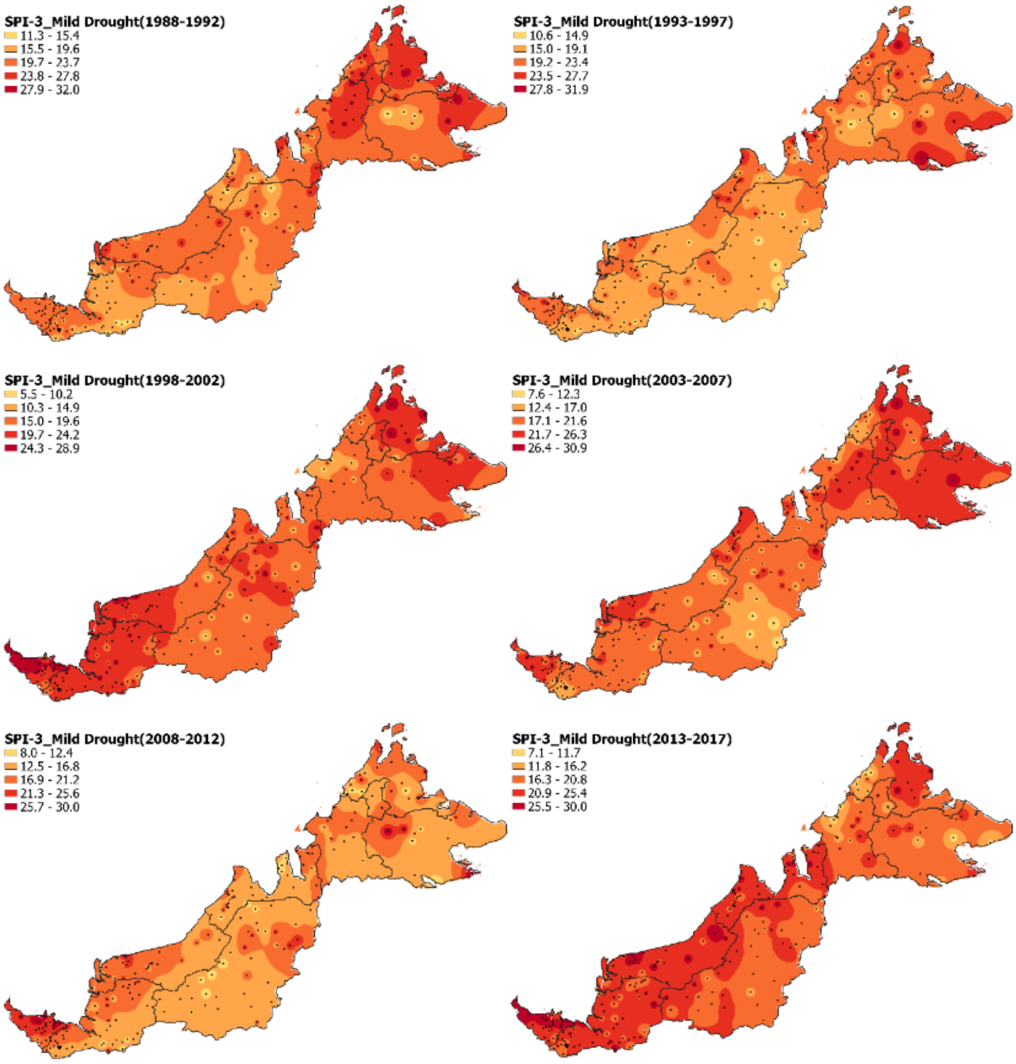

Figure 4.20: Mild Drought maps of SPI-3 for each 5-years sub-period along 1988-2017.

Figure 4.20 shows the SPI-3 analysis, where the occurrence of Mild Drought was high in sub-period 1988-1992 as compared to other sub-periods. Peak Mild Drought with the range of 27.9-32.0 had occurred in Region 1 of East Malaysia, and it was predicted that the high Mild Drought was caused by El-Niño episodes due to its location being near to seashore. In sub-period 1993-1997, the occurrence of Mild Drought was considered low among the sub-periods. Peak Mild Drought with the range of 27.8-31.9 had occurred in Region 1 of East Malaysia. By referring to the location of drought events, it was predicted that high Mild Drought was caused by mountainous topography. On average, the occurrence of Mild Drought was considered high in sub-period 1998-2002. Peak Mild Drought with the range of 24.3-28.9 had occurred in

Region 2 of East Malaysia, and it was caused by El-Niño episodes due to its location being near to seashore. For sub-period 2003-2007, the occurrence of Mild Drought was high among the sub-periods. Peak Mild Drought with the range of 26.4-30.9 was observed in Region 1 of East Malaysia, and it was predicted that the high Mild Drought was caused by El-Niño episodes. For sub-period, 2008-2012, peak Mild Drought with the range of 25.7-30.0 was observed in Region 2 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. For sub-period 2013-2017, peak Mild Drought with the range of 25.5-30.0 was observed in Region 2 of East Malaysia, and it could be caused by El-Niño episodes too. In overall, SPI-3 had shown that peak Mild Drought had occurred often in Eastern and South-West parts of East Malaysia. Besides, Region 2 had shown most occurrence of peak Mild Drought. Regarding the location of Mild Drought, peak Mild Drought were cause by El-Niño episodes rather than mountainous topography.

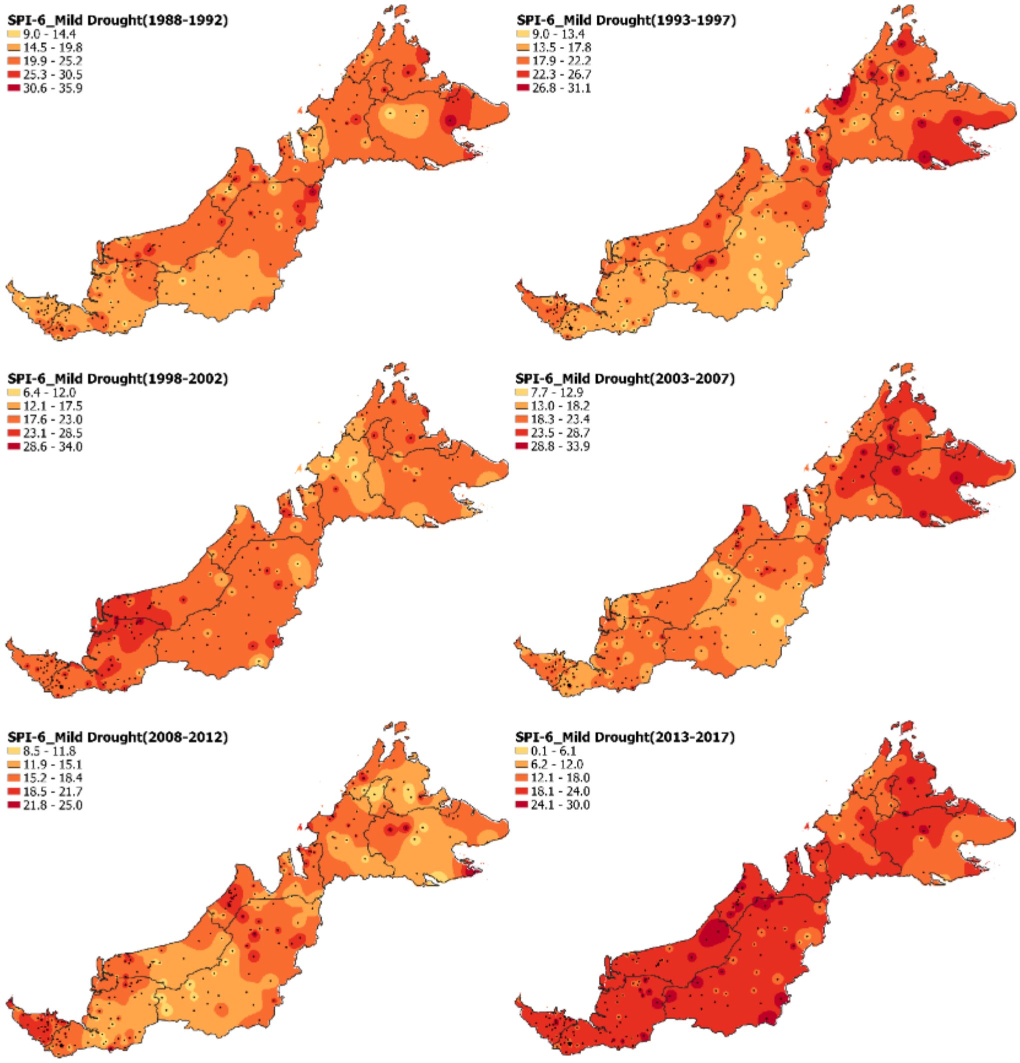

Figure 4.21: Mild Drought maps of SPI-6 for each 5-years sub-period along 1988-2017.

