RAINFALL VARIABILITY INDEX (RVI) ANALYSIS OF DRY SPELLS IN MALAYSIA

CHUNG JING WAY

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

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

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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.

Signature : ______________________

Name : Chung Jing Way

ID No. : 1602221

Date : 30 April 2021

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"RAINFALL VARIABILITY INDEX (RVI) ANALYSIS OF DRY SPELLS IN MALAYSIA"** was prepared by **CHUNG JING WAY** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ____________________

Supervisor : Ir. Dr. Huang Yuk Feng

Date : 30 April 2021

Signature : ____________________

Co-Supervisor : ____________________

Date : ____________________

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ABSTRACT

The lower number of rainfall events causing the environment to become drier over the years is a crucial phenomenon attracting the concern of all around the world. The impacts of rainfall event deficiencies will lead to the issues of availability of water resources, both for the agricultural sector and the human health development. Therefore, the studies on the rainfall variability in term of the dry spells (DS) and the drought characteristics of the regions are necessary for a better understanding for the DS and their associated spatial and temporal variations. In this study, the study period is from 1988 to 2017, and the intricacies of the DS and extreme DS occurrences, spatial distribution for drought characteristics over Malaysia were analysed. The study was confined to the 30-year period of monthly and annual rainfall data that was graciously provided by the Malaysian Meteorological Department and the Drainage and Irrigation Department. All of the raw data were then analysed using the Rainfall Variability Index (RVI) with two different timeframes, that being the 30-year long-term period and subsequently over six 5-year sub-periods consecutive sections of the 30-year long period. The findings showed that the Northern Region and Central Region located in Peninsular Malaysia, and the regions that lie between Sabah and Sarawak had more DS occurrences due to the higher number DS exhibited over the study period. The next part of the study was the spatial analysis for drought frequency (DF) and mean drought duration (MDD) over the 13 regions throughout Malaysia. It showed that the DF was significant for both the annual and monthly RVI, and for the MDD significant for the monthly RVI over the 30-year period. For the six 5-year sub-periods, the spatial differences varied for both DF and MDD, based on annual RVI.

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LIST OF SYMBOLS / ABBREVIATIONS

i	study year
N	number of years
P_i	annual rainfall in year i, mm
μ	average annual rainfall, mm
δ_i	rainfall variability index in particular year
σ	study period standard deviation, mm

ARB	Aksu River Basin
BMD	Bangladesh Meteorology Department
BNWA	Brazilian National Water Agency
CI	Concentration Index
CMSN	China Meteorological Sharing Network
CV	coefficient of variation
DES	Directorate of Economics and Statistics
DF	drought frequency
DI	Deciles Index
DID	Drainage and Irrigation Department
DRB	Doce River Basin
DS	dry spells
IMO	Iranian Meteorological Organisation
JRB	Johor River Basin
LP	long-term precipitation
MDD	mean drought duration
MMD	Malaysian Meteorological Department
MPDSI	Modified Palmer Drought Severity Index
NCC-CMA	National Climate Centre of China Meteorological Administration
PAI	Percentage of Area Index
PCA	Principal Component Analysis
PCI	Precipitation Concentration Index
PDSI	Palmer Drought Severity Index

PET	potential evapotranspiration
PMAZI	Palmer Moisture Anomaly Z-Index
PMD	Pakistan Meteorological Department
PNPI	Percent of Normal Precipitation Index
PRB	Pearl River Basin
PV	precipitation variability
QGIS	Quantum Geographic Information System
RAI	Rainfall Anomaly Index
RDI	Reconnaissance Drought Index
RVI	Rainfall Variability Index
SCA	South Central Asian
SP	short-term precipitation
SPI	Standardized Precipitation Index
SPTI	Standardized Precipitation Temperature Index
SRB	Sarawak River Basin
SVM	Support Vector Machine
SWSI	Surface Water Supply Index
TVDI	Temperature Vegetation Drought Index
WASPI	Weighted Anomaly Standardized Precipitation Index

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The dry spells (DS) are known as the periods of time when the regions or districts experience lower rainfall amounts from the normal rainfall. The less frequency of the rainfall events can cause lower amount of soil moisture or groundwater low, minimises the streamflow, agriculture losses, as well as the water shortage. The start and the end of the DS period is difficult to be identified. Therefore, the researchers or scientists study the DS timeframe according to a weekly, monthly or an annually period of time. This is because a DS event can happen that may take up to weeks, months or even years. When this event happens over a longer period of time, the living organisms could suffer more severe issues and thus would be more harmful and disastrous to them.

In the 1980s, the Sabah state had suffered large scale wildfires where approximately one million hectares of forest were ruined whence the monthly rainfall amount was only about 50 mm. The DS events were said to have occurred repeatedly and had gradually increased in terms of frequency in the recent years. This was mentioned in the events of 1997-1998 and 2014 where the El Nino-Southern Oscillation event had happened. The long-term DS had also occurred in the urban areas of the southwest region in Malaysia. The DS disaster frequently required the respective authorities to ration the water resources supply to both residential and industrial areas in many cases for up to a few months, thus leading to the daily activity interruptions and inconveniences.

The rainfall amount over Malaysia is considered as quite a variation because in the months of March, July and September, the lowest rainfall amount can occur. The mean annual rainfall that is received in Malaysia is more than 2000 mm, where the rainfall varies during the two monsoon seasons, that is the Northeast and the Southwest Monsoons. However, different areas may receive different amounts of rainfall. During the monsoon seasons rainfall can be more abundant in the areas where the areas are directly exposed to the monsoons. In all likelihood, the Northeast Monsoon occurs between the months of October to January, and this affects the Peninsular Malaysia (East Coast) and the Sabah state. However, the Southwest Monsoon that occurs within the months of June to September, will have the less rainfall in these similar places. According to Zainol Fadzi Paharuddin (2014), the Jelebu district is the driest district in Peninsular Malaysia. Kuala Kelawang (the new name for Jelebu) located in the Jelebu district, receives the average rainfall of only 1600 mm or less, annually. This is a huge rainfall difference from that received at the Ipoh city (5000 mm annually), as well as the Sabah and Sarawak states with the average mean annual rainfall of 2700 mm and 3000 mm respectively (Lockard, et al., 2020).

The climate change studies are also concerned about the aspects of DS variability. The DS is said to be a continuous and long-term process that can cover over the years. In general, the DS will not provide any signal to warn the communities to raise the awareness to the climate change, unless some sort of the issues were being triggered. Issues such as for instance, human health, agricultural and water resources availability and its distribution are definite signs of impending DS disasters. In 2016, there was a serious drop in the water levels at the Linggiu reservoir that affected approximately seven million people and this had led to impeded access of fresh potable water (Tan, et al., 2019).

There had been a few studies that were conducted with consideration of some other index analysis, in Malaysia to identify the way in order to meet certain water demands for the population and predict the future meteorological changes based on the DS severity. The DS that were observed had happened at the east, west and northwest of Peninsular Malaysia, frequently during the monsoon seasons (Jamaludin, et al., 2010). Therefore, in this case the purpose of this study also includes the Rainfall Variability Index (RVI) study to analyse the severity of the DS, from the past 30 years (1988-2017) data in Malaysia.

1.2 Importance of the Study

The rainfall variability study in the tropical country Malaysia is indispensable, and to have a well understanding of the DS issue in terms of the variability of the DS behaviour, throughout the historical past in order to advance the water resources knowledge on various approaches for the water resources management and planning is important.

The DS study is essential because it provides part of the important information of the climate change, especially in Southeast Asian countries that are covered with the monsoon seasons, the results of which should help in the mitigation of the climate change impacts. An analysis report with regards to the variability of the rainfall information is required for the relative agencies or water engineers to take the necessary actions in order to minimise the impacts in the future. However, the rainfall changes are quite challenging in terms of the rainfall parameter measurements due to the climate differences, and are greatly influenced by the variation of the rainfall patterns at different places and periods, even though it is on a minor scale.

In terms of livelihood, the smallholder of rain-fed agricultural practitioners can be considered as the most susceptible to the DS variability wherein the crops are most easily affected. The DS is likely to raise the environmental pressure especially where an estimation has been made for the system of crop production, especially the paddy production in Malaysia (Alam, et al., 2012).

1.3 Problem Statement

The water resources availability is one of the environment core-medium problems in which the local communities are most likely possible to encountering the direct impacts of climate change, leading to the water resources deficiency. The climate change that may decrease the frequency of the interannual rainfall variability as well as the DS period elongation could lead to the difficulties affecting the local communities in their daily water demands. The uneven DS occurrences would cause the imbalance of the water cycle and alternate the rainfall variability, evaporation progression, atmospheric water vapour circulation, as well as the availability of soil moisture.

Despite the fact that the location of the Malaysia is within the region of the Southeast Asia where there are abundant water resources, there is a possibility that the local communities would encounter the issues of looming water crisis arising from the increasing in water demands with the population increasing annually throughout the Malaysia. According to Sim and Lai (2020), the quantity of water consumption per capita in Malaysia has increase from 222 litres per capita per day to 230 litres per capita per day within the 2017-2020 period. With the DS expected to happen more frequently in the future due to the intensifying effects of the climate change, therefore the phenomenon of the DS is important to be better understood so that mitigating efforts can be put into proper perspective to avoid a human catastrophe (Payus, et al., 2020).

1.4 Aim and Objectives

The aim of the study is to develop the Rainfall Variability Index (RVI) analysis for the regions in Malaysia, and to determine the DS for the past 1988-2017 period. The two main objectives that required to be fulfilled in order to accomplish the study goal are:

(i) To identify the occurrences of the DS in Malaysia using the RVI approach.

(ii) To determine the variations of the RVI over the six 5-year sub-periods in the 1988-2017 timeframe. The 30-year data set is split up into six consecutive 5-year sub-periods according to the years. Each sub-period is studied separately to check on the differences over and it is important to state that they are arbitrarily assumed to be independent of each other.

1.5 Scope and Limitation of the Study

Malaysia is the marked study area to carry out the study for the analysis of the DS, using the RVI. The long-term continuous rainfall period of 30 years (1988-2017) was selected, and specifically the monthly rainfall data is set for use in the DS analysis. The DS is then determined based on the climate regimes of the RVI in which the availability of the parameter consideration is the monthly rainfall data.

1.6 Contribution of the Study

The study targets to identify the rainfall variations in term of the DS occurrences throughout the regions based in Malaysia. This is because the water resources are one of the natural resources which can easily affected by the climate change, especially the prolong of the DS period that can occur over Malaysia. Deficiency in water resources could be encountered in view of the potential of uneven water cycles happening in the future, courtesy of climate change. Therefore, a better comprehension for the rainfall variability analysis of the DS is important in order to minimise the possible impacts due to the climate change while the water demands are gradually increasing all over Malaysia.

Apart from that, the DS analysis study is significant as the necessary information can be provided to the relative authorities, as well as the water engineers to ease the environmental pressure and to manage the water resources towards the agriculture fields. The water preservation actions could be beneficial where the study involves both annual and monthly rainfall data of Malaysia to aid the DS variability knowledge. This is to have a better command over the management of water resources in the country.

1.7 Outline of the Report

The report consists of a total of five chapters and they are Chapter 1 as the general introduction, Chapter 2 as the literature review, Chapter 3 as the methodology and work plan, Chapter 4 as the results and discussion and lastly Chapter 5 as the conclusions and recommendations. The brief descriptions for each of the chapter in the report are written as shown in the following paragraph.

Chapter 1 provides the introduction, importance, as well as the aim and objectives to this study which focus in Malaysia.

Chapter 2 reviews the past researches from other researchers with regard to the dry spells, provided with various type of indices for the analysis. This is to determine the applicable indices based on the study regions, countries and climate change. Another subtopic called climate change also reviews under this chapter.

Chapter 3 provides the detail descriptions of the study procedures, which include the research workflow, study area, mapping and data acquisition, monthly and annual rainfall time series analysis, as well as the climate change analysis.

Chapter 4 shows the results and discussions based on the study analysis for 1988-2017 in Malaysia.

Chapter 5 in this case concludes the report for the entire study, providing with the appropriate recommendations for the further improvement in the future with the related study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the dry spells (DS) indices analysis forwarded by the different countries with different indices applied. The DS indices analysis is mainly applied to the countries or districts where the precipitation variability (PV) was found to be significant, especially for the agricultural production and water resources management. Most of the indices' classifications were according to the respective index intervals, whereby a positive value indicates as wetness while a negative value would indicate as dryness. A detailed analysis would be run based on the annual precipitation data derived from the monthly precipitation data obtained from the existing meteorological stations. In addition, there are some reviews on the suitability and consistency of the applied indices.

2.2 Rainfall Variability Index (RVI)

The RVI was developed and served as a precipitation analysis tool in manipulating the homogeneous precipitation withdrawal which conveniently divided the study time series into four climatic stages namely, extreme dry, dry, normal and wet period (Gocic and Trajkovic, 2013). It was a simple index tool compared to other indices; as the calculation, involves the annual precipitation minus the mean annual precipitation and divided by the standard deviation of the particular study period. The particular year would be known as a dry period when the computed index indicated a negative sign and vice versa.

Oguntunde, et al. (2011) conducted a long-term PV research at seven districts in Nigeria. The PV was analysed quite a detail in terms of the dryness and wetness organisations, provided with the precipitation period range. The RVI was calculated based on two different timescales, that is, on a per annum basis and a per decadal basis. Analysis presented showed that the driest years were obtained in 1981-1990 for the majority of the studied districts in Nigeria. However, at Short Grass Savanna, an approximate value of –1.2 of RVI was calculated, indicating the highest negative value among the seven districts. In 1951-1960, Short Grass Savanna and Marginal Savanna achieved the highest positive RVI among others. Therefore, the researchers concluded that the northern of Nigeria had uneven precipitation distribution.

Milan and Slavisa (2013) carried out the RVI analysis in Serbia to monitor the shortage of water supplies especially in agricultural domains, as well as the permanent water supplement. There was a total of 12 meteorological stations selected for studying the monthly, seasonal and annual PV. The RVI analysis was calculated for both the index and percentage shifting to identify the DS years and intensity of precipitation for each of the meteorological station respectively. According to Milan and Slavisa (2013), there were two different time series that had contributed severe dry period expansion, whereas in 2000, the driest period was obtained at a majority of the meteorological stations, with the highest negative RVI obtained over the past 30 years.

Adnan, et al. (2017) conducted a research in Pakistan to observe the DS changes over the past 64 years. Precipitation data was obtained from 58 meteorological stations. RVI was used to analyse the DS in terms of PV. The monthly precipitation was then shifted to annual precipitation to perform the analysis for DS period severity. A comparison was done by the researchers and they had found that the DS intensity obtained in the RVI was far different from what was expected in the Standardized Precipitation Index (SPI).

Seven districts were targeted as the research regions due to the popular DS prone districts in Karnataka (north) by using the RVI. Jayasree and Venkatesh (2015) had carried out this research by locating the daily precipitation data from the Directorate of Economics and Statistics (DES). Results presented that majority of the districts encountered DS expansion where the DS occurrences were about 50 %. A minimum of two years DS period was encountered in majority of the regions studied and the RVI illustrated that the consecutive DS will occur in the decades following.

Over, in China, Zhang, et al. (2015) conducted a research for the management of water resources which was significant in the DS regions, for drought risk management at the Aksu River Basin (ARB). The RVI analysis showed the severe DS expansion for two major precipitation periods over the past 50 years of precipitation record. Besides, four separate years were considered as the DS years where about 89 % of the negative annual RVI was obtained.

Further on, a research had been completed by Sharma (2009) to implement a solution to overcome the retention of precipitation (runoff). RVI was introduced in this research to determine the behaviour of precipitation. Historical annual precipitation data (25 years) was collected from seven different land use. The analysis presented that India (northeast) encountered DS in a majority of the study period. However, the critical index, the driest period was in 1990, whereas the wettest period was in 1991. The RVI results were linked to the flood frequencies for the past 25 years to indicate the DS severity.

Adnan, et al. (2016) selected Pakistan as a prior focus country in South Central Asia (SCA) to identify the monthly PV, as well as the relationship between different indices based on the data provided. Monthly precipitation data with over 60 years of precipitation record was collected from 58 meteorological stations in which the data was presented by Pakistan Meteorological Department (PMD). The RVI in this case analysed the monthly and annual precipitation of SCA, followed by the comparison between the SPI and Percent of Normal Precipitation Index (PNPI). It was found that the three indices displayed high relationship between each other. This study did not mention the accuracy of the indices, but analysed the consistency of the data from various units in order to achieve the sustainable development during the DS period.

Murata (1990) carried out a research for the PV during the Baiu season in Japan. Monthly precipitation data record (84 years) was obtained from 50 meteorological stations, for the month of June. The stations were further divided into four areas for the RVI analysis using rotated Principal Component Analysis (PCA). The RVI was applied to detect the periodicity of the PV in Japan. Analysis presented were the wet and DS in particular timeframe for long-term period (ranged between 50-60 years) instead of short-term period (< 10 years). There was a total of two PCA rotated, indicated the well performance of the RVI in this study.

2.3 Standardized Precipitation Index (SPI)

McKee, et al. (1993) formulated the SPI based on the PV probability with certain time series that was required to be studied. The input of time series into the SPI results in effect of PV during the DS period. The long-term time series (minimum 30 years precipitation record) such as three, six, nine, 12, 24 and 48 months were considered as the study period of the desired research. The desired study period will be inserted into homogeneous probability distribution in order to identify the variations in sign convention for the SPI when compared to the median of the precipitation. The SPI with positive value indicated that it was larger than the median precipitation and vice versa.

Mou, et al. (2019) conducted a research at the Johor River Basin (JRB) in Malaysia to identify the method in which the water resources were sufficient for the population from Malaysia and Singapore. Five major branches of JRB had been considered while the daily precipitation data from 18 meteorological stations had been obtained, provided by the Malaysian Meteorological Department (MMD) and the Drainage and Irrigation Department (DID). Climate models were applied together with the SPI to analyse the DS and forecast the future climatologic at JRB. The DS behaviour in particular study area were determined and analysed with different time scale.

Bong and Richard (2019) completed the research based on the SPI analysis at the Sarawak River Basin (SRB) where 30 years of continuing precipitation record were collected from 15 meteorological stations in Malaysia. Based on the SPI analysis, most of the meteorological stations at the SRB obtained SPI values of lower than –1, which means the DS cumulation was higher. One of the factors that caused the high severity in Sarawak is the El Nino phenomenon. The future prediction for the location is that it will be facing even higher severity of DS.

Besides, Khalili, et al. (2011) carried out the climatologic characteristics where the PV was intended for figuring them out. Monthly precipitation data of 50 years records were collected from 10 meteorological stations, where the data was provided by the Iranian Meteorological Organisation (IMO). According to Khalili, et al. (2011), the SPI was implemented in the DS analysis based on various time series. The result expressed was that there was a slide shifting in six months when compared to three months. In addition, the results thereafter were compared with the three months analysis of the Reconnaissance Drought Index (RDI), and it was reported that significant differences were found.

Milan and Slavisa (2013) conducted the SPI in Serbia to monitor the insufficient water delivery especially in agricultural domains, as well as the long-lasting of water supplement. Out of 12 meteorological stations, there were two stations which obtained the critical annual precipitation variation. A critical precipitation intensity of 1282.3 mm was obtained from the Zlatibor station while the lowest precipitation intensity of 247.1 mm was obtained at the Palic station. The SPI can be considered as an appropriate tool for precipitation study in terms of monthly, seasonal and annual periods because it was capable to identify the DS period specifically, provided the long period of precipitation, as well as the variability of the time series were studied.

Furthermore, Adnan, et al. (2017) conducted a study in Pakistan to determine the DS behaviour over the past 64 years. Analysis data was obtained from the PMD with respect to 58 meteorological stations. SPI was used in this study to perform an analysis based on dryness and wetness of climatology. There were more indices being addressed and compared to the SPI due to the well performance of DS in terms of the deficiency of soil moisture.

On the other hand, Adnan, et al. (2016) carried out a research for the SCA region where more concentration was put on Pakistan to boost the water resources management, as well as the agricultural programs. The PV was analysed based on the monthly precipitation data provided by the PMD while for other regions, data were provided by the Global Precipitation Climatological Centre. According to Adnan, et al. (2016), the SPI was applied with a timescale of 12 months. From the past 60 years, Pakistan contributed a total of 18 DS years among the SCA, while extreme DS was found in 1952, with the highest negative value being 2.23. In addition, the computed results were consistent when compared to the RVI and PNPI.

Kumar, et al. (2009) conducted a research for two wet and DS prone states in India, namely Khammam and Ananthpur, in which the precipitation events happened irregularly. Five months precipitation data with 39 years continuous records were requested from the DES for the analysis. The attention of this research was to capture the sensitivity and behaviour of the SPI based on the precipitation data. Ananthpur contributed the lowest SPI value where it was significant to the agricultural cropping. However, Khammam had achieved the highest SPI which represented the excessive of precipitation. The SPI of Ananthpur was compared to precipitation deviation in term of DS years and eventually obtained the similar results where high severity of DS condition was indicated.

Pai, et al. (2011) also completed the research based in India to carry out the intensity of the precipitation for the Southwest Monsoon using the SPI and PNPI. About 458 of meteorological stations with over 60 years of records had been used for the analysis. In this case, the comparison between the PNPI and the SPI were made in term of DS climatology for the Southwest Monsoon. Although both the PNPI and SPI presented there were about 15 % or more of the DS climatologic found at northwest of India, but the SPI performed with a better result in which almost all of the study districts were seen as having 5 % or more of the moderate DS. The coefficient of variation (CV) usually taken into account in the SPI rather than the PNPI which caused the drawbacks in the PNPI, such that the probability of the PNPI increased when the CV increased.

Preethi, et al. (2019) conducted an SPI analysis based in India to forecast the DS during the summer monsoon period. Monthly precipitation data was requisite from the Indian Institute of Tropical Meteorology as the input parameter for analysis. Other indices such as the PNPI and the Percentage of Area Index (PAI) were participated in this research to analyse the PV. The SPI provided the result with a total 22 of DS years. In addition, the SPI showed there were two different time series in which the moderately DS was obtained with the SPI lesser than –1.5. A comparison was made between the SPI, PNPI and PAI to observe the obtained PV accuracy. Both the SPI and PNPI obtained a total of 15 DS years whereby three years of extreme dry period were detected.

Zhang, et al. (2015) conducted a research for the management of water research in which it was important in DS districts for DS risk administration at the ARB. 40 years of daily precipitation data was obtained from nine meteorological stations. The SPI (12 months) analysis showed that there were three meteorological stations that contributed the total number of DS years, ranging from 14 to 19 years. In addition, the west of the ARB was found more dryer in the past 40 years.

In addition, Zhang, Chong and Zhang (2009) analysed the DS characteristics based on one to three months of the precipitation time series at the Pearl River Basin (PRB). The PRB is important as it supplies water resources for the population in Hong Kong and the PRB Delta. The monthly rainfall data was obtained from 42 meteorological stations with over 46 years of data recording. The SPI expressed there was a declination for majority of the

PRB regions during the rainy season. In the southeast of the PRB, however, a wet spell was obtained and reflected higher in the SPI. Therefore, it can be concluded that DS season happened during seasonal period (raining) at the PRB.

Christos, et al. (2011) conducted a research on the DS season at the southeast of Europe, specifically Greece. The monthly precipitation data of 48 years precipitation records were obtained from 46 meteorological stations where the majority of the stations were located at the mainland, provided by the National Meteorological Service of Greece. The SPI indicated two worst period in which the DS phenomena was encountered within 48 years, yet a recovery of precipitation period in 2004 was established in which the majority of the Greece regions achieved positive SPI. The authors believed that the so-called meteorological alert indicator (SPI) could enhance the strategy in terms of DS management, in order to boost the DS flexibility and minimise the defencelessness at the same time.

Lima, et al. (2019) carried out the SPI research at the Doce River Basin (DRB), Brazil to identify the frequency and characteristics of the DS. 89 meteorological stations were selected for collecting the monthly precipitation data with 30 years historical record, supported by the Brazilian National Water Agency. The Rainfall Anomaly Index (RAI), PNPI and Deciles Index (DI) were invoked in this research to further implement a system of precipitation organisation in order to identify the PV in the simplest way. It was found that three out of nine of the sub-areas suffered extreme dry period in the recent years. The analysis presented similar results from other indices and this can be proof that the high accuracy of the SPI is needed in order to monitor the water level in DRB in future application.

Hoekema and Sridhar (2011) carried out a research on the SPI based in Idaho to investigate the effects of climatology for water resources management planning improvement. Precipitation parameters with over 35 years record were taken for the analysis. Palmer Drought Severity Index (PDSI) and other indices were involved to compare in terms of their relationship, for the summer precipitation. In this case, the SPI correlation based on one, two, three and six months of timescale frame was the objective; yet no relationship was obtained when compared to the Palmer Moisture Anomaly Z-Index (PMAZI). The comparison between these two indices indicated the lack of consideration of temperature and potential evapotranspiration (PET) when calculating the respective index. Although several parameters were taking into account for analysis, but Hoekema and Sridhar (2011) mentioned that the SPI performed well especially in the month of May and the particular analysis result was suitable for the second month irrigation alteration prediction.

2.4 Standardized Precipitation Evapotranspiration Index (SPEI)

The SPEI was widely applied in most of the research districts to identify the DS behaviour prevalent considering the unpredictable climatologic changes. It considered parameters such as moisture content, temperature, rate of wind, as well as precipitation in the calculation whereby the DS onset, time series and magnitude can be analysed. In addition, the PET which was involved in the SPEI calculation allowed for the identification of the DS severity and effect on global warming. The organisation of DS in the SPEI analysis was almost similar as mentioned in SPI, index range basis.

Water resources balancing and DS distribution were significant especially when the discussions of global warming are raised, as these would affect the vegetation recovery and the sustainability of environmental. Therefore, Gao, et al. (2017) carried out a SPEI analysis to identify the future climatology and predict the occurrence of wet and DS period in the Loess Plateau. Necessary parameters were obtained from the China Meteorological Sharing Network (CMSN). The classification method of the SPEI was similar as the SPI, in which positive and negative indices represented wet and DS state, respectively. The SPEI obtained the longer event for both wet and DS in which the precipitation distribution can be more easily to evaluate based on the time series of 12 months. As a result, the authors predicted that the Loess Plateau could receive better climatology in the future, subjected to uncertainties of the district downscaling model being used in this study (Gao, et al., 2017).

Yu, et al. (2014) had conducted an analysis of frequency and severity of DS in China. Precipitation with 40 years continuous records were selected from approximately 600 meteorological stations for the SPEI analysis. The majority of the districts encountered the long-term DS period (≥ 10 months) and the DS occurrence had increased frequently (except east, south and southwest of China). The SPEI proved that most of the districts in China are subject to the variability of DS period in which the temperature was the main affecter in this analysis, and eventually leaded to the increment of the precipitation percentage in every 10 years.

Inner Mongolia, China was focused by Liu, Kang and Wang (2016) as a research area in order to understand the climatologic circumstances for agricultural improvement, as well as the desertification control by renovating the ecology system. Precipitation with over 50 years continuous records were obtained from 46 meteorological stations as the inputs of SPEI analysis. The additional index, Temperature Vegetation Drought Index (TVDI) was applied in this study to observe the consistency of SPEI. According to Liu, Kang and Wang (2016), a high severity of DS period can be identified at the Sino-Mongolia area in the past few decades. The SPEI conducted multi-scalar for DS period in Inner Mongolia where the performance of this index showed the detail of DS variability in each specified time series (Liu, Kang and Wang, 2016). The authors concluded that the SPEI achieved well in DS variability analysis with long-term timescale and this statement was assisted by TVDI.

Adnan, et al. (2017) conducted a research in Pakistan to observe the DS behaviour over the past 64 years. Parameters were obtained from 58 meteorological stations in this research to analyse the DS in term of PV. Analysis from the SPEI had given a range between 1.0 and –1.0 and a high relationship to the SPI was contributed. The SPEI in this case shared the same parameters as mentioned in the RDI, to which the analysis was more accurate and suitable for monitoring the DS period in Pakistan.

Md Giashuddin Miah, et al. (2017) conducted a DS assessment to determine the current total amount intensity, frequency, as well as the precipitation event that had occurred in Bangladesh. Relevant data with 57 years continuous records were selected from 26 of meteorological stations, provided by the Bangladesh Meteorology Department (BMD). Existing grid data was also involved in this assessment to do the comparison with the SPEI. Assessment was conducted using the multi-scalar for SPEI (similar situation as in Inner Mongolia) where different timescales were created and analysed. Comparing to the whole study districts, the northwest of Bangladesh was at a time around the corner of desertification, in which highest severity of DS and lowest precipitation intensity were reported. The analysed results explained that

Bangladesh would encounter longer DS, and priority given to the DS prone districts. Both precipitation and grid data obtained high accuracy results and were said to be appropriate in assessing, detecting and monitoring for DS.

Mohsenipour, et al. (2018) carried out the DS characteristics in Bangladesh in which 18 meteorological stations with over 54 years of precipitation records had been selected to analyse. The Z-statistic based on the SPEI was applied in this case to observe the changes in terms of quantity of precipitation event that had occurred. The SPEI analysis presented the DS had risen in the later years from the past 54 years. The number of DS occurrences, however, was less in most DS prone districts but increased in the less DS prone districts. Although the number of DS frequencies increased, but it did not affect much in vegetation production. Therefore, the DS was significant where the SPEI was required to be studied to identify the meteorological changes in Bangladesh to minimise the impact on major productions.

2.5 Palmer Drought Severity Index (PDSI)

Palmer (1965) identified the PV by using the invented PDSI, whereby precipitation and surface air temperature were considered. The maximum and minimum index values varied from +6 to –6 for surface moisture conditions. The PDSI equalised both study districts and time series to differentiate the PV. It computes the coefficients (recharge, runoff, loss, evapotranspiration and weighting factor) to define certain moisture characteristics for the study districts. However, there were a few assumptions that must be made to recover the deficiencies of the index especially when dealing with the water balance model. Due to the PDSI characteristics, usually it is not recommended to be used in regions that are frozen or where there is a snow accumulation.

Vasiliades and Loukas (2009) who had marked Thessaly as one of the research districts in Greece to perform the analysis of monthly precipitation during DS period, meanwhile determine the moisture content of soil and river runoff in the particular watershed using the PDSI. Another three Palmer indices were applied and the results obtained among the four indices were compared. Data based on monthly precipitation, mean monthly basin-wide temperature and monthly areal precipitation were obtained and estimated according to 27 meteorological stations in Greece. As a result, the PDSI was not recommended in analysing the DS as it generated high variability index based on the specified drought events. Results generated from the two other Palmer indices were more consistent to analyse the DS in term of districts runoff and moisture content of soil, rather than precipitation event.

Dai, Trenberth and Qian (2004) conducted a research based on the data from surface air temperature and precipitation for the seasonal countries. Long-term monthly data (56 years) was requested from the National Centres for Environmental Prediction Climate Prediction. The PDSI was compared between the moisture content of soil and streamflow of river. The PDSI analysis achieved the highest consistency towards the observed moisture content for both autumn and summer period. However, the lowest significance was obtained during winter period as snowmelt was out of consideration for the PDSI. Compared to the precipitation data analysed using PDSI, it had lower consistency and therefore the precipitation data was less beneficial for analysing the DS when using the PDSI.

Besides, Guttman, Wallis and Hosking (1992) conducted a research for the DS analysis in United States. This research was significant for improving the management of water resources, as well as the agricultural production. The PDSI in this case was computed based on the precipitation data with over 60 years records from 1035 meteorological stations across the United States. The Modified Palmer Drought Severity Index (MPDSI) was also used to compute the PV and compared with PDSI. The analysis disclosed that PDSI had more differences for the extreme DS at several districts in United States, compared to the MPDSI. The authors emphasized that the MPDSI can only performed at the specific timeframe of six months, and is not as user-friendly as the PDSI.

Hoekema and Sridhar (2011) carried out a research for the PDSI based in Idaho to investigate the effect of climatology over the past 35 years for future water resources management, planning and development. The Snake River was marked as the research district in Idaho. From the analysis presented, the PDSI indicated the shifting of the surface runoff to water demand for soil moisture at the beginning of the study period, such that the high negative PDSI was reflected in the DS years. However, the PDSI as a soil moisture measurement was restricted in this research due to the irrigation of monthly climate anomalies during sub-seasonal period (Hoekema and Sridhar, 2011).

2.6 Precipitation Concentration Index (PCI)

The PCI (numerical precipitation device) was developed by Oliver (1980) to analyse the PV, especially the precipitation concentration for dryness, wetness, as well as seasonal period. There was total four divisions of precipitation organisation, where extreme irregular (PCI $\geq$ 20), irregular distribution (16 < PCI $\leq$ 20), moderate distribution concentration (10 < PCI $\leq$ 15) and uniform distribution (PCI $\leq$ 10).

Milan, et al. (2016) conducted the PCI analysis with the references from 29 meteorological stations in Serbia. The Support Vector Machine (SVM) was as an advanced technical device to enhance the PCI in which more features were analysed into more detail such as forecasting, classification of PCI, regression analysis and behaviour of precipitation (Milan, et al., 2016). The quantity of the DS was greater in the north region compared to the south region in Serbia. The analysis expressed that two of the meteorological stations obtained the minimum value of PCI (wet spells) while the rest were considered as moderately DS region.

Luis, et al. (2011) carried out the research for the mean annual precipitation in Spain where the modern monthly precipitation database of Spain was applied. This research was important as the long-term of DS had brought inconvenient circumstances in agricultural domains. The PCI was calculated according to two different timeframes in which the timeframes were 30 years long. Luis, et al. (2011) tracked that the PCI in terms of annual precipitation was peaking at the south of Spain while the lowest was at the north of the Iberian Peninsula. Also, the northeast and southwest of Spain were found significant in index increment. The PCI clearly expressed the wet and DS seasons with a simplest precipitation gradient organization in Iberian Peninsula. Therefore, the PCI identified a clear information of PV with a good modern precipitation database.

Huang, et al. (2015) conducted the PCI analysis based on the monthly precipitation at Qinghai province to identify the precipitation behaviour in China. Precipitation data record (50 years) was obtained from the National Climate Centre of China Meteorological Administration (NCC-CMA) with respect to 28 meteorological stations. The analysis showed that the majority of districts in Qinghai is subjected to the abnormal precipitation spreading whereby severe DS was detected in some districts. The frequency of precipitation was low during the raining season compared to that during the summer. Besides, the Concentration Index (CI) in this case also included to analyse the daily precipitation. Both the PCI and CI were compared according to the precipitation frequency, and both results expressed decreasing in the precipitation frequency.

2.7 Percent of Normal Precipitation Index (PNPI)

The formulation of the PNPI was simple and easy, where the total precipitation for particular year was divided by the average annual precipitation for the given studied period and multiplying with hundred percentage. The analysis could easily be conducted to identify the PV for various droughts.

According to Adnan, et al. (2017), the PNPI was applied mainly in Pakistan to determine the long-term climatologic changes. There was a total of 58 meteorological stations selected to collect the monthly precipitation data. The PNPI resulted a critical impact of dryness in first few years over 64 years. The authors defined the PNPI was a good indicator of DS period as it was able to tackle the negative SPI historical DS period provided that the SPI determined DS well in the absence of soil humidity.

The Southwest Monsoon in India was studied by Pai, et al. (2011) to classify the DS variability in terms of the precipitation intensity. There were a total 458 meteorological stations with over 60 years of precipitation record used for the analysis. The approached index – the PNPI was applied and grouped the study districts into five regions (percentage range basis). The precipitation intensity (severe dry) was found to be little in the northwest of India. The only weakness detected in the PNPI analysis was the less consideration of CV arid districts which caused the inaccurate of the result when compared to the SPI.

Lima, et al. (2019) conducted a research for DS intensity, as well as the precipitation rate at the DRB in Brazil. Monthly precipitation data was collected from 89 meteorological stations. The PNPI as an index analysis tool was used to classify the parameters provided for nine of the sub-areas in DRB. The ‘mono-index’ analysis was then accompanied with three other indices, namely the SPI, RAI and Deciles Index (DI) to identify the similarities of the results. Almost all nine of the sub-areas obtained the normal and moderate DS over the last 30 years. However, the extreme DS period was found in the recent years at most of the sub-areas. This statement was proven with the accompanied indices analysis.

The monthly precipitation data and average gridded precipitation dataset had been collected from the respective departments over India. The PNPI, SPI and PAI were used to analyse the PV over India during the summer monsoon. It was reported that the PNPI obtained a total of 21 DS years over the past century (Preethi, et al., 2019). However, the PNPI achieved the highest percentage of more than 60 % in 1918, 1972 and 2002. An analysis observation had been made with these indices to compare the differences. The consistency for the computed indices were said to be correlated as there were similar 15 years of DS years obtained.

2.8 Deciles Index (DI)

The DI was developed by Gibbs and Maher (1967) to determine the severity of the DS. It measures the intensity of precipitation and frequency of precipitation based on the variation of time series provided with computed cumulative precipitation distribution. The classification of the DI was ranged between 1-10, and each of the integer represented a specified range of DS percentage. The highest integer indicated the extreme wet conditions whereas the lowest integer indicated the extreme dry conditions.

Adnan, et al. (2017) conducted a research in Pakistan to identify the DS behaviour over the past 64 years. Analysis data was obtained from 58 meteorological stations. The DI was introduced to perform an analysis based on the monthly precipitation data provided by the PMD. The computation of the DI was presented that majority of the years were not suffering severe dry, yet normal to moderate dry. The results were said to be statistically inconsistent over the past 64 years but authors recommended this index due to its capability to capture the DS period when compared to the SPI with good feedback to the deficiency of soil moisture.

Adnan, et al. (2016) also carried out the DI analysis to determine the PV in SCA, where Pakistan was the main country focused on. The DI was introduced in this study to analyse the DS period over SCA for the past 60 years. Other indices such as the RVI, SPI and PNPI were used to analyse the severity.

The differences between the DI, RVI and SPI was that DI analyse the DS severity based on the percentage calculated while the SPI and RVI presented based on the index itself (ranged between positive and negative values). Most of the regions contributed moderate dry in the later years except Pakistan, suffered extreme dry period when the analysis was according decadal timeframe.

According to Lima, et al. (2019), DI was conducted to analyse the PV whereby the DRB was selected as a research area in Brazil. Long-term parameters such as monthly precipitation data was collected from the Brazilian National Water Agency (BNWA) with a total of 89 meteorological stations. Additional indices, the PNPI, SPI and RAI were also introduced to determine the PV. The DRB was further categorized into nine different sub-areas to increase the performance of the DI analysis. The DI results were what had been expected as in the PNPI, SPI and RAI analysis, normal and moderate DS period was identified in most of the years. The consistency of analysis was significant to invent the DS classification system for future PV simplification.

2.9 Reconnaissance Drought Index (RDI)

The RDI was established to analyse the PV by considering both the precipitation and the PET. It provided reconnaissance assessment that was appropriate for the DS analysis. There were four divisions in RDI classification, reported as such that extreme dry ($RDI \leq -1.0$), severe dry ($-1.5 \leq RDI < -2.0$), moderate dry ($-1.0 \leq RDI < -1.5$) and mild dry ($-0.5 \leq RDI < -1.0$) indicated the various classification.

Adnan, et al. (2017) conducted a research in Pakistan to observe the DS behaviour over the past 64 years. Analysis data was obtained from 58 meteorological stations. The RDI was adopted in this research to analyse the DS in term of PV. The analysis presented the overall RDI ranged between 1.0 and –1.5, and a high correlation to the SPI was contributed. The RDI comprised more than 50 % of the analysis efficiency due to the parameters such as the PET and precipitation data were involved in the analysis. Therefore, it was recommended for forecasting and monitoring the DS over Pakistan.

Khalili, et al. (2011) studied the climatologic characteristics where the PV was planned to figure out. Precipitation data with over 50 years records were collected from 10 meteorological stations provided by the IMO. According to

Khalili, et al. (2011), the DS period was determined according to three, six and twelve months period. A critical negative integer of two was contributed when six months period was analysed, as well as 12 months period. The same circumstance occurred when annual precipitation analysis was involved in the analysis. This means that the PET considered in RDI analysis was significant, and can be concluded that the accuracy achieved was even better than the SPI.

The mountainous country, Iran was selected as a DS study district. Zarch, et al. (2011) applied the RDI and SPI to determine the characteristics of precipitation. There was a total of 40 meteorological stations with over 30 years precipitation records selected and data such as monthly precipitation, evapotranspiration, relative humidity, wind speed and sunshine data were taken for the analysis. The analysis presented the RDI obtained lower value compared to the SPI due to the consideration of evapotranspiration factor in the RDI itself. Although both the RDI and SPI obtained high relationship result in terms of time series, yet the RDI in this case performed in which the deficiency of precipitation was determined from different time series.

2.10 Concentration Index (CI)

The CI (numerical precipitation tool) was developed by Martin (2004) to analyse the PV in terms of the weighted precipitation (per day) and precipitation distribution for the raining period. This numerical index was used to evaluate the daily concentration of precipitation provided with the total precipitation within the desired study period and eventually to determine the critical daily precipitation event.

A research on climate change in extreme flooding and DS had been carried out by Jamaludin and Jemain (2012) where 50 sample locations of meteorological stations in Malaysia with over 30 years period were involved for the investigation. Necessary data was requested from the MMD and the DID. The CI was applied to analyse the statistical structure in term of the precipitation characteristics (Jamaludin and Jemain, 2012). It generated the percentage of quantity of collected precipitation for every class interval of the precipitation on rainy days. The CI in this case presented the satisfaction in stability of the daily precipitation distribution, especially in east of the Peninsular Malaysia, where higher PV was detected. The peak CI generated indicated approximate 70 % of the total precipitation had been captured given 25 % of the rainy period (Jamaludin and Jemain, 2012). The CI was improved followed by the increment of the area in the exponential concentration curve (between straight line and concentration curve).

The Qinghai area, China was studied by Huang, et al. (2015) with the CI to analyse the DS. Precipitation data (50 years) was obtained from the NCC-CMA with respect to 28 meteorological stations. The CI organised Qinghai into two regions, the highest (north) and lowest (south) CI values. The CI exhibited a refined data analysis in term of percentage of precipitation, precipitation intensity, as well as fractional contribution (Huang, et al., 2015). This study was followed with the PCI analysis to identify the precipitation quantity that occurred in the past 50 years. The CI in this case described well as mentioned in refined data analysis as compared to the PCI, although both indices showed the decreasing in precipitation frequency.

2.11 Rainfall Anomaly Index (RAI)

RAI was developed to determine the DS especially the districts related to humid and rainy spell. Monthly precipitation data with at least 30 years continuing records were required to perform the calculation for determining the wetness and dryness from different time frame. There were four divisions in the RAI organisation; such as that normal ($0.85 \leq RAI < 1.10$), moderate dry ($0.75 \leq RAI < 0.85$), severe dry ($0.5 \leq RAI < 0.75$) and extreme dry ($RAI \leq 0.50$) period are defined.

Kisaka, et al. (2015) conducted a research at eastern Kenya (county of Embu). There were five districts selected in this research. The long-term precipitation (LP) and short-term precipitation (SP) were the main precipitation-fed for agriculture cropping in Kenya in which are noted significant for productivity. Daily precipitation data was obtained from the Kenya Meteorological Department as the parameter inputs for the RAI. The analysis expressed that Embu suffered the highest positive RAI during the LP as compared to other districts, meaning that it comprised more precipitation in particular time series whereas extreme dry season was found during the SP. Besides, the DS occurred beyond 15 days in the month of March and December for most of the study districts.

Lima, et al. (2019) selected the DRB as one of the study areas in southeast of Brazil. The DRB area was then further separated into nine sub-areas in order to conduct the RAI analysis. Monthly precipitation data with over 30 years records were collected from 89 meteorological stations. Additional indices such as the SPI, PNPI and DI were applied together to implement a DS classification system for the DRB to which the frequency and the intensity of precipitation were able to be classified. The RAI was well established in the system when analysing the DS at each sub-area, as well as other indices. A detailed classification could even be presented to show the anomaly interannual variability of DS with different time series.

2.12 Other Indices

The following findings are from review references with regards to the comparison and the correlation between the indices from the various particular research districts. There is a total of five indices findings described below.

2.12.1 Percentage of Area Index (PAI)

India was selected as a study area to identify the PV during the summer monsoon period. Preethi, et al. (2019) conducted the PAI under moderate and severe DS circumstances (> 40 %). The SPI and the PNPI were applied as well to compute and analyse the PV. The PAI analysis showed that there were only 16 years of DS with over 40 % area coverage in India. However, a similarity of 15 DS years were concluded with the SPI and PNPI. The PAI did not have much information with regards to time series over the past century precipitation records due to the function of this index was only analyse based on the gridded area.