Figure 4.21 shows the study by SPI-6, where the occurrence of Mild Drought was average in sub-period 1988-1992 as compared to other sub-periods. Peak Mild Drought with the range of 30.6-35.9 had occurred in Region 1 of East Malaysia, and it was predicted that the high Mild Drought was caused by El-Niño episodes due to its location being near to seashore. In sub-period 1993-1997, the occurrence of Mild Drought was considered high among the sub-periods. Peak Mild Drought with the range of 26.8-31.1 had occurred in Region 1 of East Malaysia. By referring to the location of drought events, it was predicted that high Mild Drought was caused by mountainous topography. Averagely, the occurrence of Mild Drought was considered high in sub-period 1998-2002. Peak Mild Drought with the range of 28.6-34.0 had occurred in

Region 7 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, the occurrence of Mild Drought was high among the sub-periods. Peak Mild Drought with the range of 28.8-33.9 was observed in Region 1 of East Malaysia, and it was predicted that the high Mild Drought was caused by El-Niño episodes. For sub-period, 2008-2012, peak Mild Drought with the range of 21.8-25.0 was observed in Region 1 of East Malaysia, and it could be caused by El-Niño episodes due to its location being near to seashore. For sub-period 2013-2017, the occurrence of Mild Drought is the highest among the sub-periods. Peak Mild Drought with the range of 24.1-30.0 was observed in Region 9 of East Malaysia, and it could be caused by El-Niño episodes too. In overall, SPI-6 had shown that peak Mild Drought had occurred often in Eastern part of East Malaysia. Besides, Region 1 had shown most occurrence of peak Mild Drought. Regarding the location of Mild Drought, peak Mild Drought was caused by El-Niño episodes rather than mountainous topography.

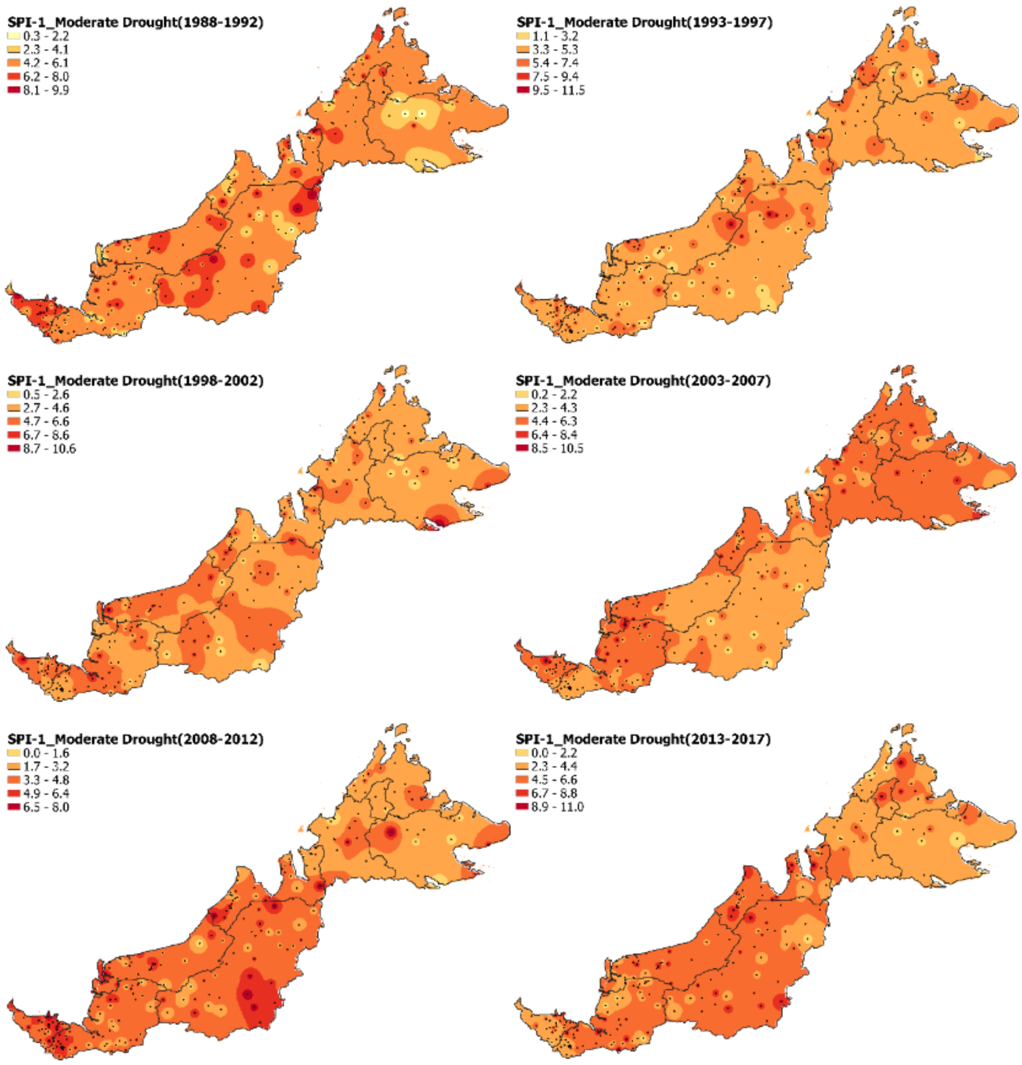

Figure 4.22: Moderate Drought maps of SPI-1 for each 5-years sub-period along 1988-2017.

Figure 4.22 shows the study by SPI-1, where the occurrence of Moderate Drought was high in sub-period 1988-1992 as compared to other sub-periods. Peak Moderate Drought with the range of 8.1-9.9 had occurred in Region 3 of East Malaysia, and it was predicted that the high Moderate Drought was caused by mountainous topography due to its specific location. In sub-period 1993-1997, the occurrence of Moderate Drought was the lowest among the sub-periods. Peak Moderate Drought with the range of 9.5-11.5 had occurred in Region 9 of East Malaysia. By referring to the location of drought events, it was predicted that high Moderate Drought was caused by El-Niño episodes due to its location being near to seashore. On average, the occurrence of Moderate Drought was considered low in sub-period 1998-2002. Peak Moderate Drought with the range of 8.7-10.6 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography. For sub-period 2003-2007, the occurrence of Moderate Drought was high among the sub-periods. Peak Moderate Drought with the range of 8.5-10.5 was observed in Region 1 of East Malaysia, and it was predicted that the high Moderate Drought was caused by El-Niño episodes. For sub-period, 2008-2012, peak Moderate Drought with the range of 6.5-8.0 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. For sub-period 2013-2017, the occurrence of Moderate Drought is high among the sub-periods. Peak Moderate Drought with the range of 8.9-11.0 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. In overall, SPI-1 had shown that peak Moderate Drought had occurred often in Central part of East Malaysia. Besides, Region 3 had shown most occurrence of peak Moderate Drought. Regarding the location of Moderate Drought, peak Moderate Drought was caused by mountainous topography rather than El-Niño episodes.