2.12.2 Palmer Moisture Anomaly Z-Index (PMAZI)

Hoekema and Sridhar (2011) conducted a research for the PMAZI based in Idaho to investigate the climatologic effect from the past 35 years to improve the continuing water resources management preparation. The Snake River was marked as the research districts in Idaho. From the analysis presented, the PMAZI (March) can be applied for the prediction of the following month (said in April). It was helpful when it came to management planning to forecast the diverters demands provided with short-term forecasting. In addition, the PMAZI comprised low relationship with the SPI although both of the indices performed significantly for April and May. The authors did not emphasize the most valued index in this research but different index analysis was performed with different correlation to the annual diversion of the precipitation which can forecast the climatologic changes in Idaho.

2.12.3 Weighted Anomaly Standardized Precipitation Index (WASPI)

The WASPI was developed by Lyon (2004) to forecast the DS period according to monthly and annual precipitation data (provided at least 25 years long-term data record). Basically, the WASPI was applied to the wet tropical districts. The idea of this index was to standardise the analysis in order to differentiate the DS level on each study district.

Adnan, et al. (2017) conducted a research in Pakistan to observe the DS changes over the past 64 years. Analysis data was obtained from 58 meteorological stations. The WASPI was conducted based on climatology and it was found that DS was turning better when the time span was longer. Adnan, et al. (2017) mentioned the performance of the WASPI with regards of capturing the historical DS period from SPI analysis without data of soil moisture content.

2.12.4 Surface Water Supply Index (SWSI)

Hoekema and Sridhar (2011) carried out a research for the climatologic effects by using the Surface Water Supply Index (SWSI) for the future development of water resources management in Idaho. Several agricultural districts (Henry's Fork, Payette River, Snake River and Boise River) were selected as the research districts. Parameters such as annual streamflow and storage with over 35 years continuous records were involved in the calculation. The calculated SWSI was then compared to the annual diversion. It can be observed that the streamflow and the storage water were decreased in the specified two different time series within the studied period. However, the index showed low relationship to the piecewise function that had been analysed from existing method.

2.12.5 Standardized Precipitation Temperature Index (SPTI)

Adnan, et al. (2017) conducted a research in Pakistan to analyse the DS behaviour in terms of the dryness and wetness over the past 64 years. Analysis data was obtained from 58 meteorological stations. From the analysis performed, the Standardized Precipitation Temperature Index (SPTI) obtained approximate –3 (extreme dry) in the later years. It responded vigorously when the timescale was elongated. A comparison was done between the SPTI and SPI where higher negative PV was obtained from the SPTI.

2.13 Climate Change

DS events have been taken into cognizance and are now being of concern to researchers due to the unpredictable of duration, frequency, as well as the intensity of precipitation, which seem to have regularly decreased over the years. Climate change studies were next then established as to overcome the issues in the aspects of physical and biological system since majority of the human activities were depended on the physical environment. Parameters such as precipitation and temperature often applied in the climate change studies to analyse the needed understanding of accompanying climatologic behaviour.

Jamaludin, et al. (2010) investigated the seasonal precipitation (Southwest and Northeast Monsoons) behaviour for the past 30 years in Peninsular Malaysia. The daily precipitation data (1975-2004) was obtained from 30 meteorological stations, which were provided by the MMD and DID. The Southwest Monsoon was observed significantly at northwest of the Peninsular Malaysia, with the average precipitation from 550 mm to 950 mm. The minimum precipitation, however, observed at the east and west districts have an average range from 350 mm to 550 mm (Jamaludin, et al., 2010). The northwest districts were said to be wettest region during Southwest Monsoon since more precipitation was received then. In addition, declination of precipitation happened at a majority of the districts especially the east, west and northwest regions during the Southwest Monsoon. Compared this to the Northeast Monsoon, where the east region contributed about 1300 mm of precipitation while the total amount of precipitation has increased over years. The authors concluded that the heavy precipitation obtained at the east region was due to the topography of the Titiwangsa Range which affected significantly the west region from receiving precipitation.

In addition, Kwan, Tangang and Liew (2013) analysed the climate change from the past 30 years in order to forecast the upcoming climatologic changes in Malaysia. Comparison between historical and future of climatological cycle were determined in which the precipitation frequency was observed higher in the month of September to November in the west of Peninsular Malaysia. The high possibility of extreme precipitation frequency expansion may exist for the future climate during the autumn traditional period in west of Peninsular Malaysia. However, it was predictable that the future climate tends to improve the convective activities, land-sea thermal distinction, as well as the precipitation intensity modulation for local areas (Kwan, Tangang and Liew, 2013). Moreover, the north coast of East Malaysia (Kota Kinabalu, Bintulu and Miri) contributed heavy precipitation events in the latter half of the climatological months.

Mansell (1997) conducted a research in Scotland to identify the climatological behaviour which led to the reduction of precipitation in terms of catchment runoff. The monthly precipitation data with over 30 years of historical records were obtained and considered at Paisley. The analysis showed that more precipitation occurred during the winter while no significant changes occurred during summer. In 1970-1980, the results indicated the precipitation increment in the particular studied catchment areas. Therefore, the author concluded the precipitation had increased with obvious runoff volume in the past 30 years of the study period where precipitation volume increased during the winter season, compared to summer season.

Batisani and Yarnal (2010) carried out the climatic phenomena research especially at the moderate aridity district, Botswana for further investigation and identify the appropriate policy implications to overcome the current climate change. Research was important in this case due to the precipitation-fed (rainfed) agriculture in South Africa, where PV being a part of challenge for diet security. Information such as daily and monthly precipitation were obtained from eight meteorological stations that were distributed evenly in Africa. A majority of the meteorological stations were subject to the DS period at the first three months each year in the past 30 years. The maximum frequency of rainy days was found in northwest of Africa while the least frequency of rainy days was found in southeast of Africa. Botswana contributed the DS period where precipitation reduction was significant in both annual and monthly precipitation in the past although analysis showed some of the station received high intensity with low frequency precipitation or vice versa. Huge effects of climate change reflected in this research in terms of the PV where the DS period was significant in Botswana.

Guhathakurta, Sreejith and Menon (2011) conducted a research in India, to determine the climate change effects on the PV. There were about 3000 meteorological stations with over 100 years of recorded daily precipitation data. The information was obtained from the India Meteorological Department. The occurrences of rainy days were found to be less in most of the districts, especially the north, east and central regions. However, analysis had been presented on the occurrence of a total 100 of rainy days that had happened in the northeast of India, in which precipitation was found to be severe compared to the other regions in India. Besides, the authors also had carried out the 25-year return period stormwater assessments for several time series over the past century. It was concluded that the northeast of India received more precipitation while the DS frequency had increased in most of the districts in India.

Kumar, et al. (2013) studied the climate change impacts on the PV at the Teesta River Basin in the northwest of Bangladesh, where the precipitation was significant to the flood disasters. Ten meteorological stations were selected for obtaining the 43 years of daily precipitation data in order to run the annual precipitation analysis, using the modern 15 Global Climate Models stimulations. The DS period with 3 % of the annual precipitation received was from the month of November, December and January (the non-monsoon season period). However, the stimulated results detected the amount of precipitation increased annually during the seasonal period (June, July and August). The river basin was expected to receive higher precipitation in the future. The authors concluded that the analysis obtained was useful to determine the hydrological processes especially about the flood disasters.

2.14 Summary

The review covered the indices analyses, where the precipitation data was the main concern in the analyses of the DS event. It was observed that the SPI rather than the RVI, presented the good performance in the DS event since it is considered with different time scales. On the aspect of DS sensitivity, satisfactory results were obtained from both the SPEI and the RDI in which the PET parameter was taken into consideration when performing the analysis. Both of these indices were applied in the countries where higher frequency of DS periods were reported.

Besides, from the findings reviewed, several popular indices in which the authors found useful for water resources management, future climatologic forecasting and sustainable development requires further probing. There was no appropriate index analysis; as the applied index merely depended on which country environment and geographical characteristics was selected as a study district, especially the countries with seasons and different types of index required different parameters such as moisture content of soil, relative humidity, relative temperature, PET and other meteorological parameters.

Lastly, the findings also reviewed that the historical precipitation data of over at least 30 years period is best in order to determine or forecast the unpredictable climate change in term of duration, frequency, and intensity of precipitation in the past years. Analysis is important especially for the country where disasters may happen due to the alternation of physical environment.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Research Workflow

Chapter 3 discusses the Rainfall Variability Index (RVI) methodology, that is the RVI analysis procedures that are to be carried out. The necessary formulae are presented as well as the respective parameters involved in the calculation. The methodology described the procedures to carry out the index analysis with detailed explanation, especially for each of the parameter applied in the calculation. There are a total eight subtopics under this chapter and there are; research workflow, study area, mapping and data acquisition, RVI, annual and monthly rainfall time series analysis, climate change analysis, spatial analysis and lastly the summary. The procedures of the research flow are shown in Figure 3.1

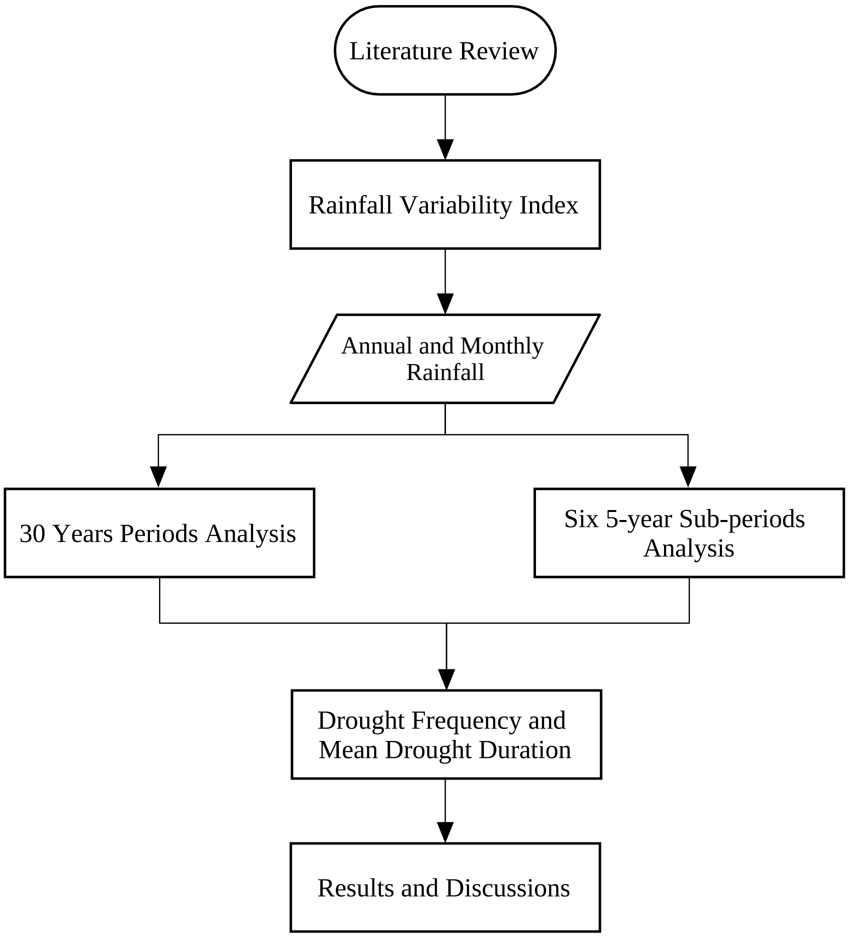


Figure 3.1: Rainfall Variability Index Analysis Workflow.

3.2 Study Area

The rainfall variability as a part of the study parameter is included to determine the rainfall behaviour of the past 1988-2017 period in Malaysia. The tropical country, Malaysia is the study area for the RVI analysis research; where it is located at 4.2105° north and 101.9758° east. There are two main land areas in Malaysia, Peninsular Malaysia and the East Malaysia land mass (northern Borneo, excluding Brunei). Peninsular Malaysia is located at 3.9743° north and 102.4381° east with a land surface area of 132 000 km^2 while East Malaysia (Sabah and Sarawak) is located at 3.7035° north and 102.4381° east with the land surface area of 198 000 km^2. Figure 3.2 shows the Peninsular Malaysia is further divided into four sub-regions whereas Figure 3.3 shows the division of the nine sub-regions in East Malaysia.

3.3 Mapping and Data Acquisition

The Quantum Geographic Information System (QGIS) is applied in the research to combine the sub-areas of the Peninsular Malaysia and East Malaysia, in order to have a better understanding and overview for the graphical mapping of Malaysia. All of the rainfall stations with their respective station identifications from the prepared Comma Separated Values delimited text files were “dragged” or merged into the QGIS layer to identify the locations for the rainfall stations throughout the whole Malaysia.

There is a total of 244 and 251 of rainfall stations allocated in Peninsular Malaysia and East Malaysia respectively (Figure 3.2 and Figure 3.3). Monthly rainfall data covering over 30 years of continuous rainfall records (1988-2017) were obtained from the DID and MMD of Malaysia. The annual rainfall data that calculated using the summation of the monthly rainfall in each year for all the 30 years. The data is then input into a worldwide-recognised data visualisation and analysis tool – Microsoft Excel in the research to boost the calculation performance and thereafter the spatial analysis in QGIS.

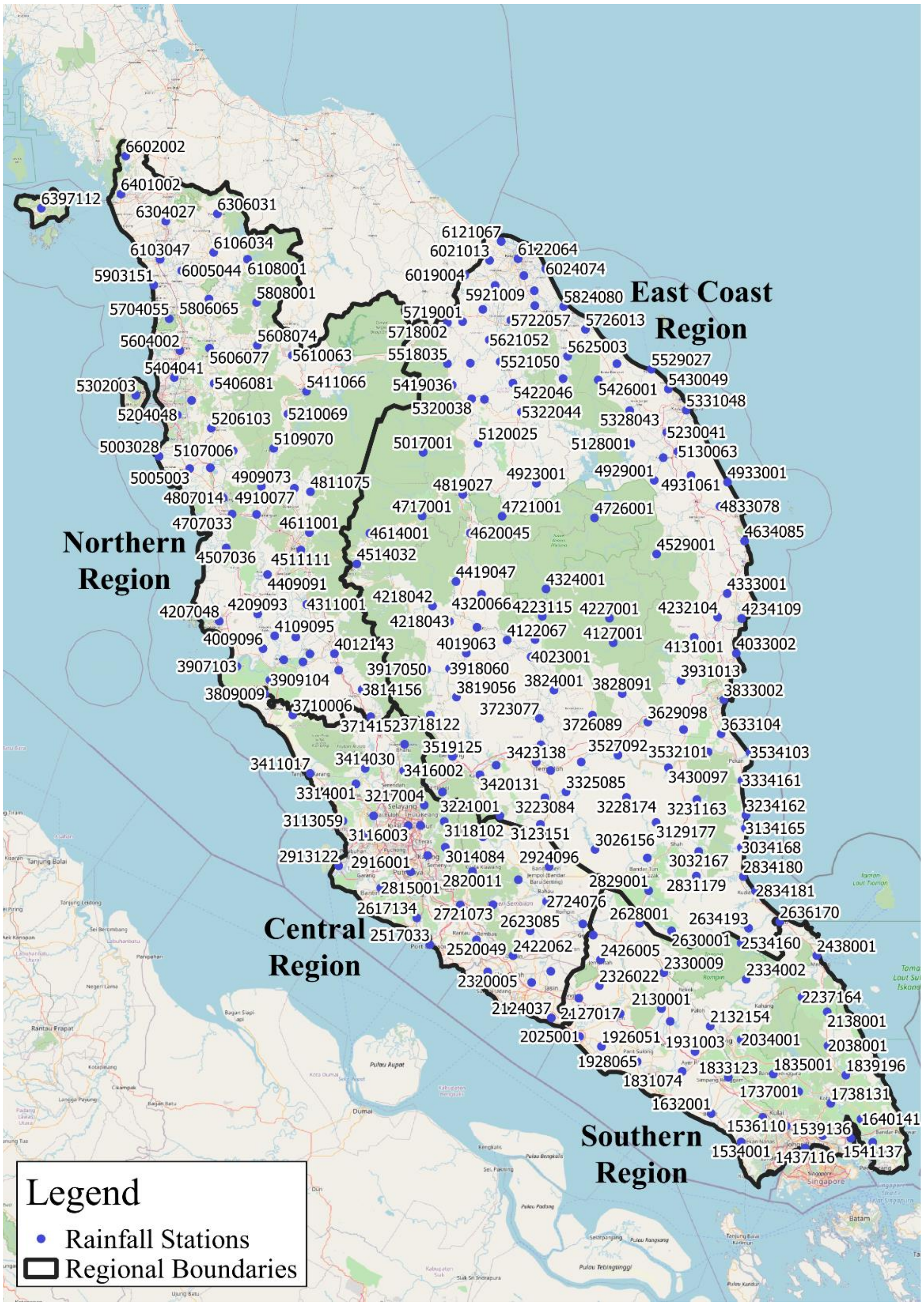


Figure 3.2: Locations of the Rainfall Stations in Peninsular Malaysia.

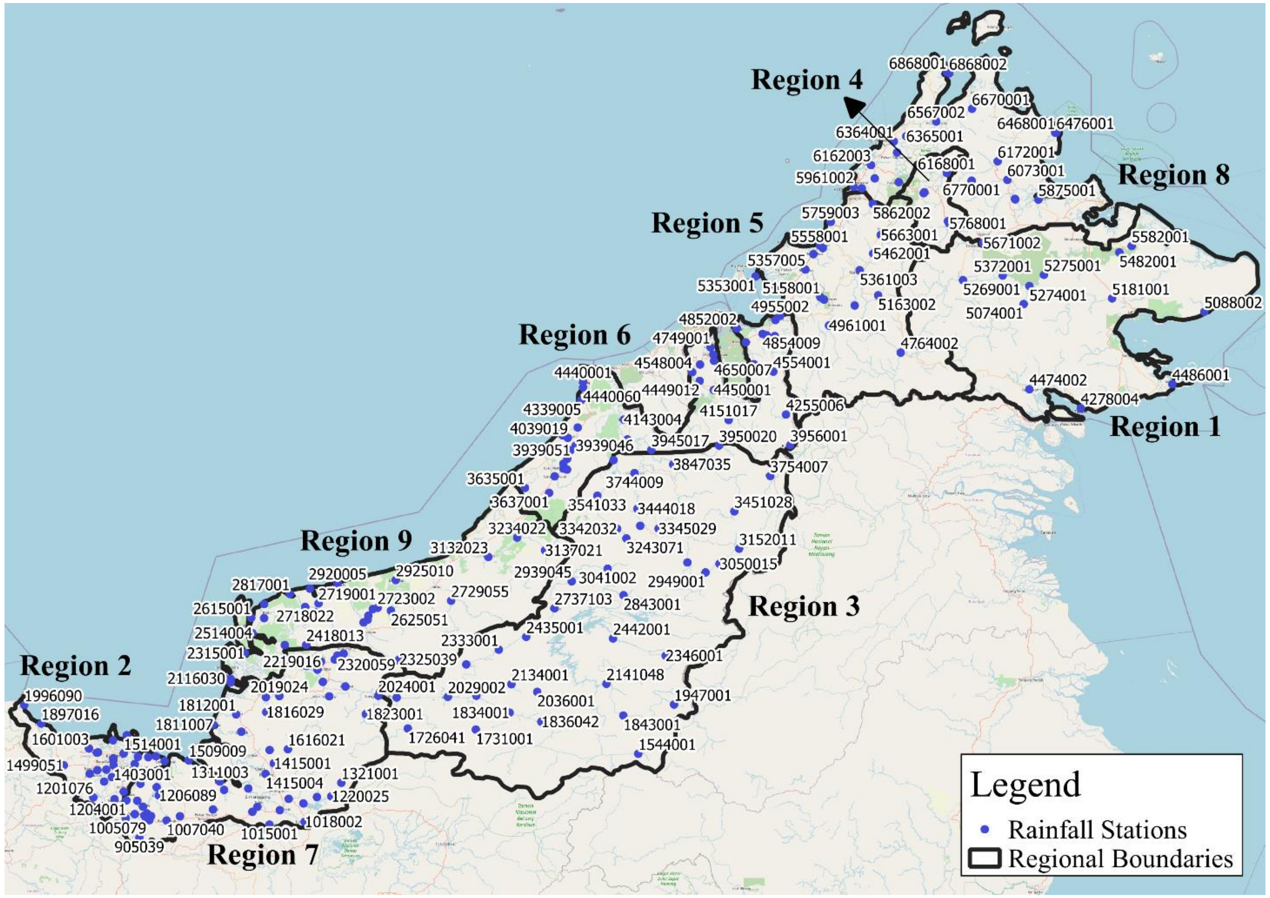


Figure 3.3: Locations of the Rainfall Stations in Sabah and Sarawak.

3.4 Rainfall Variability Index (RVI)

The RVI applied in the research is mainly because of its dispensable element that allows for the DS qualification as well as the identification for the DS monitoring and analysis. The index can be analysed over the short period, as the only parameter concerned in RVI formula, is the rainfall data. The study's rainfall time series will be divided into four basic climate regimes classification, namely the wet, normal, dry and extreme dry; as shown in Table 3.1 (Jayasree and Venkatesh, 2015).

Table 3.1: Classification of Dry Spell (Jayasree and Venkatesh, 2015).

Criterion	**Climate Regimes**
$P > \mu + \sigma$	Wet
$\mu - \sigma < P < \mu + \sigma$	Normal
$\mu - 2\sigma < P < \mu - \sigma$	Dry
$P < \mu - 2\sigma$	Extreme dry

The RVI is to calculate the standardised rainfall departure for the whole country in Malaysia. It required the monthly and annual rainfall data with at least 30-year of continuous rainfall records to analyse the climatologic change in the past 30-year (1988-2017). The particular study period indicated as the DS period when the RVI showed a negative sign value from the analysis results and vice versa. The RVI is computed with the derived equation as defined in Equation 3.1:

$$\delta_i = \frac{P_i - \mu}{\sigma} \tag{3.1}$$

where

i = study year

P_i = annual rainfall in year i, mm

δ_i = rainfall variability index in particular year

μ = average annual rainfall, mm

σ = study period standard deviation, mm

From the Equation 3.1, the mean annual rainfall is calculated based on the formula denoted in Equation 3.2:

$$\mu = \frac{\sum P_i}{N} \tag{3.2}$$

where
i = study year
N = number of years
P_i = annual rainfall in year i, mm
μ = average annual rainfall, mm

Based on the RVI equation defined in Equation 3.1, the standard deviation (σ), that is within 1988-2017 is calculated based on the formula shown in Equation 3.3:

$$\sigma = \sqrt{\frac{\sum P_i^2}{N} - \left(\frac{\sum P_i}{N}\right)^2} \tag{3.3}$$

where
i = study year
N = number of years
P_i = annual rainfall in year i, mm
σ = study period standard deviation, mm

3.5 Monthly and Annual Rainfall Time Series Analysis

The research was conducted with two different time series, on the annual basis and on the monthly basis, for the long-term period of 30-year (1988-2017) in Malaysia. The annual rainfall data that is derived from the monthly rainfall data considered as the input data for the RVI analysis. Both the monthly and annual rainfall data are then calculated and analysed by taking the average of rainfall data for each of the rainfall stations of each and every region from 1988-2017 study period.

The subsequent analysis is carried out based on each month, in which there is a total 12 months of period, from January until December. Each of the month (for the period from 1988-2017) is analysed for over Malaysia. For instance, in the case of the month of January, then January 1988, January 1989, January 2000, …, January 2017 and so on. Similar procedures where the average of the monthly and annual rainfall data based on each region is considered for the RVI analysis.

3.6 Climate Change Analysis

The analysis for the climate change conducted based on the monthly and annual rainfall data from 1988-2017. The annual rainfall data for the long-term period of 30 years is first analysed based on the six five-year sub-periods to observe the variability of the DS period. Subsequently, a further analysis is then proceeded for the monthly rainfall data where six, each of five-year of sub-periods, are considered, to study the DS period from the past 1988-2017 regionally in Malaysia. For instance, the resulting six January; January in 1988-1992, January in 1993-1997, January in 1998-2002, January in 2008-2012 and January in 2013-2017. The procedures are repeatedly applied to all the other eleven months.

3.7 Spatial Analysis

The drought characteristics for drought frequency (DF) and mean drought duration (MDD) are to be identified to observe the DS variations regionally throughout the Malaysia, as the drought characteristics may vary from the aspects of geographical features. Therefore, the spatial analysis is carried out over Malaysia to monitor the DS variations from 1988-2017 study period, with two different time series, that are in 30-year period basis and six five-year sub-periods basis.

3.7.1 Drought Frequency (DF)

The DF is denoted by the summation of the total number of DS occurrence. The DS events are indicated by the RVI when the index values showed negative sign value for the particular event. The onset and offset of DF are identified by the starting and ending of the consecutive negative RVI values. The DF is calculated with the derived equation as defined in Equation 3.4:

$$\text{Drought Frequency} = \sum \text{number of consecutive DS events} \qquad (3.4)$$

3.7.2 Mean Drought Duration (MDD)

The MDD is defined as the period of one DS event which indicated with negative RVI index values over the total number of DS events identified for the particular study period. The MDD is calculated based on the formula as defined in Equation 3.5:

$$\text{MDD} = \frac{\sum_{i=1}^{N} DD_i}{N} \qquad (3.5)$$

where

DD = drought duration of single drought event

i = number of months with negative drought index values

N = number of droughts over study period

3.8 Summary

As mentioned in the subtopics of the Chapter 3, the workflow of the research is illustrated as in Figure 3.1. The monthly rainfall data from the total of 495 rainfall stations (Peninsular Malaysia and East Malaysia) were requested from both the MMD and DID Malaysia for the length of the DS study period of the past 30 years (1988-2017). The QGIS is introduced in the research to enhance the understanding of graphical mapping and also for performing the spatial analysis for the drought characteristics over Malaysia. The following Figure 3.4 shows the overall research methodology of the study where 30 years that covered the six 5-year sub-periods are considered for the DS analysis in Malaysia.

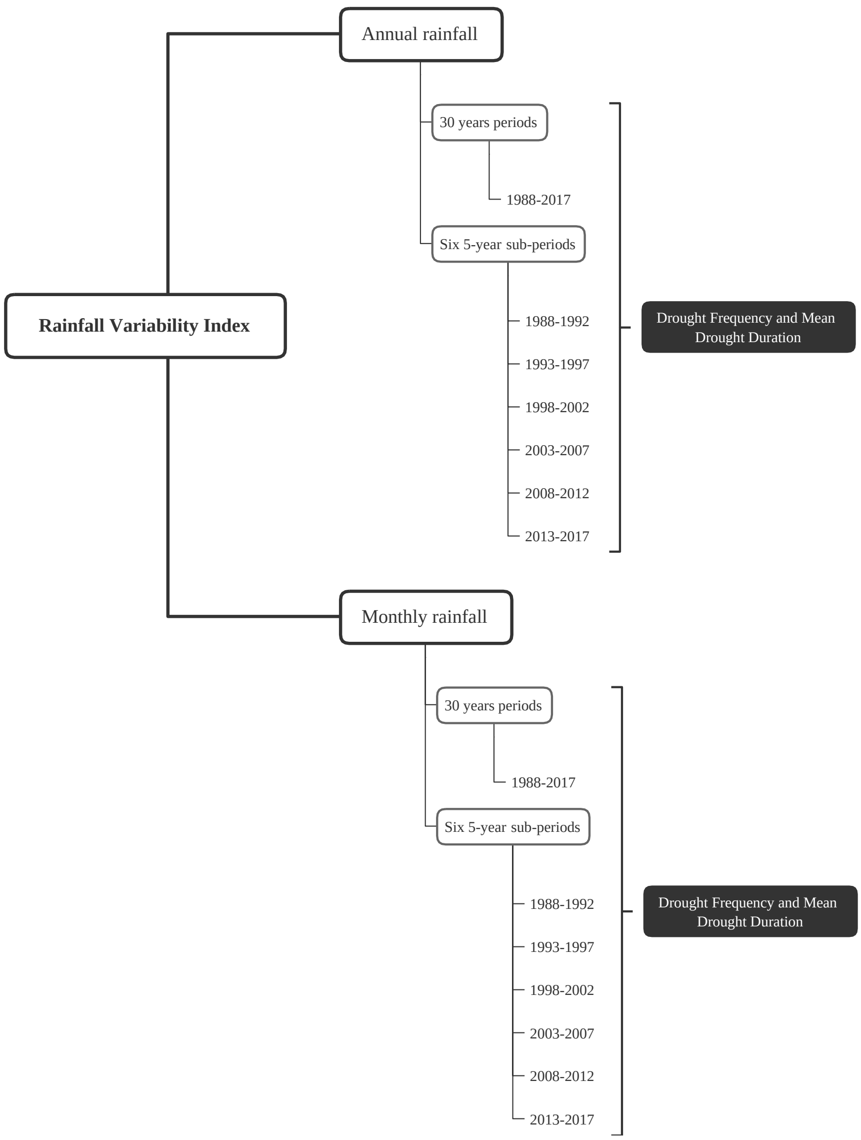


Figure 3.4: Overall Research Methodology for the RVI.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The analysis was carried out based on the rainfall variability index (RVI) to have a better visualisation on the dry spells (DS) in Malaysia. Both of the annual and monthly rainfall data were involved in analysing the RVI according to the 30-year period and thereafter, separated into six 5-year sub-periods for the 13 regions that were based in Malaysia. RVI analysis classified the particular index into four levels, the extreme dry (RVI < –2), dry (–2 < RVI < –1), normal (–1 < RVI < 1) and wet (RVI > 1) in order to generate the RVI graphs. Apart from that, the DS characteristics, for drought frequency (DF) and mean drought duration (MDD) were being discovered based on the RVI analysis for spatial distribution mapping.

4.2 Regional Analysis Based on 30-year Period

The following subsection discussed the generated analysis results in which the long-term period of 30 years rainfall data (1988-2017) from both Peninsular Malaysia and East Malaysia were considered. There was a total of four subsections for the 30-year analysis, the regional annual RVI, regional monthly RVI, regional monthly RVI (January-December) and lastly the spatial distribution and drought characteristics

4.2.1 Regional Annual RVI

The analysis for the annual RVI provided with the long-term of 30-year period was conducted in order to understand the variation of the RVI in terms of the DS throughout the Malaysia. Therefore, the results of the annual RVI for all regions, including Peninsular Malaysia and Sabah and Sarawak are presented in Figure 4.1 and Figure 4.2 respectively.

First of all, Figure 4.1 shows the DS occurrences over 30-year period for the four regions (Northern, East Coast, Central and Southern Regions) in Peninsular Malaysia, which were ranged from four to five for DS, and one occurrence of extreme DS for each region. The extreme DS detected which was experienced between the year from 2015 to 2016, for Northern Region and East Coast Region, negative RVI values of –2.349 and –2.177 respectively. But for the Central Region and Southern Region, the extreme DS were however detected in 1990 (–2.126) and 1997 (–2.038) respectively. These showed that there was lower rainfall variation (low extreme DS occurrences) over the long-term study period in Peninsular Malaysia.

In Figure 4.2 the DS occurrences of 30-year period for all the nine regions (from Region 1 to Region 9) in Sabah and Sarawak, which had the DS ranged from one to six, and extreme DS ranged from zero to two are shown. Based on Figure 4.2, it can be seen that there were two regions (Region 8 and Region 9) experienced the highest DS occurrences (no extreme DS was observed) whereas for another two regions (Region 4 and Region 7) experienced highest extreme DS occurrences with relatively lower number of DS over 30-year period as compared to other regions in Sabah and Sarawak. Also, the DS and extreme DS tended to occur in different periods over 30-year period, that were 1990-1992 (except Region 7), 1997-1998 (except Region 5), 2004-2006 (except Region 3, Region 8 and Region 9) and 2014-2016 (except Region 4, Region 5 and Region 8). This indicated that the rainfall variability over the Sabah and Sarawak was varied from time to time.

By combining the findings from Figure 4.1 and Figure 4.2, the regions located in Peninsular Malaysia tended to have relatively higher DS occurrences, as well as the regions in Sabah and Sarawak, except for Region 3, Region 4 and Region 7, where DS had experienced relatively lower occurrences over 30-year period. Apart from that, the effect of extreme DS can be detected in almost all the regions (except for Region 5, Region 6, Region 8 and Region 9). These indicated that although the extreme DS distributed may not be seen for all the regions, but the effect of DS existed for every region over the long-term study period in 1988-2017.

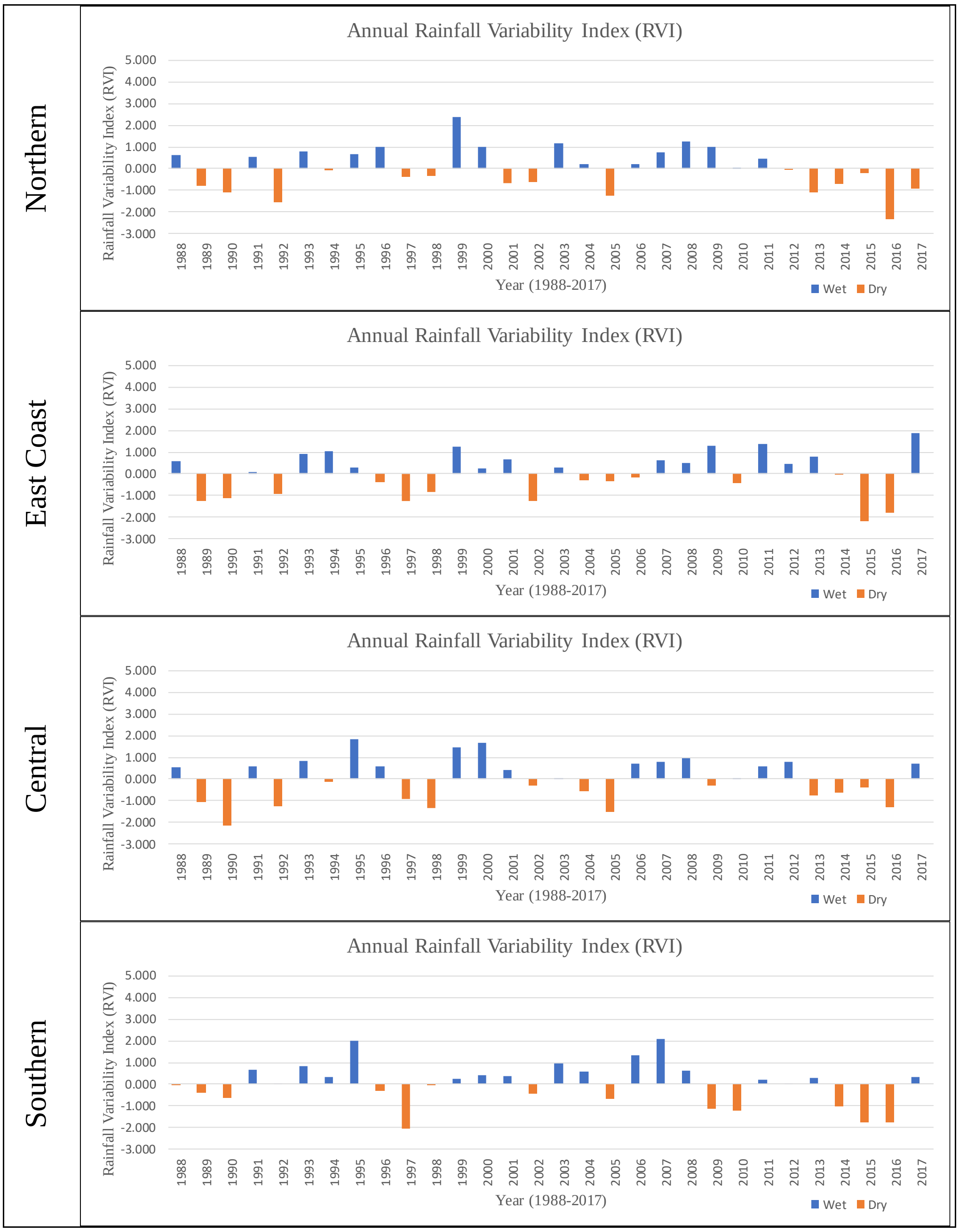


Figure 4.1: Annual RVI for 30-year Period in Peninsular Malaysia.

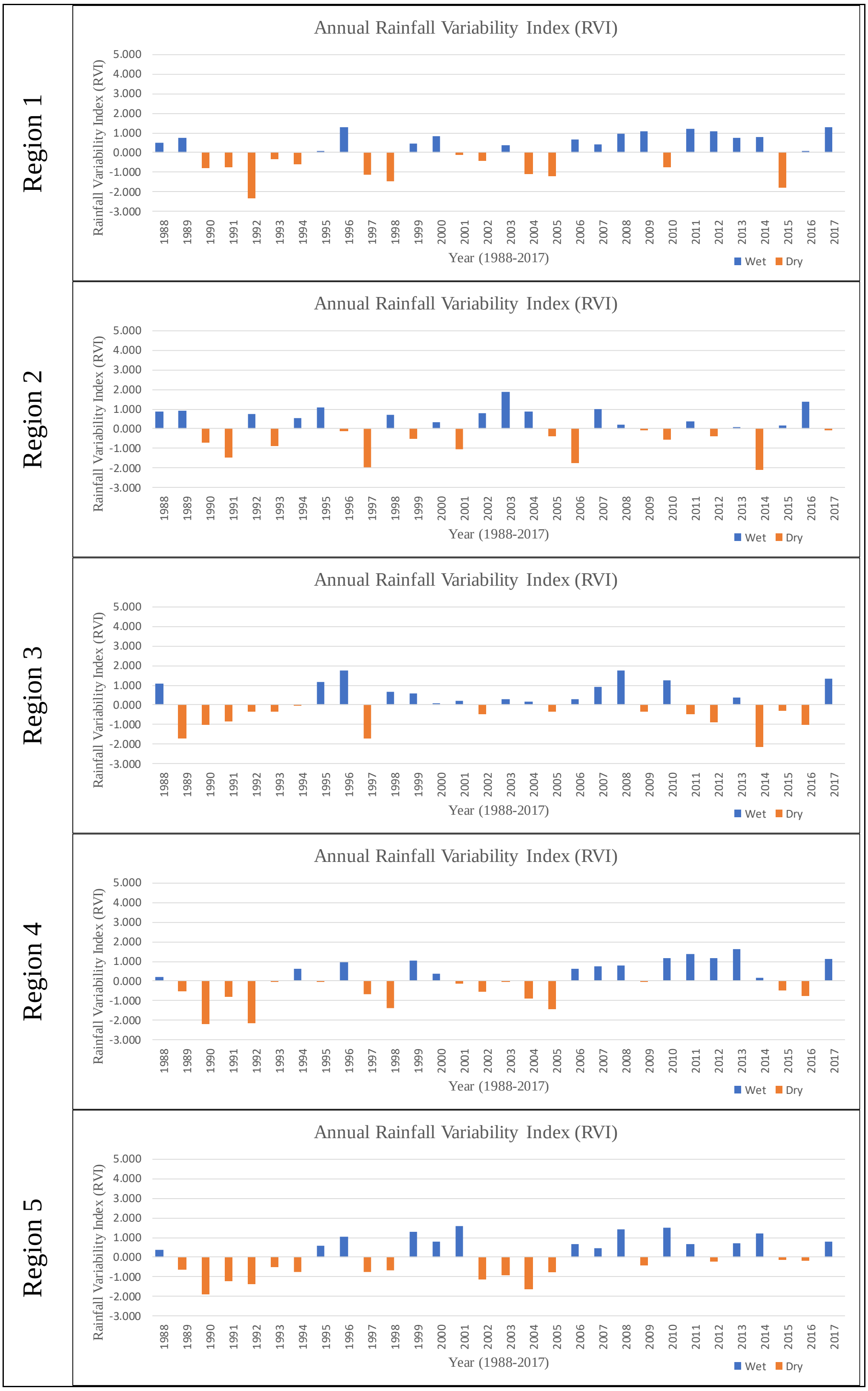


Figure 4.2: Annual RVI for 30-year Period in Sabah and Sarawak.

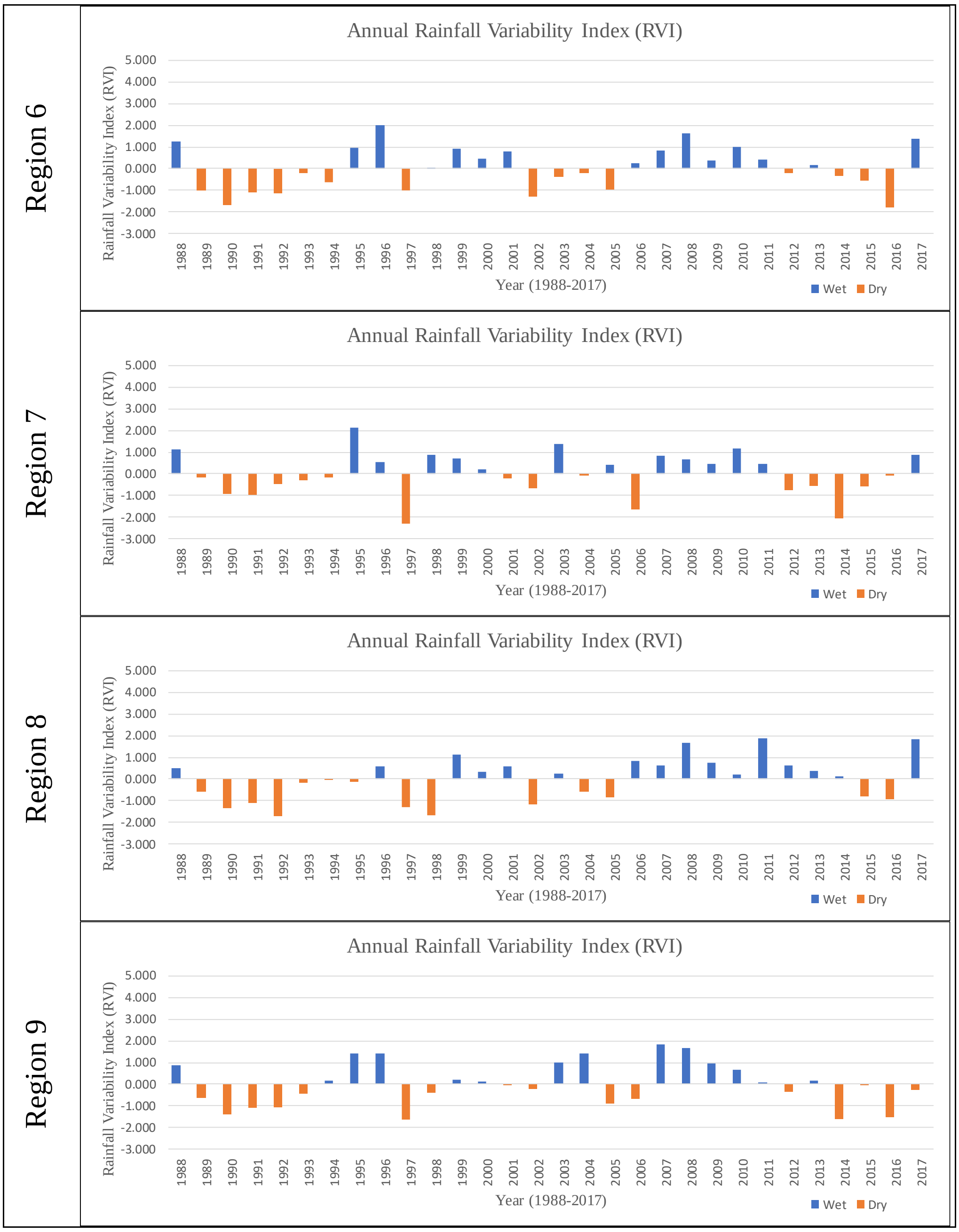


Figure 4.2 (Continued)

4.2.2 Regional Monthly RVI

The RVI analysis that was based on the monthly rainfall data was carried out for the regions located in Malaysia, through 1988-2017 study period. In this subsection, there was a total of 360 monthly RVI plotted for each region to determine the monthly DS occurrences where the regions had been categorised into two parts, the Peninsular Malaysia and the Sabah and Sarawak, as presented in Figure 4.3 and Figure 4.4 respectively. The number of DS occurrences had the ranges from 25 to 60 for the regions in Peninsular Malaysia and from 22 to 57 for the regions in Sabah and Sarawak. Whereas for the number of extreme DS ranged from zero to two for the regions in Peninsular Malaysia and zero to six for the regions in Sabah and Sarawak.