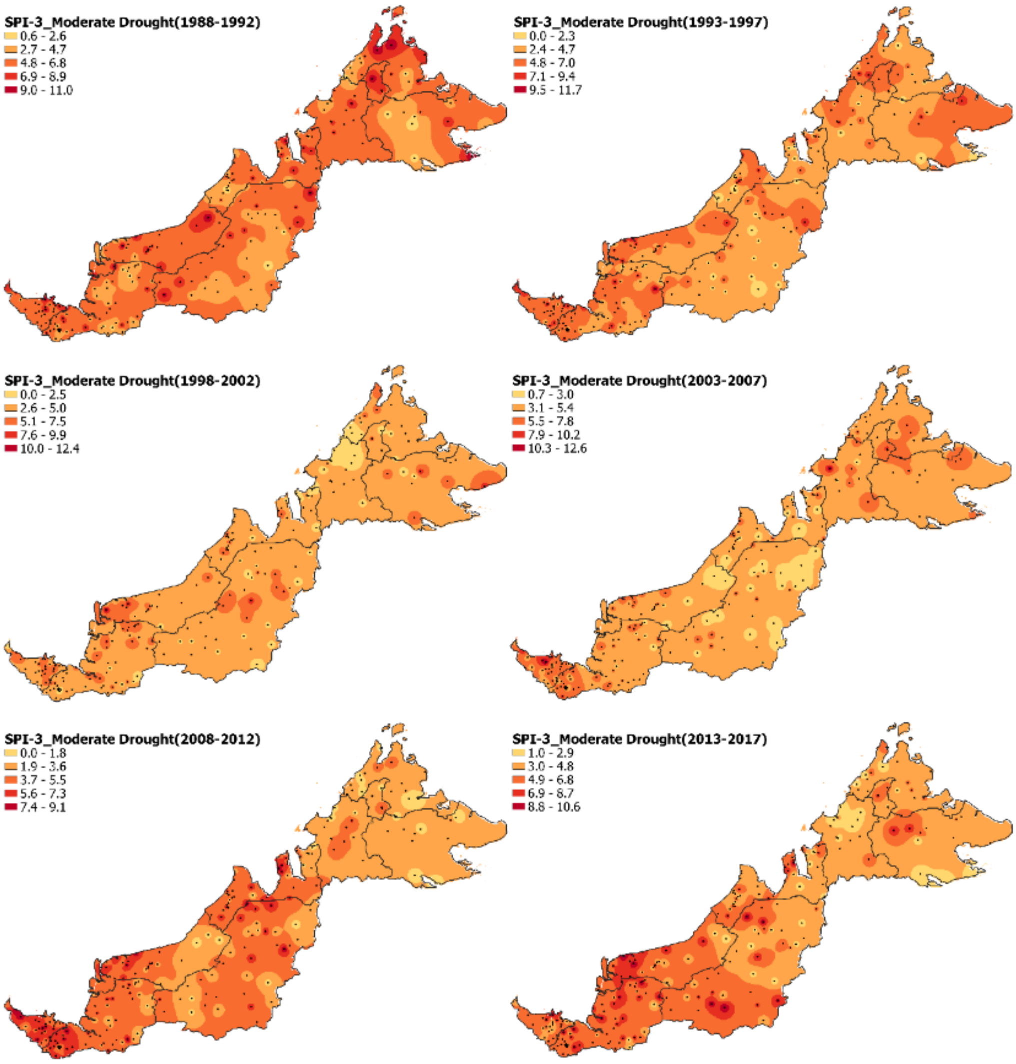

Figure 4.23: Moderate Drought maps of SPI-3 for each 5-years sub-period along 1988-2017.

Figure 4.23 shows the study by SPI-3, the occurrence of Moderate Drought was the highest in sub-period 1988-1992 as compared to other sub-periods. Peak Moderate Drought with the range of 9.0-11.0 had occurred in Region 8 of East Malaysia, and it was predicted that the high Moderate Drought was caused by El-Niño episodes due to its location being near to seashore. In sub-period 1993-1997, the occurrence of Moderate Drought was low among the sub-periods. Peak Moderate Drought with the range of 9.5-11.7 had occurred in Region 7 of East Malaysia. By referring to the location of drought events, it was predicted that high Moderate Drought was caused by mountainous topography. On average, the occurrence of Moderate Drought was the lowest in sub-period 1998-2002. Peak Moderate Drought with the range of 10.0-12.4 had occurred in Region 9 of East Malaysia, and it was caused by El-Niño episodes. For sub-period 2003-2007, the occurrence of Moderate Drought was low among the sub-periods. Peak Moderate Drought with the range of 10.3-12.6 was observed in Region 2 of East Malaysia, and it was predicted that the high Moderate Drought was caused by El-Niño episodes. For sub-period, 2008-2012, peak Moderate Drought with the range of 7.4-9.1 was observed in Region 2 of East Malaysia, and it could be caused by El-Niño episodes. For sub-period 2013-2017, the occurrence of Moderate Drought is high among the sub-periods. Peak Moderate Drought with the range of 8.8-10.6 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. In overall, SPI-3 had shown that peak Moderate Drought had occurred often in South-West of East Malaysia. Besides, Region 2 had shown most occurrence of peak Moderate Drought. Regarding the location of Moderate Drought, peak Moderate Drought was caused by El-Niño episodes rather than mountainous topography.

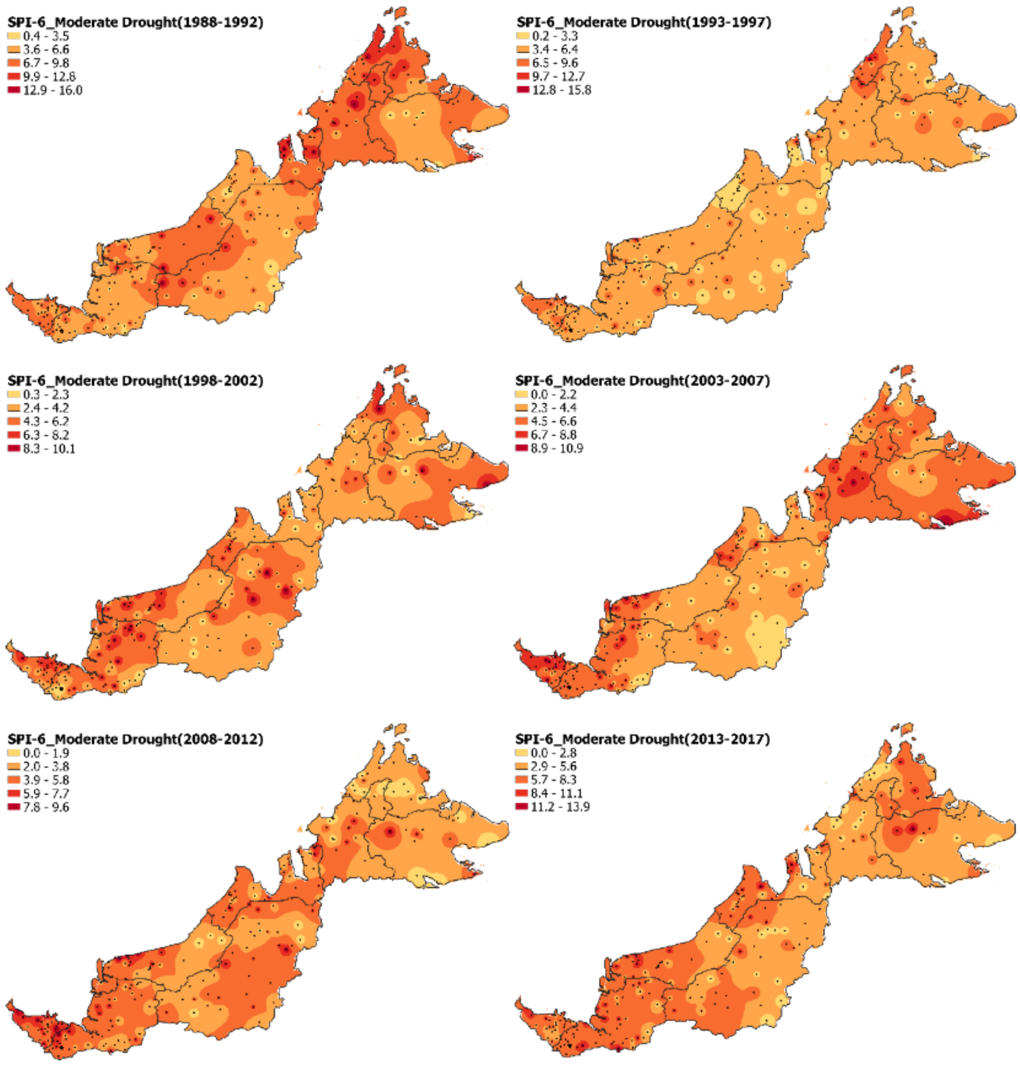

Figure 4.24: Moderate Drought maps of SPI-6 for each 5-years sub-period along 1988-2017.

Figure 4.24 shows the study by SPI-6, where the occurrence of Moderate Drought was the highest in sub-period 1988-1992 as compared to other sub-periods. Peak Moderate Drought with the range of 12.9-16.0 had occurred in Region 5 of East Malaysia, and it was predicted that the high Moderate Drought was caused by mountainous topography. In sub-period 1993-1997, the occurrence of Moderate Drought was the lowest among the sub-periods. Peak Moderate Drought with the range of 12.8-15.8 had occurred in Region 8 of East Malaysia. By referring to the location of drought events, it was predicted that high Moderate Drought was caused by El-Niño episodes due to its locations being near to seashore. On average, the occurrence of Moderate Drought was the high in sub-period 1998-2002. Peak Moderate Drought with the range of

8.3-10.1 had occurred in Region 8 of East Malaysia, and it was caused by El-Niño episodes. For sub-period 2003-2007, the occurrence of Moderate Drought was high among the sub-periods. Peak Moderate Drought with the range of 8.9-10.9 was observed in Region 1 of East Malaysia, and it was predicted that the high Moderate Drought was caused by mountainous topography. For sub-period, 2008-2012, peak Moderate Drought with the range of 7.8-9.6 was observed in Region 2 of East Malaysia, and it could be caused by El-Niño episodes. For sub-period 2013-2017, the occurrence of Moderate Drought was low among the sub-periods. Peak Moderate Drought with the range of 11.2-13.9 was observed in Region 1 of East Malaysia, and it could be caused by mountainous topography. In overall, SPI-6 had shown that peak Moderate Drought had occurred often in Eastern of East Malaysia. Besides, Region 1 had shown most occurrence of peak Moderate Drought. Regarding the location of Moderate Drought, peak Moderate Drought was caused by El-Niño episodes rather than mountainous topography.

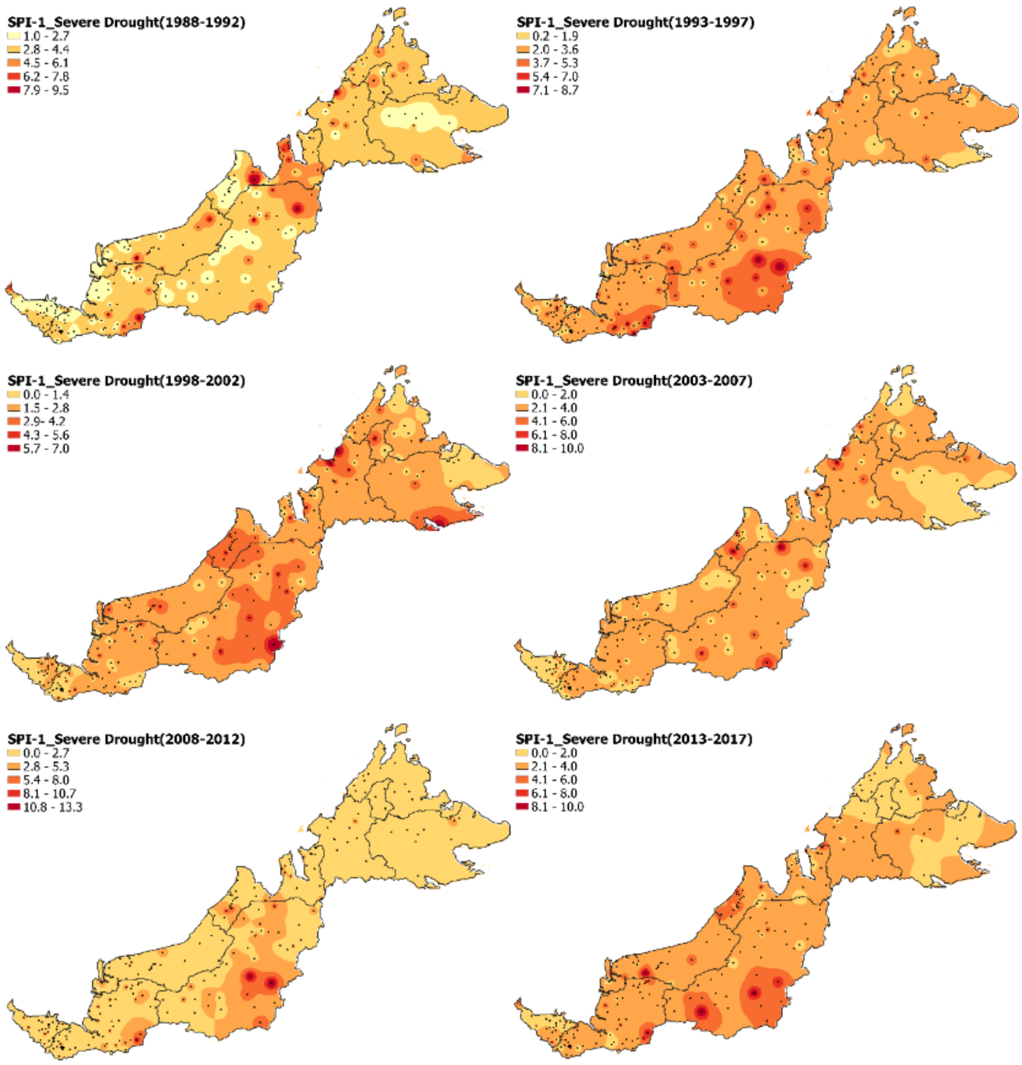

Figure 4.25: Severe Drought maps of SPI-1 for each 5-years sub-period along 1988-2017.

Figure 4.25 shows the study by SPI-1, where the occurrence of Severe Drought was low in sub-period 1988-1992 as compared to other sub-periods. Peak Severe Drought with the range of 7.9-9.5 had occurred in Region 6 of East Malaysia, and it was predicted that the high Severe Drought was caused by El-Niño episodes due to its locations being near to seashore. In sub-period 1993-1997, the occurrence of Severe Drought was high among the sub-periods. Peak Severe Drought with the range of 7.1-8.7 had occurred in Region 3 of East Malaysia. By referring to the location of drought events, it was predicted that high Severe Drought was caused by mountainous topography. Averagely, the occurrence of Severe Drought was the high in sub-period 1998-2002. Peak Severe Drought with the range of 5.7-7.0 had occurred in Region 3 of East

Malaysia, and it was caused by mountainous topography as well. For sub-period 2003-2007, the occurrence of Severe Drought was low among the sub-periods. Peak Severe Drought with the range of 8.1-10.0 was observed in Region 3 of East Malaysia, and it was predicted that the high Severe Drought was caused by mountainous topography. For sub-period, 2008-2012, peak Severe Drought with the range of 10.8-13.3 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. For sub-period 2013-2017, the occurrence of Severe Drought was low among the sub-periods. Peak Severe Drought with the range of 8.1-10.0 was observed in Region 1 of East Malaysia, and it could be caused by mountainous topography. In overall, SPI-1 had shown that peak Severe Drought had occurred often in Central of East Malaysia. Besides, Region 3 had shown most occurrence of peak Severe Drought. Regarding the location of Severe Drought, peak Severe Drought was caused by mountainous topography rather than El-Niño episodes.