Figure 4.3 shows the monthly RVI for the Northern Region, East Coast Region, Central Region and Southern Region, where two regions contributed relatively higher number of DS over the 30-year period. The Central Region in this case was detected the highest DS occurrences (60) over 1988-2017 period (58 for Northern Region, 25 for East Coast Region and 37 for Southern Region). Similar results were observed for the extreme DS, in which the Central Region had the highest DS occurrences (two) over the 30-year period when compared to other regions (one occurrence detected for Northern Region and Southern Region). Among the regions in Peninsular Malaysia, the year in 2014 was recorded which the effect of extreme DS had brought toward the regions (except for East Coast Region) over the 30-year period. These showed that both the Northern Region and Central Region that were located in the western part of Peninsular Malaysia generally experienced more DS, as compared to the East Coast Region and Southern Region.

As for the results of monthly RVI for the nine regions in Sabah and Sarawak (Region 1 to Region 9), these are presented in Figure 4.4. From this, it can be seen that from Region 3 to Region 7 detected with relatively higher number of DS, wherein the Region 6 in this case experienced the highest DS occurrences (57) over the 30-year period (51 for Region 3, 52 for Region 4 and Region 7 and 54 for Region 5). But for the Region 1, Region 2, Region 8 and Region 9 had suffered relatively lower of DS occurrences, where Region 2 experienced the least number of DS (22) in this case (49 for Region 1, 45 for Region 8 and 42 for Region 9). As for the extreme DS, four regions (Region 1, Region 3, Region 5 and Region 6) were detected with the highest number of DS (six) over 1988-2017 period. In contrast, the Region 8 had the lowest extreme DS occurrences while Region 4 and Region 7 were found with three extreme DS occurrences. No extreme DS can be detected from Region 2 and Region 9 over the 30-year period. These indicated that the regions which located in the middle part of Sabah and Sarawak were slightly more severe (higher DS occurrences) compared to other regions over 1988-2017 period. Also, the parts which close to the South China Sea experienced more DS, as per the results shown in Figure 4.4.

By combining both results from Figure 4.3 and Figure 4.4, it can be described considering the seasonal monsoons, as well as the topography of the Malaysia. Since the Northeast Monsoon and Southwest Monsoon are the main factor where the DS can be easily affected throughout the study period. The seasonal monsoons had the minor influence towards the western part of Peninsular Malaysia and Sabah and Sarawak, which resulted higher DS occurrences experienced over 1988-2017 period. These results showed agreement with the study of Jamaludin, et al. (2010). Due to the topography of Malaysia, especially in Peninsular Malaysia, had less impact of seasonal monsoons (higher DS) which can be seen clearly from Northern Region and Central Region (less impact of Southwest Monsoon for the regions in Sabah and Sarawak).

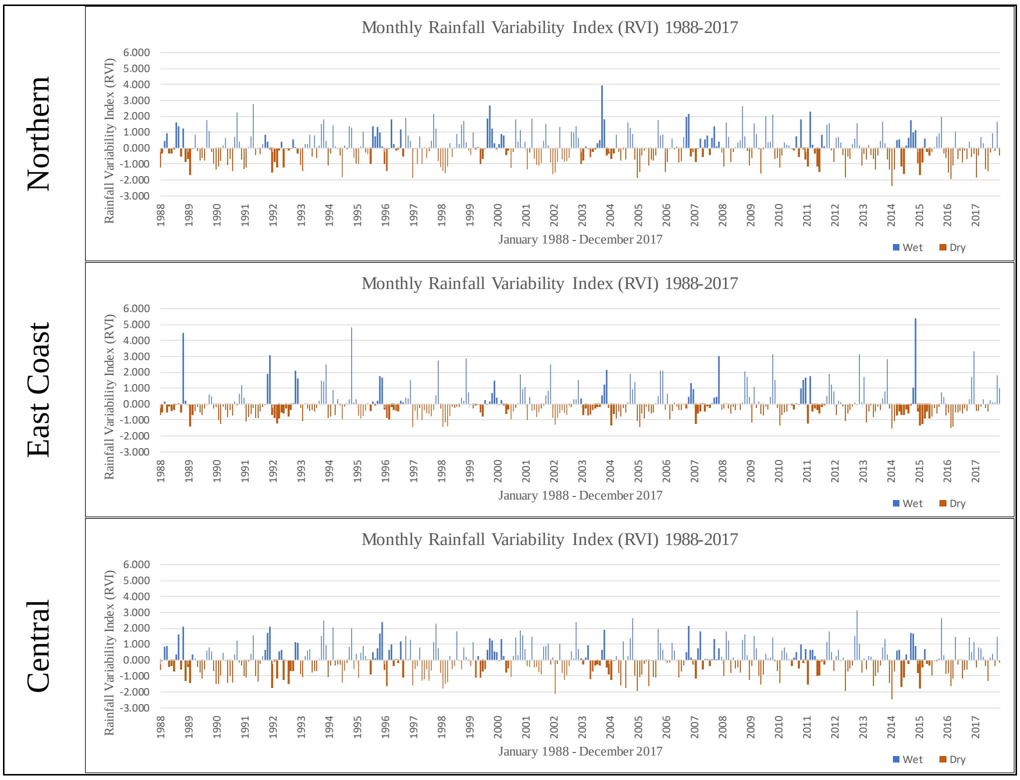


Figure 4.3: Monthly RVI for 30-year Period in Peninsular Malaysia.

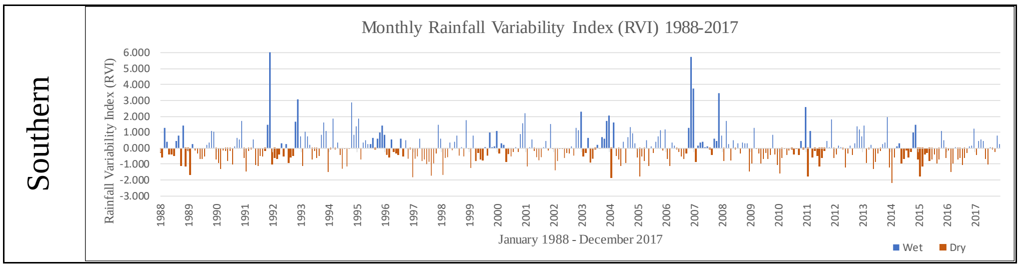


Figure 4.3 (Continued)

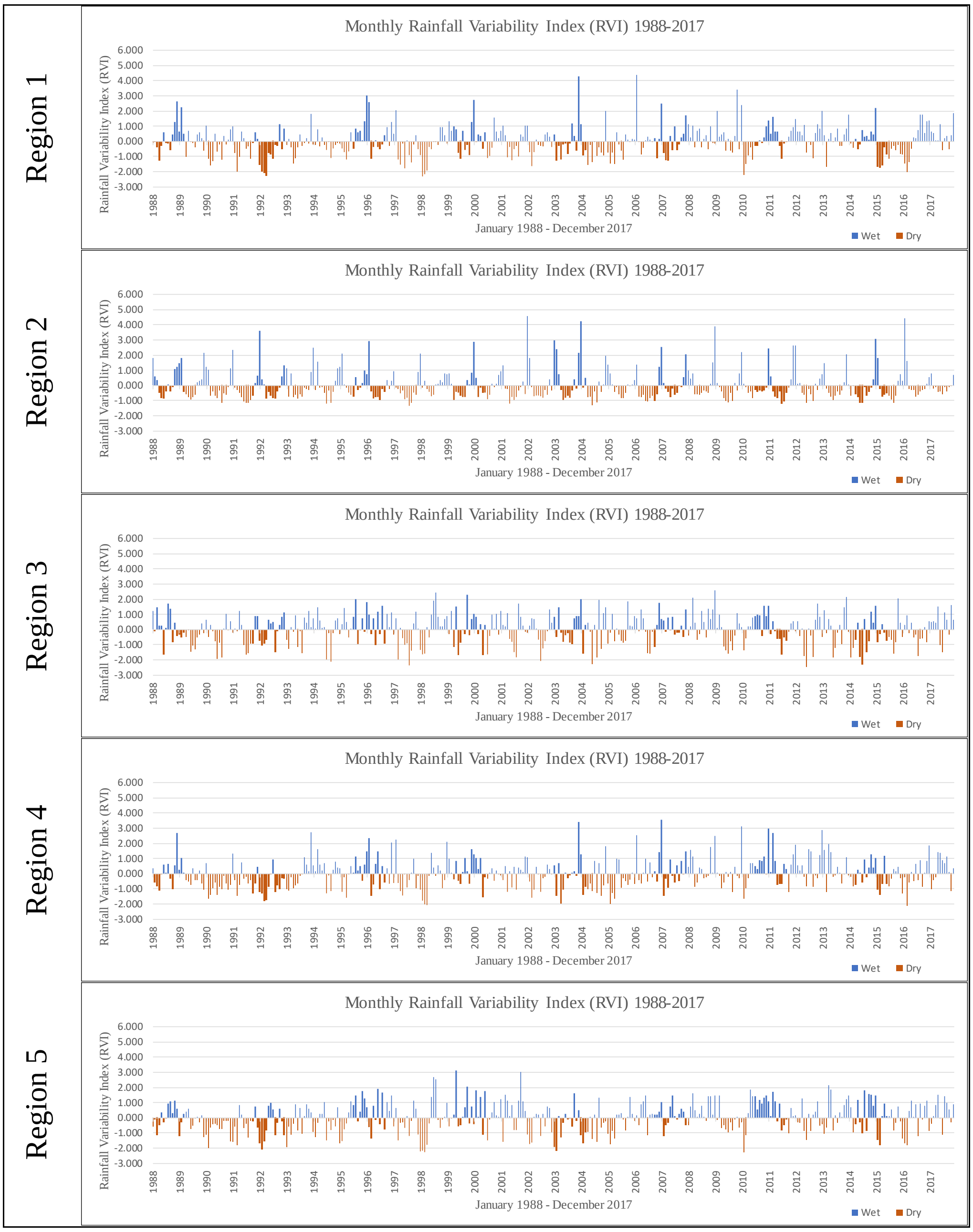


Figure 4.4: Monthly RVI for 30-year Period in Sabah and Sarawak.

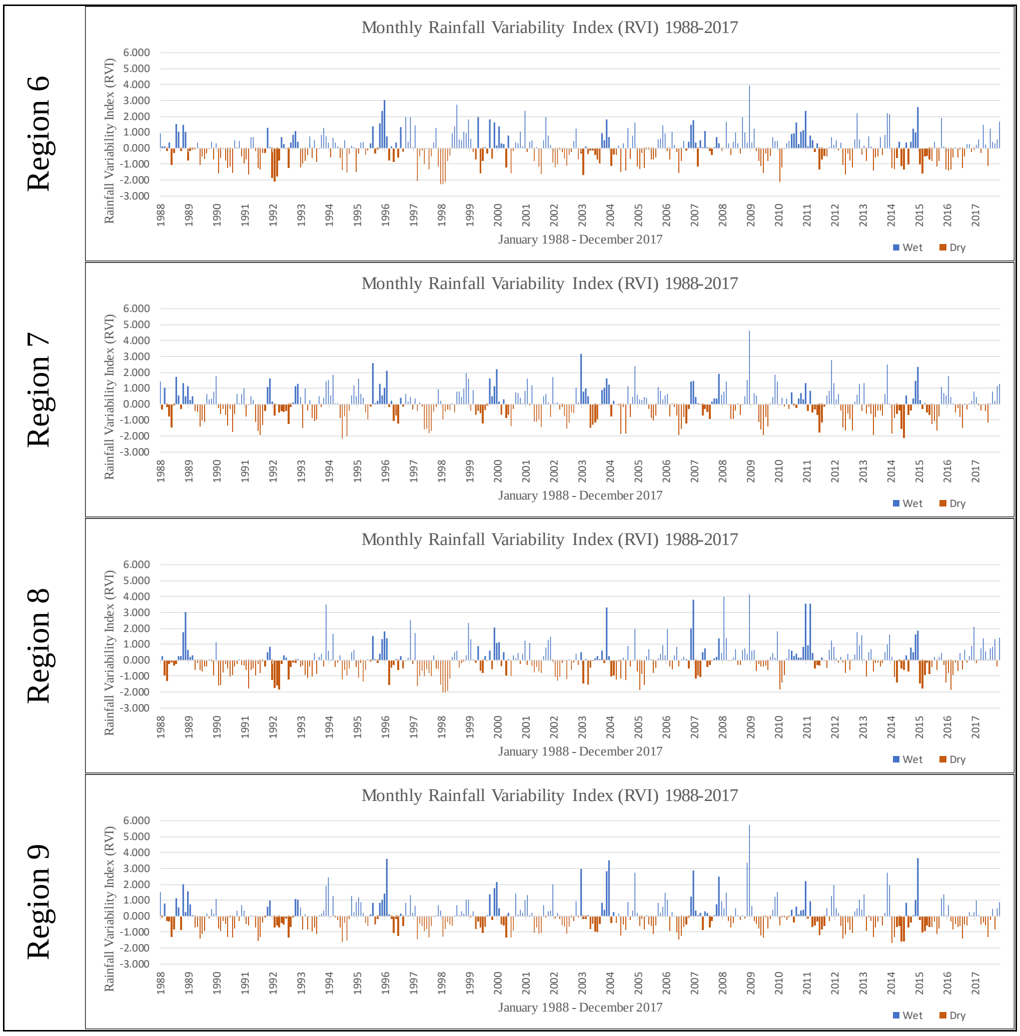


Figure 4.4 (Continued)

4.2.3 Regional Monthly RVI (January-December)

The subsequent monthly RVI analysis for each month (a total of 12 months) in different regions was carried out to have a better understanding for the DS that were based on months in Malaysia. The analysis for the monthly RVI for each region was completed and presented in this subsection, from Figure 4.5 to Figure 4.17. There was a total of 12 months provided with 30-year period (1988-2017) of monthly RVI displayed for each of the region.

From Figure 4.5 to Figure 4.8, the DS occurrences detected based on months within each region in Peninsular Malaysia, from 1988-2017 are presented. From this, the total number of DS detected for Northern, East Coast, Central and Southern Regions were 58 (1 extreme DS), 25, 60 (2 extreme DS) and 37 (1 extreme DS) respectively. This indicated that for the Northern Region and Central Region suffered relatively higher DS over the 30-year period. The DS effect can be observed significantly from the month of January to August, for Northern Region and Central Region. But for East Coast Region and Southern Region, the DS months started from January to April (from June to October were observed in Southern Region). There was a similarity for the DS month, in which the month of February, detected with the highest number of DS occurrences for each region in Peninsular Malaysia, wherein the Northern Region has the highest DS occurrences (16), compared to other regions.

In addition, the RVI that was based on months for the nine regions in Sabah and Sarawak also analysed and presented (from Figure 4.9 to Figure 4.17). Based on the figures presented, the effect of DS toward the nine regions in Sabah and Sarawak was slightly difference, wherein the DS effect can be observed from almost all the months for Region 1, Region 3, Region 4, Region 5, Region 6 and Region 8. Whereas for Region 2, Region 7 and Region 9, the DS started from May to September. The total number of DS detected over 30-year period for each region, from Region 1 to Region 9 were 49 (with six extreme DS), 22, 51 (with six extreme DS), 52 (with three extreme DS), 54 (with six extreme DS), 57 (with six extreme DS), 52 (with three extreme DS), 45 (with two extreme DS) and 42 respectively. From this, it can be observed that all the regions in Sabah and Sarawak had relatively higher number of DS occurrences, except for Region 2 which had lower significant of the DS over 1988-2017 study period. Furthermore, the months, especially February (Region 4 and Region 5), April (Region 1 and Region 8), July (Region 3, Region 6, Region 7 and Region 9) showed the highest DS occurrences. On top of the monthly highest DS occurrences, the extreme DS that was detected from seven regions generally occurred at the beginning of the year (January-March), except for Region 3 and Region 7, occurred at the mid-year (June-September).

Based on the findings from Figure 4.5 to Figure 4.17, it can be concluded that all of the regions suffered the DS events over the 30-year period, where the majority of the regions experienced the DS for more than eight months. This is in agreement with the findings of Jamaludin and Jemain (2012), as well as Bong and Richard (2019), which obtained the low intensity of rainfall (more DS) when using other drought indices for analysis. This can be described by the location of the Malaysia, that is nearest to the Equator (the tropical climate country), therefore the DS events that happened in Malaysia could be the factor of frequent DS being detected.

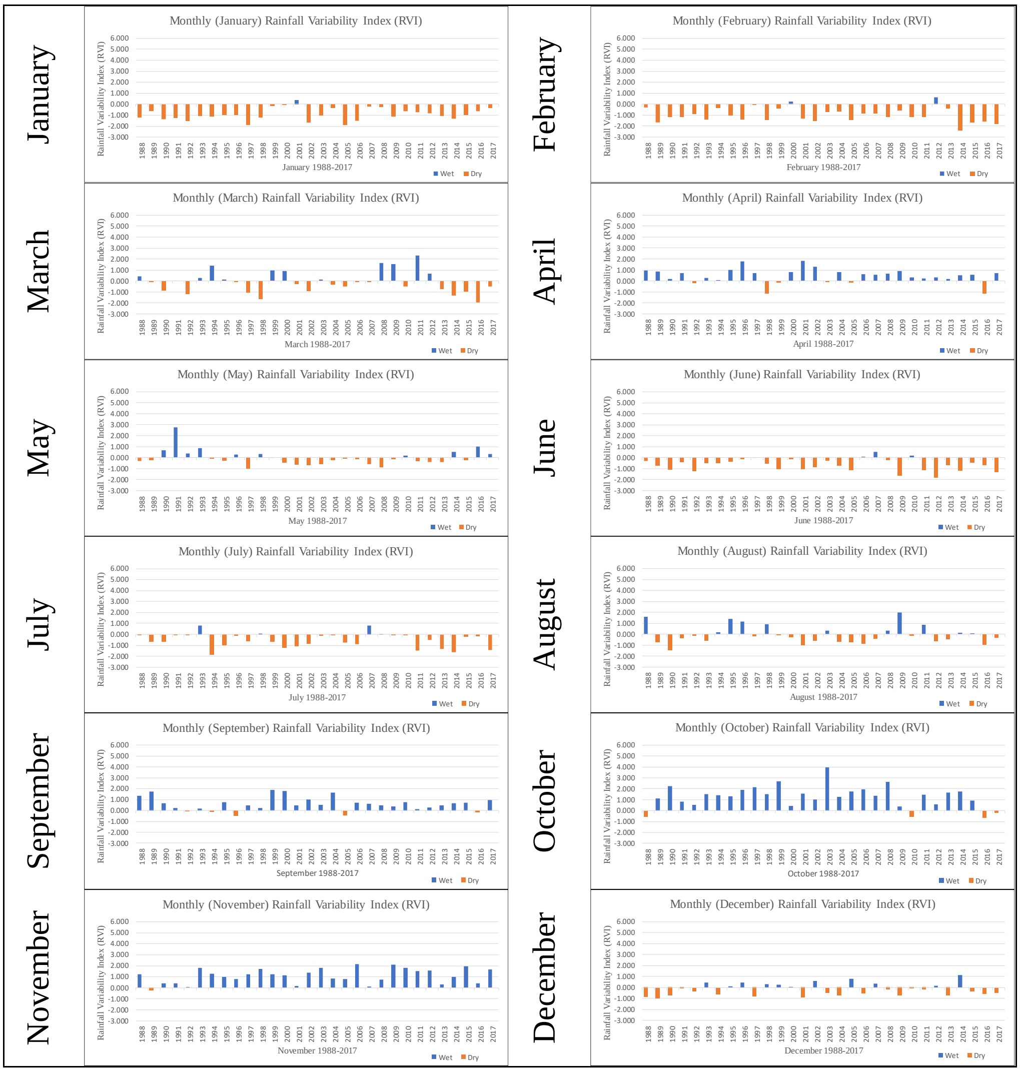


Figure 4.5: Monthly RVI of 30-year Period for Each Month in Northern Region.

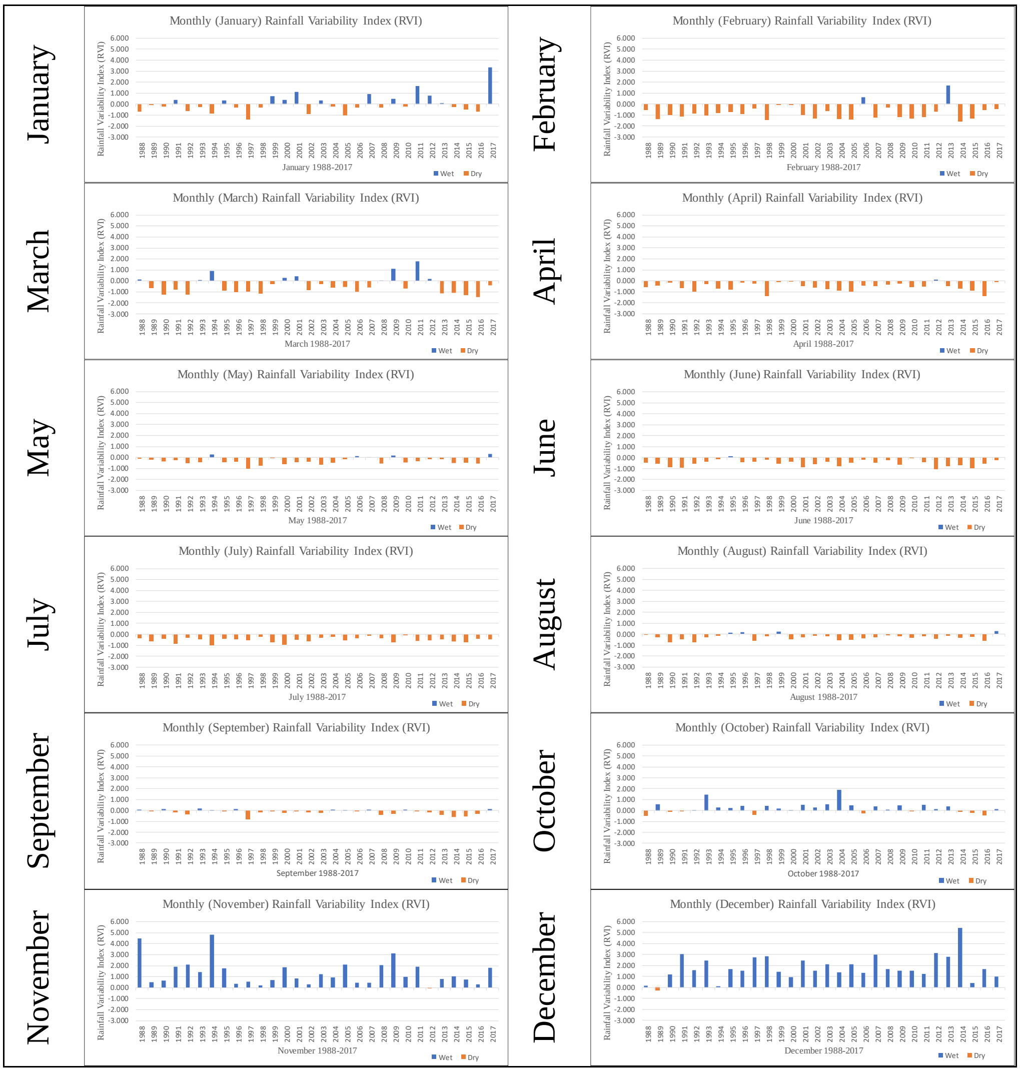


Figure 4.6: Monthly RVI of 30-year Period for Each Month in East Coast Region.

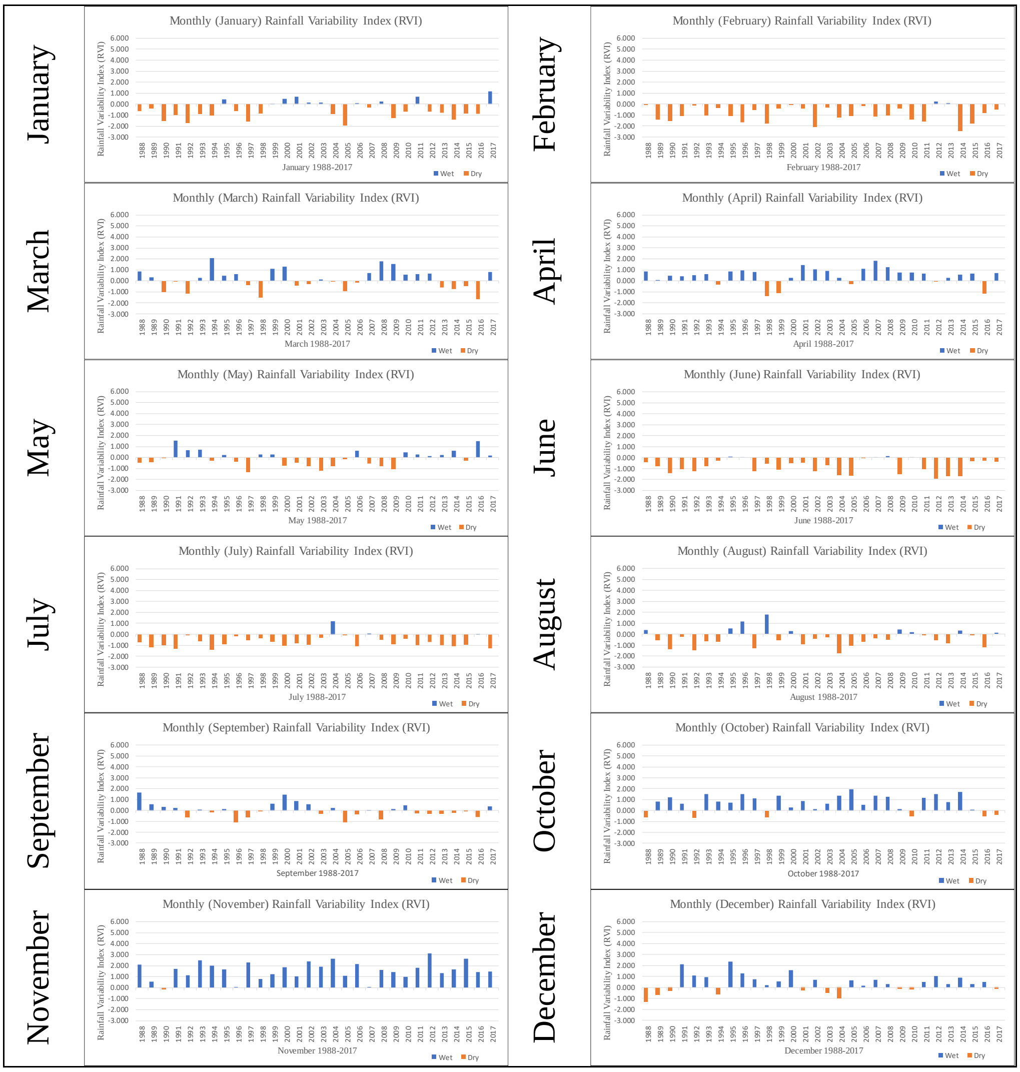


Figure 4.7: Monthly RVI of 30-year Period for Each Month in Central Region.

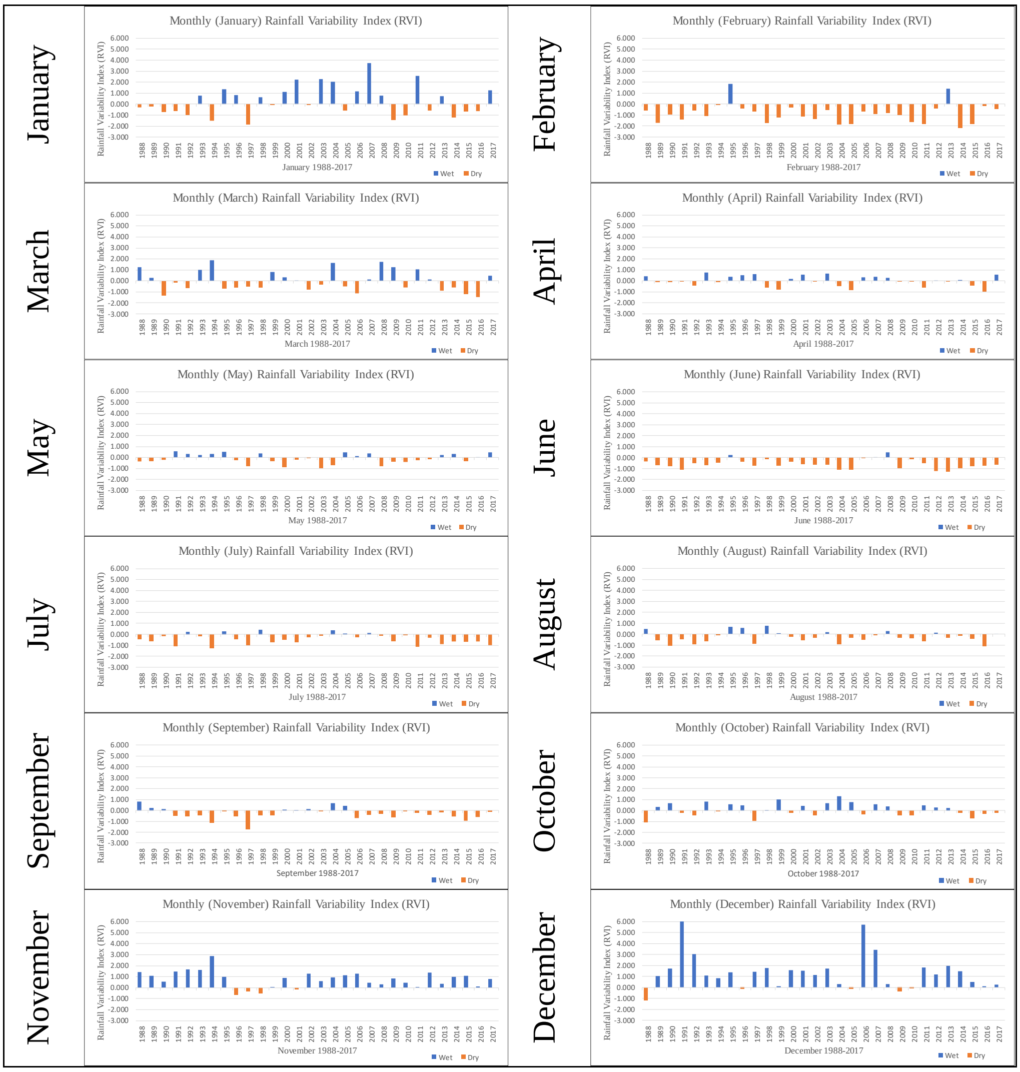


Figure 4.8: Monthly RVI of 30-year Period for Each Month in Southern Region.

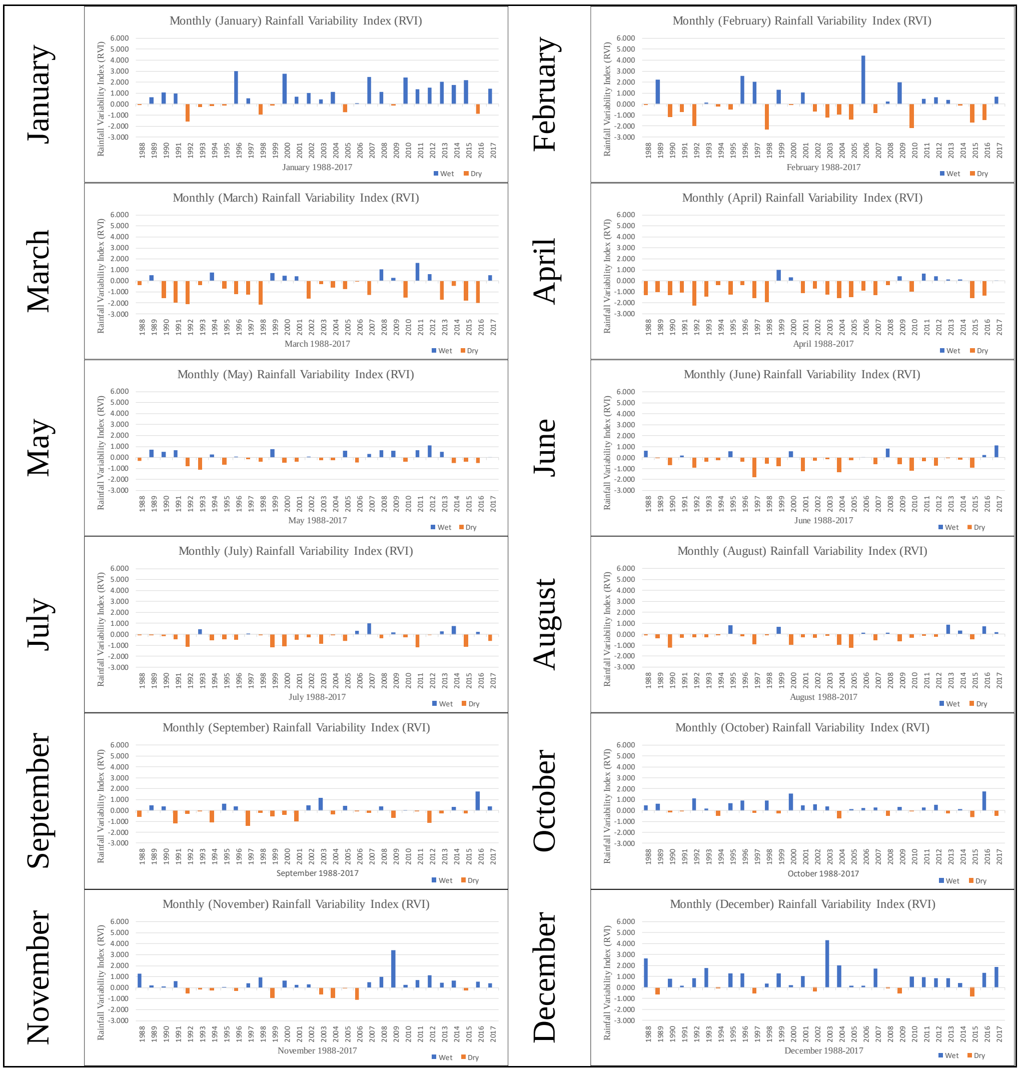


Figure 4.9: Monthly RVI of 30-year Period for Each Month in Region 1.

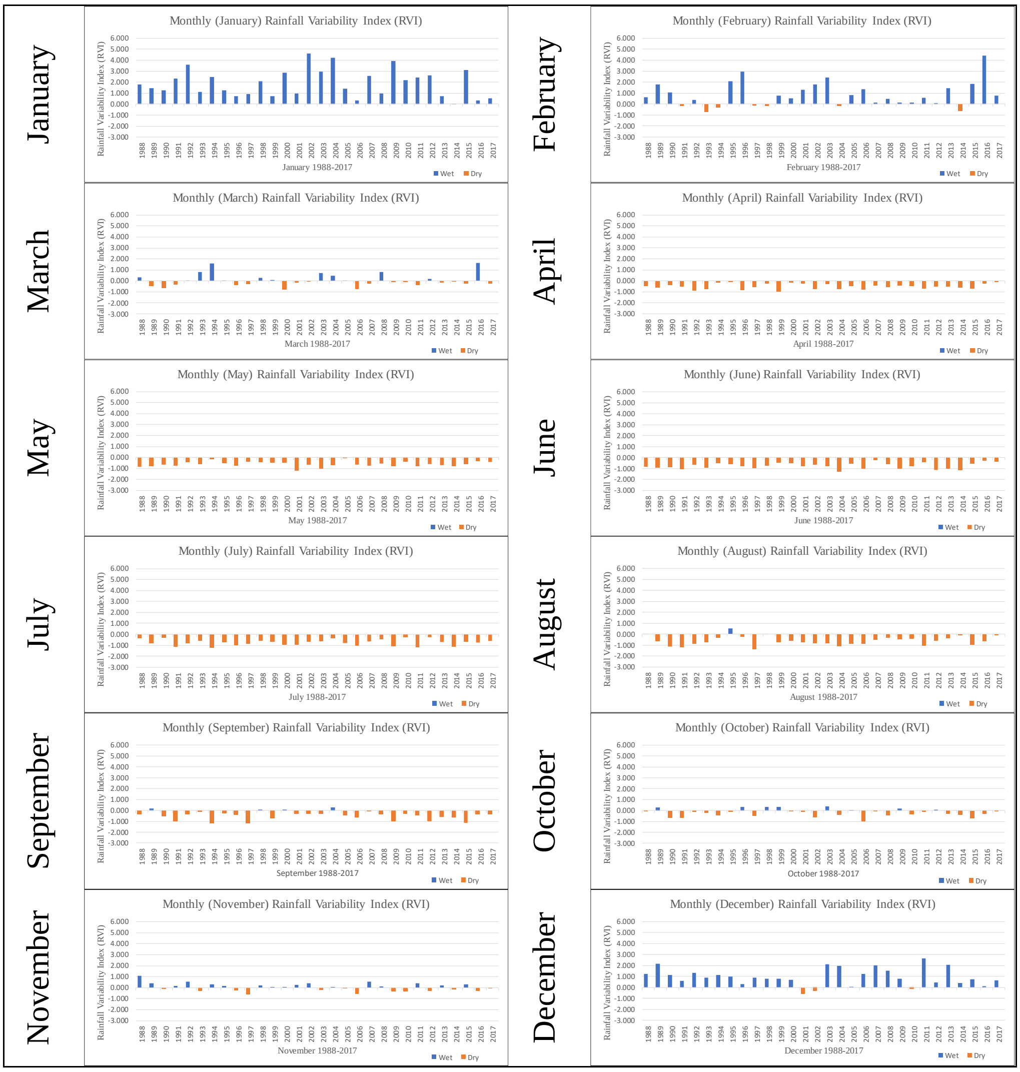


Figure 4.10: Monthly RVI of 30-year Period for Each Month in Region 2.

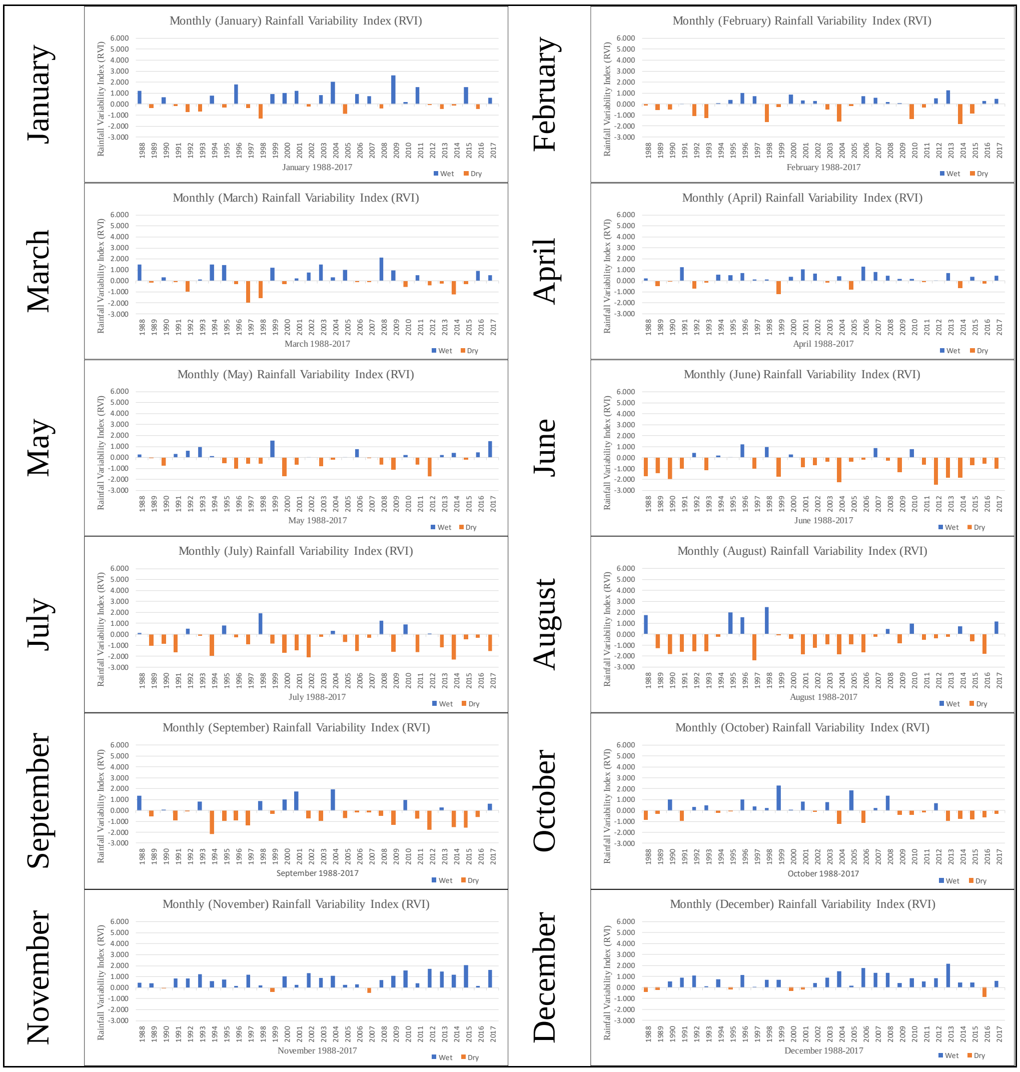


Figure 4.11: Monthly RVI of 30-year Period for Each Month in Region 3.

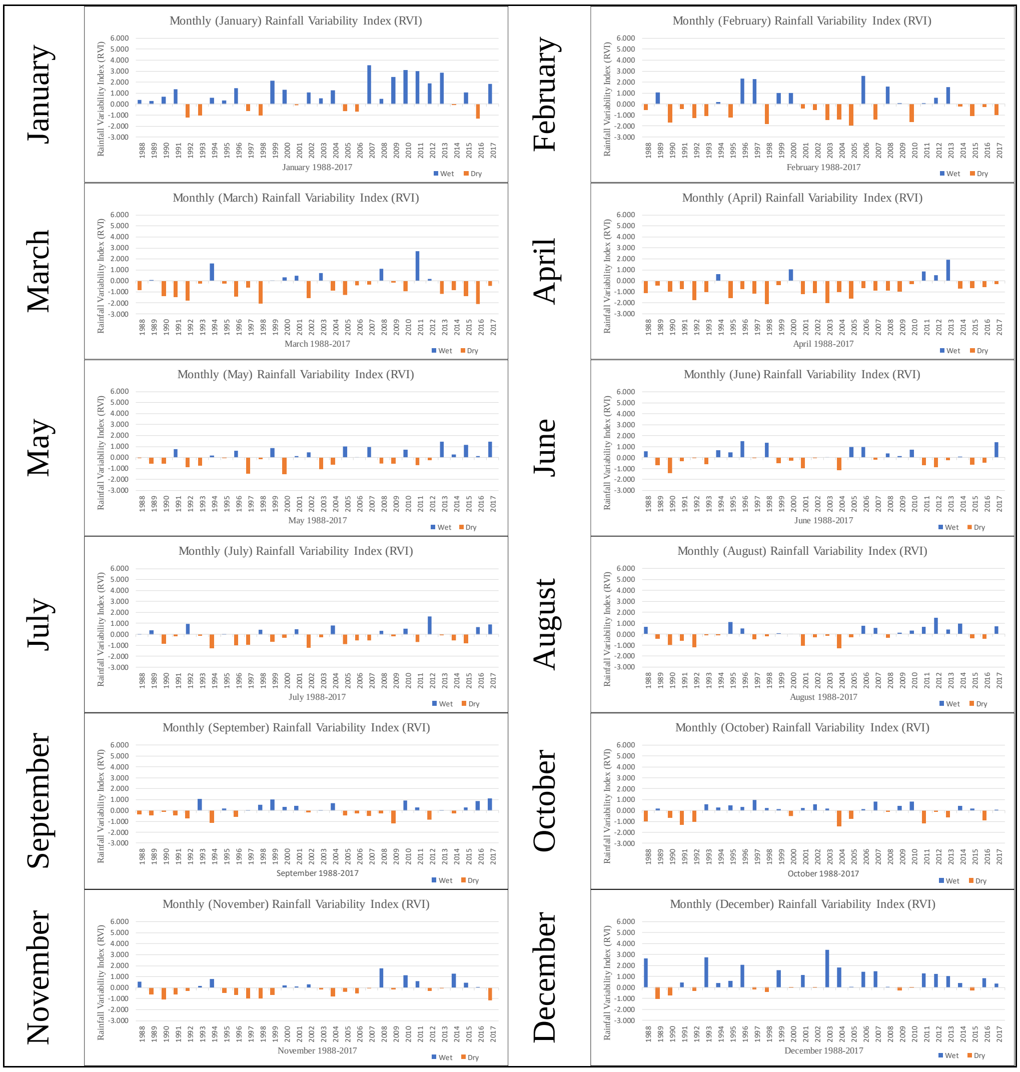


Figure 4.12: Monthly RVI of 30-year Period for Each Month in Region 4.