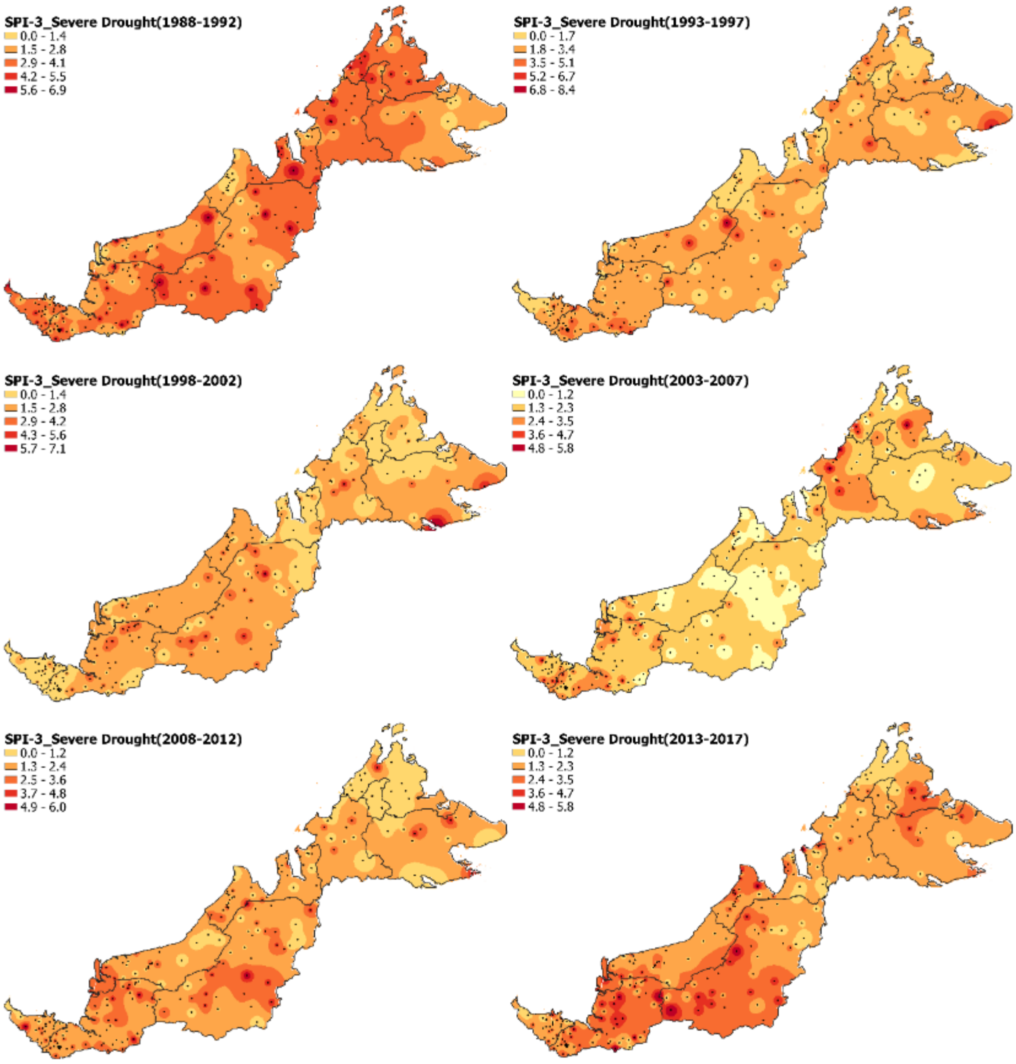

Figure 4.26: Severe Drought maps of SPI-3 for each 5-years sub-period along 1988-2017.

Figure 4.26 shows study by SPI-3, where the occurrence of Severe Drought was the highest in sub-period 1988-1992 as compared to other sub-periods. Peak Severe Drought with the range of 5.6-6.9 had occurred in Region 6 of East Malaysia, and it was predicted that the high Severe Drought was caused by El-Niño episodes due to its locations being near to seashore. In sub-period 1993-1997, the occurrence of Severe Drought was low among the sub-periods. Peak Severe Drought with the range of 6.8-8.4 had occurred in Region 9 of East Malaysia. By referring to the location of drought events, it was predicted that high Severe Drought was caused by mountainous topography. Averagely, the occurrence of Severe Drought was the low in sub-period 1998-2002. Peak Severe Drought with the range of 5.7-7.1 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography as well. For sub-period 2003-2007, the occurrence of Severe Drought was the lowest among the sub-periods. Peak Severe Drought with the range of 4.8-5.8 was observed in Region 5 of East Malaysia, and it was predicted that the high Severe Drought was caused by mountainous topography. For sub-period, 2008-2012, peak Severe Drought with the range of 4.9-6.0 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. For sub-period 2013-2017, the occurrence of Severe Drought was high among the sub-periods. Peak Severe Drought with the range of 4.8-5.8 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. In overall, SPI-3 had shown that peak Severe Drought had occurred often in Eastern part of East Malaysia. Besides, Region 1 and Region 3 had shown most occurrence of peak Severe Drought. Regarding the location of Severe Drought, peak Severe Drought was caused by mountainous topography rather than El-Niño episodes.

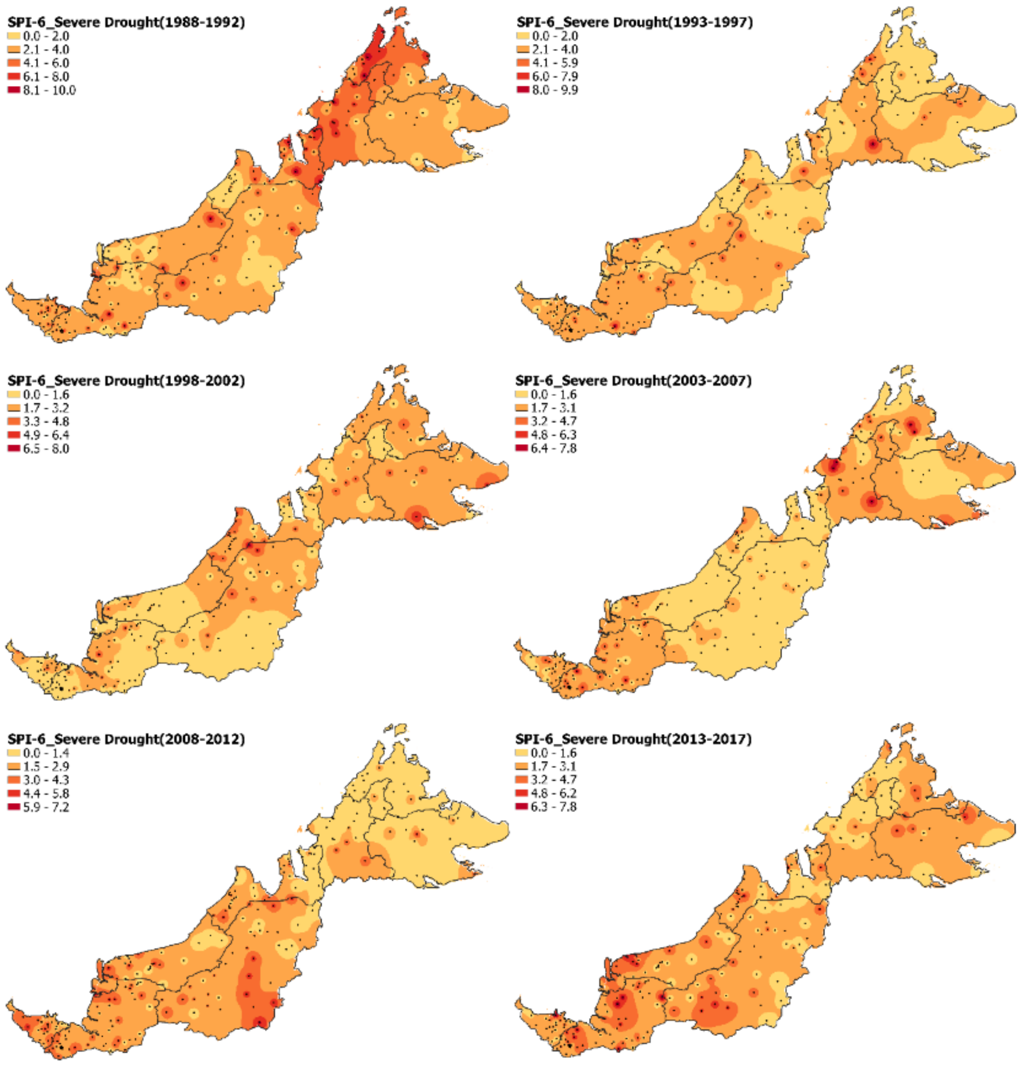

Figure 4.27: Severe Drought maps of SPI-6 for each 5-years sub-period along 1988-2017.

Figure 4.27 shows the study by SPI-6, the occurrence of Severe Drought was the highest in sub-period 1988-1992 as compared to other sub-periods. Peak Severe Drought with the range of 8.1-10.0 had occurred in Region 8 of East Malaysia, and it was predicted that the high Severe Drought was caused by El-Niño episodes due to its locations being near to seashore. In sub-period 1993-1997, the occurrence of Severe Drought was low among the sub-periods. Peak Severe Drought with the range of 8.0-7.9 had occurred in Region 5 of East Malaysia. By referring to the location of drought events, it was predicted that high Severe Drought was caused by mountainous topography. On average, the occurrence of Severe Drought was low in sub-period 1998-2002. Peak Severe Drought with the range of 6.5-8.0 had occurred in Region 1 of East Malaysia, and it was caused by mountainous topography as well. For sub-period 2003-2007, the occurrence of Severe Drought was low among the sub-periods. Peak Severe Drought with the range of 6.4-7.8 was observed in Region 5 of East Malaysia, and it was predicted that the high Severe Drought was caused by mountainous topography. For sub-period, 2008-2012, peak Severe Drought with the range of 5.9-7.2 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. For sub-period 2013-2017, the occurrence of Severe Drought was high among the sub-periods. Peak Severe Drought with the range of 6.3-7.8 was observed in Region 9 of East Malaysia, and it could be caused by El-Niño episodes. In overall, SPI-6 had shown that peak Severe Drought had occurred often in Eastern part of East Malaysia. Besides, Region 5 had shown most occurrence of peak Severe Drought. Regarding the location of Severe Drought, peak Severe Drought was caused by mountainous topography rather than El-Niño episodes.

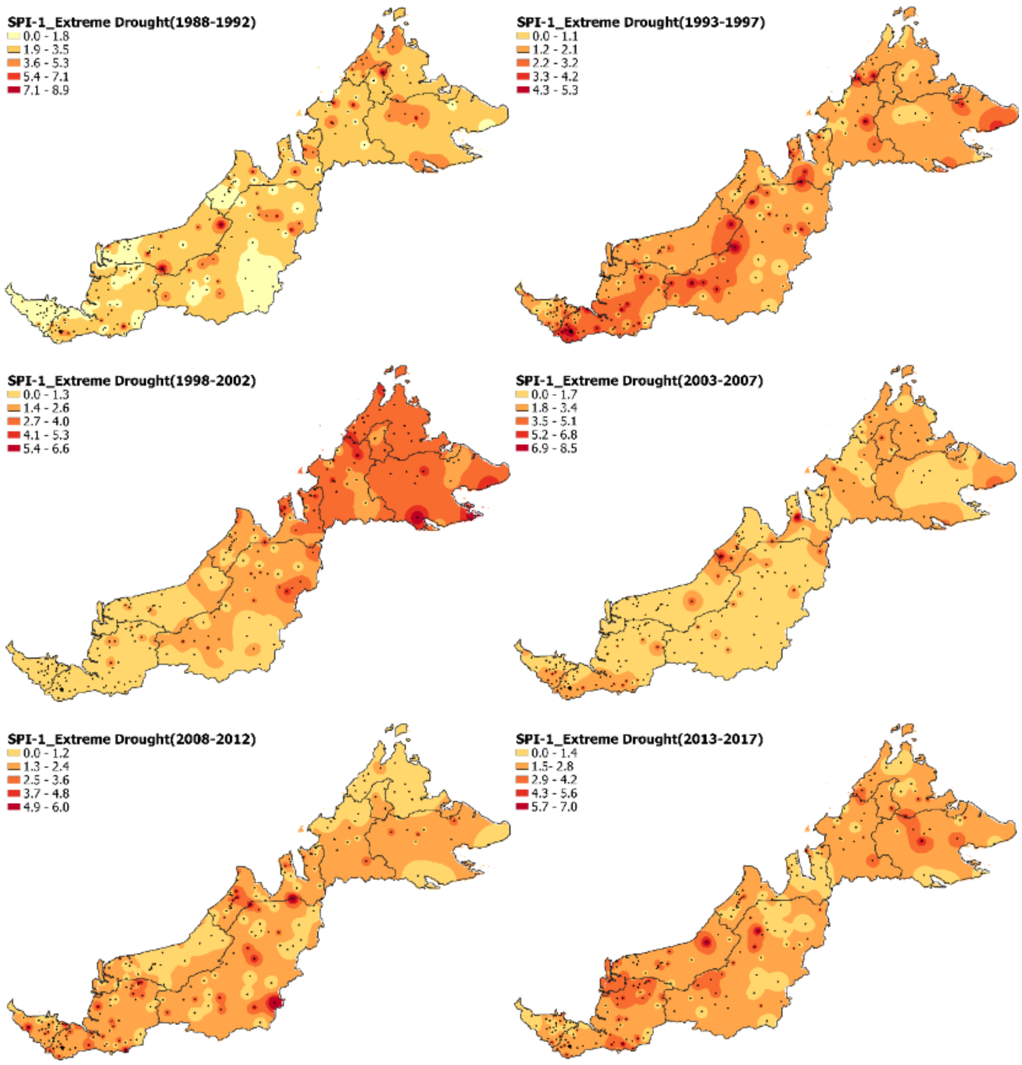

Figure 4.28: Extreme Drought maps of SPI-1 for each 5-years sub-period along 1988-2017.

Figure 4.28 the study by SPI-1, the occurrence of Extreme Drought was high in sub-period 1988-1992 as compared to other sub-periods. Peak Extreme Drought with the range of 7.1-8.9 had occurred in Region 4 of East Malaysia, and it was predicted that the high Extreme Drought was caused by mountainous topography due to its specific location. In sub-period 1993-1997, the occurrence of Extreme Drought was low among the sub-periods. Peak Extreme Drought with the range of 4.3-5.3 had occurred in Region 7 of East Malaysia. By referring to the location of drought events, it was predicted that high Extreme Drought was caused by the mountainous topography. On average, the occurrence of Extreme Drought was high in sub-period 1998-2002. Peak Extreme Drought with the range of 5.4-6.6 had occurred in Region 1 of East

Malaysia, and it was caused by the mountainous topography as well. For sub-period 2003-2007, the occurrence of Extreme Drought was low among the sub-periods. Peak Extreme Drought with the range of 6.69-8.5 was observed in Region 6 of East Malaysia, and it was predicted that the high Extreme Drought was caused by the El-Niño episodes. For sub-period, 2008-2012, peak Extreme Drought with the range of 4.9-6.0 was observed in Region 3 of East Malaysia, and it could be caused by the mountainous topography. For sub-period 2013-2017, the occurrence of Extreme Drought was high among the sub-periods. Peak Extreme Drought with the range of 5.7-7.0 was observed in Region 9 of East Malaysia, and it could be caused by El-Niño episodes. Overall, SPI-1 had shown that peak Extreme Drought had occurred often in Central and Eastern part of East Malaysia. Regarding the location of Extreme Drought, peak Extreme Drought was caused by mountainous topography rather than the El-Niño episodes.