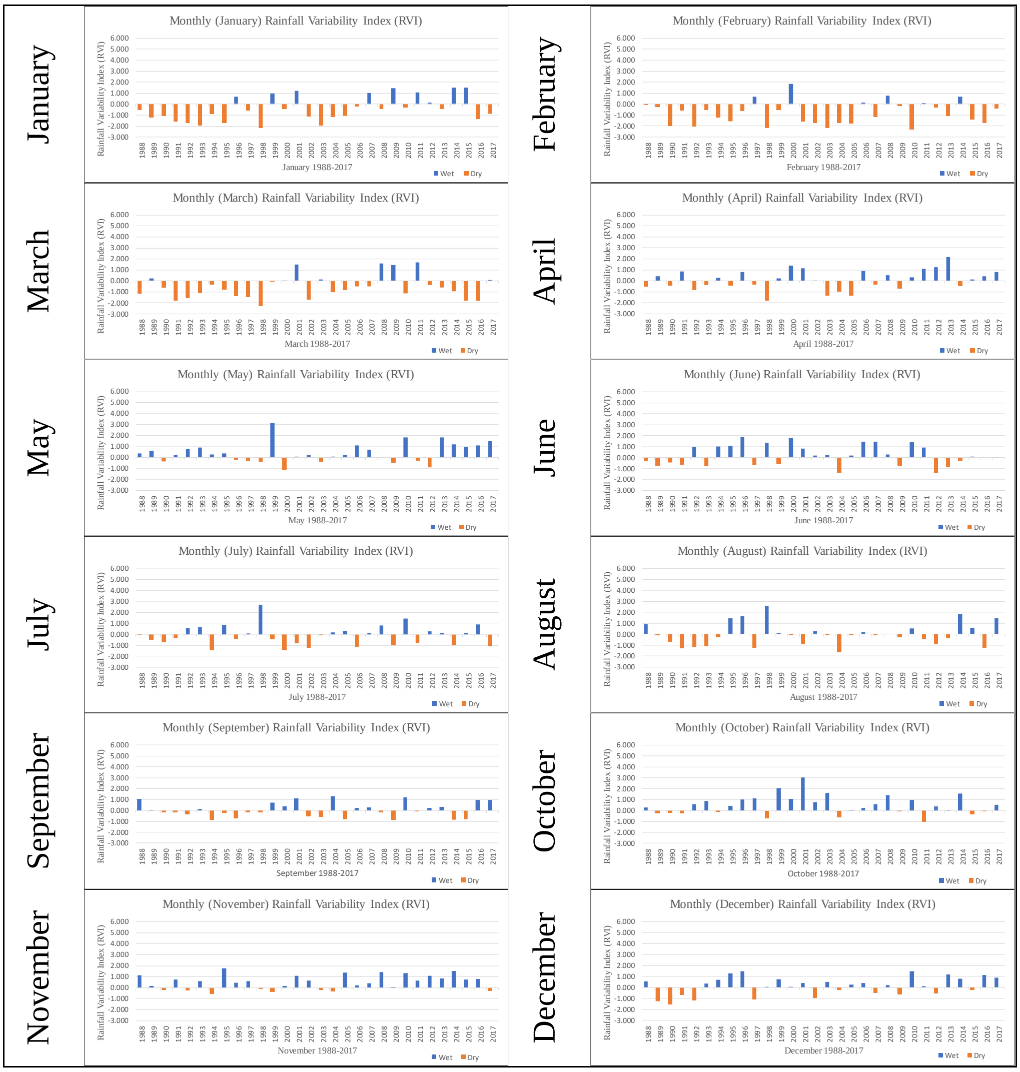


Figure 4.13: Monthly RVI of 30-year Period for Each Month in Region 5.

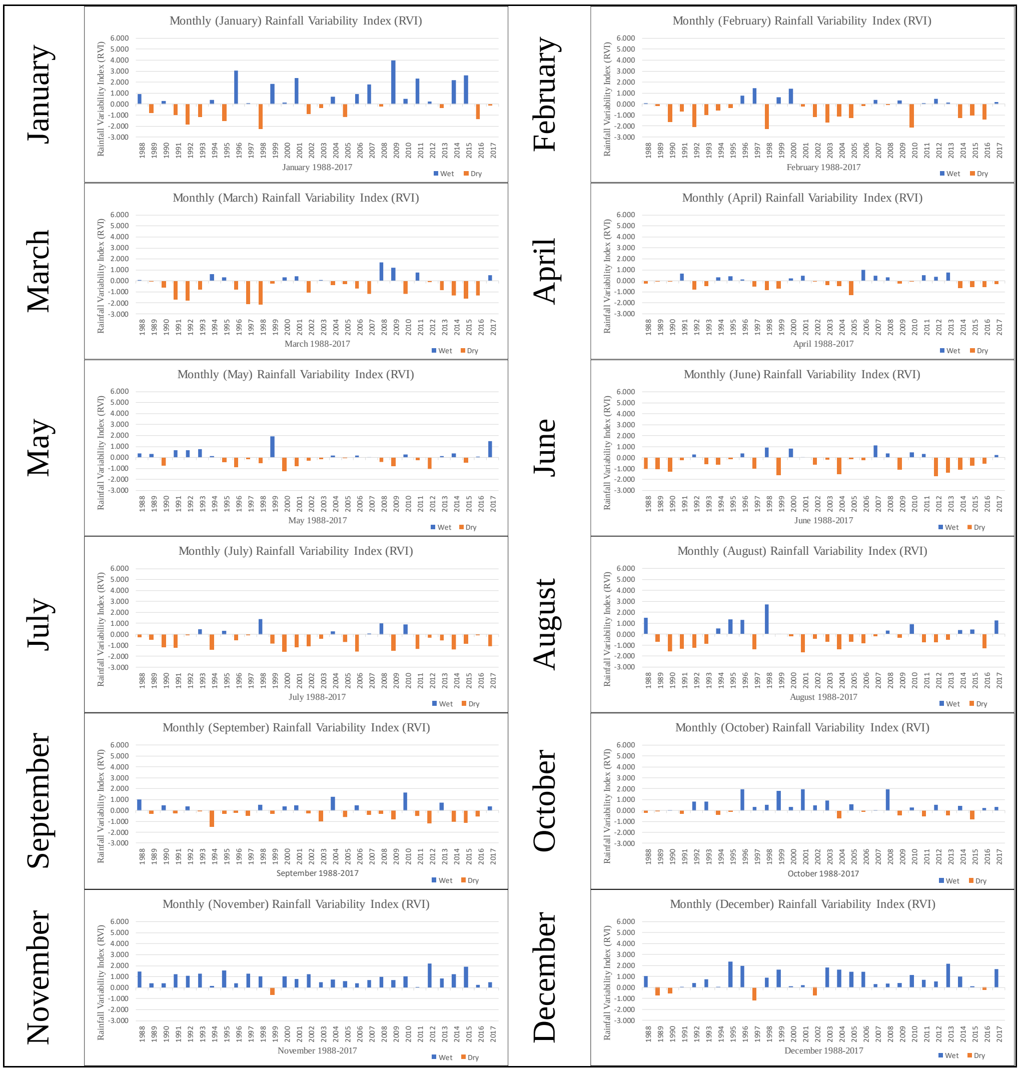


Figure 4.14: Monthly RVI of 30-year Period for Each Month in Region 6.

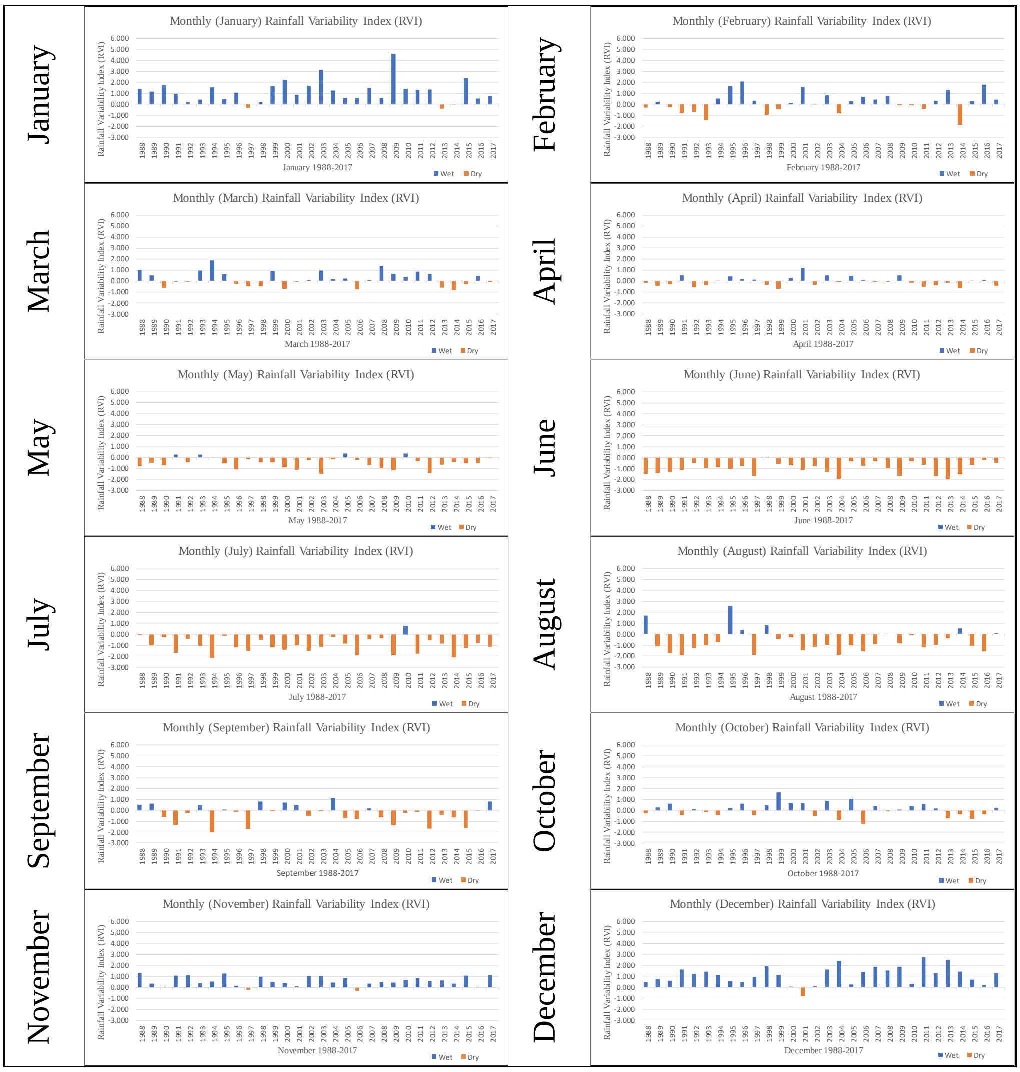


Figure 4.15: Monthly RVI of 30-year Period for Each Month in Region 7.

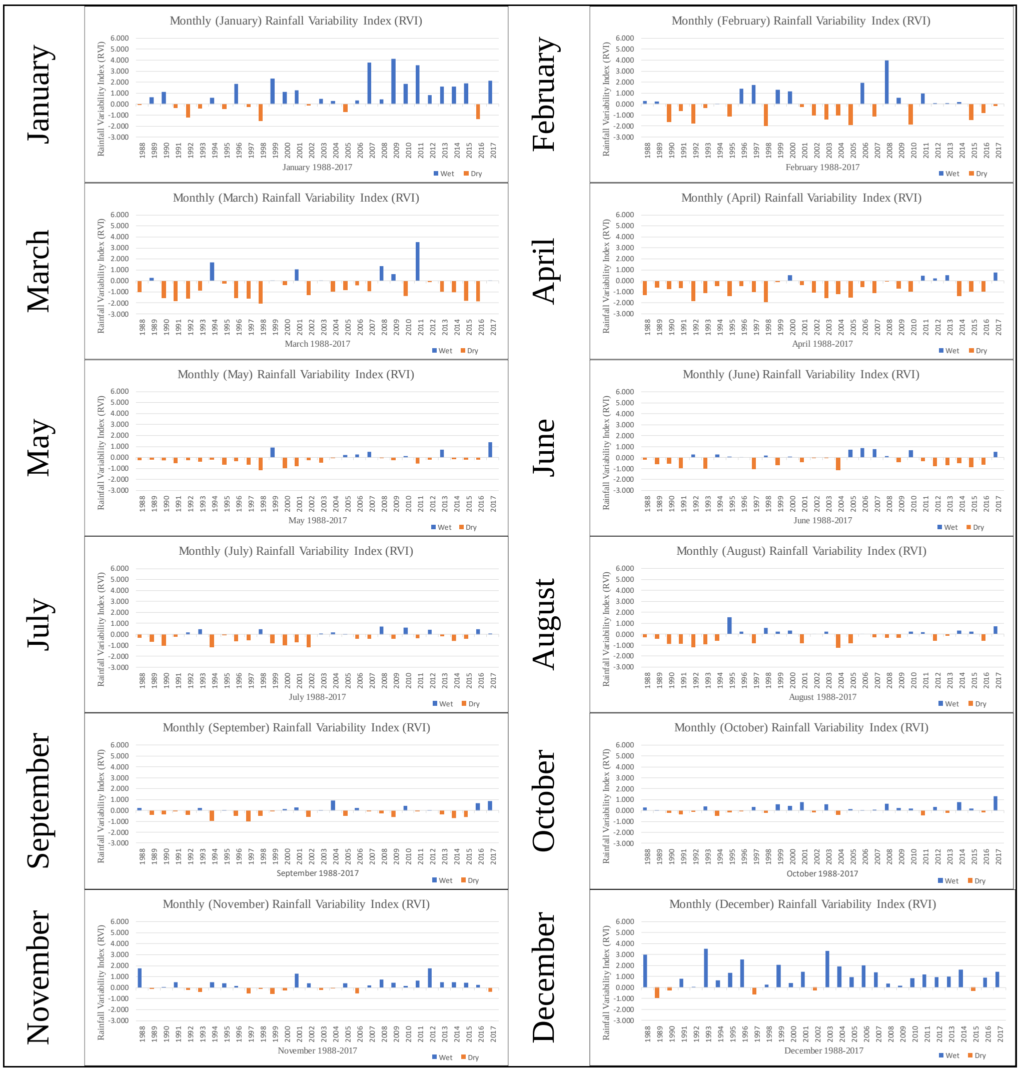


Figure 4.16: Monthly RVI of 30-year Period for Each Month in Region 8.

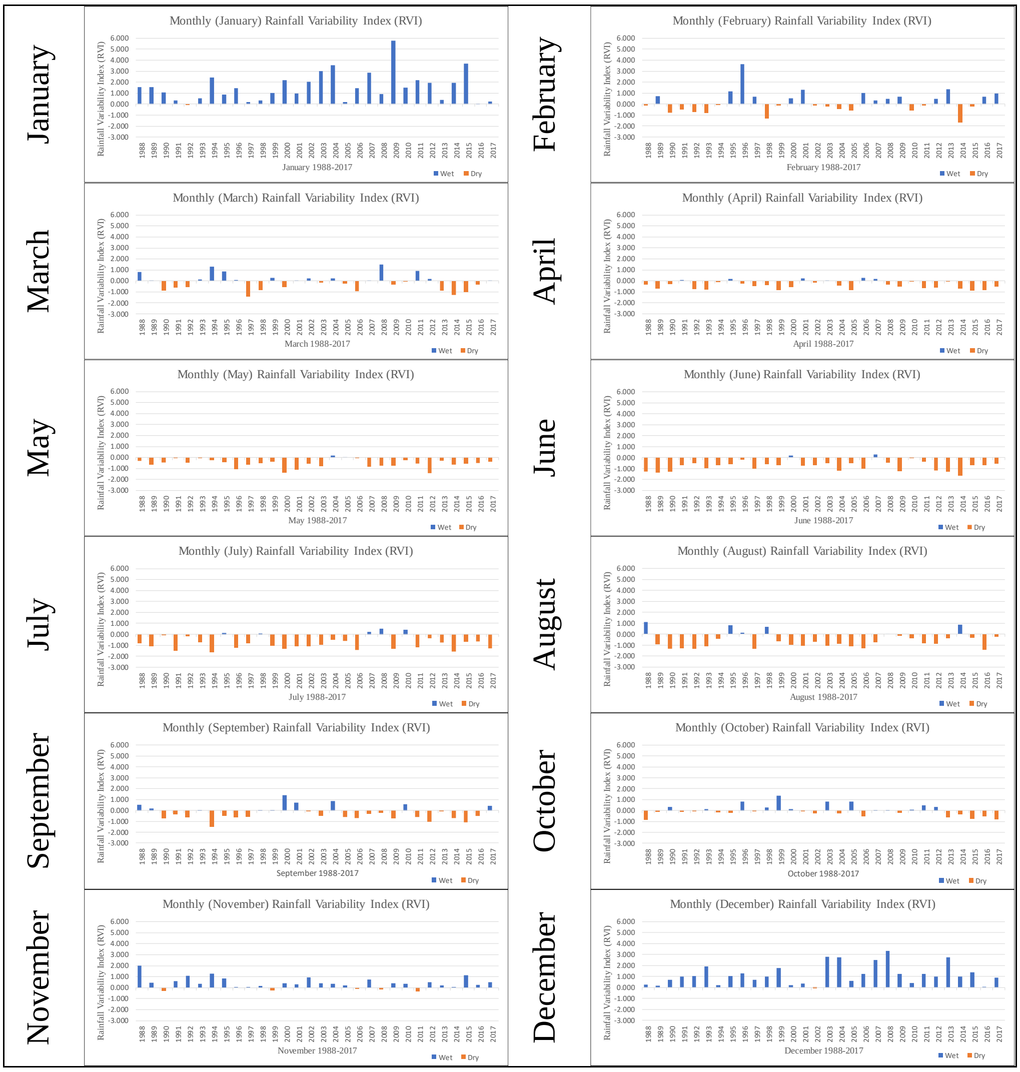


Figure 4.17: Monthly RVI of 30-year Period for Each Month in Region 9.

4.2.4 Spatial Analysis of Drought Characteristics

The spatial analysis for the drought characteristics that was based on the annual and monthly RVI analysis being applied in order to understand the DS variations within 1988-2017 in Malaysia. In this subsection, the drought characteristics, for the DF and MDD were assessed and presented in Figure 4.18 and Figure 4.19. The DF and MDD for annual RVI were ranged between 5-15 and 0-20 respectively, with the interval of 0.5. whereas for monthly RVI, the range for DF and MDD were in between 40-95 (interval of 5) and 2-6 (interval of 0.5) respectively.

From the spatial analysis presented in Figure 4.18, most of the regions showed relatively higher DF, except for the Southern Region, Region 1, Region 4 and Region 9. This showed that the Southern Region, Region 1, Region 4 and Region 9 experienced lower DS occurrences, based on 30-year period of annual RVI. Among the 13 regions in Malaysia, the north part of Northern Region and the Region 2 in Sabah and Sarawak were detected with relatively higher DF (dark red symbolised) from the period of 1988-2017. On the aspect of MDD that is shown in Figure 4.18; it can be observed that almost all of the regions experienced relatively low MDD over the 30-year period. However, for the East Coast Region in Peninsular Malaysia, a dark red of symbolisation was marked at the east part of East Coast Region, indicated that the highest MDD was experienced in that area over the study period. The dark red symbolised area that found in the East Coast Region was distinguished by the higher MDD with relatively lower DF. This is because of the lesser DS events with longer duration had experienced.

Based on Figure 4.19, the monthly DS events detected with relatively higher DF, were experienced in all the regions in Malaysia. The south part of the Peninsular Malaysia (including south part of East Coast Region, Central Region and Southern Region) as well as Sabah and Sarawak (except Region 2, Region 7 and Region 9) suffered high impact of DS events (high DF) when the spatial distribution of monthly RVI analysis was applied. In contrast, some areas in Malaysia (east part of the East Coast Region, Region 2, Region 7, north part of Region 8 and south part of Region 1) suffered lesser DF (symbolised with low red intensity) over the 30-year period. Furthermore, the MDD that is presented in Figure 4.19 showed a higher spatial variation, in which almost all regions in Malaysia experienced relatively lower MDD over the 30-year period. But for some regions (east part of East Coast Region which adjacent to the South China Sea, Region 2, north part of Region 8 and south part of Region 1) were detected with relatively higher MDD, compared to other regions. Higher MDD that was experienced in these regions indicated that the longer duration but lesser DS events happened. In contrast, Region 3, Region 5 and Region 6 experienced the lowest MDD (shaded with low intensity of symbolisation) with higher DF as compared to other regions in Malaysia.

To conclude the findings for Figure 4.18 and Figure 4.19, the spatial distribution of DF between annual and monthly RVI showed significant difference throughout the Malaysia over the 30-year period. But for the MDD, it can be seen clearly that the east part of East Coast Region suffered more MDD, based on the annual and monthly RVI, compared to other regions in Malaysia.

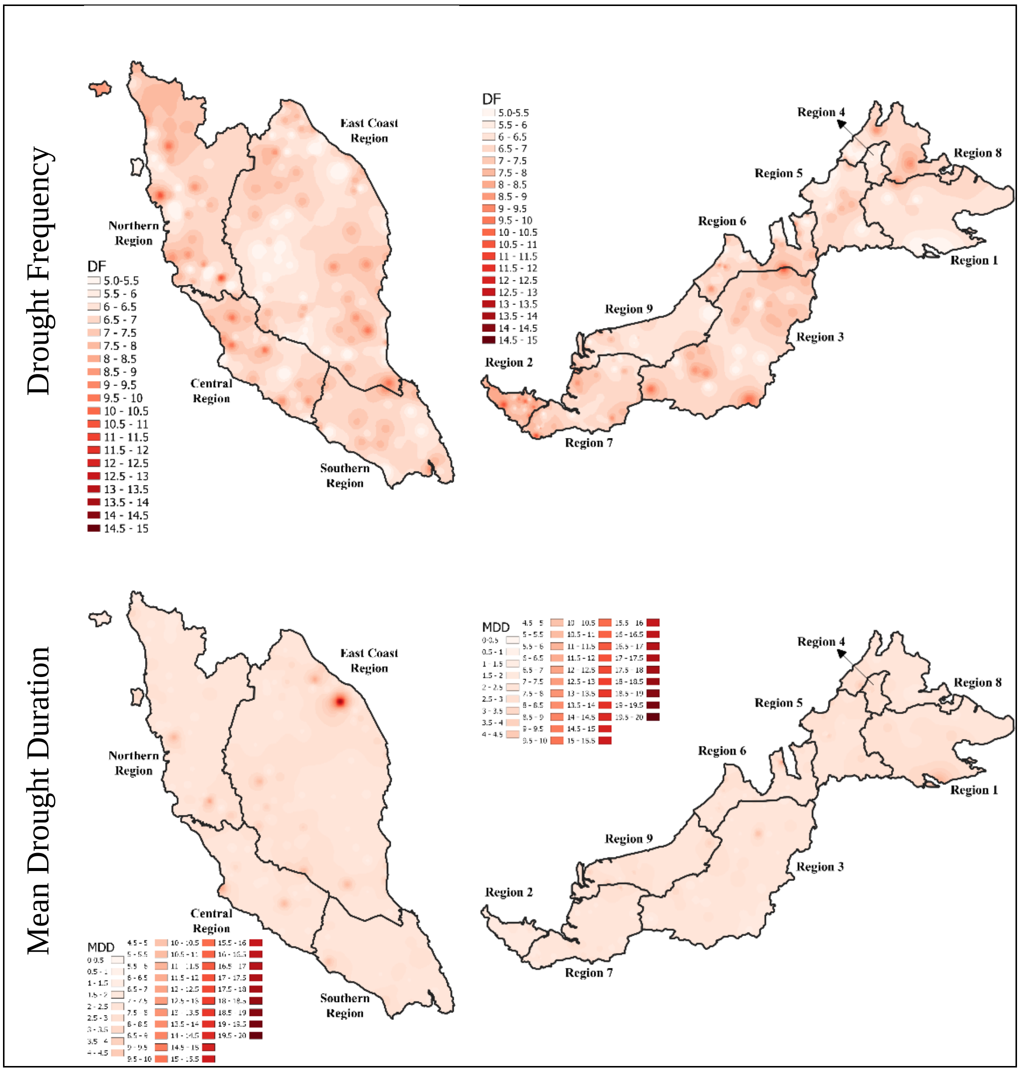


Figure 4.18: Drought Frequency and Mean Drought Duration for Annual RVI of 30-year Period in Malaysia.

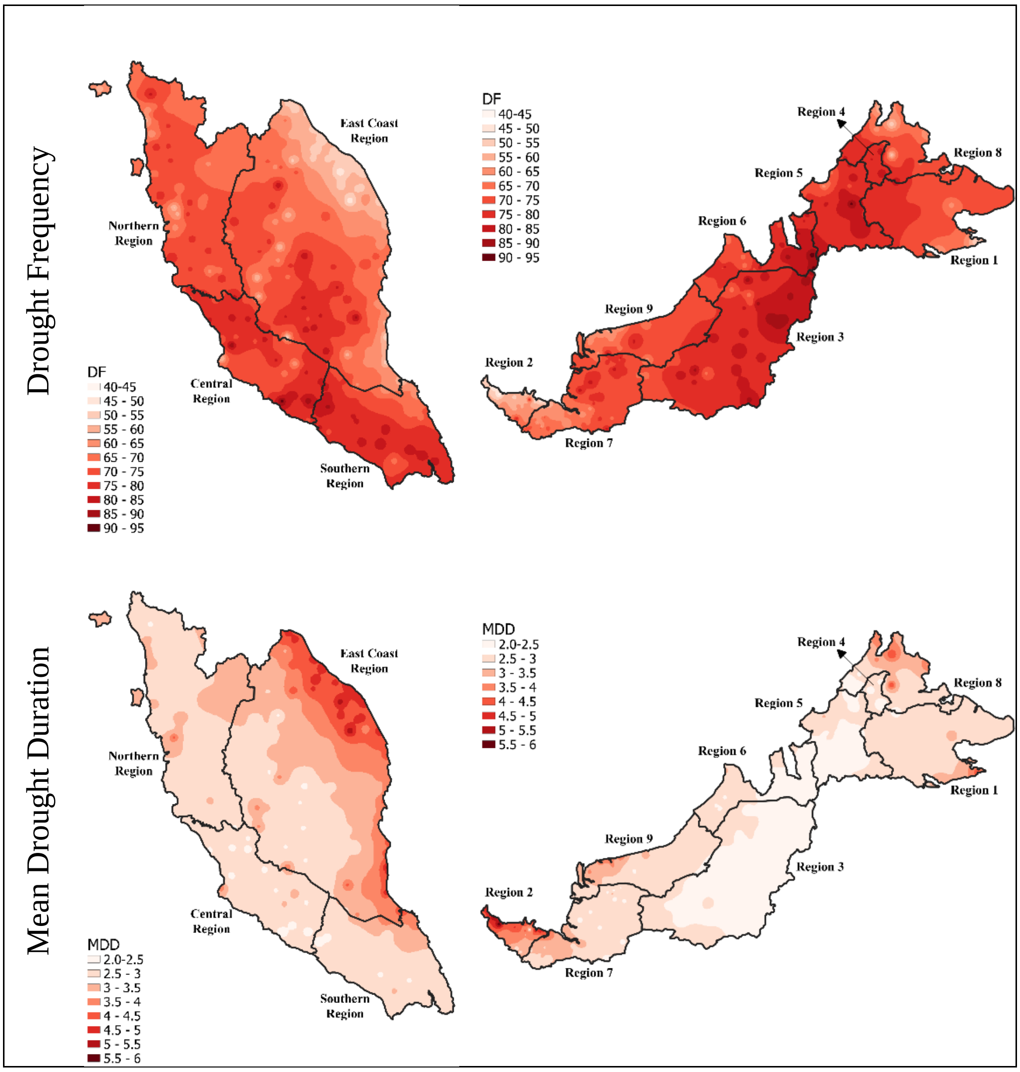


Figure 4.19: Drought Frequency and Mean Drought Duration for Monthly RVI of 30-year Period in Malaysia.

4.3 Regional Analysis Based on Six 5-year Sub-periods

The following subsections discussed the analysis results which had included the regional annual RVI, regional monthly RVI, regional monthly RVI (January-December) and also the spatial distribution and drought characteristics for each of the six 5-year sub-periods, for both the annual and monthly rainfall data based in Malaysia. The sub-periods are according to 1988-1992, 1993-1997, 1998-2002, 2003-2007, 2008-2012 and 2013-2017 periods for each region in Malaysia.

4.3.1 Regional Annual RVI

The analysis for the annual RVI was next separated into six 5-year sub-periods in order to visualise the variation of the rainfall variability in terms of the DS over the sub-periods in Malaysia. The analysis was carried out and the annual RVI results for all 13 regions are presented in Figure 4.20 (for Peninsular Malaysia) and Figure 4.21 (for Sabah and Sarawak). The DS and extreme DS occurrences detected over the sub-periods which had the ranges from zero to three and zero to two respectively.

Based on the RVI analysis that was presented in Figure 4.20, the DS in 1988-1992 sub-period experienced relatively higher of occurrences as compared to other sub-periods for the Northern Region. This is followed by the East Coast Region and Central Region, wherein the Central Region detected one extreme DS. This indicated that from the first sub-period (1988-1992), the Central Region experienced higher DS period as compared to other regions in Peninsular Malaysia. From the results presented, it can be seen that the Southern Region experienced highest number of DS occurrences in 2013-2017 sub-period when compared to other regions with the same sub-period. Although the 2013-2017 sub-period was observed with a relatively lower DS occurrences for Northern Region, East Coast Region and Central Region, yet there was an extreme DS detected in Northern Region and East Coast Region.

As for the annual RVI analysis based in Sabah and Sarawak that presented in Figure 4.21, the DS were observed significantly, especially for the first sub-period (1988-1992), in which the Region 5 showed the highest number of DS occurrences (no extreme DS was observed). Similar results were observed for the Region 6, Region 8 and Region 9 as well. In contrast, for the other regions (Region 1, Region 2, Region 3 and Region 7) had less significant, where relatively lower effect of DS experienced over the sub-periods. These indicated that from the regions which found the highest DS occurrences had more DS severe over the sub-periods in Sabah and Sarawak. The Region 4, however, exhibited a different behaviour when compared to Region 5, Region 6, Region 8 and Region 9, wherein it experienced the highest extreme DS occurrences (two) in 1988-1992 sub-period.

From the significant results for the annual RVI that was based on six 5-year sub-periods in Malaysia, as shown in Figure 4.20 and Figure 4.21 it can be concluded that majority of the regions in Malaysia encountered higher DS severity (with higher DS occurrences) in the first sub-period over six 5-year sub-periods.

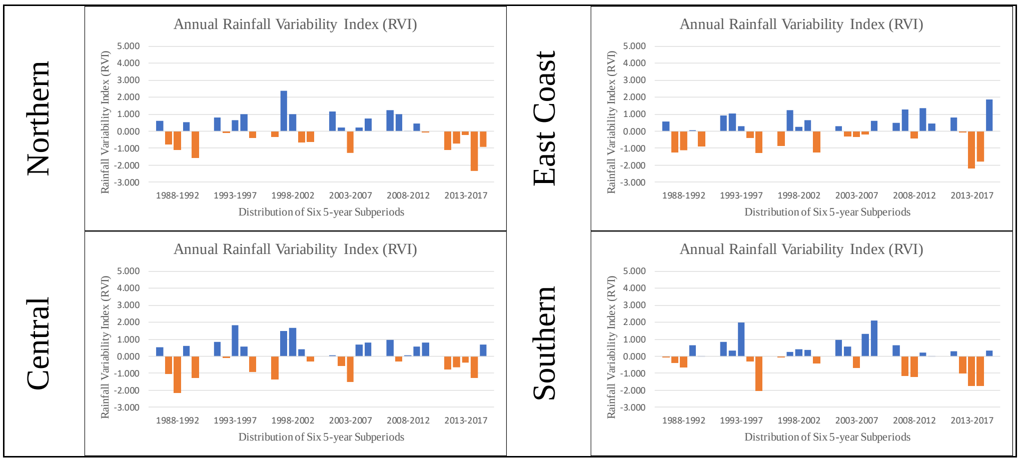


Figure 4.20: Annual RVI for Six 5-year Sub-periods in Peninsular Malaysia.

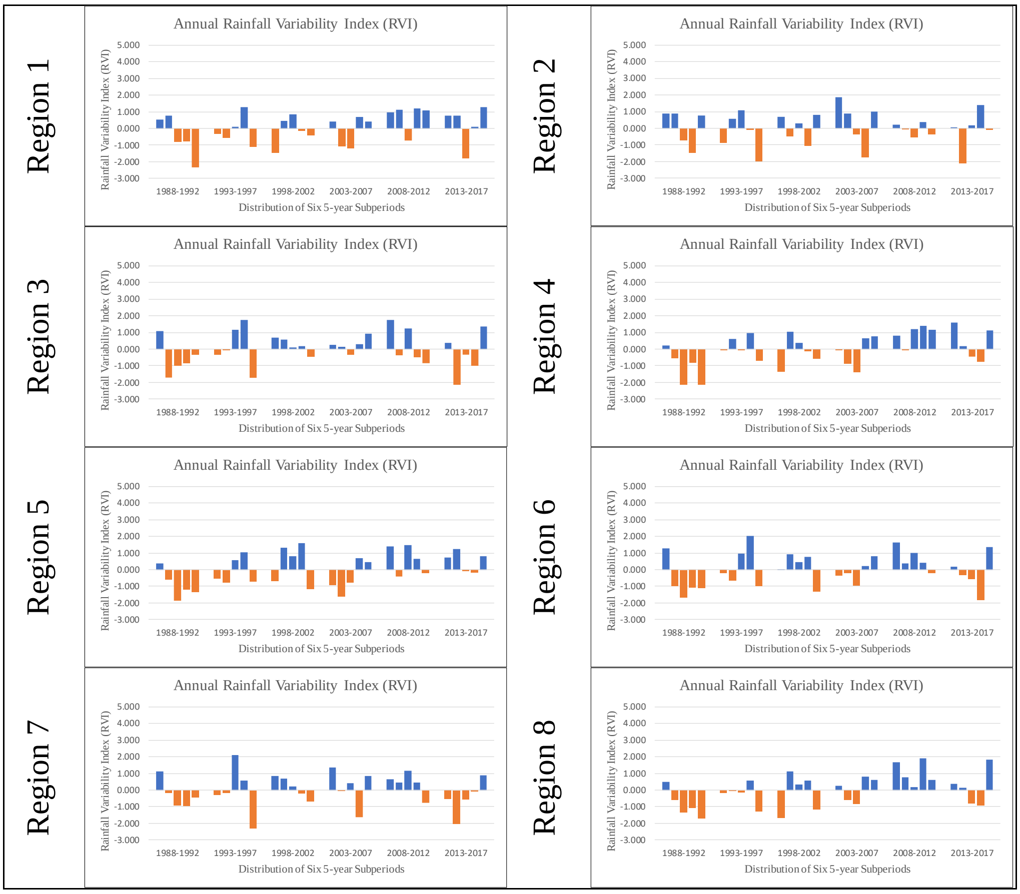


Figure 4.21: Annual RVI for Six 5-year Sub-periods in Sabah and Sarawak.

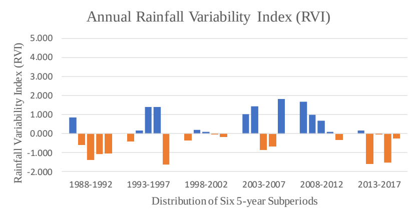
Region 9		

Figure 4.21 (Continued)

4.3.2 Regional Monthly RVI

The analysis of six 5-year sub-periods for the monthly RVI in 1988-2017 period was assessed in terms of the rainfall variability for the regions in Malaysia. The results of these analysis presented in this subsection, are from Figure 4.22 to Figure 4.34. Each region with the respective six 5-year sub-periods were plotted in each figure individually to have a better observation for the DS variations.

The monthly RVI for the Northern Region, East Coast Region, Central Region and Southern Region in Peninsular Malaysia are presented in Figure 4.22, Figure 4.23, Figure 4.24 and Figure 4.25 respectively. The number of DS over the sub-periods for these regions had the range of 2-14. It can be seen that all the sub-periods for the respective regions had the effect of DS, wherein the East Coast Region experienced relatively lower of DS occurrences for each sub-period (least number of two DS was observed in 1993-1997 sub-period) when compared to the sub-periods for other regions. In contrast, the Northern Region and Central Region suffered relatively higher number of DS over the sub-periods, wherein the 1988-1992 sub-period (14 for Central Region) and the 2013-2017 sub-period (13 for Northern Region) contributed more DS occurrences. Furthermore, there was a similarity which can be seen from all the regions in Peninsular Malaysia, except for East Coast Region, where an extreme DS detected which suffered in 2013-2017 sub-period. These indicated that both the Northern Region and Central Region experienced more severe (higher DS) over the sub-periods, followed by the Southern Region, in descending order. Also, the sixth sub-period (2013-2017) observed from these three regions tended to have higher DS severity since the extreme DS was detected.

Figure 4.26 to Figure 4.34 show the six 5-year sub-periods of monthly RVI for the nine regions in Sabah and Sarawak (from Region 1 to Region 9).

The effect of the DS can be detected for all the sub-periods in each of the respective regions, where the range varied from 1-15. Based on the analysis presented, the first sub-period (1988-1992) experienced a relatively higher number of DS in most of the regions over the sub-periods (12 for Region 1, 11 for Region 3, 15 for Region 4, 13 for Region 5 and 11 for Region 7). The Region 6, however, suffered relatively higher DS occurrences in 1988-1992 sub-period, but 2013-2017 sub-period was distinguished with a highest number of DS (14) over the sub-periods. These indicated that most of the regions experienced more DS events which can be observed clearly in the 1988-1992 sub-period. Furthermore, for the Region 2 in this case, has the similar rainfall variation as per the East Coast Region located in Peninsular Malaysia, in which a relatively lower DS occurrences detected over the sub-periods as compared to other regions in Sabah and Sarawak (1998-2002 sub-period detected with least DS of one). Apart from that, the extreme DS also detected which can be seen through all the regions, except for Region 2 and Region 9. The extreme DS observed occurred in five sub-periods for Region 3. This is followed by four sub-periods (for Region 1, Region 5 and Region 6), two sub-periods (for Region 4 and Region 7) and one sub-period (for Region 8). These showed that Region 3 has higher impact for the extreme DS based on the six 5-year sub-periods, as compared to other regions in Sabah and Sarawak.

By combining the findings from Figure 4.22 to Figure 4.34, the DS effect can be seen through all the six 5-year sub-periods for all the regions, wherein the 1988-1992 sub-period suffered higher DS occurrences for the majority of the regions in Malaysia. Although the DS detected over the sub-periods for all the regions, but for the East Coast Region and Region 2 show less significant of DS (less DS occurrences), indicating these two regions have less impact of rainfall variability in term of DS as compared to other regions.

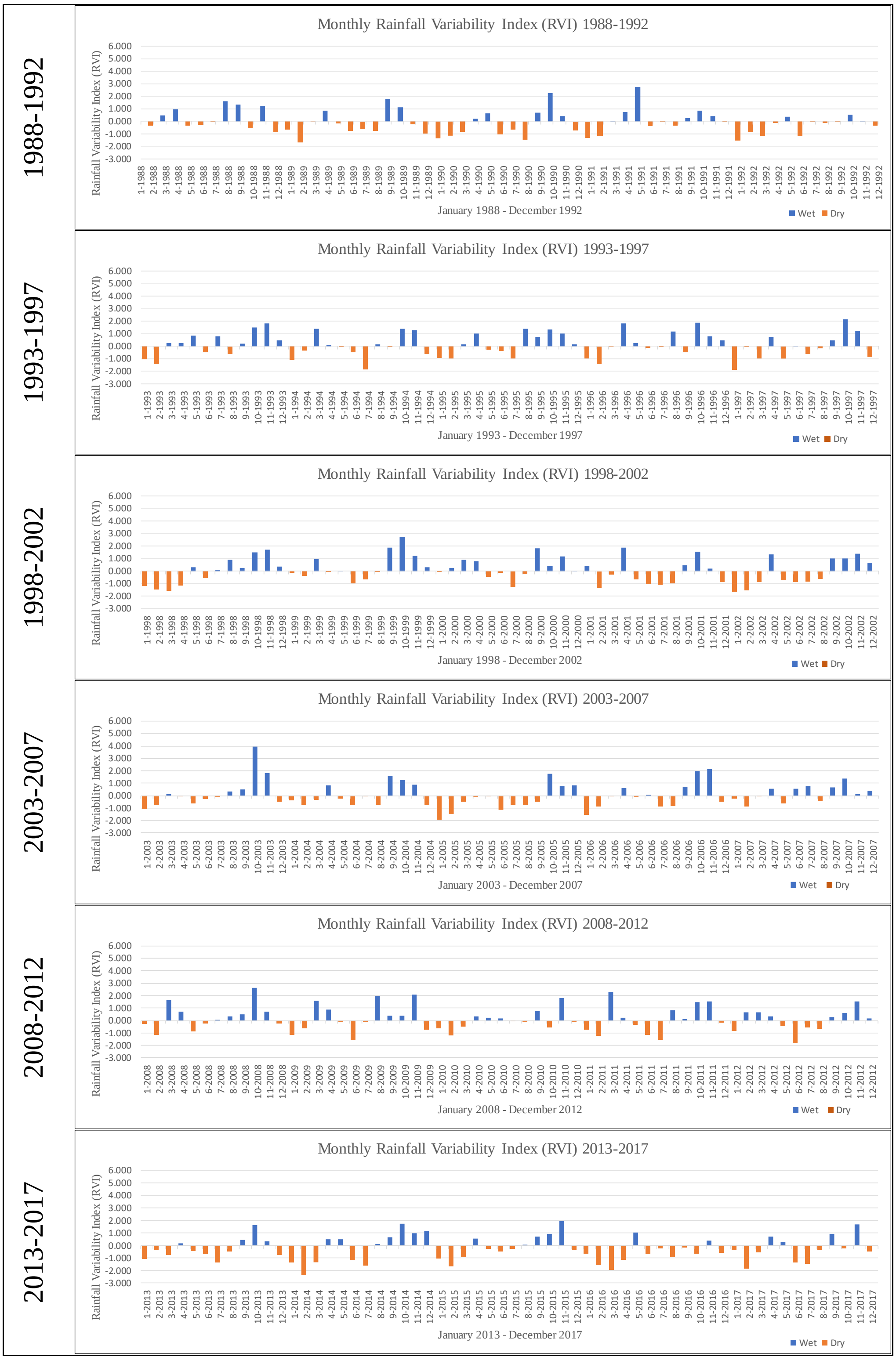


Figure 4.22: Monthly RVI for Six 5-year Sub-periods in Northern Region.