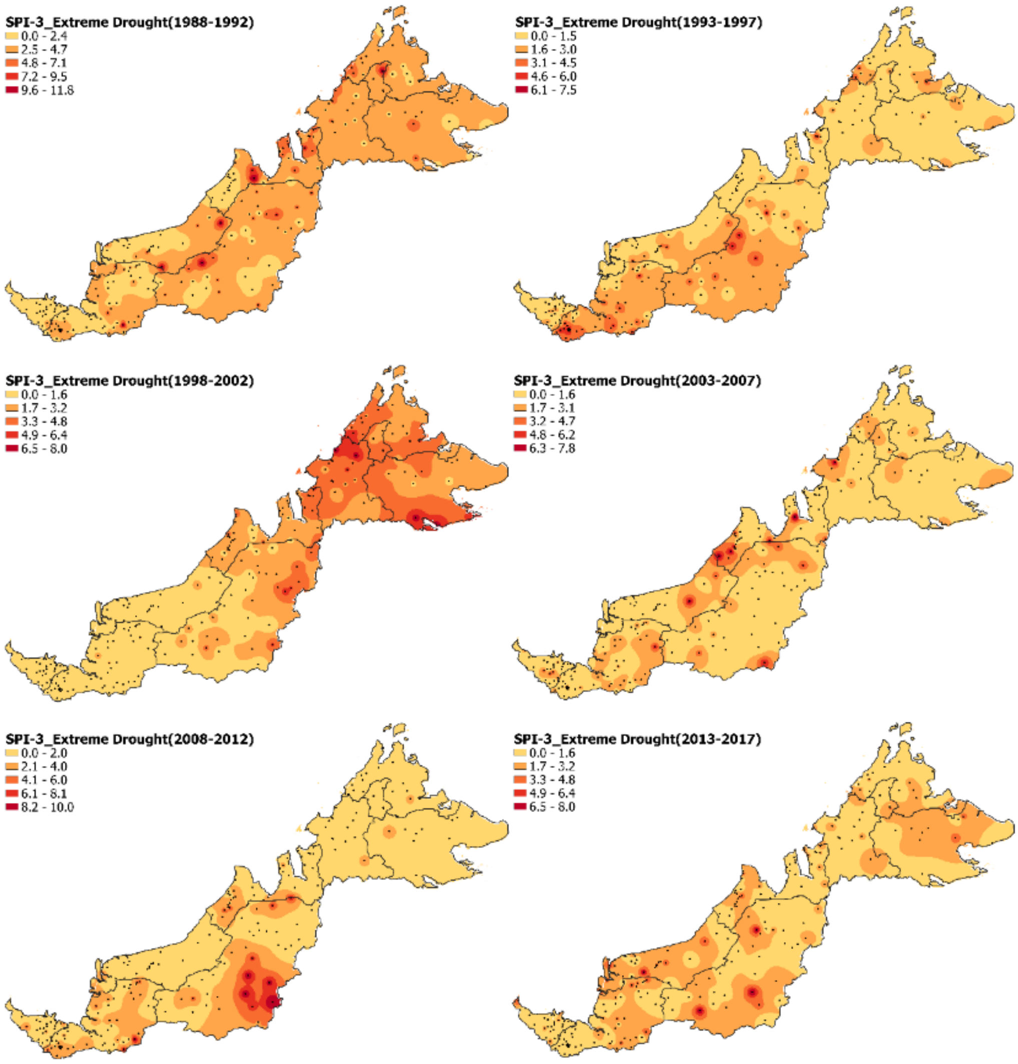

Figure 4.29: Extreme Drought maps of SPI-3 for each 5-years sub-period along 1988-2017.

Figure 4.29 shows the study by SPI-3, the occurrence of Extreme Drought was high in sub-period 1988-1992 as compared to other sub-periods. Peak Extreme Drought with the range of 9.6-11.8 had occurred in Region 6 of East Malaysia, and it was predicted that the high Extreme Drought was caused by El-Niño episodes due to its locations being near to seashore. In sub-period 1993-1997, the occurrence of Extreme Drought was low among the sub-periods. Peak Extreme Drought with the range of 6.1-7.5 had occurred in Region 7 of East Malaysia. By referring to the location of drought events, it was predicted that high Extreme Drought was caused by mountainous topography. On average, the occurrence of Extreme Drought was the highest in sub-period 1998-2002. Peak Extreme Drought with the range of 6.5-8.0 had occurred in Region 1 of

East Malaysia, and it was caused by the mountainous topography as well. For sub-period 2003-2007, the occurrence of Extreme Drought was low among the sub-periods. Peak Extreme Drought with the range of 6.3-7.8 was observed in Region 6 of East Malaysia, and it was predicted that the high Extreme Drought was caused by the El-Niño episodes. For sub-period, 2008-2012, peak Extreme Drought with the range of 8.2-10.0 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. For sub-period 2013-2017, the occurrence of Extreme Drought was high among the sub-periods. Peak Extreme Drought with the range of 6.5-8.0 was observed in Region 3 of East Malaysia, and it could be caused by mountainous topography. Overall, SPI-3 had shown that peak Extreme Drought had occurred often in Central part of East Malaysia. Besides, Region 3 had shown most occurrence of peak Extreme Drought. Regarding the location of Extreme Drought, peak Extreme Drought was caused by mountainous topography rather than El-Niño episodes.