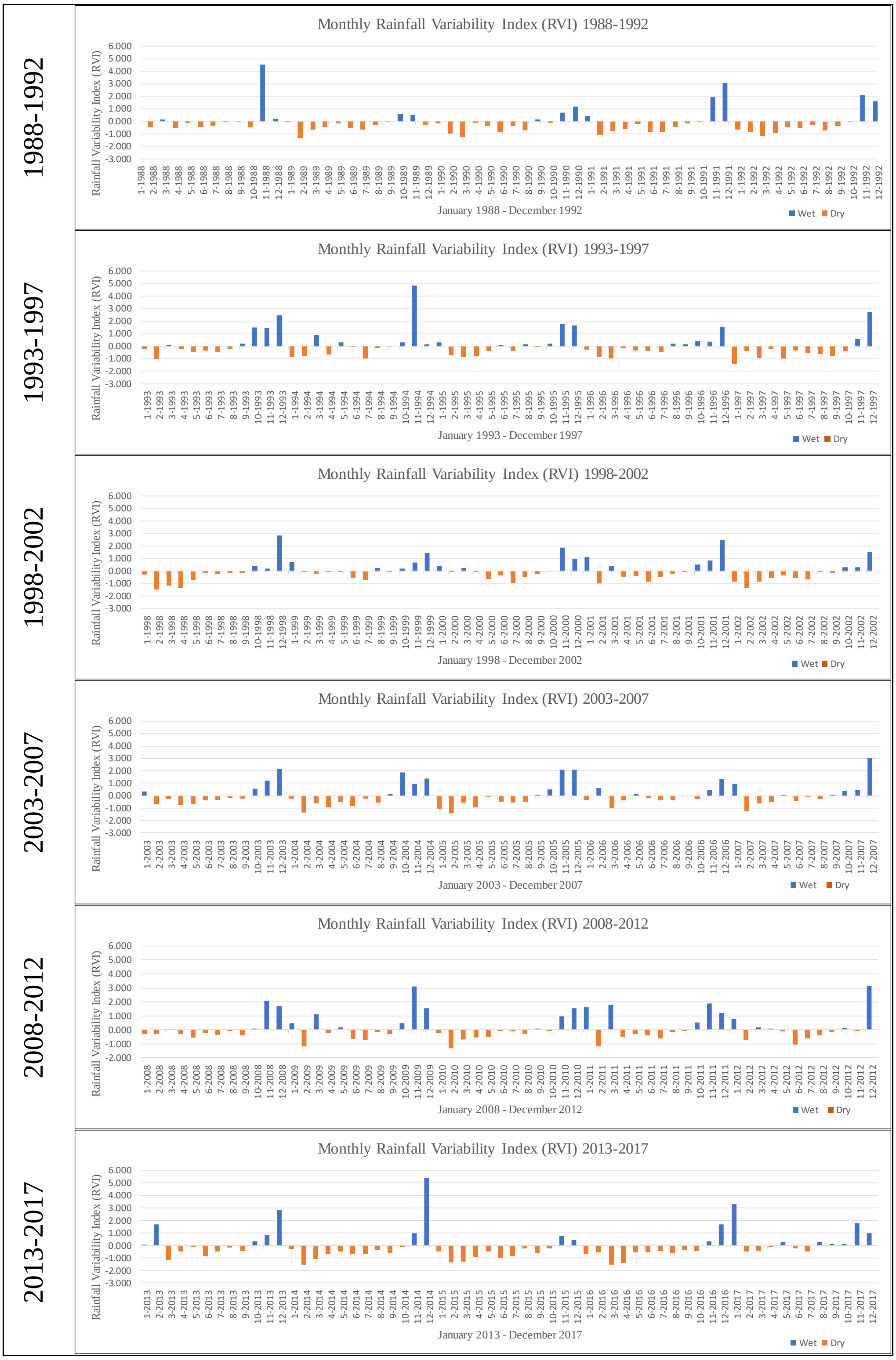


Figure 4.23: Monthly RVI for Six 5-year Sub-periods in East Coast Region.

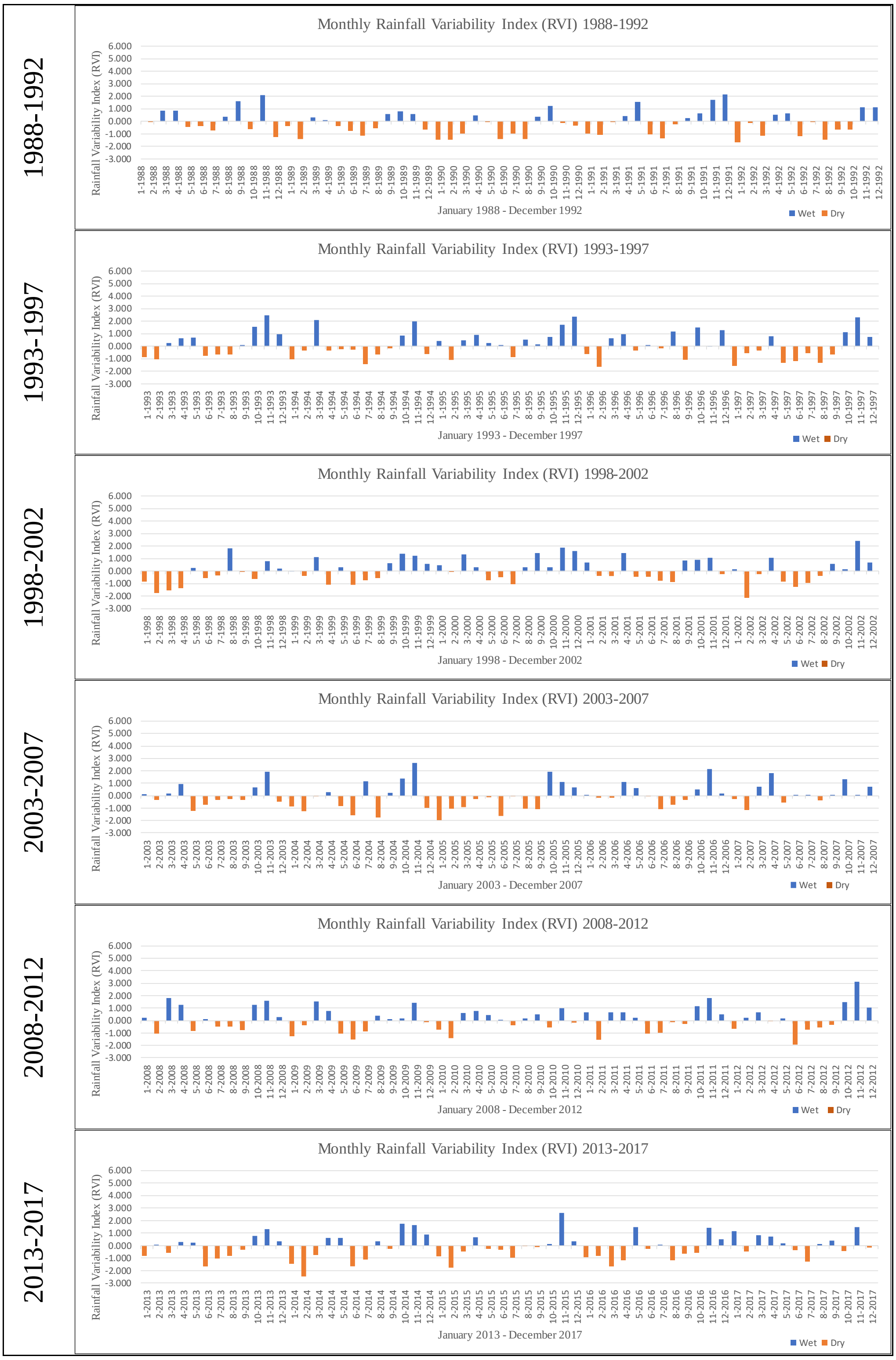


Figure 4.24: Monthly RVI for Six 5-year Sub-periods in Central Region.

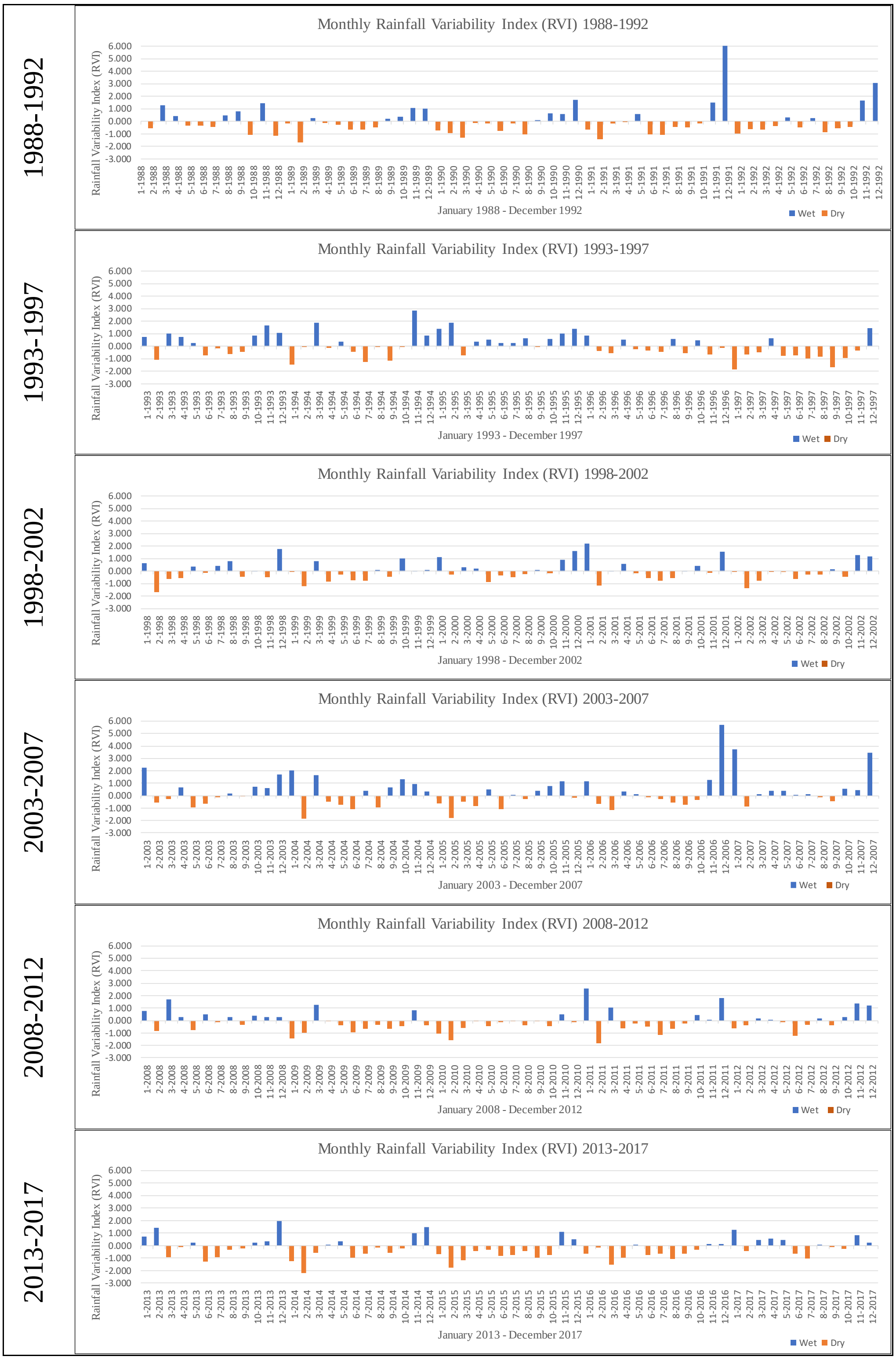


Figure 4.25: Monthly RVI for Six 5-year Sub-periods in Southern Region.

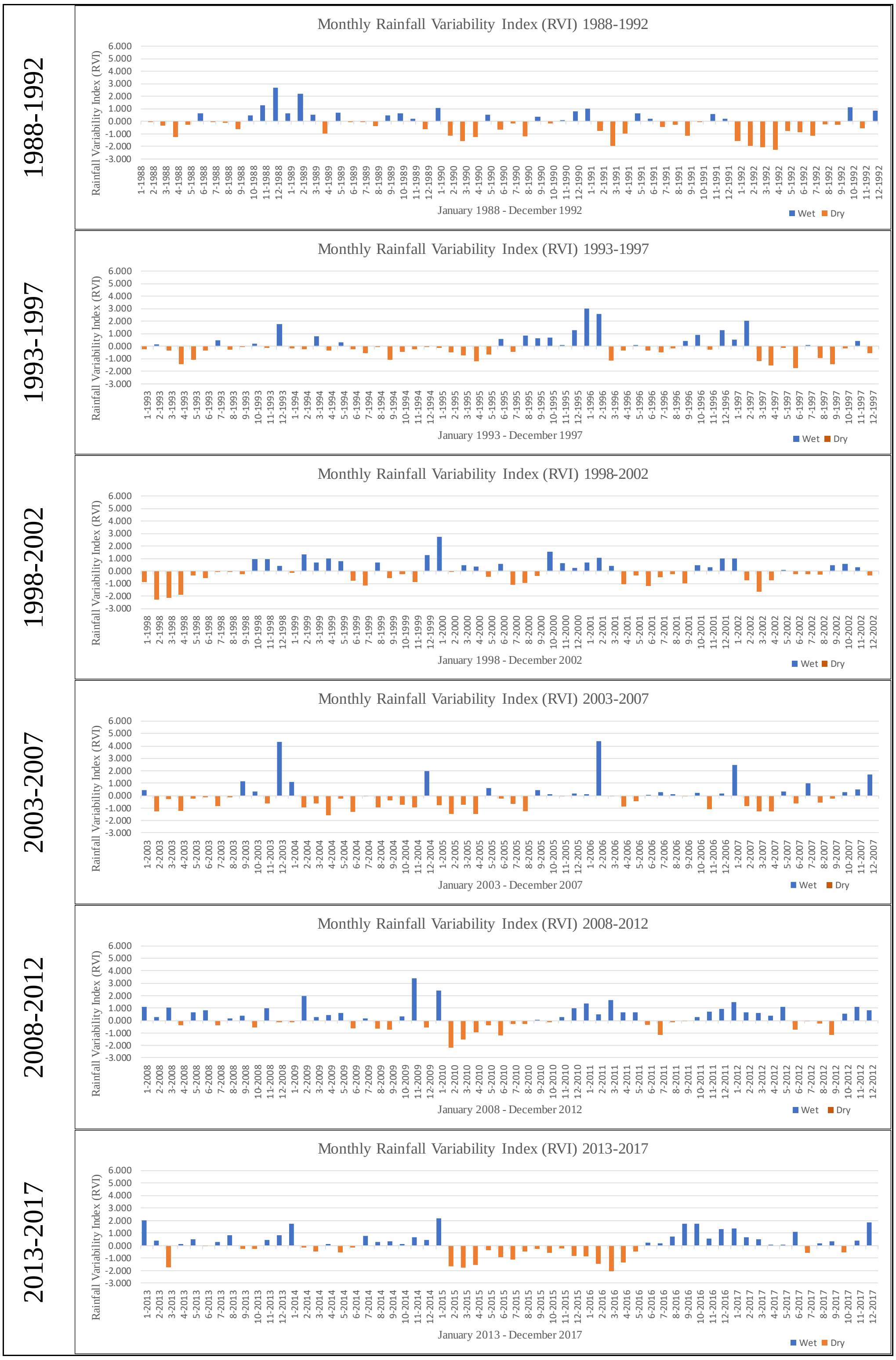


Figure 4.26: Monthly RVI for Six 5-year Sub-periods in Region 1.

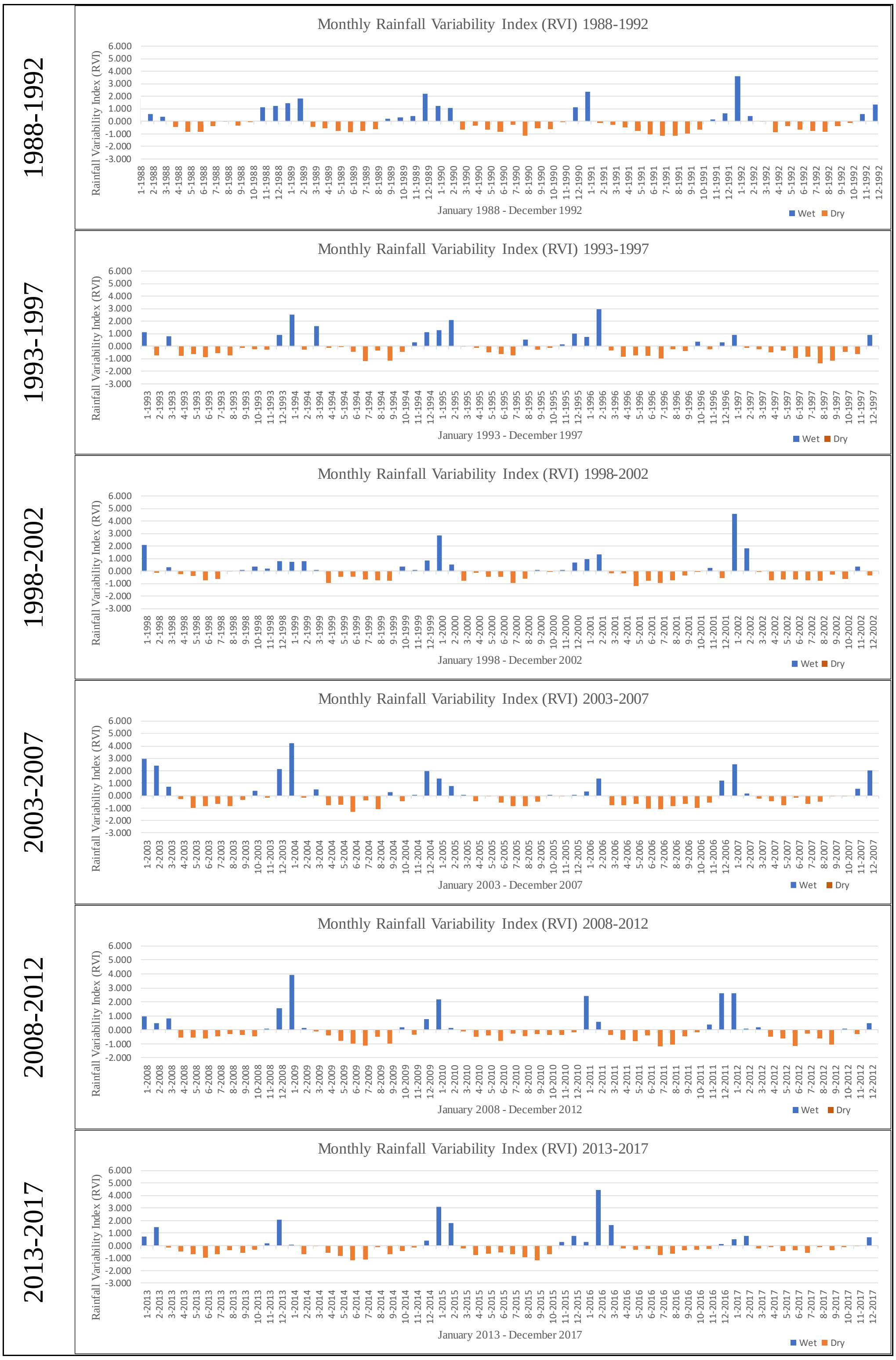


Figure 4.27: Monthly RVI for Six 5-year Sub-periods in Region 2.

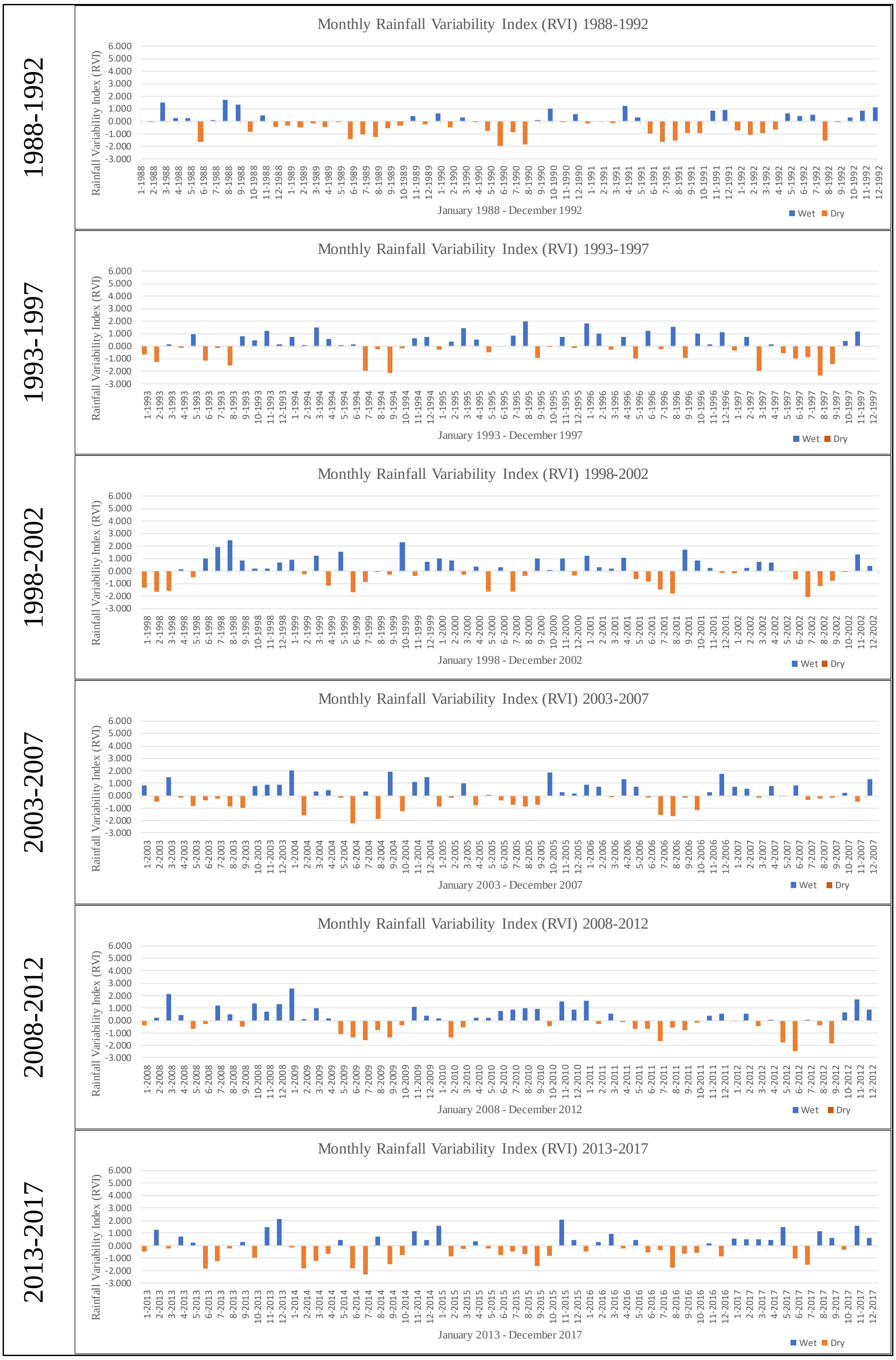


Figure 4.28: Monthly RVI for Six 5-year Sub-periods in Region 3.

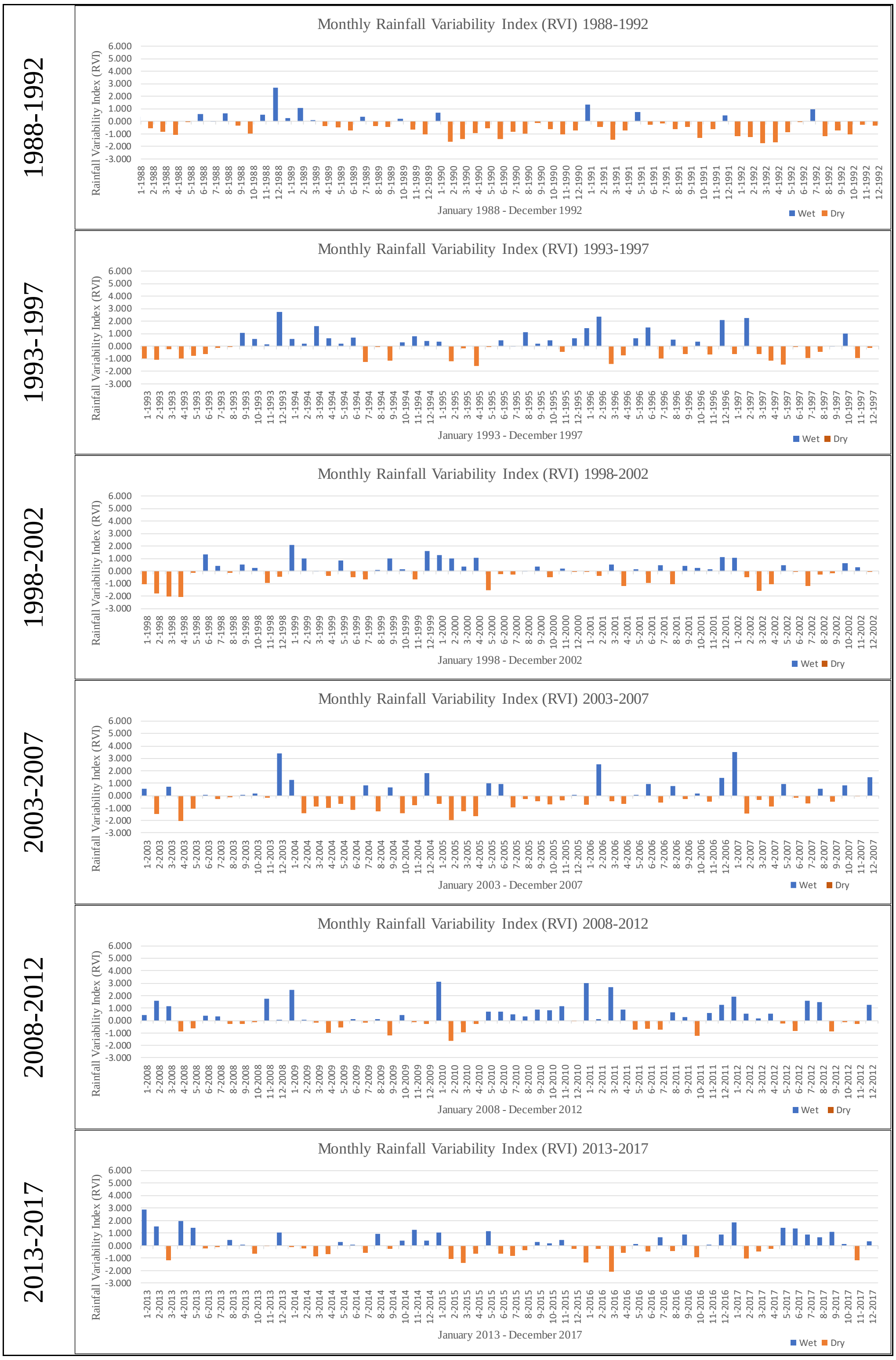


Figure 4.29: Monthly RVI for Six 5-year Sub-periods in Region 4.

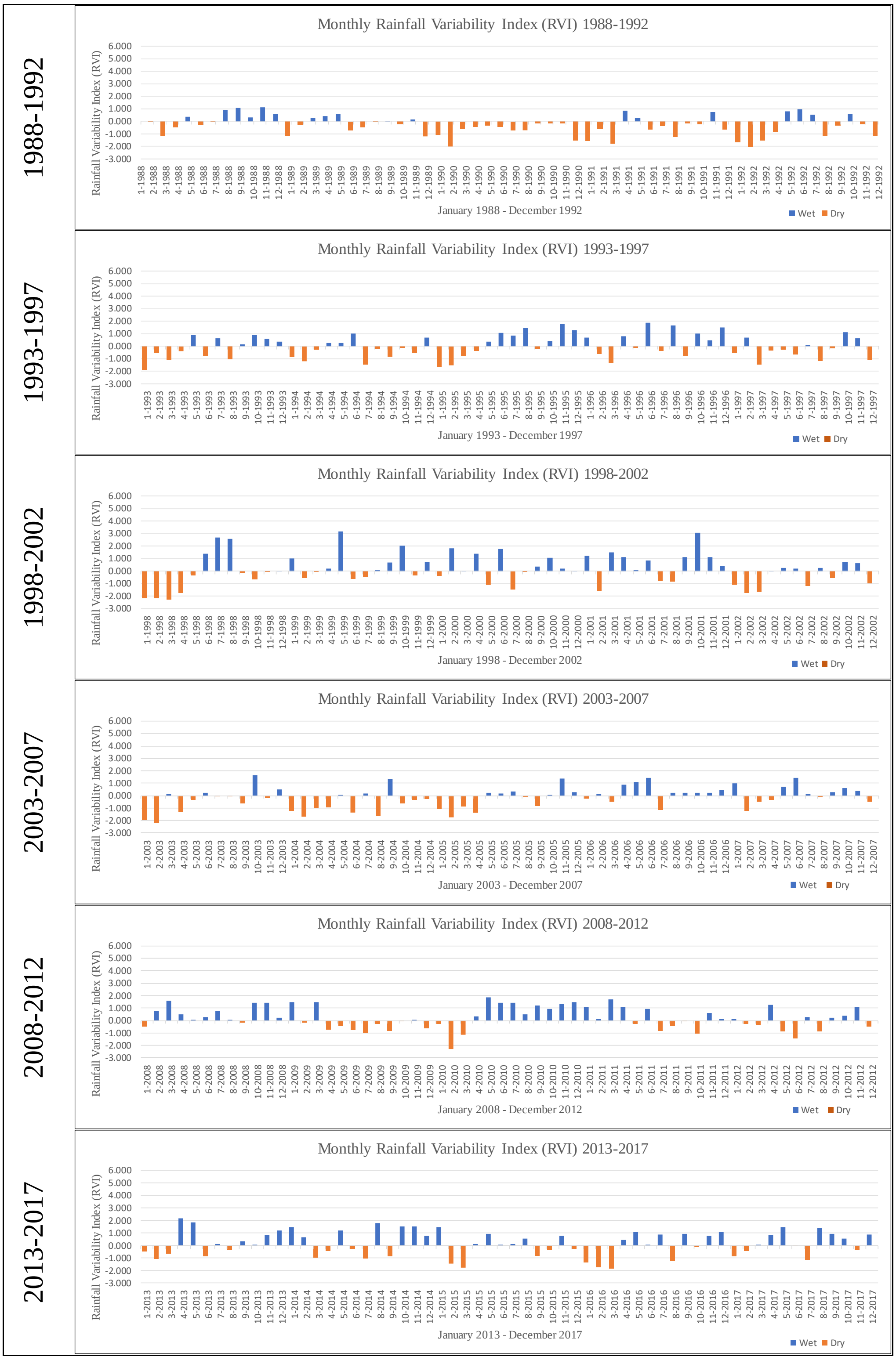


Figure 4.30: Monthly RVI for Six 5-year Sub-periods in Region 5.

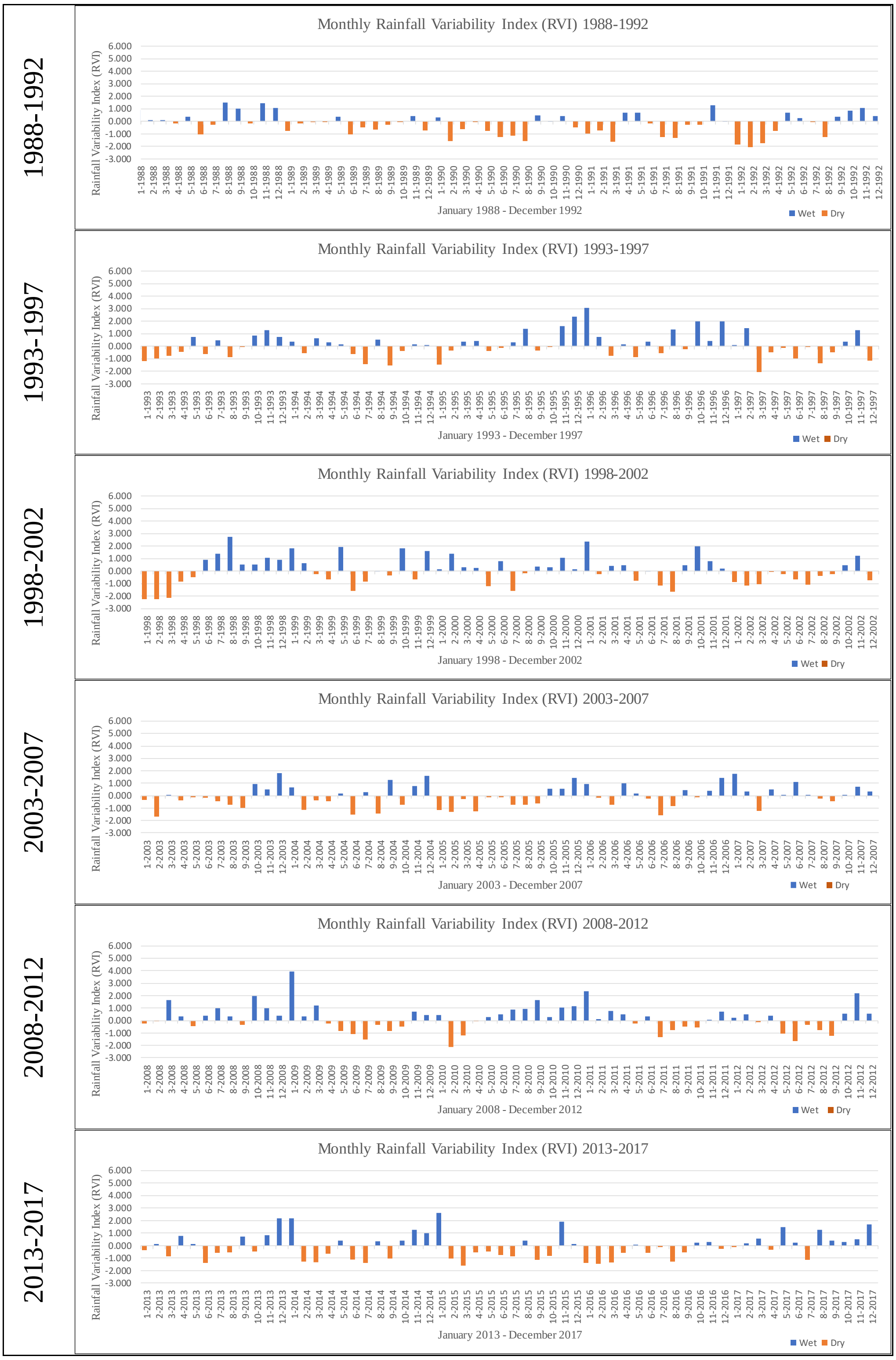


Figure 4.31: Monthly RVI for Six 5-year Sub-periods in Region 6.

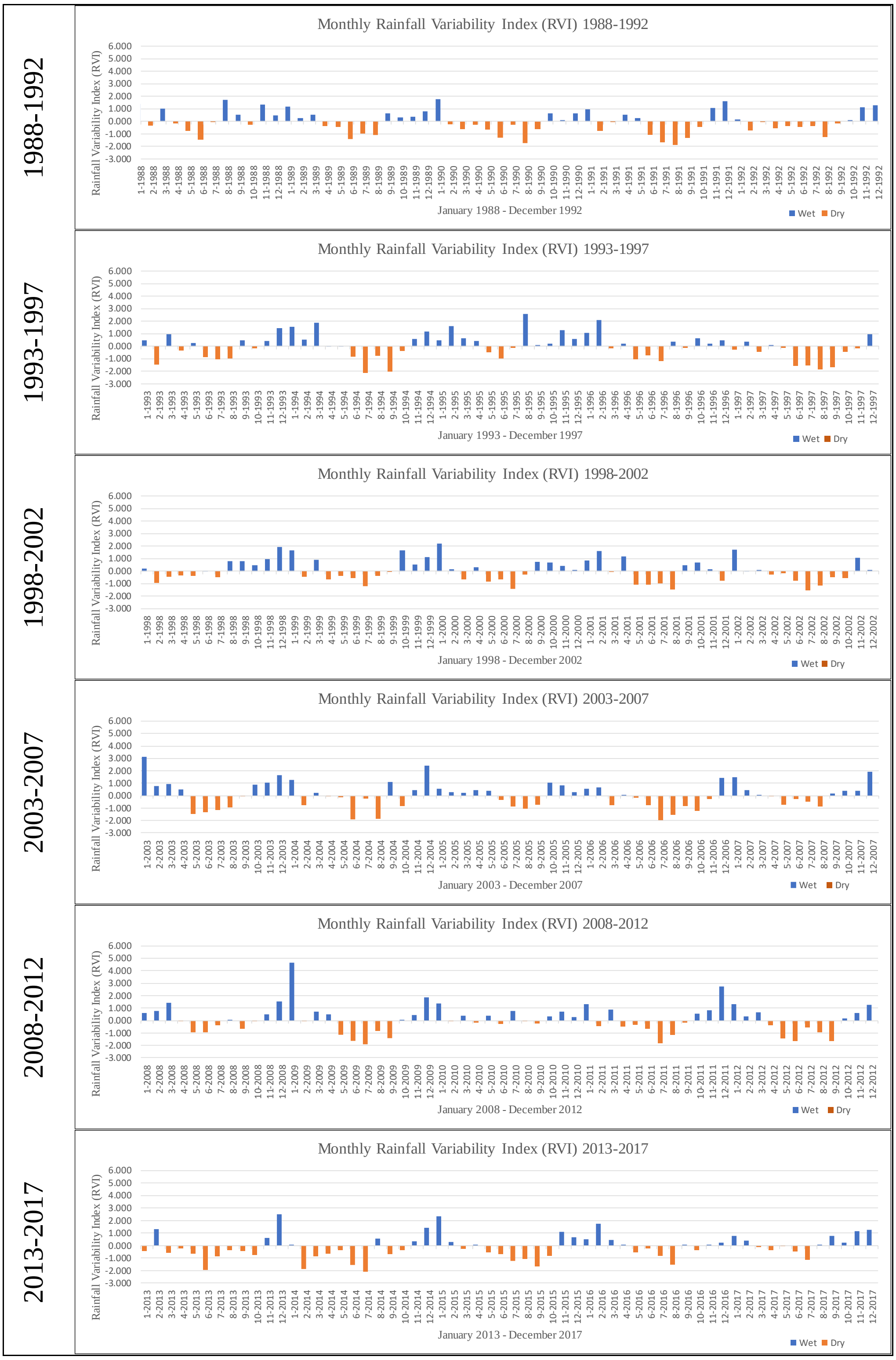


Figure 4.32: Monthly RVI for Six 5-year Sub-periods in Region 7.

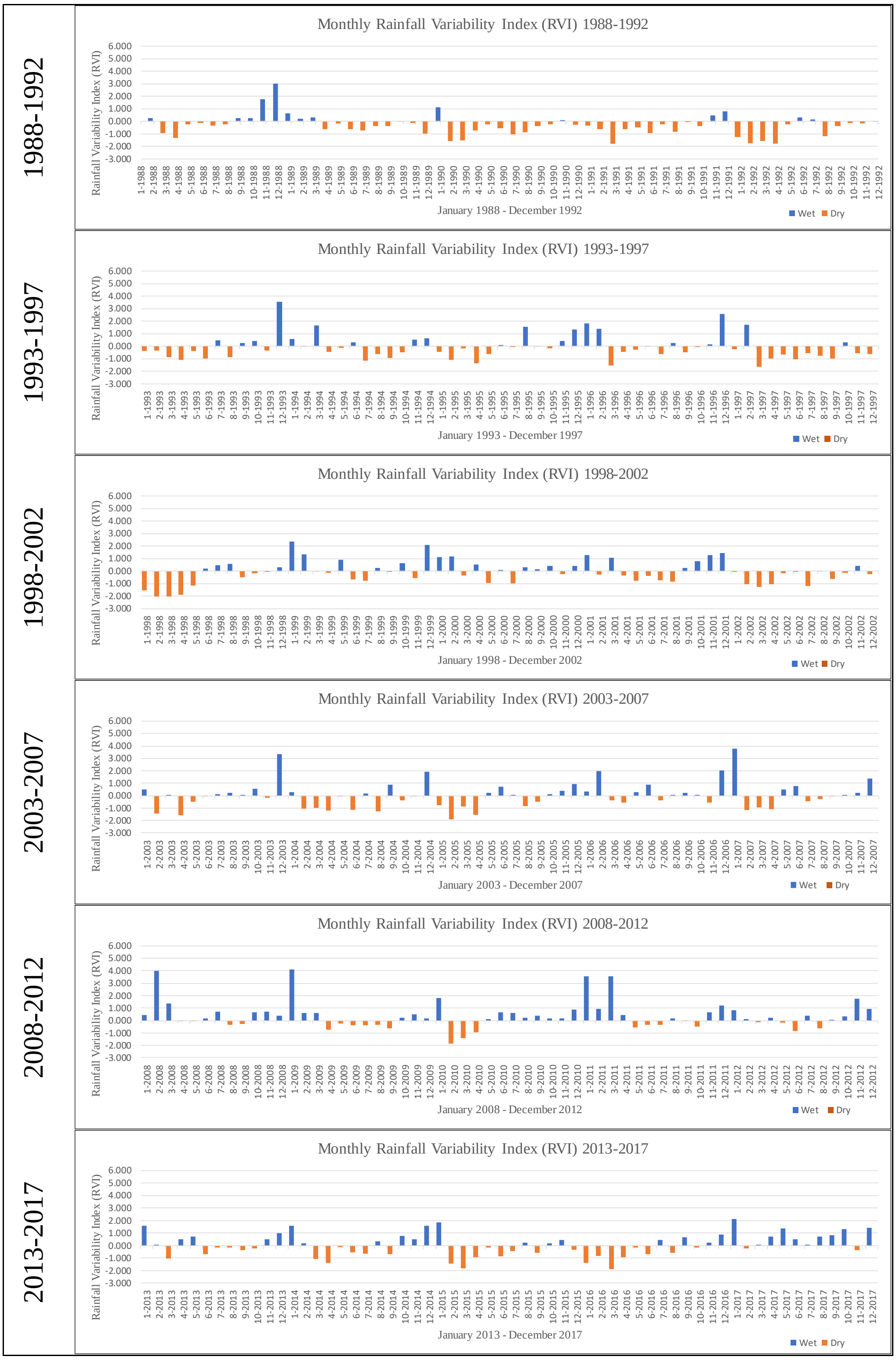


Figure 4.33: Monthly RVI for Six 5-year Sub-periods in Region 8.

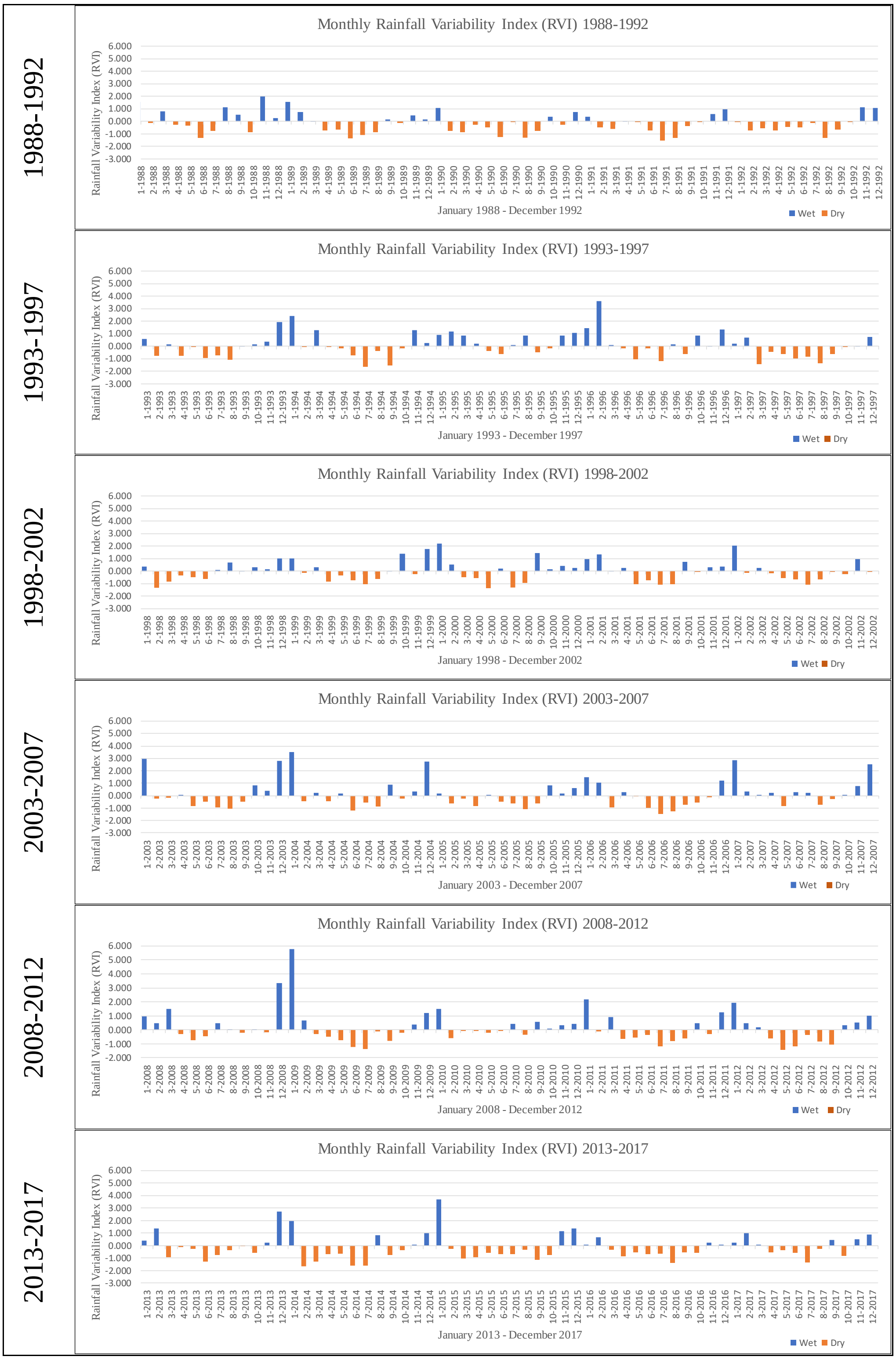


Figure 4.34: Monthly RVI for Six 5-year Sub-periods in Region 9.

4.3.3 Regional Monthly RVI (January-December)

The subsequent six 5-year sub-periods of monthly RVI analysis in different regions for both Peninsular Malaysia and Sabah and Sarawak were analysed, within the 1988-2017 study period. In this subsection, the results of 12 months (January-December) for a total of 13 regions in Malaysia are presented in order to visualise the change of DS variations over the sub-periods (from Figure 4.35 to Figure 4.47).

For the monthly RVI that based in Northern Region (Figure 4.35), the DS occurrences were found relatively higher, in the month of January, February, June and July over the sub-periods. The DS can be observed almost each sub-period from these particular months (extreme DS in the month of February was observed). As for the East Coast Region, as shown in Figure 4.36, the monthly RVI exhibited slightly different behaviour, in which January, February, March, April and June were found to have the effect of DS over the sub-periods, wherein the DS in the month of February detected relatively higher occurrences, as compared to other months. In addition, for the six 5-year sub-periods of monthly RVI in Central Region, as shown in Figure 4.37, DS were seen in all the months, except October and November. Similar result was found as in Northern Region, where the months for January, February, June and July experienced relatively higher DS occurrences over the sub-periods, wherein extreme DS were detected in two sub-periods for February, in 1998-2002 and 2013-2017 sub-periods. As for the Southern Region (Figure 4.38), the months of January, February, June and July showed significant monthly RVI over the sub-periods as well. Generally, the month of February showed significant of DS events due to the relatively higher DS occurrences (extreme DS in 2013-2017 sub-period was observed).

For the regions that were based in Sabah and Sarawak, Figure 4.39 shows the monthly RVI of six 5-year sub-periods for Region 1. The DS can be detected in each of the month, except October and December. It can be seen that the DS were significant starting from February to April, that were relatively higher DS occurrences (extreme DS were observed) over the sub-periods as compared to other months in Region 1. As for the Region 2 which presented in Figure 4.40, the DS variations had slightly different as from Region 1, where the DS suffered starting from June to September over the sub-periods, wherein July recorded relatively higher DS occurrences. Furthermore, the months (except November and December) were detected with the DS severity over the sub-periods in Region 3 (Figure 4.41), where four months (from June to September) were found significant in term of the extreme DS occurrences. Also, the highest number of DS that occurred in the 1988-1992 sub-period were observed for the month of June and August. For the results of Region 4 as presented in Figure 4.42, the effect of DS had significant in the beginning of the months (January to April), wherein the 2003-2007 sub-period experienced the highest DS occurrences, in the month of February as compared to other months. Similar result was observed for Region 5 as shown in Figure 4.43, in which there was a relatively higher of DS occurrences in the beginning of months. Extreme DS also detected in this case where February found more severe as compared to January and March over the sub-periods. This showed that both Region 4 and Region 5 had more influence on DS in the beginning of the months but had less influence thereafter months over the sub-periods.

In addition, based on the Figure 4.44 that presented the results for Region 6, the months (January to March and June to September) were found with relatively higher of the RVI variation in term of the DS occurrences over the sub-periods. There was a similarity for both Region 5 and Region 6, where the highest occurrences of extreme DS were experienced in the month of February over the sub-periods. In Figure 4.45, the monthly RVI detected starting from May to September had relatively higher DS, especially June, July and August over the sub-periods. It was seen that the 1988-1992 sub-period had the highest number of DS for the month of June and August, for Region 7. As for the Region 8 that presented in Figure 4.46, the monthly RVI exhibited slightly different behaviour, in which from January to August were found to have the effect of DS over the sub-periods, wherein the DS in the month of February to April detected with relatively higher occurrences, as compared to other months. This indicated that for the first eight months in Region 8 had influence on the DS whereas no significant in the later months. For the Region 9 that presented in Figure 4.47, the five months (May to September) were observed significantly where the DS detected over sub-periods, wherein July recorded a relatively higher of occurrences compared to other months.

Based on the findings for the six 5-year sub-periods and which is according to months in the 13 regions, the monthly sub-periods between January to April and June to September have more significant DS effect over 1988-2017. February is the month where the DS detected with relatively higher occurrences in majority of the regions in Malaysia when compared to the other months which found with DS effect. This is in agreement with Jamaludin, et al. (2010), in which the western part of Peninsular Malaysia tended to have more DS severe during the climate change of seasonal monsoons. In addition, for the Sabah and Sarawak, most of the regions suffered more DS during the Northeast Monsoon period, but for Region 2, Region 7 and Region 9 were found more DS severe during the Southwest Monsoon period.

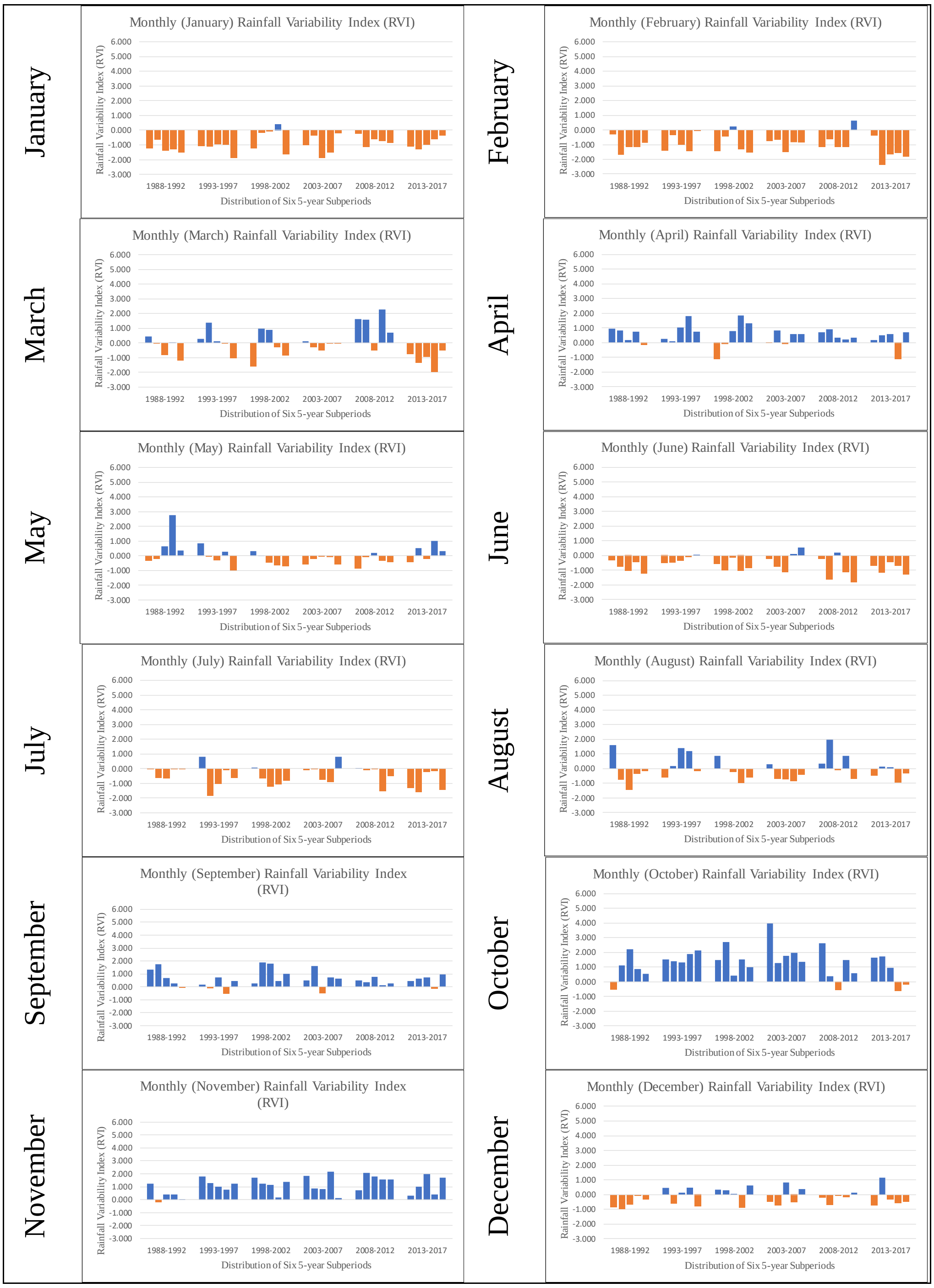


Figure 4.35: Monthly RVI of Six 5-year Sub-periods for Each Month in Northern Region.

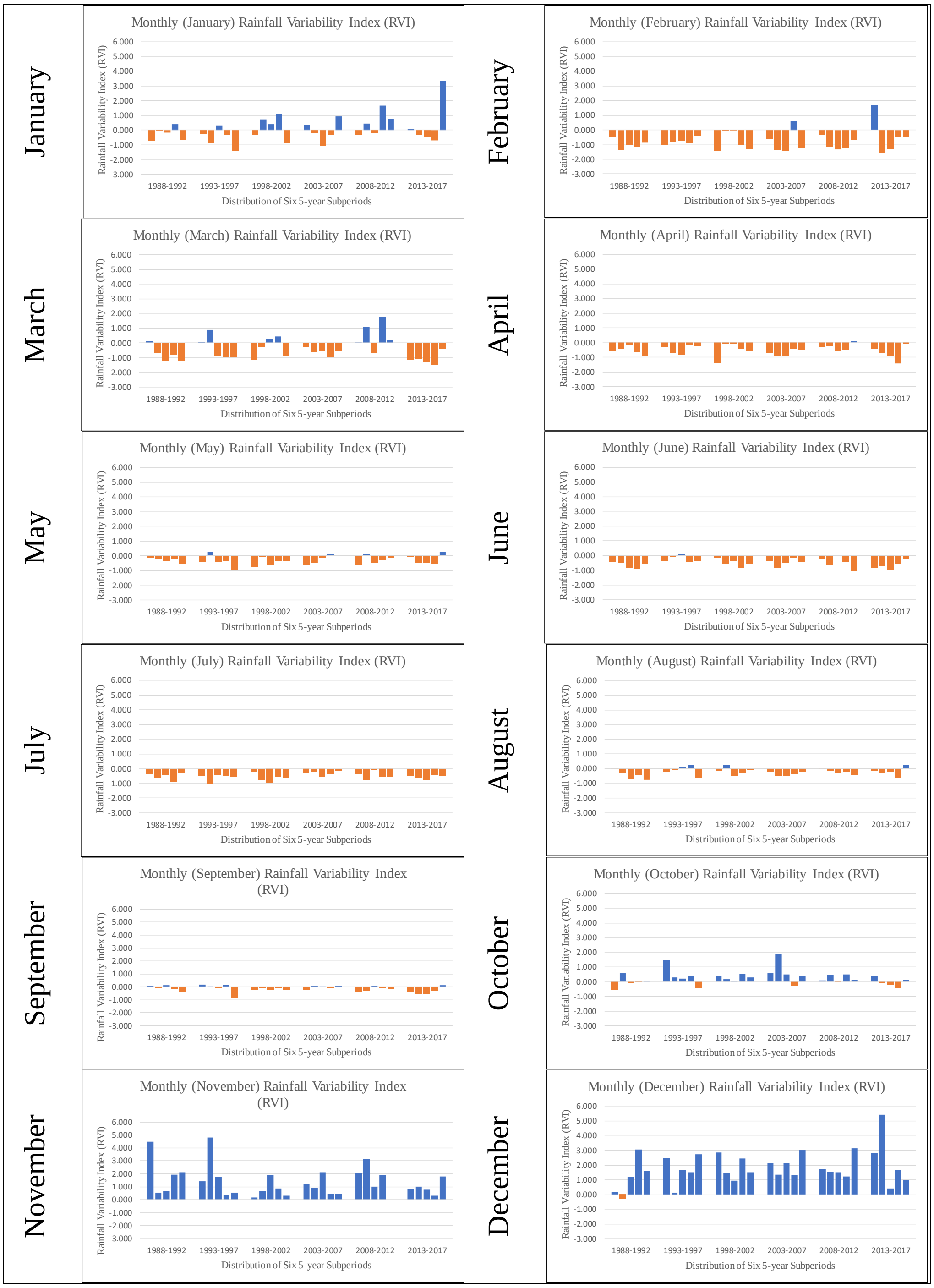


Figure 4.36: Monthly RVI of Six 5-year Sub-periods for Each Month in East Coast Region.

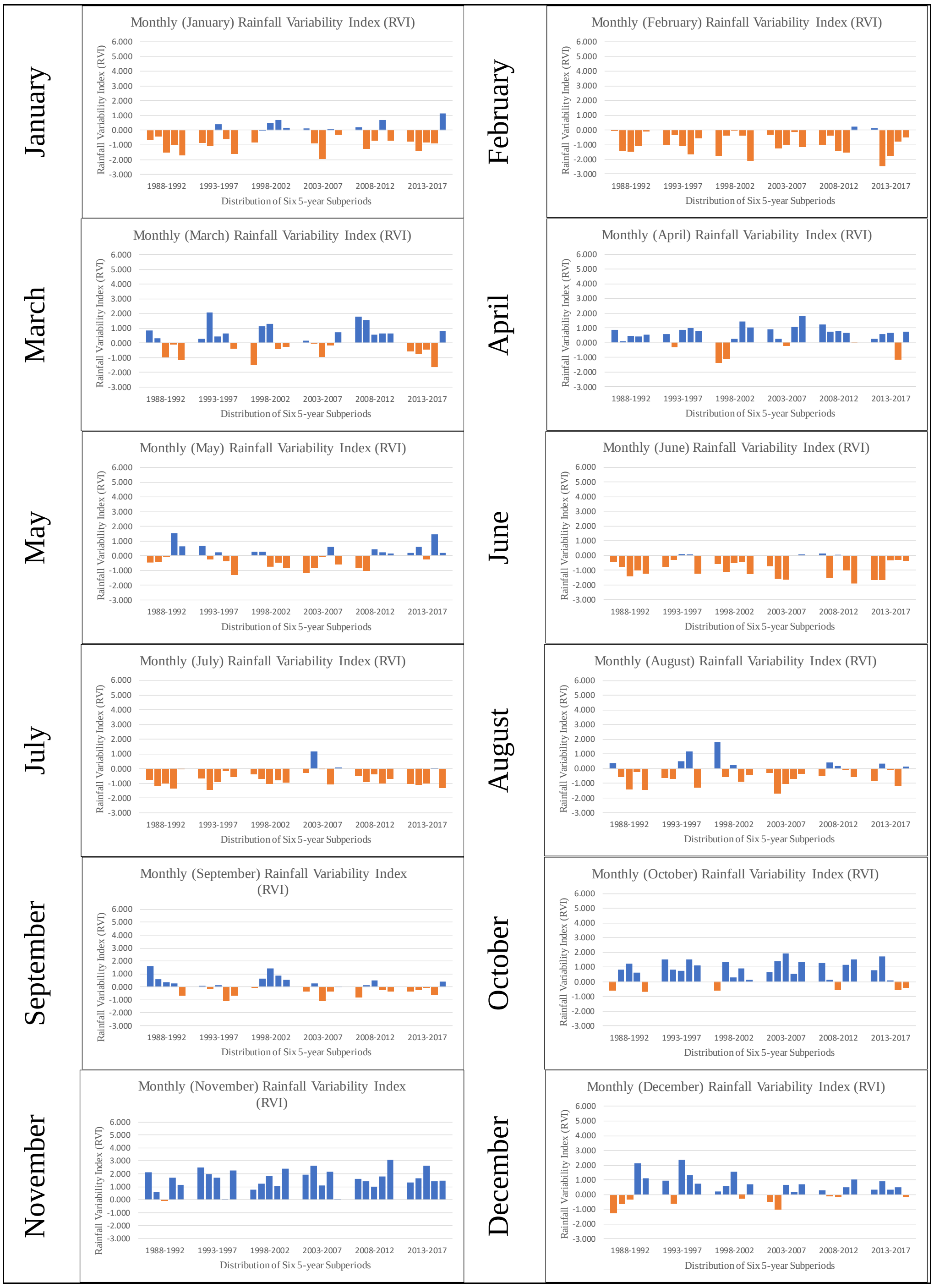


Figure 4.37: Monthly RVI of Six 5-year Sub-periods for Each Month in Central Region.

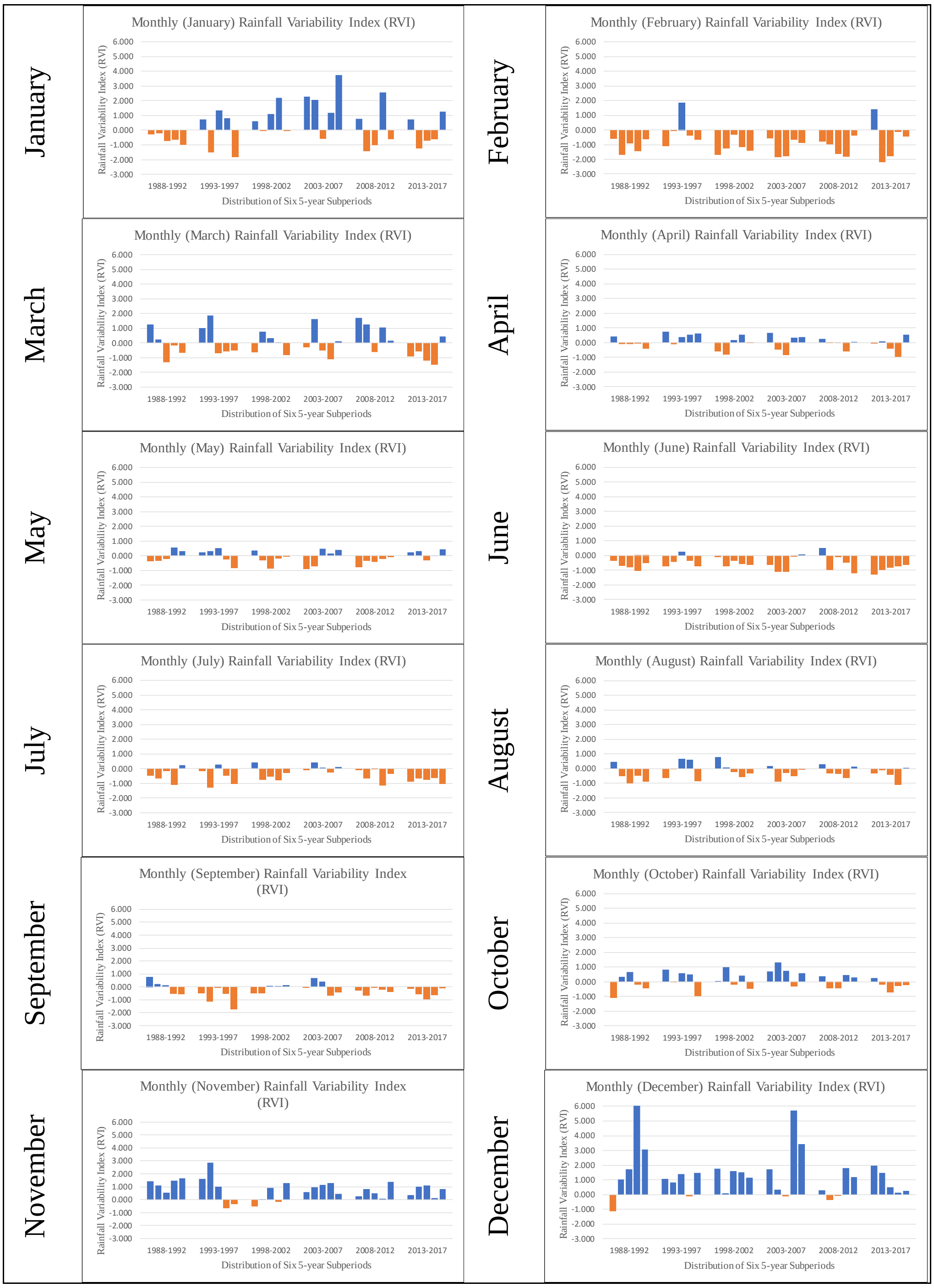


Figure 4.38: Monthly RVI of Six 5-year Sub-periods for Each Month in Southern Region.

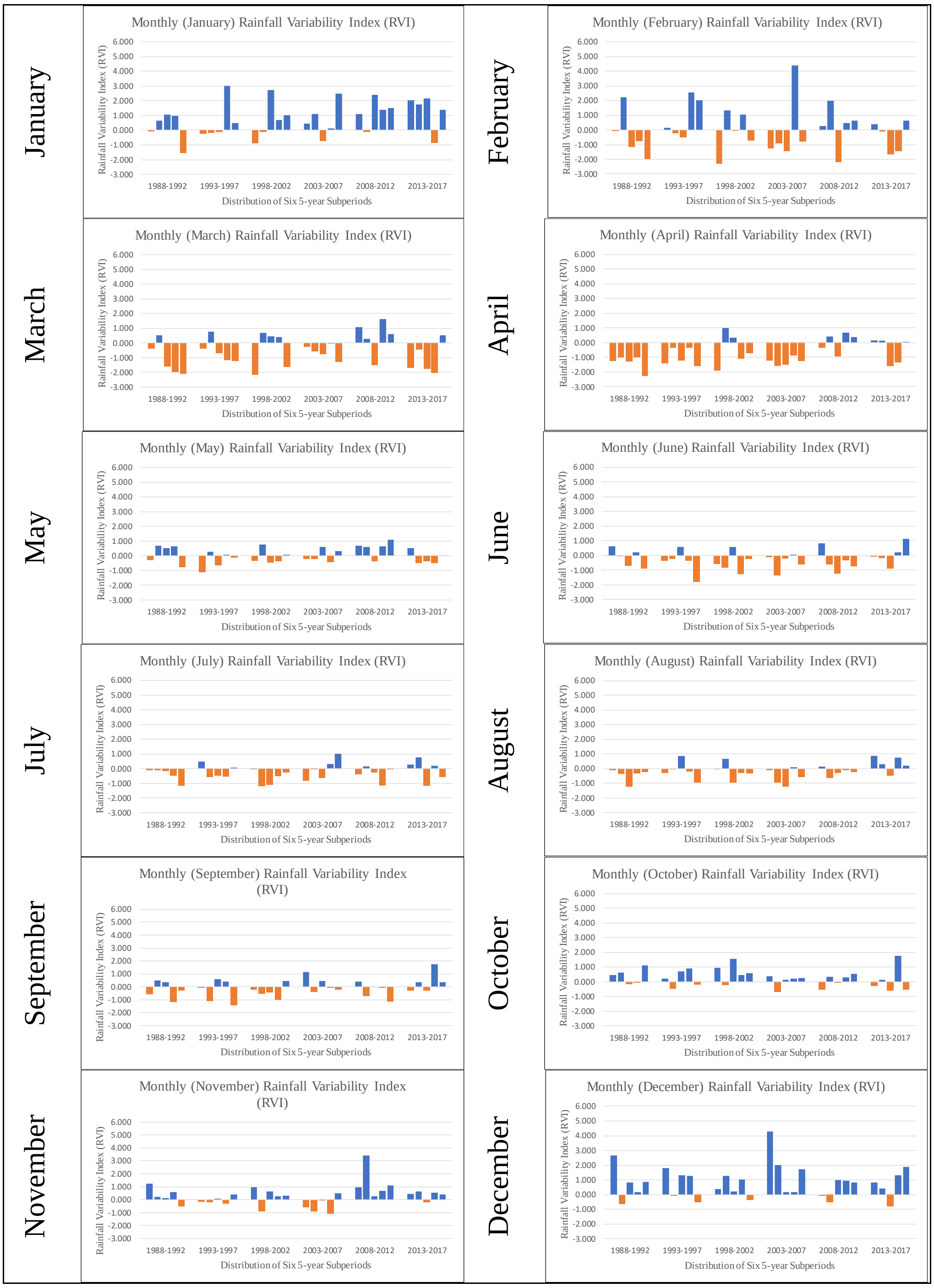


Figure 4.39: Monthly RVI of Six 5-year Sub-periods for Each Month in Region 1.

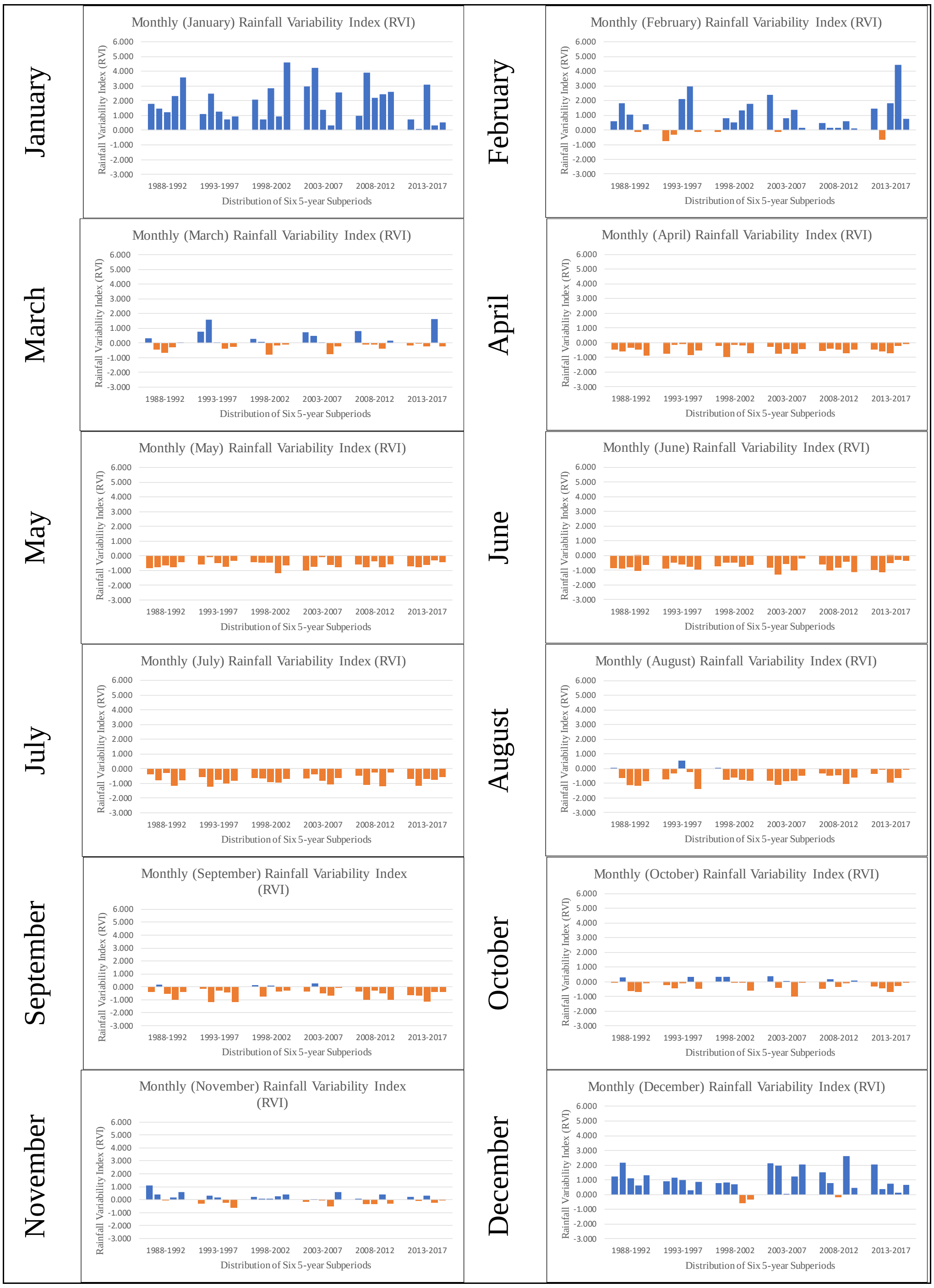


Figure 4.40: Monthly RVI of Six 5-year Sub-periods for Each Month in Region 2.

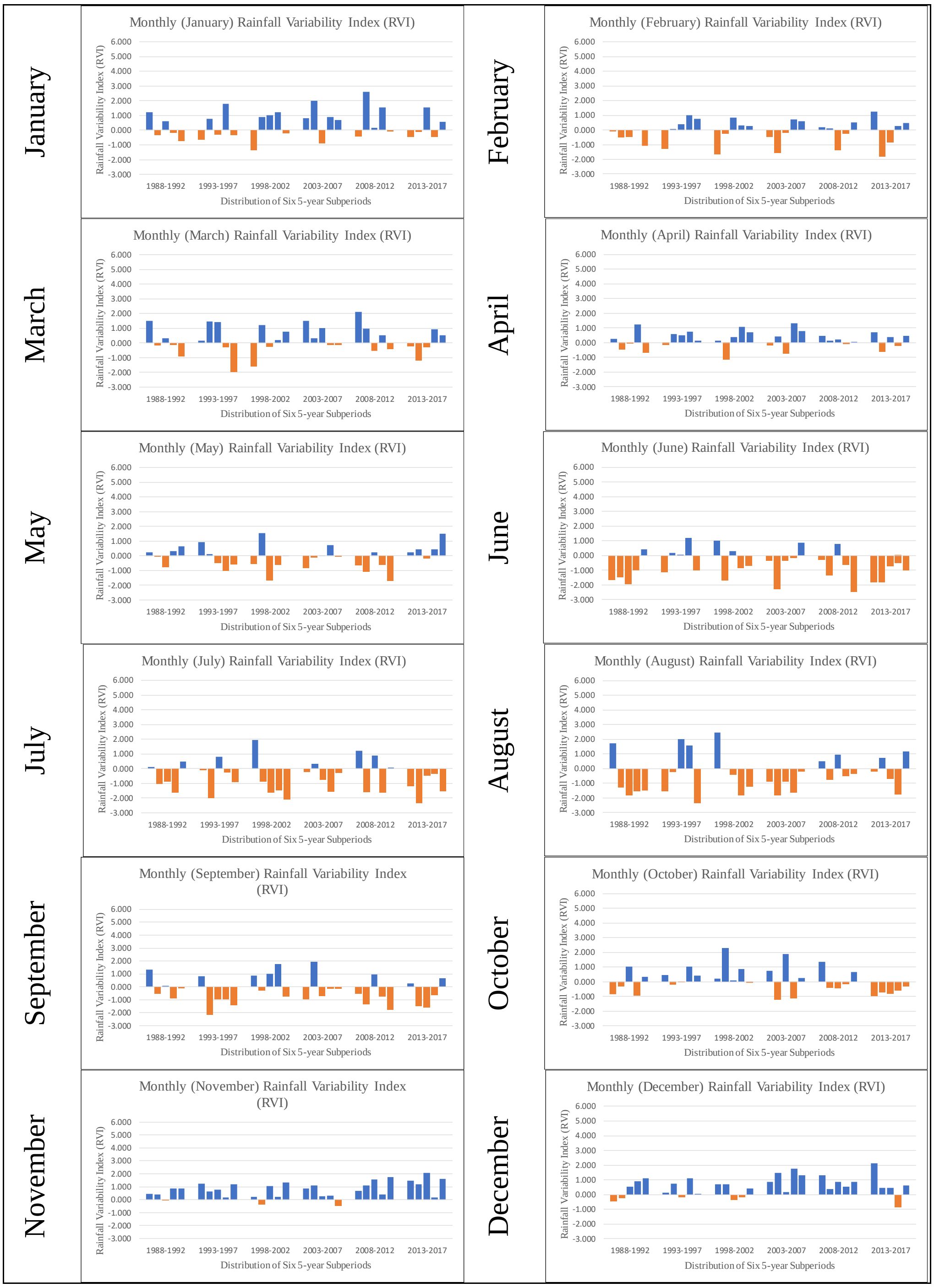


Figure 4.41: Monthly RVI of Six 5-year Sub-periods for Each Month in Region 3.

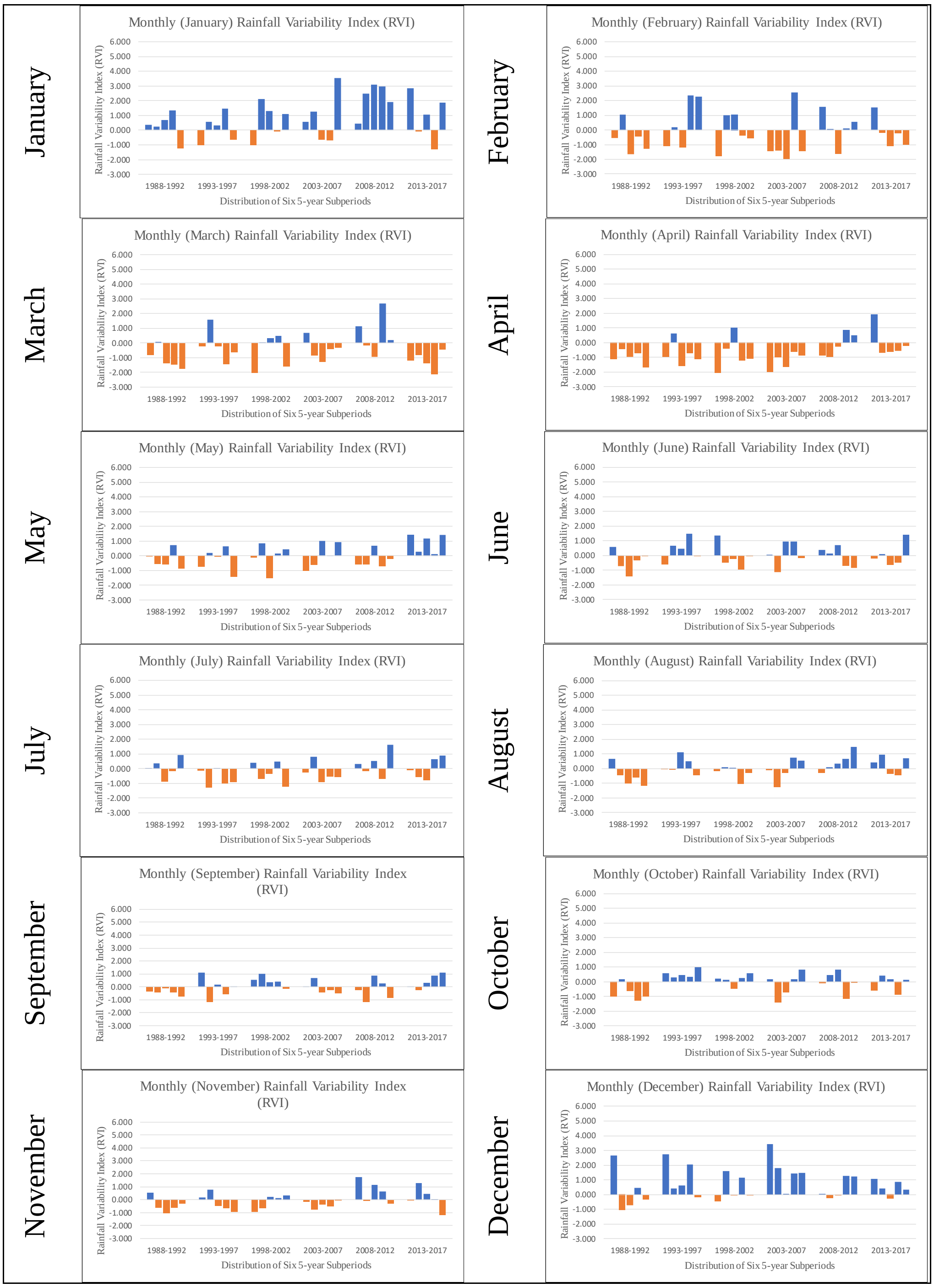


Figure 4.42: Monthly RVI of Six 5-year Sub-periods for Each Month in Region 4.

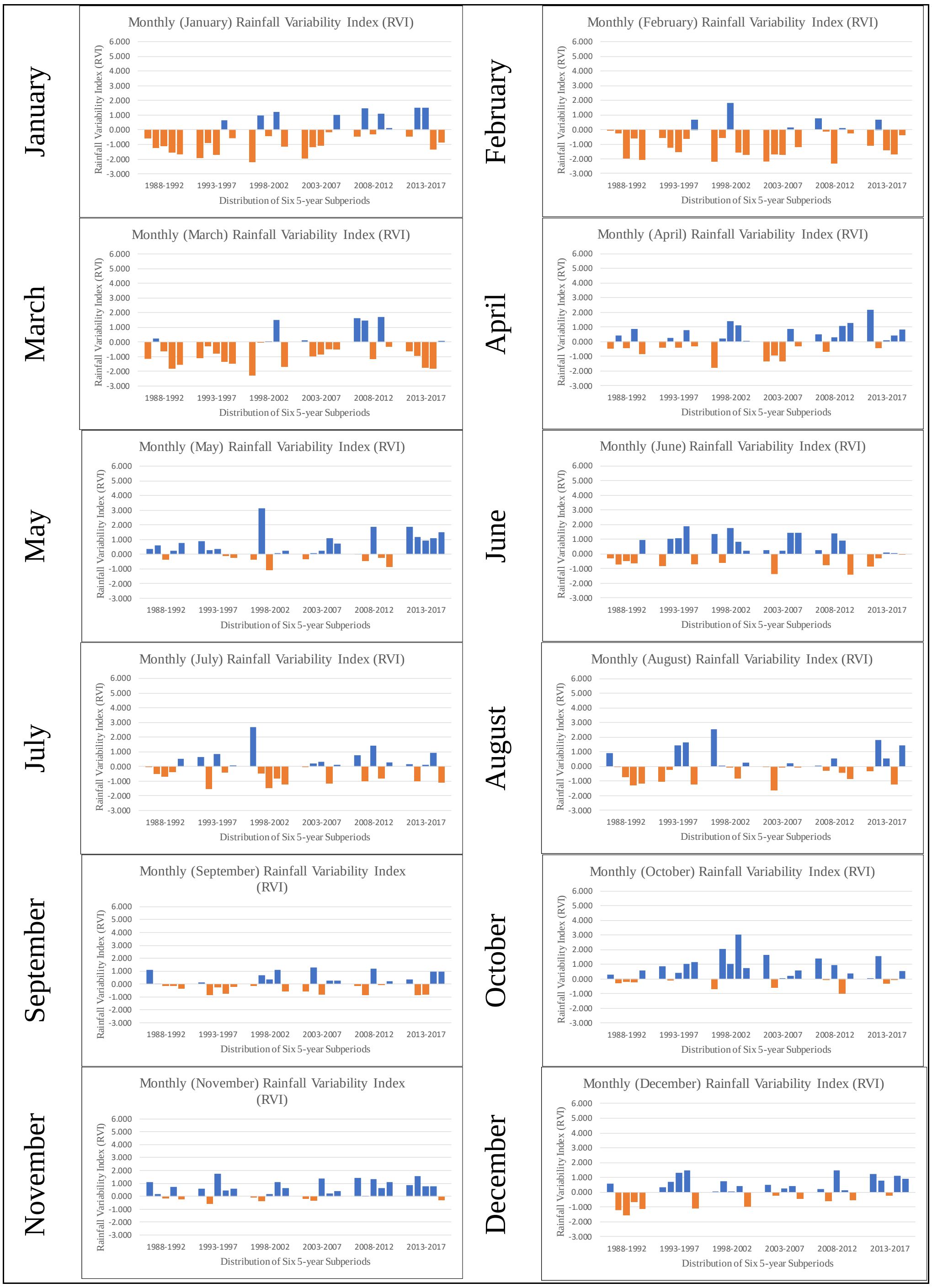


Figure 4.43: Monthly RVI of Six 5-year Sub-periods for Each Month in Region 5.

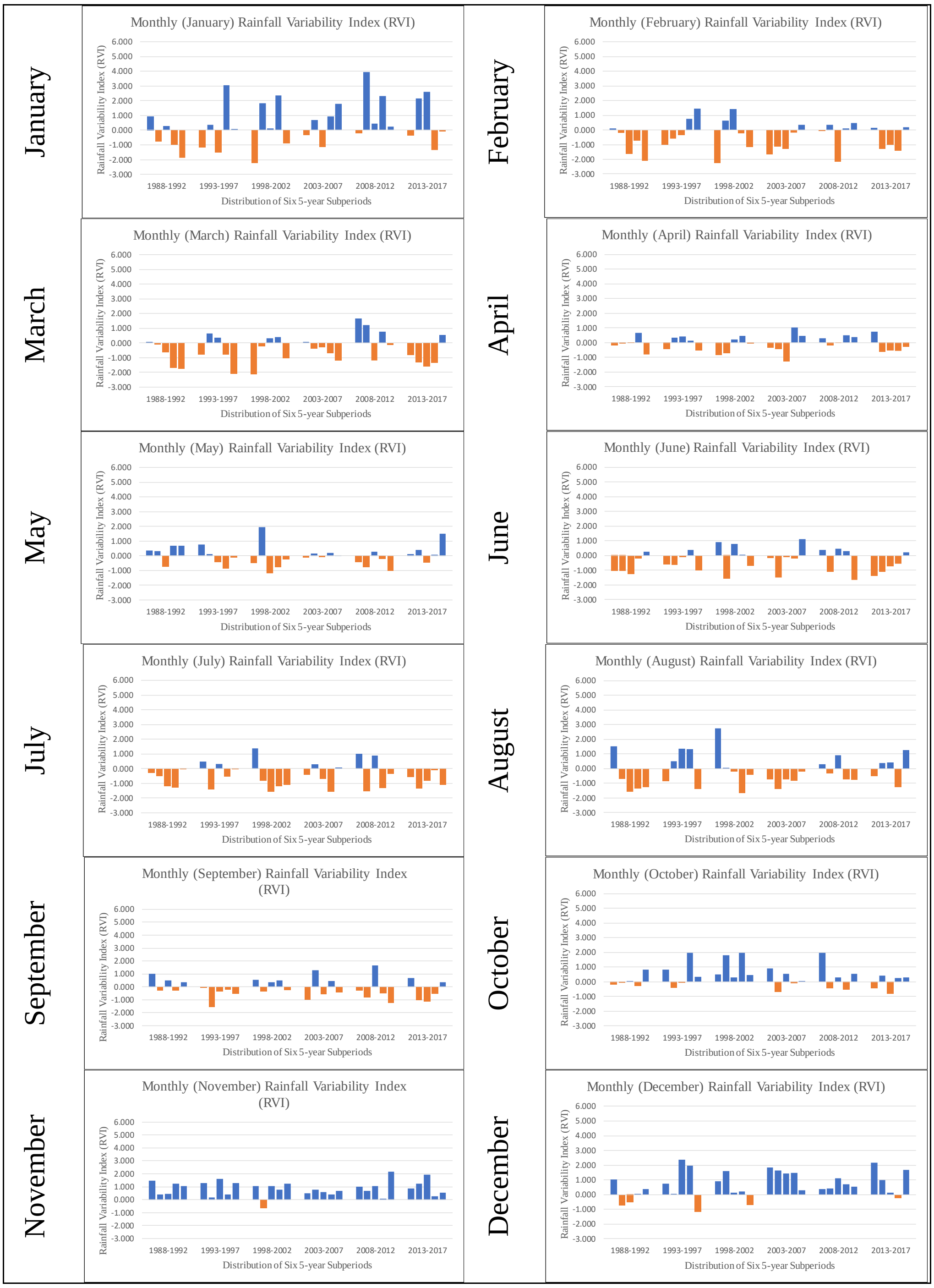


Figure 4.44: Monthly RVI of Six 5-year Sub-periods for Each Month in Region 6.