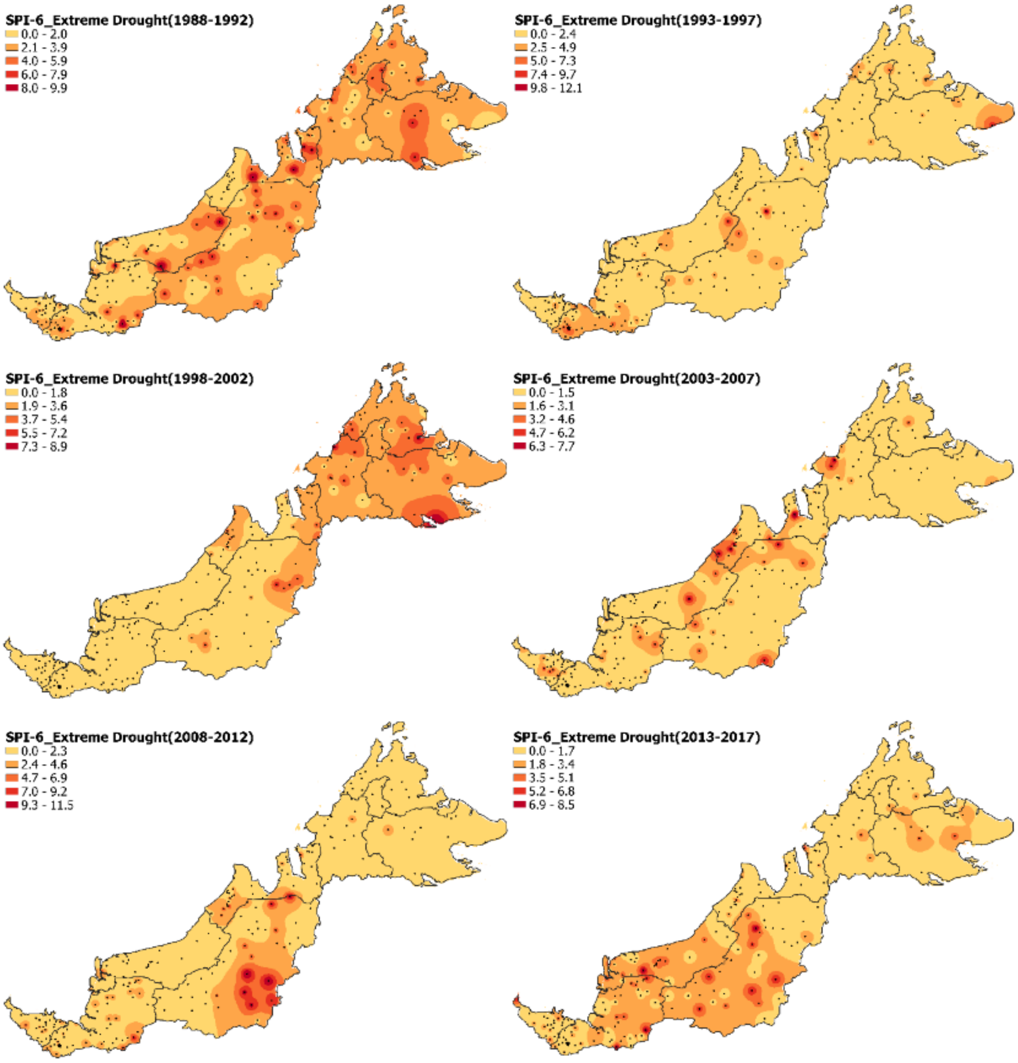

Figure 4.30: Extreme Drought maps of SPI-6 for each 5-years sub-period along 1988-2017.

Figure 4.30 shows the study by SPI-6, the occurrence of Extreme Drought was high in sub-period 1988-1992 as compared to other sub-periods. Peak Extreme Drought with the range of 8.0-9.9 had occurred in Region 6 of East Malaysia, and it was predicted that the high Extreme Drought was caused by the El-Niño episodes due to its locations being near to seashore. In sub-period 1993-1997, the occurrence of Extreme Drought was low among the sub-periods. Peak Extreme Drought with the range of 7.4-9.7 had occurred in Region 3 of East Malaysia. By referring to the location of drought events, it was predicted that high Extreme Drought was caused by the mountainous topography. On average, the occurrence of Extreme Drought was high in sub-period 1998-2002. Peak Extreme Drought with the range of 7.3-8.9 had occurred in Region 1 of

East Malaysia, and it was caused by the mountainous topography as well. For sub-period 2003-2007, the occurrence of Extreme Drought was low among the sub-periods. Peak Extreme Drought with the range of 6.3-7.7 was observed in Region 6 of East Malaysia, and it was predicted that the high Extreme Drought was caused by the El-Niño episodes. For sub-period, 2008-2012, peak Extreme Drought with the range of 9.3-11.5 was observed in Region 3 of East Malaysia, and it could be caused by the mountainous topography. For sub-period 2013-2017, the occurrence of Extreme Drought was high among the sub-periods. Peak Extreme Drought with the range of 6.9-8.5 was observed in Region 3 of East Malaysia, and it could be caused by the mountainous topography. Overall, SPI-3 had shown that peak Extreme Drought had occurred often in Central part of East Malaysia. Besides, Region 3 had shown most occurrence of peak Extreme Drought. Regarding the location of Extreme Drought, peak Extreme Drought was caused by mountainous topography rather than El-Niño episodes.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Droughts have always been thought of as a natural phenomenon that we people have to endure from time to time. Especially in many countries where this calamity has befallen on them. According to the research, this phenomenon will most likely increase in severity compared to current situations in the coming years ahead. Therefore, it is important to investigate the drought characteristics in order to mitigate and minimise its impacts either to the economy, social or the environment. Based on the drought assessment in Sabah and Sarawak, drought characteristics of different Regions at 251 stations from year 1988 to 2017 has been investigated.

The Standardized Precipitation Index (SPI) was selected for this study. The SPI is an effective method for identifying drought characteristics regardless of the regions in Sabah and Sarawak. It is eligible for the studies of spatiotemporal pattern of dry and wet conditions, because of the versatility over temporal scale and its ability to represent the anomaly of precipitation. The SPI is accepted more generally because its calculation is simple and it has less input requirements, where only precipitation data is needed. Hence, the SPI has been chosen as the drought index to investigate the drought characteristics in Sabah and Sarawak given its advantage to provide multiscale drought indications using only precipitation as input.

In this study, the calculation of SPI was conducted utilizing the rainfall data from 1988-2017 (30 years), at 1-, 3- and 6-months timescales. As a comparison between SPI at the 1-, 3- and 6-timescales, the SPI-1 assessment typically compares normal precipitation for each month, and it is considered to be a more accurate representation for monthly precipitation. The SPI-3 reflects the short- and medium-term moisture conditions, besides showing a seasonal estimation of precipitation, whereas for SPI-6, it indicates medium-term trends in precipitation and is considered to be more effective showing the precipitation over distinct seasons. In this research, all the SPI at different timescales have shown multiple results of drought categories, specifically on the peak drought locations. Therefore, the SPI at different timescale can be selected according to the result expectations, in terms of short-, medium- or long- term trends of drought.

The precipitation data were utilized to study the Drought Frequency (DF), Mean Drought Duration (MDD), Mean Drought Severity (MDS), Mean Drought Intensity (MDI) and Mean Drought Peak (MDP). For clearer views of drought patterns, the droughts were categorised into mild, moderate, severe and extreme drought. It was observed that the drought patterns vary from sub-period to sub-period. However, there was a clear pattern that sub-periods 1993-1997 and 2008-2012 have shown that during these two times, the most occurrence of drought have occurred, whereas the sub-period 2003-2007 had the lowest occurrence of drought events. The phenomenon could be explained by the El-Niño episodes that had occurred in the years 1994-1995, 1997-1998 and 2009-2010.

Generally, Central (Region 3) and Eastern (Region 1) part of East Malaysia have constantly faced higher drought occurrence. For the Central part, it was predicted that the drought characteristics were influenced by the mountainous topography of East Malaysia. The stations in Region 3 that have relatively shown higher drought occurrence are surrounded by the mountainous regions of Pergunungan Iran and Pergunungan Hose. Pergunungan Iran and Pergunungan Hose could block the North-East Monsoon and the South-West Monsoon respectively from reaching those stations, thus resulting in higher drought occurrence. For the Eastern part, it was predicted that the drought characteristics were influenced by the past El Niño events. Given the location of stations that have relatively higher drought occurrence being near to seashore, the rainfall might be restricted due to increase in sea surface temperature during an El Niño event, which leads to higher drought occurrence.

5.2 Recommendations for future work

The SPI has proven its feasibility in identifying drought characteristics in Sabah and Sarawak. However, further study is required to assure a better interpretation of drought conditions in East Malaysia. Thus, some possible improvements are suggested:

(i) SPI can be compared with other drought indices such as SPEI and PDSI in order to evaluate the differences in drought characteristics, as the SPI is calculated based on precipitation only, whereas other drought indices consider multiple data such as temperature, streamflow and so on.

(ii) SPI can be computed in other timescales, such as 9-, 12-, 24- or even 48-months for better understanding of drought characteristics in various timescales.

(iii) More studies can be carried out in order to understand the factors that have caused various drought characteristics at the different locations. For instance, rainfall occurrence could be affected by land use, soil characteristics, moisture bearing winds and so on rather than just the El Niño events and mountainous topography in East Malaysia.

(iv) For a better understanding between historical and future drought characteristics, future drought pattern should be evaluated using future data predicted from different climate change scenario, such as RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

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