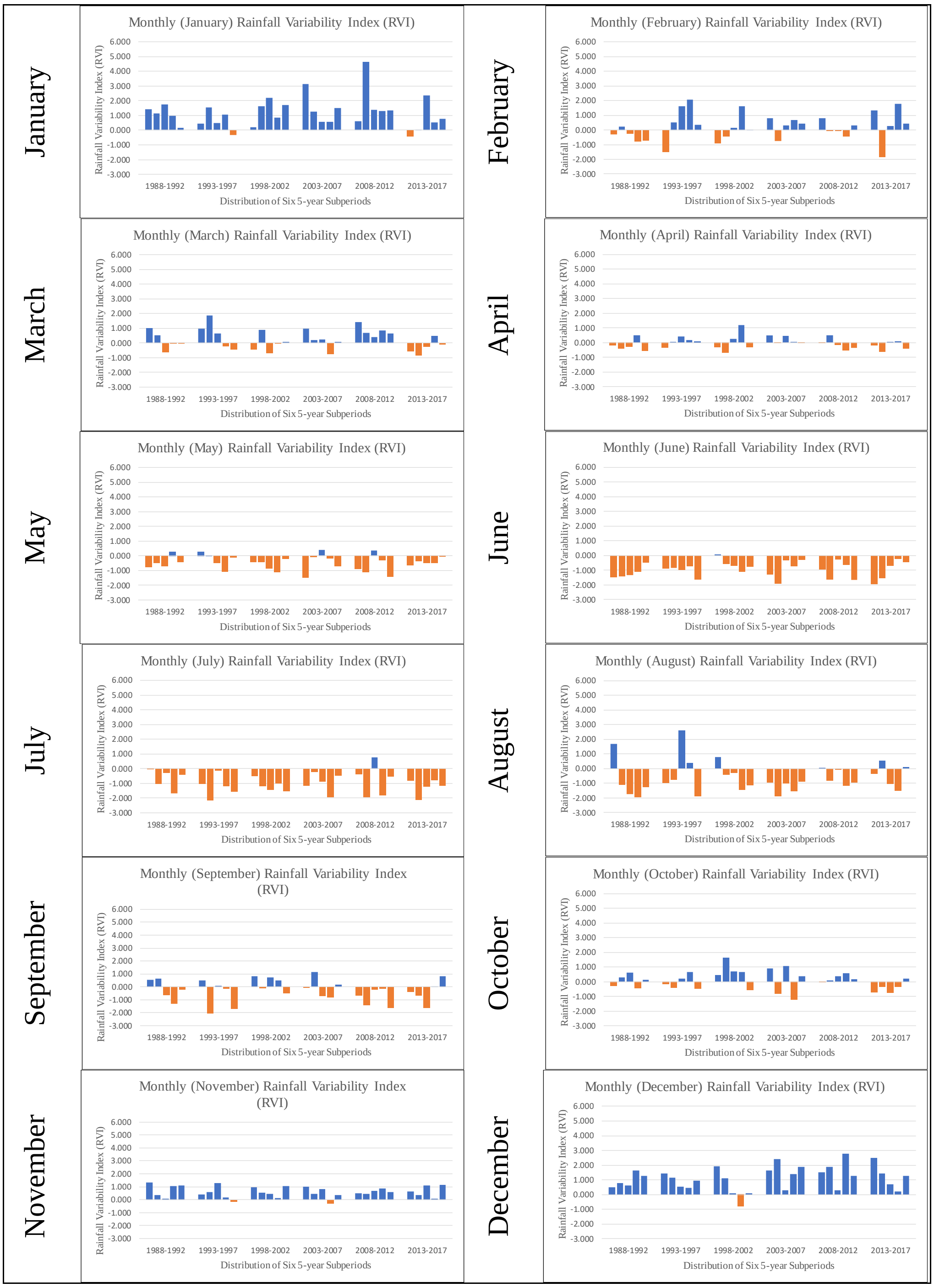


Figure 4.45: Monthly RVI of Six 5-year Sub-periods for Each Month in Region 7.

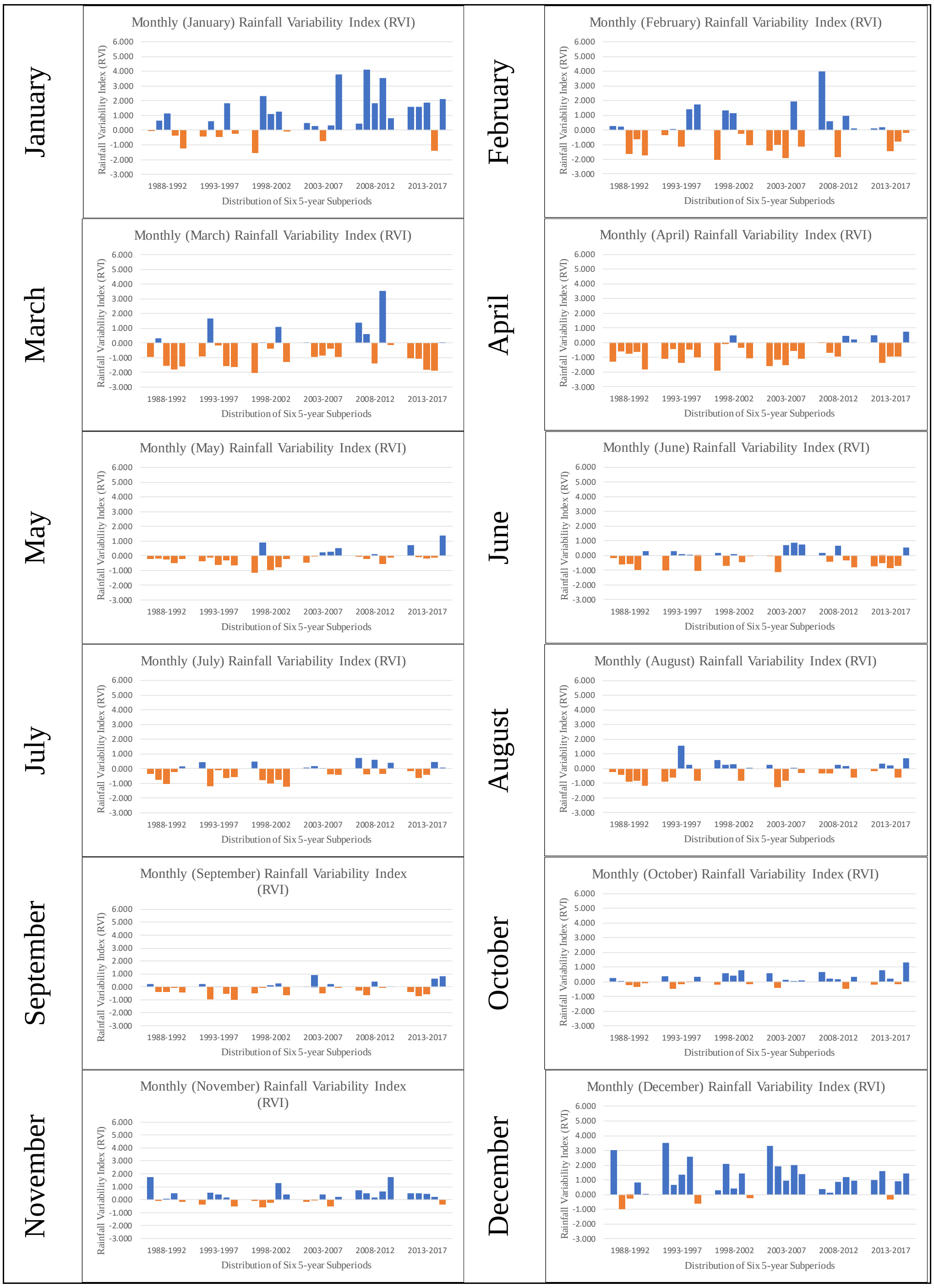


Figure 4.46: Monthly RVI of Six 5-year Sub-periods for Each Month in Region 8.

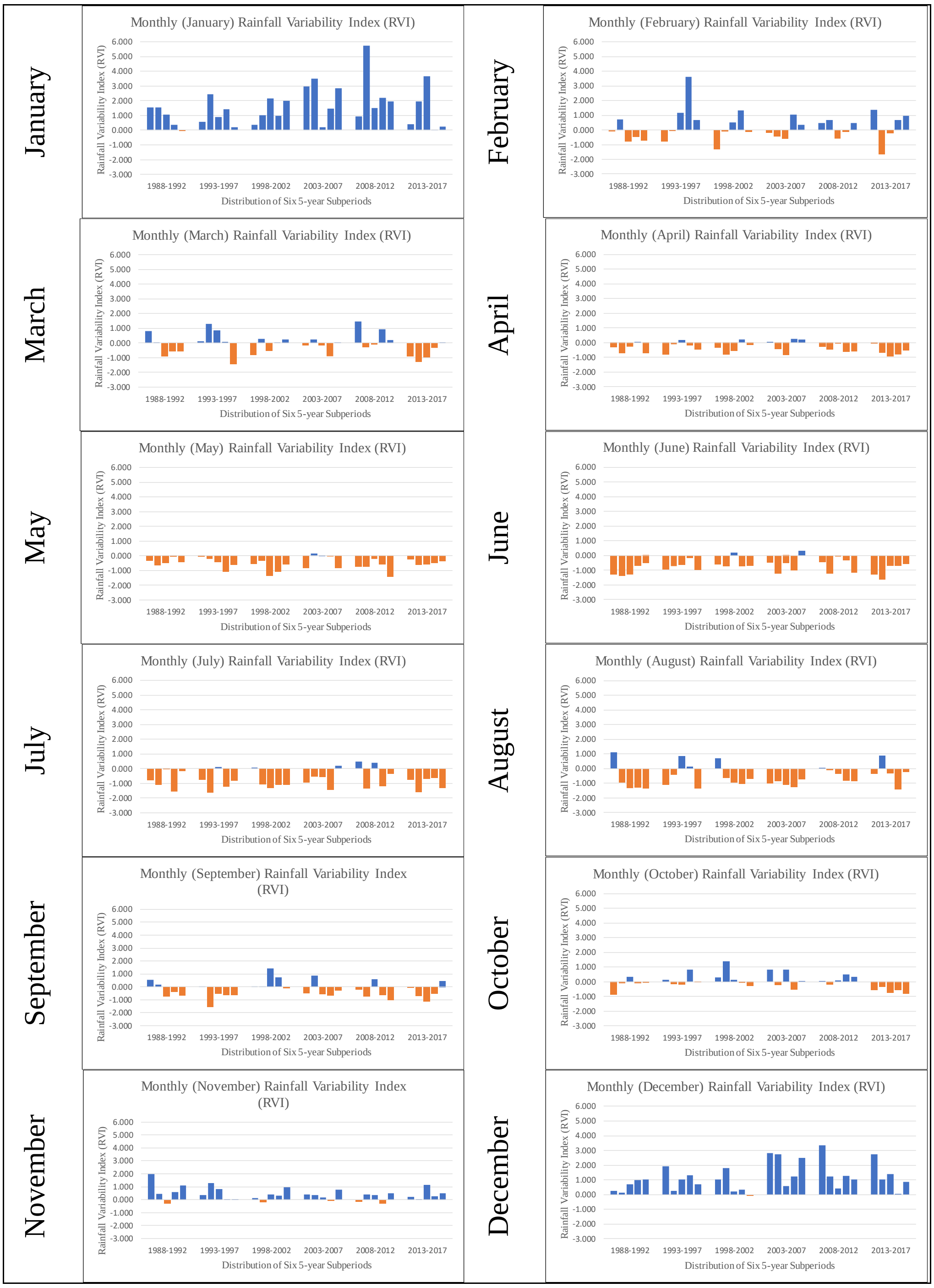


Figure 4.47: Monthly RVI of Six 5-year Sub-periods for Each Month in Region 9.

4.3.4 Spatial Analysis of Drought Characteristics

The spatial distribution for DF and MDD that were based on both of the annual and monthly RVI in 1988-2017 study period were further broken down into six 5-year sub-periods in order to observe the DS variation throughout each sub-period in Malaysia. The DF and MDD (for both annual and monthly) were assessed and they are presented in Figure 4.48, Figure 4.49, Figure 4.50 and Figure 4.51 respectively. The ranges of DF and MDD for annual RVI were in between 0-5, whereas for monthly RVI, the ranges for DF and MDD were 0-30 and 0-20 respectively.

Based on Figure 4.48 presented, the DF had increased apparently from 1988-1992 sub-period to 1993-1997 sub-period (with higher red intensity of symbolisation), in which the east and south parts of Peninsular Malaysia and the regions based in Sabah and Sarawak experienced relatively higher DF. But from the 1998-2002 sub-period towards the 2013-2017 sub-period, the intensity of red symbolisation can be observed that had degraded in which the DF had decreased gradually from most of the regions in Malaysia. These showed that the second sub-period (1993-1997) suffered higher number of DF as compared to other sub-periods. Whereas for the first sub-period (1988-1992), it had experienced a relatively lower DF among other sub-periods.

As for the spatial variation in term of the MDD, the first sub-period (1988-1992) in Figure 4.49 showed the highest intensity of the red symbolisation (highest MDD) in Malaysia, where Region 3, Region 4, Region 5 and Region 6 that were based in Sabah and Sarawak had experienced the highest MDD, compared to other regions. This indicated that the longer duration of DS events was occurred for 1988-1992 sub-period. The MDD had decreased in the following two sub-periods (1993-1997 and 1998-2002) with relatively low intensity of red symbolisations. But for some regions, especially the west coast of the Northern Region, east coast of East Coast Region and the west coast of the Sarawak suffered a relatively higher MDD. Besides, there was a spatial variation observed from the 2003-2007 sub-period to 2013-2017 sub-period, in which the MDD was relatively higher. Although the MDD was observed relatively higher for these sub-periods, yet severity was not as severe as in the first sub-period (1988-1992).

For the monthly DF (with six 5-year sub-periods) that is displayed in Figure 4.50, there were not much spatial variation through each sub-period, yet slightly increase of DF can be observed from the west coast of Peninsular Malaysia (south part of the Northern Region, west part of East Coast Region, Central Region and Southern Region), as well as the central part and south coast of the Sabah and Sarawak. In the aspect of monthly MDD that was presented in Figure 4.51, similar results were obtained, where the spatial variation has less significant for each sub-period, based on 1988-2017 study period. However, for the east part and the part that was adjacent to the South China Sea of East Coast Region was distinguished by a relatively higher MDD for each sub-period, except for the fifth sub-period (2008-2012). Also, the west coast of the Northern Region was observed for the last sub-period (2013-2017) as it had the highest intensity of red symbolisation (highest MDD) as compared to other regions for each sub-period. This indicated that the highest MDD area in Northern Region suffered the least number of DS event occurrences but that were of a relatively longer duration, for 2013-2017 sub-period, compared to East Coast Region.

Based on the findings showed in Figure 4.48, Figure 4.49, Figure 4.50 and Figure 4.51, the spatial analysis shows significance for the annual RVI in Malaysia, in which most of the regions where detected with higher DF in the beginning of the sub-periods (1988-1992, 1993-1997 and 1998-2002 sub-periods). As for the MDD of annual RVI, 1988-1992 and 2013-2017 sub-periods were found more significant to which the spatial variations of MDD were higher over the sub-periods. In contrast, the MDD for the monthly RVI showed less significant throughout the Malaysia over the sub-periods, except for the east part of East Coast Region and the west part of Northern Region (2013-2017 sub-period).

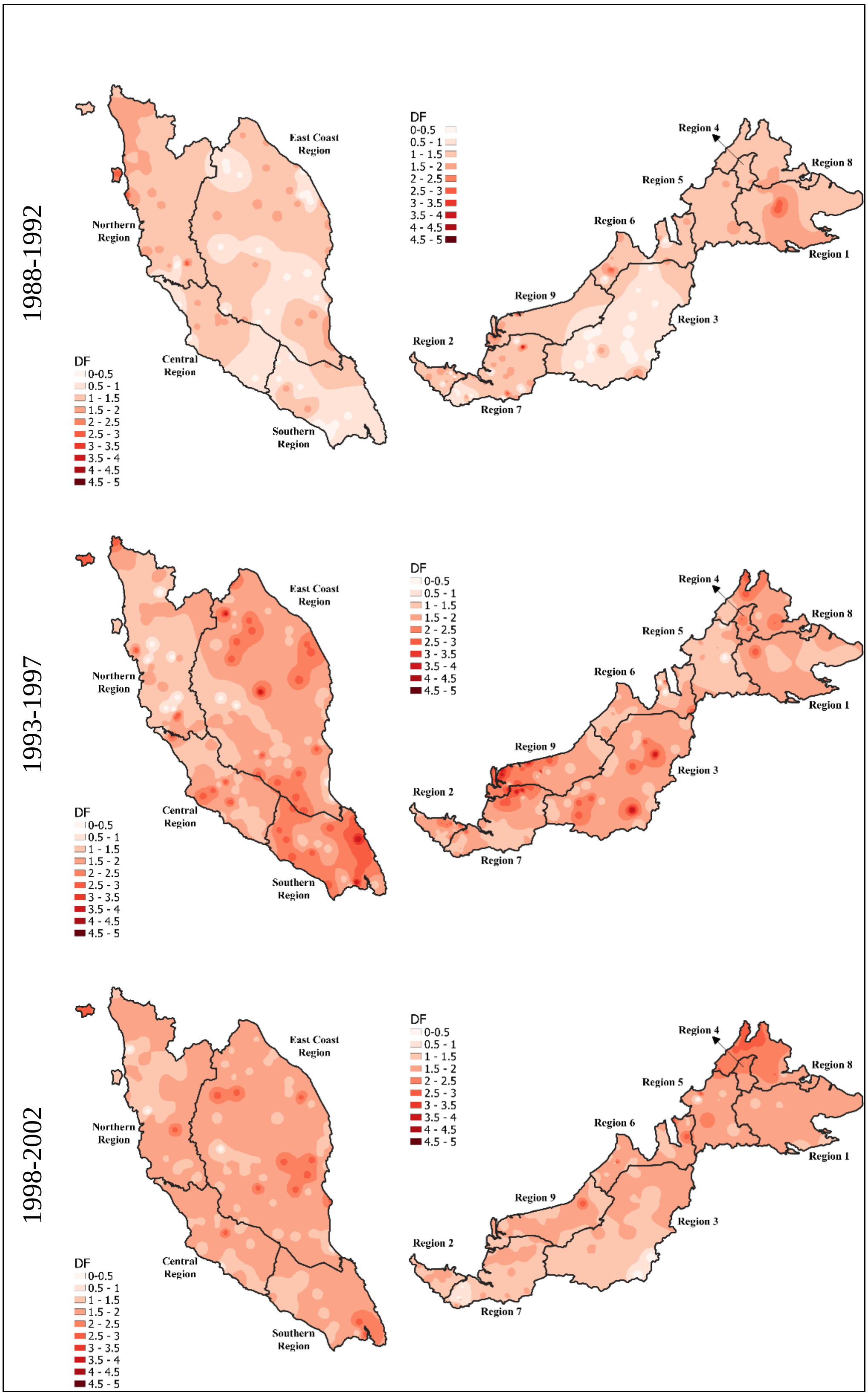


Figure 4.48: Drought Frequency for Annual RVI of Six 5-year Sub-periods in Malaysia.

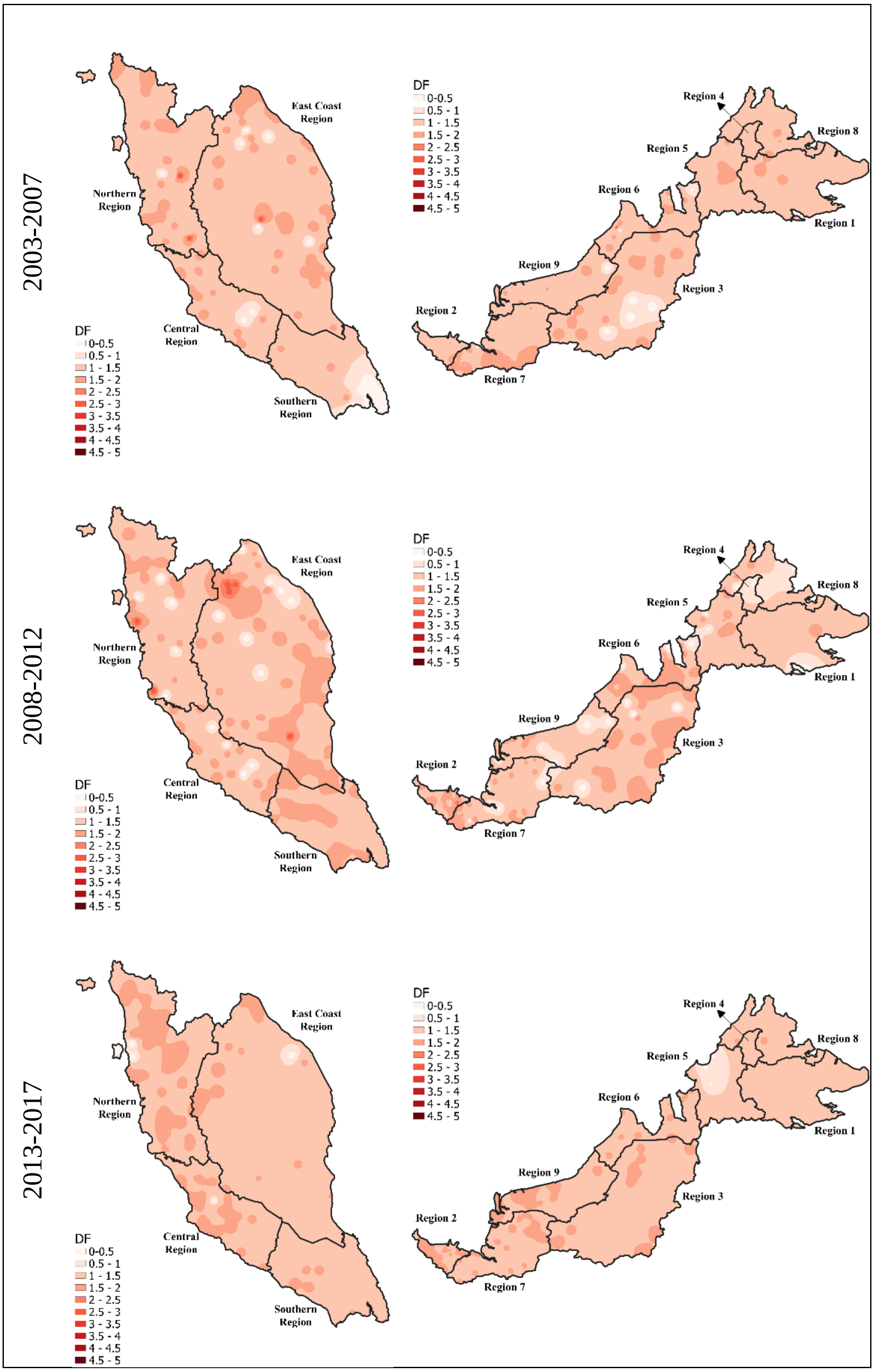


Figure 4.48 (Continued)

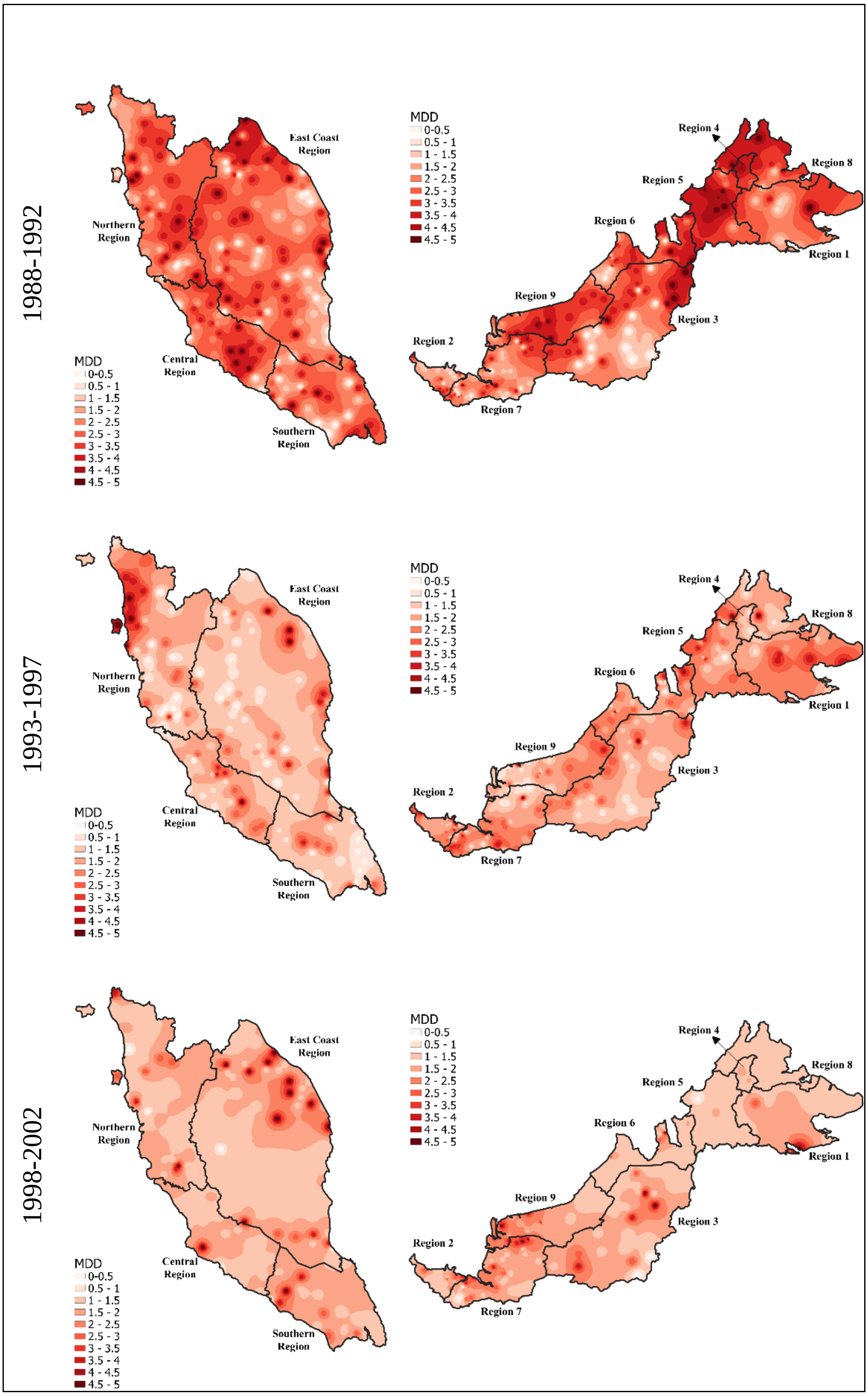


Figure 4.49: Mean Drought Duration for Annual RVI of Six 5-year Sub-periods in Malaysia.

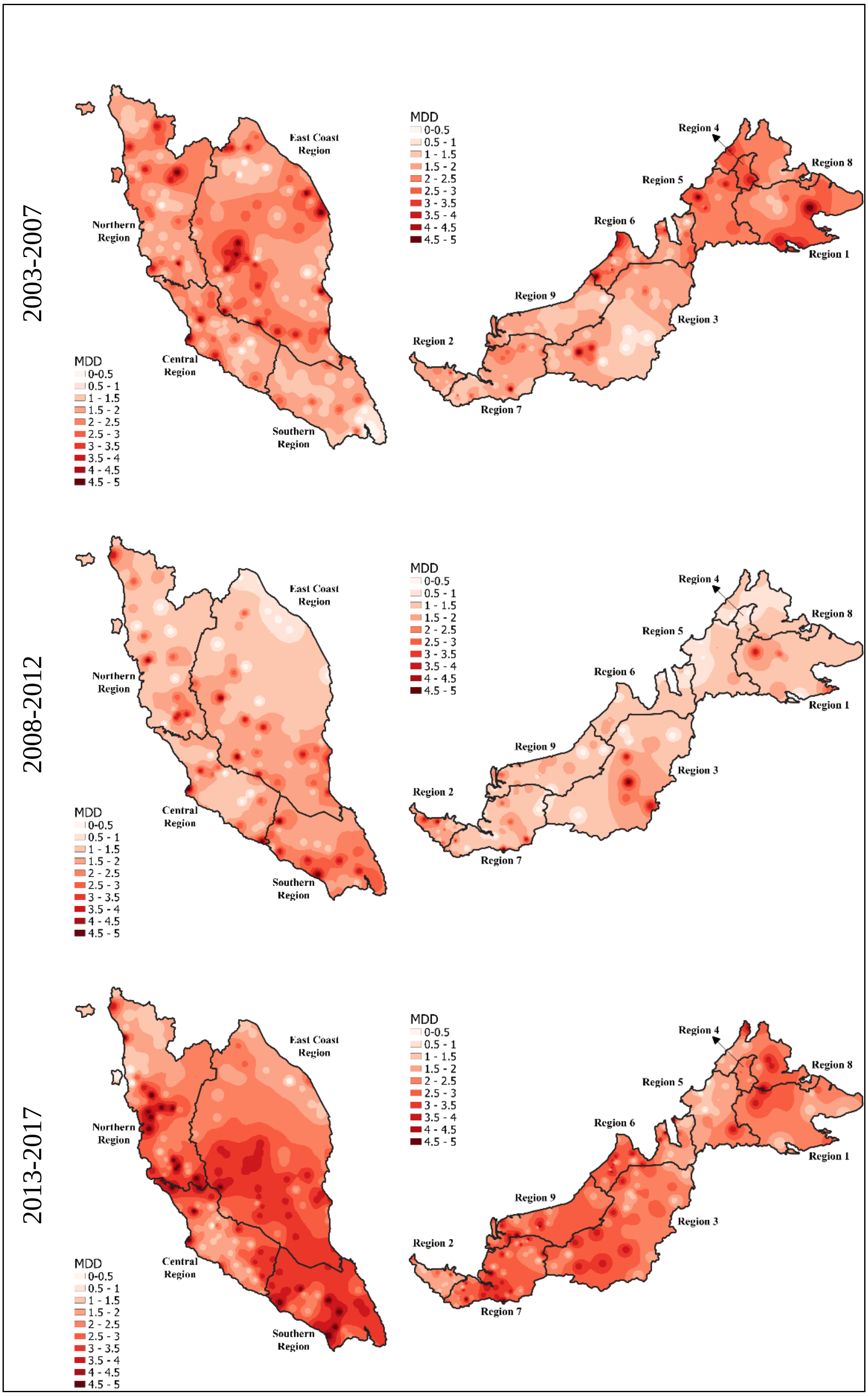


Figure 4.49 (Continued)

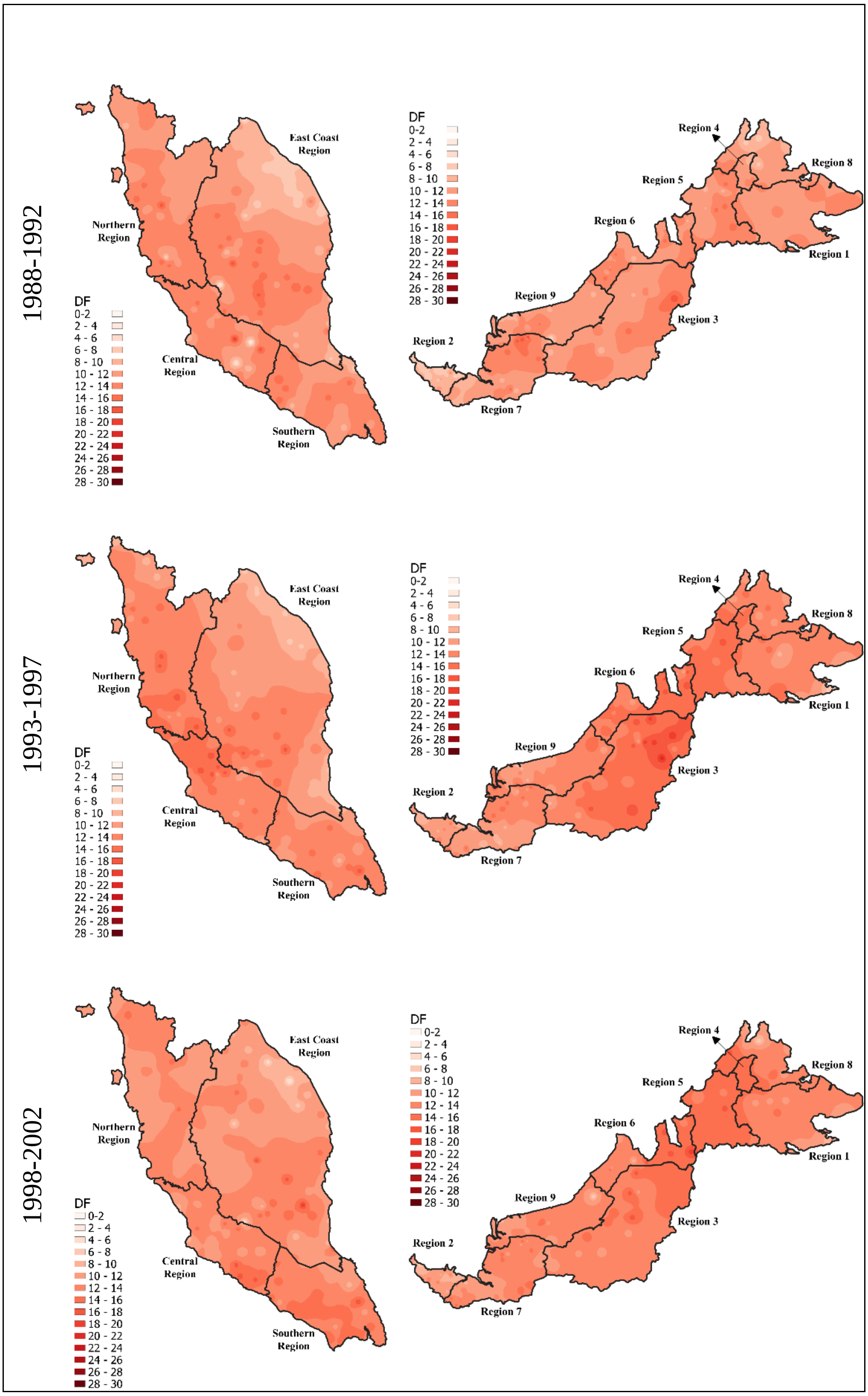


Figure 4.50: Drought Frequency for Monthly RVI of Six 5-year Sub-periods in Malaysia.

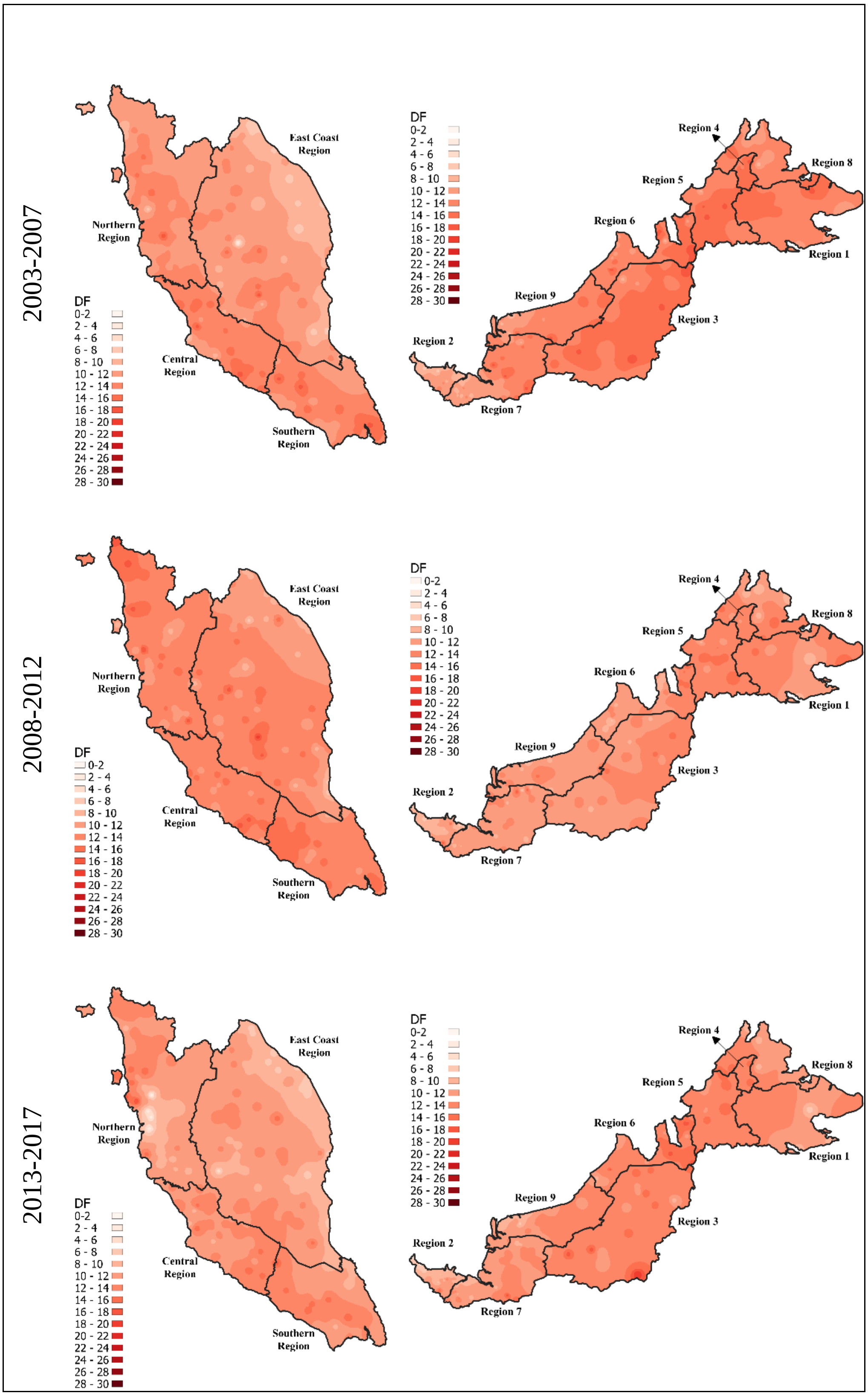


Figure 4.50 (Continued)

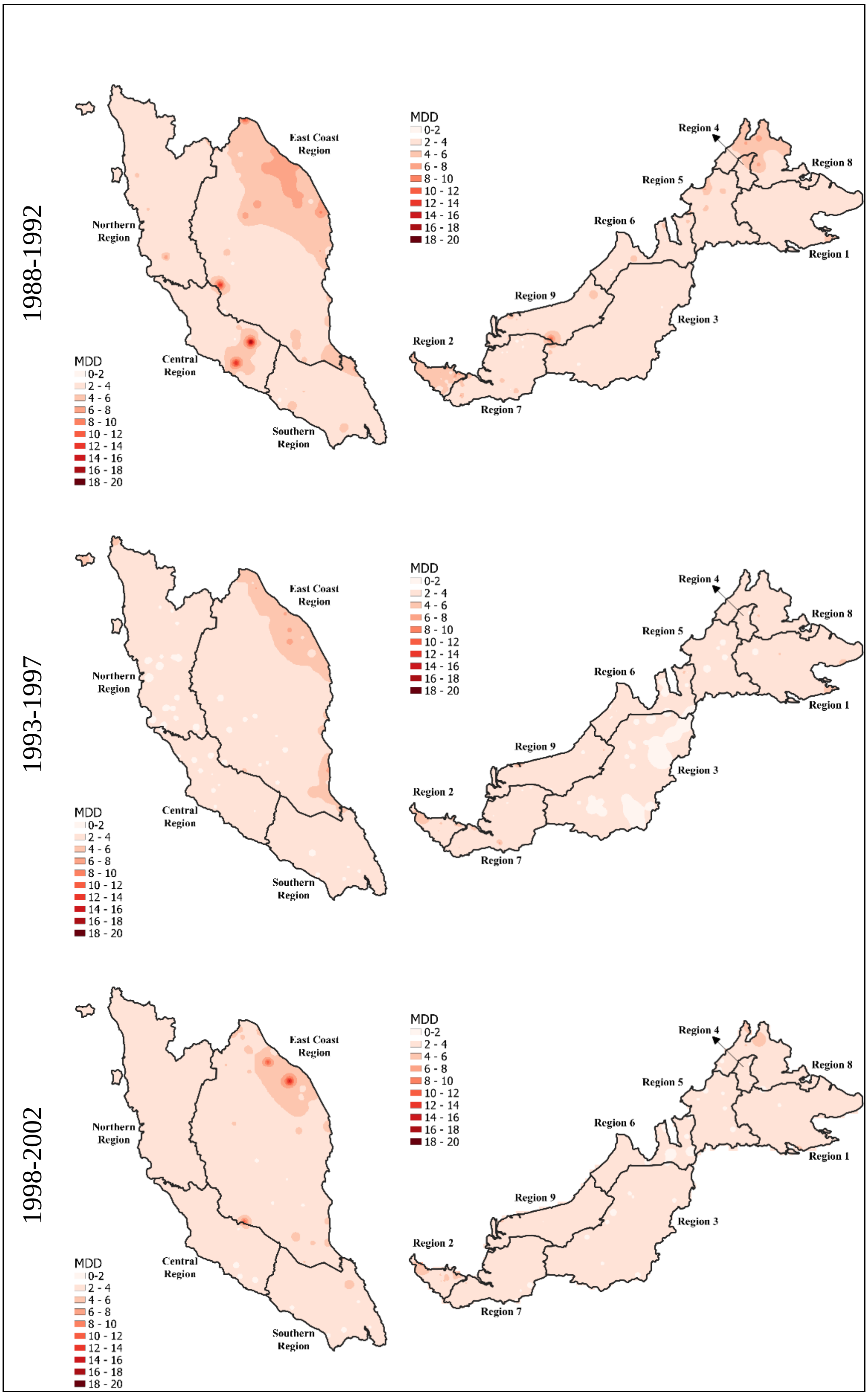


Figure 4.51: Mean Drought Duration for Monthly RVI of Six 5-year Sub-periods in Malaysia.

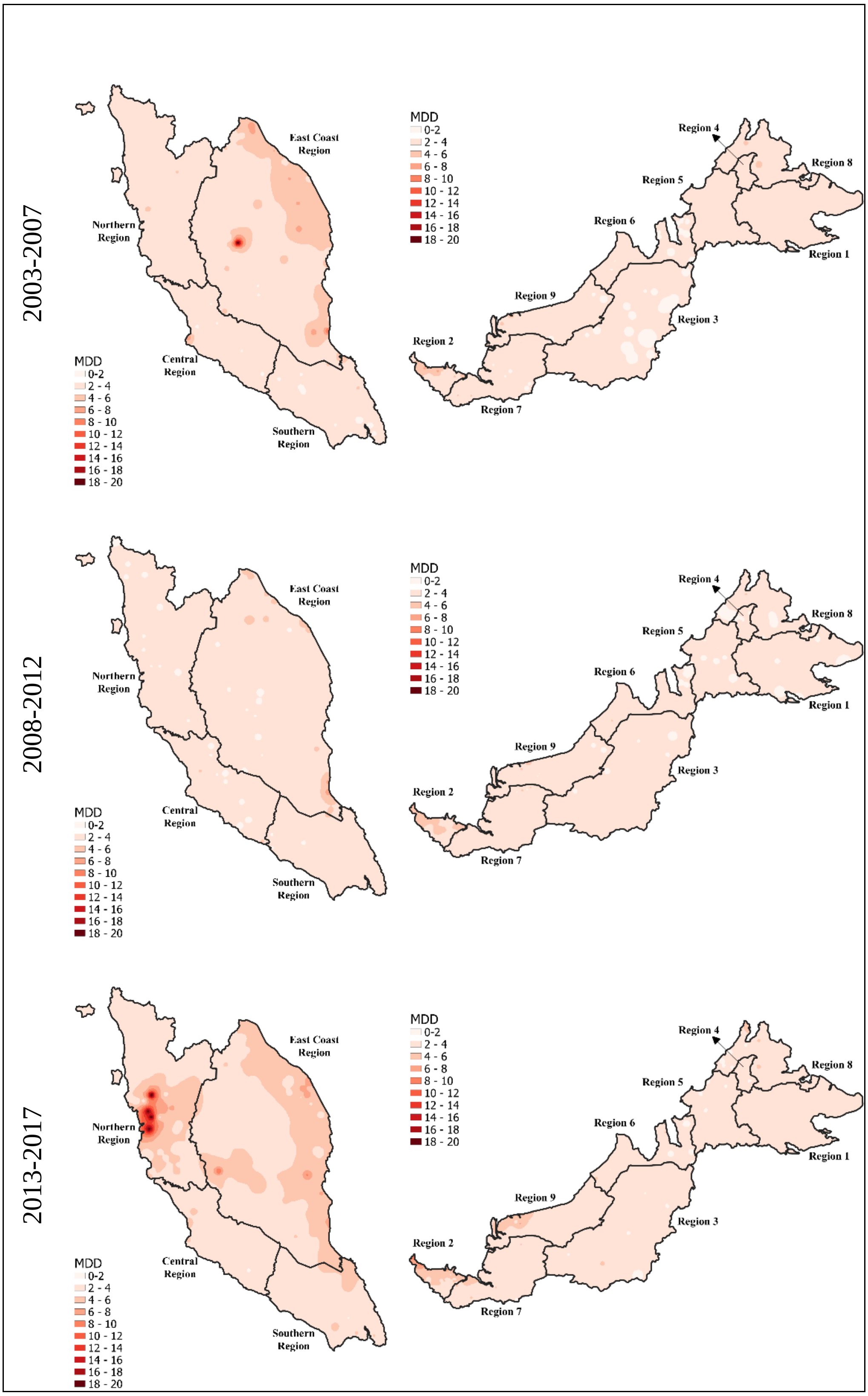


Figure 4.51 (Continued)

4.4 Summary

In essence, the analysis for the annual and monthly rainfall data were conducted based on the RVI at different timeframes (separately, over a 30-year period and also at six 5-year sub-periods) in 1988-2017. The RVI indicated the DS when the index value showed as negative index value, to identify the DS occurrences over the study period for the 13 regions located in Malaysia. Thus, the number of DS were analysed for all the regions, including both the DS and extreme DS that occurred over the regions from 1988 to 2017 study period. Furthermore, the RVI analysis for each month was also carried out to determine the DS occurrences of each month for all the regions. Further assessment for the drought characteristics, for both the DF and MDD were carried out based on the analysed RVI results over the study period. The DF and MDD were compared within the same category of RVI results to observe the climate change in term of spatial variations over the Malaysia, with different timeframes.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study on the historical regional annual and monthly rainfall data for both Peninsular Malaysia and Sabah and Sarawak were assessed using the RVI. The historical annual and monthly rainfall data from 1988 to 2017 were adopted as the input data for the RVI analysis and the computations were based on two different timeframes, the 30-year period and six 5-year sub-periods. The findings show the majority of the regions have the effect of DS with relatively higher number of DS for the annual RVI. But for the monthly RVI, the higher DS occurrences detected especially in the western part of Peninsular Malaysia and Sabah and Sarawak over the 30-year period. As for the monthly RVI for each month, most of the regions in Malaysia encountered the DS effect with more than eight months over the 30-year period. Furthermore, the spatial analysis for the two drought characteristics, that are DF and MDD being performed to observe the spatial distribution for each drought characteristics of both the annual and monthly RVI. The DF for both annual and monthly RVI show significant results over Malaysia, yet the MDD detected significantly especially in the East Coast Region.

Based on study with six 5-year sub-periods of annual and monthly RVI from 1988 to 2017, the first sub-period (1988-1992) showed higher number of DS occurrences for most of the regions over the sub-periods. There are two regions, the East Coast Region and Region 2 which induced with relatively lower DS occurrences as compared to other regions, indicating these regions have less impact on the rainfall variability in term of DS over the sub-periods. On the other hand, for the sub-periods of monthly RVI based on months, the months between January to April and June to September contributed more DS occurrences, wherein in the month of February found more significant for most of the regions over Malaysia. The DF and MDD for annual RVI have more significant of spatial difference as compared to the DF and MDD for monthly RVI over the sub-periods.

5.2 Recommendations for Future Work

There are a few recommendations that can be suggested for the future studies, especially those that are relevant to climate change based on the particular districts. The indices analysis which requires the following parameters, for instance, moisture content, temperature, wind speed are recommended for the future climatology analysis to examine the DS for the particular study district, since the parameters especially the moisture content, do have significant influences on the DS effect on agriculture. The comparison of spatial distribution for the drought characteristics with two or multiple indices analysis is also recommended in which the accuracy of the analysis results can be obtained for the better visualisation of the DS circumstances. Nevertheless, the consideration of multiple timeframes, for instance, on three, six and nine months scale analyses would benefit check on the climatology changes.

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APPENDICES

APPENDIX A: Figures

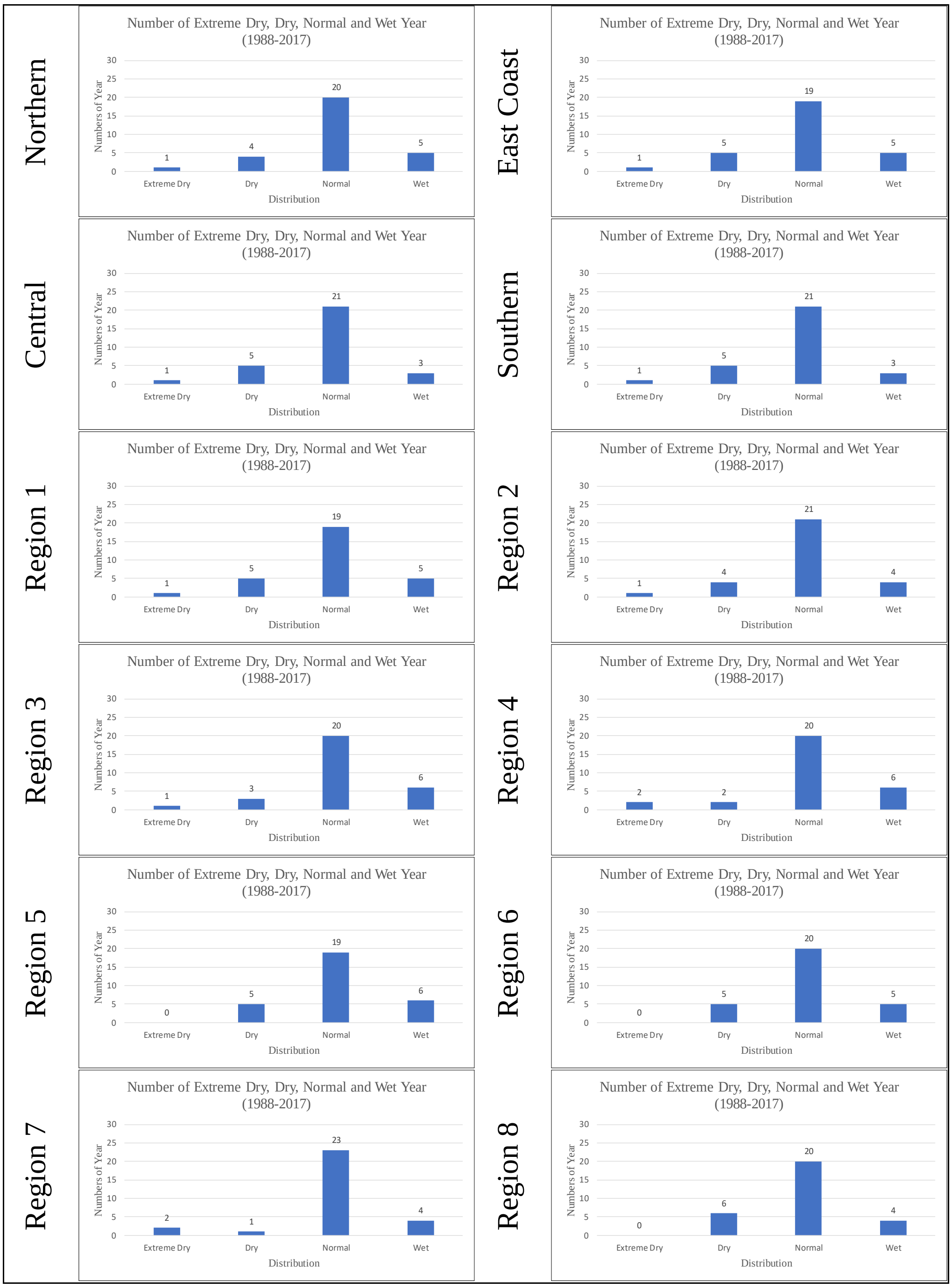
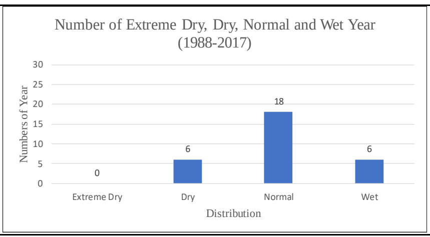


Figure A-1: Annual RVI Frequency for 30-year Period in Peninsular Malaysia and Sabah and Sarawak.

Region 9	

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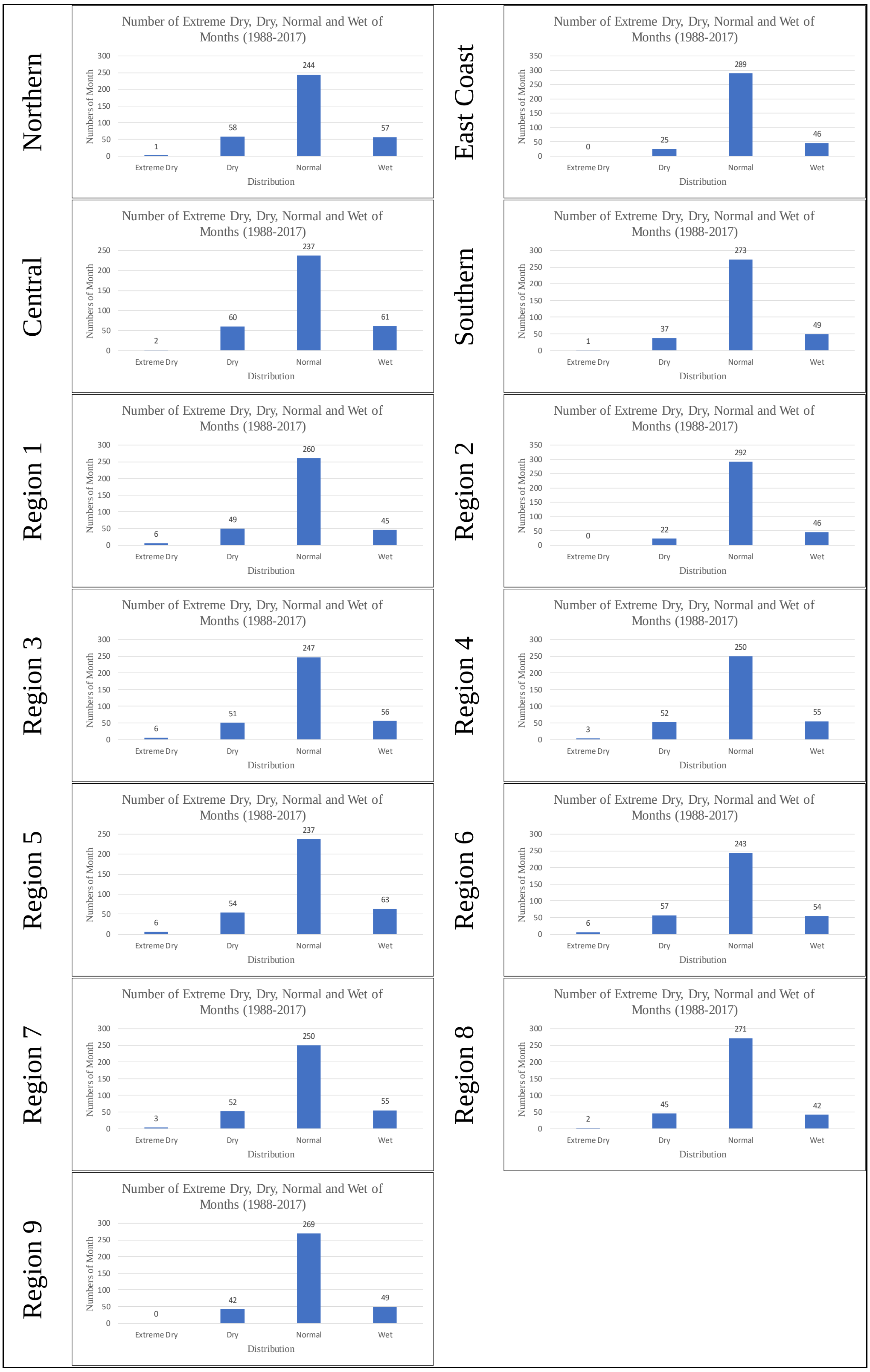

Figure A-2: Monthly RVI Frequency for 30-year Period in Peninsular Malaysia and Sabah and Sarawak.

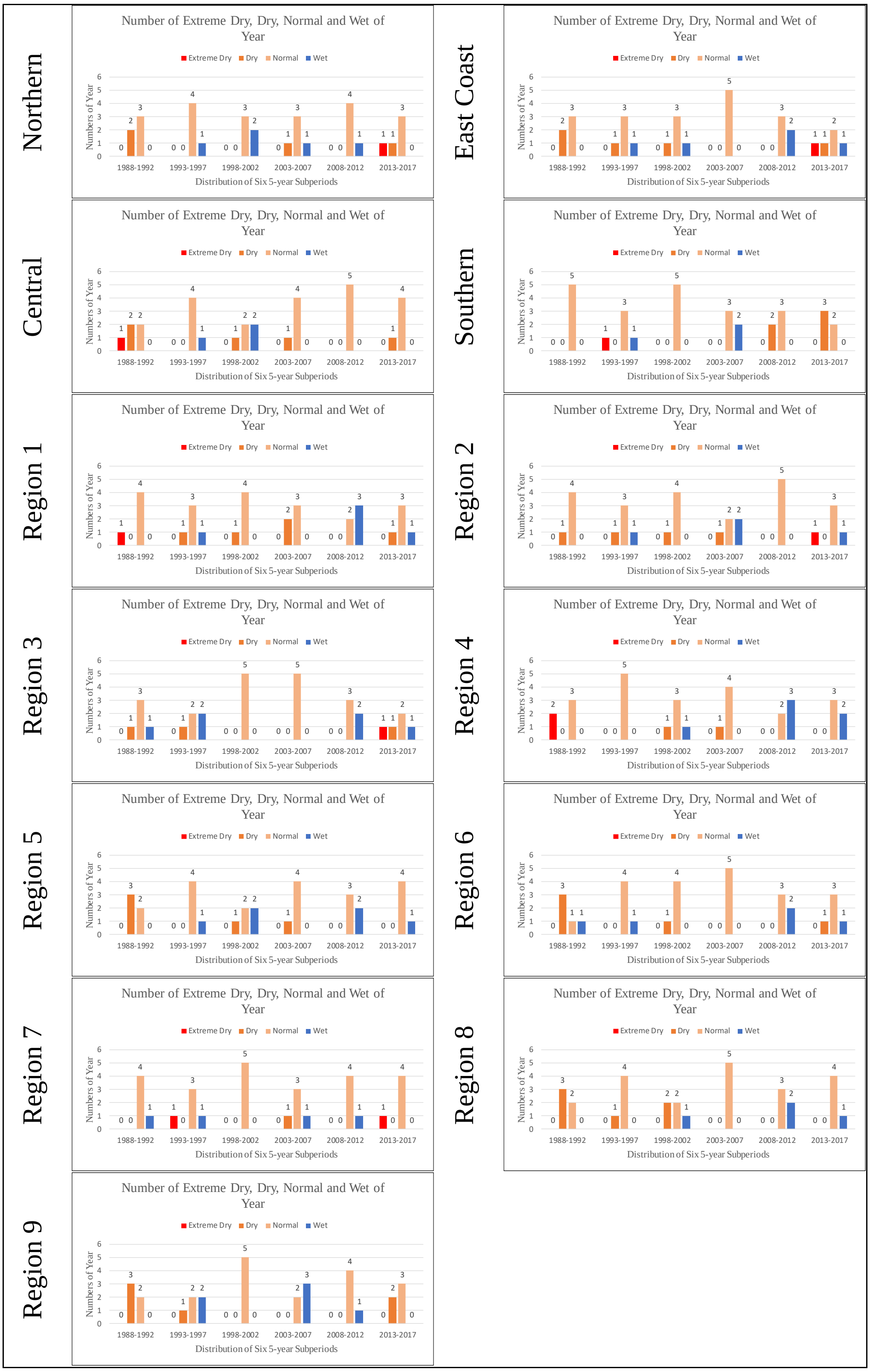

Figure A-3: Annual RVI Frequency for Six 5-year Sub-periods in Peninsular Malaysia and Sabah and Sarawak.

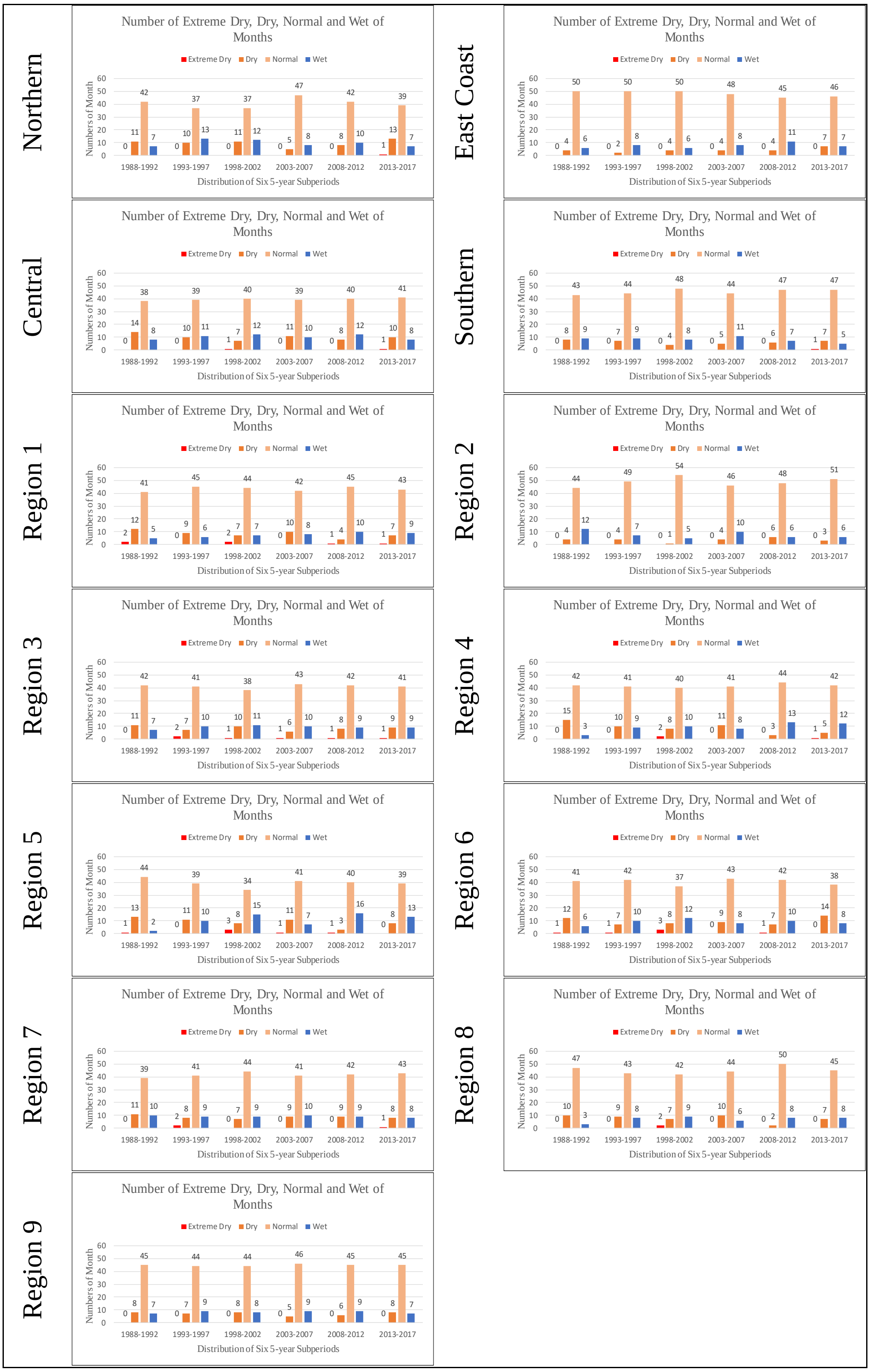

Figure A-4: Monthly RVI Frequency for Six 5-year Sub-periods in Peninsular Malaysia and Sabah and Sarawak.

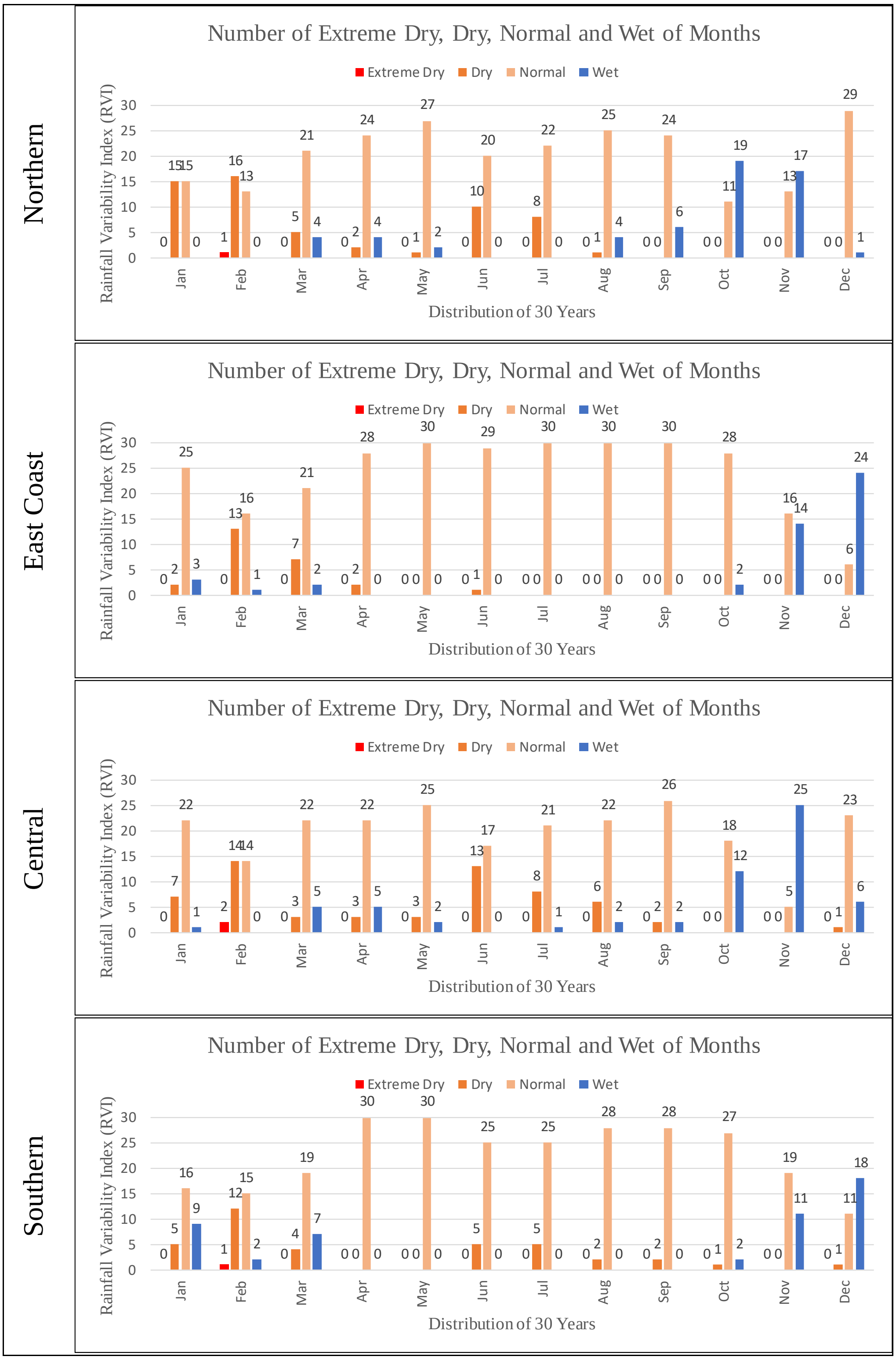

Figure A-5: Monthly RVI Frequency for 30-year Period in Peninsular Malaysia.

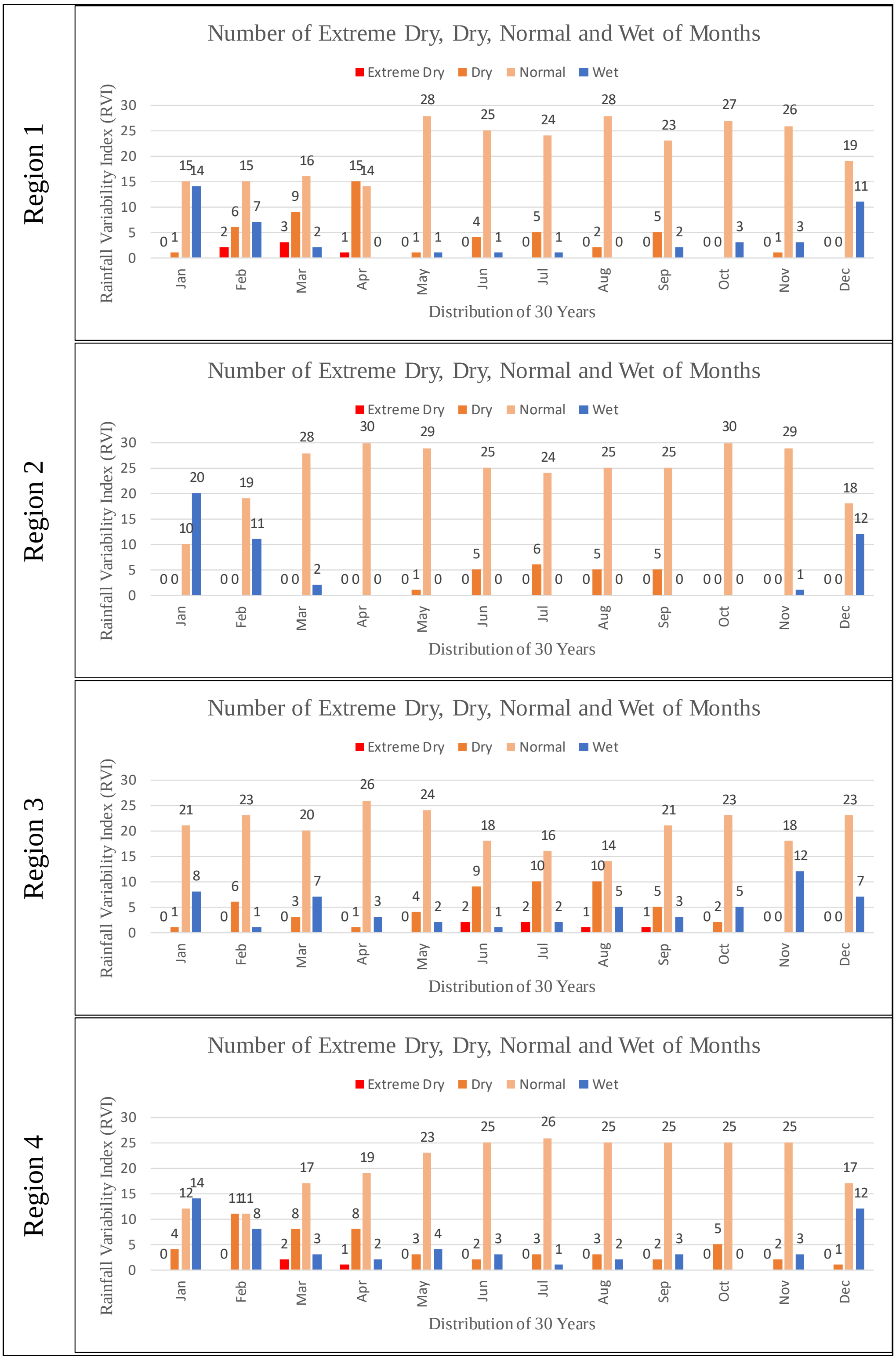

Figure A-6: Monthly RVI Frequency for 30-year Period in Sabah and Sarawak.

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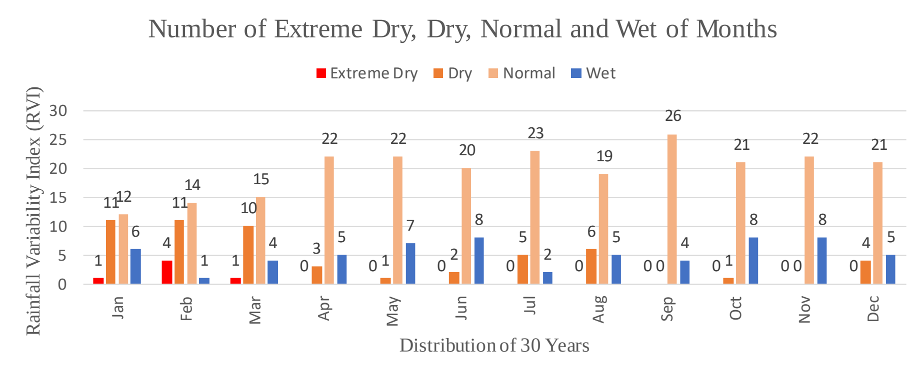
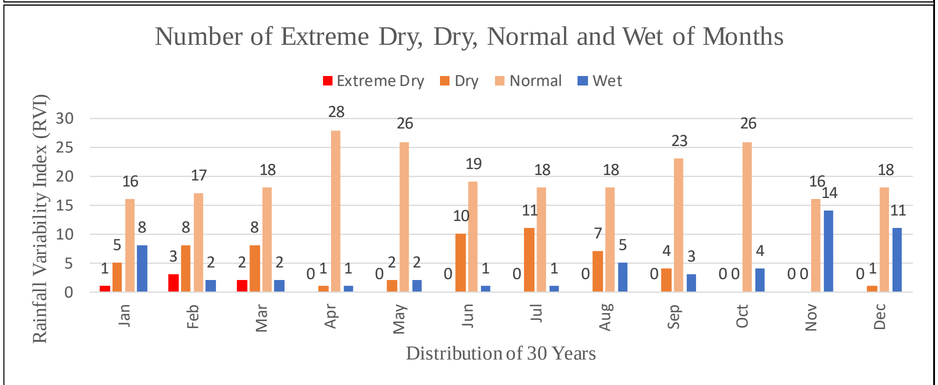
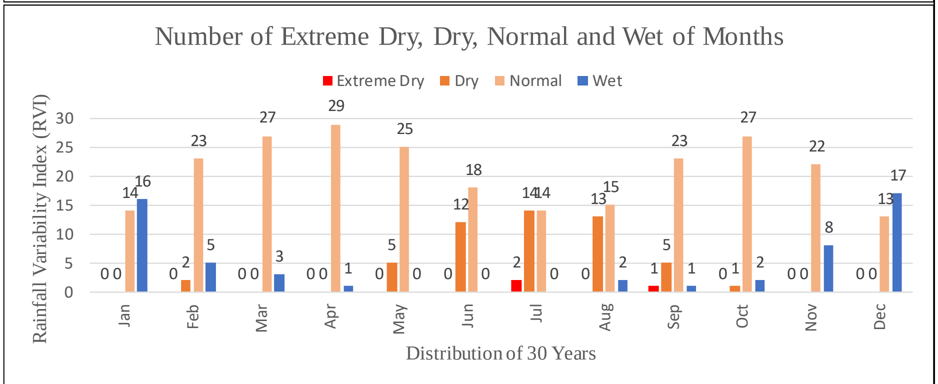


Region 6



Region 7



Region 8

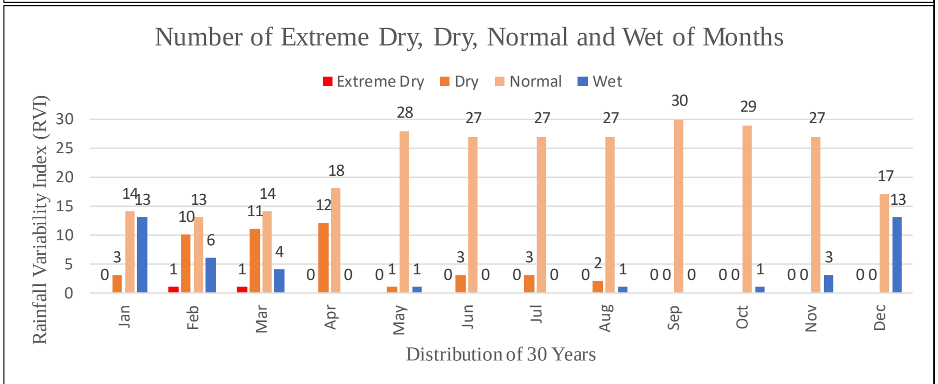


Figure A-6 (Continued)

Region 9

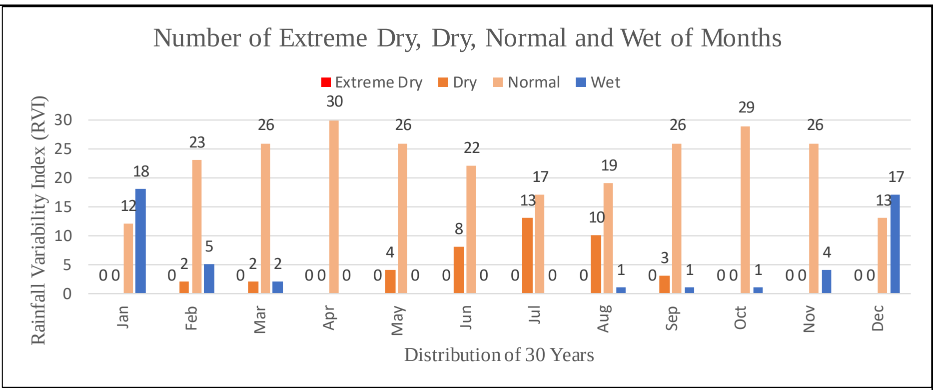


Figure A-6 (Continued)

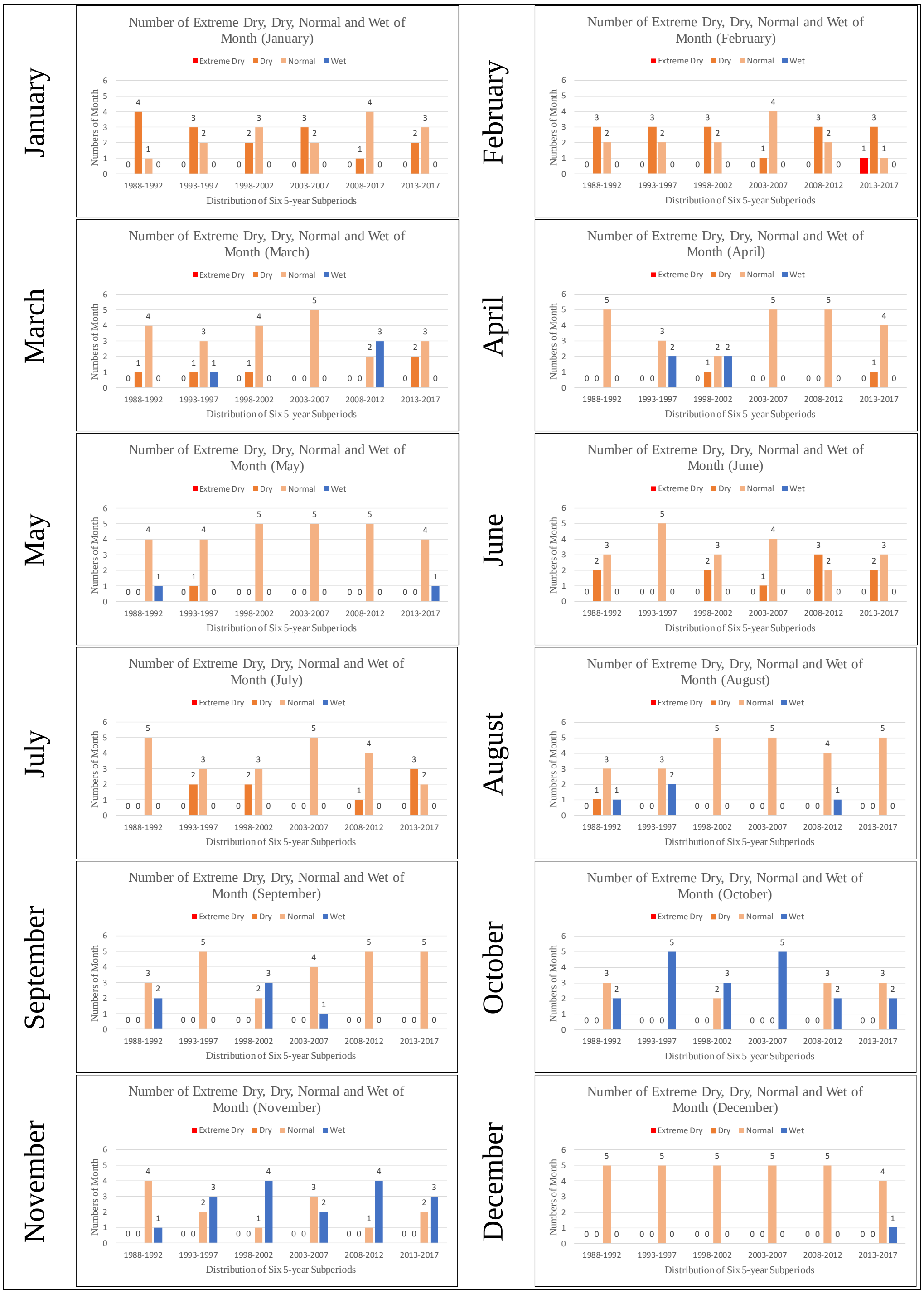


Figure A-7: Monthly RVI Frequency for Six 5-year Sub-periods in Northern Region.

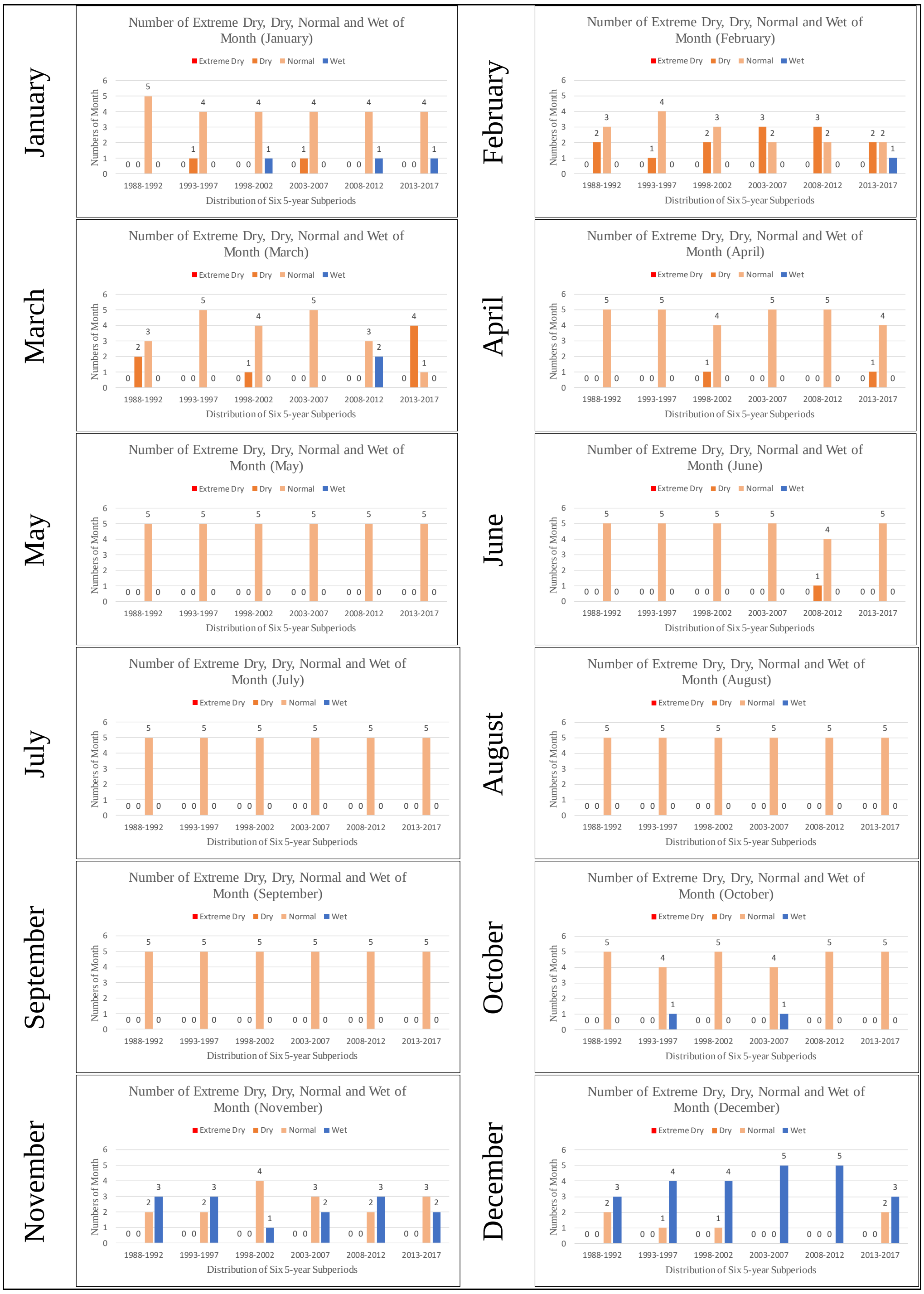


Figure A-8: Monthly RVI Frequency for Six 5-year Sub-periods in East Coast Region.

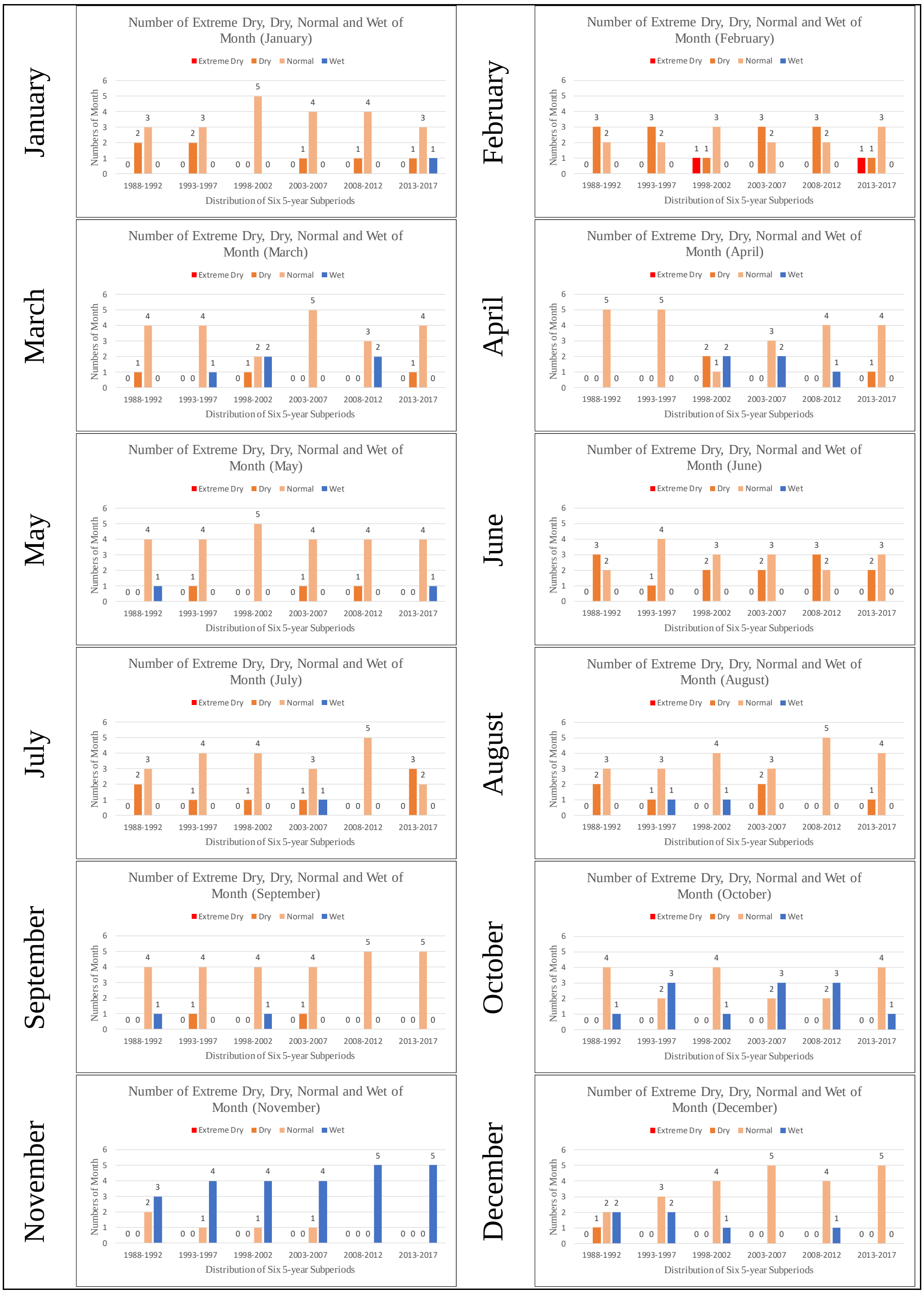


Figure A-9: Monthly RVI Frequency for Six 5-year Sub-periods in Central Region.

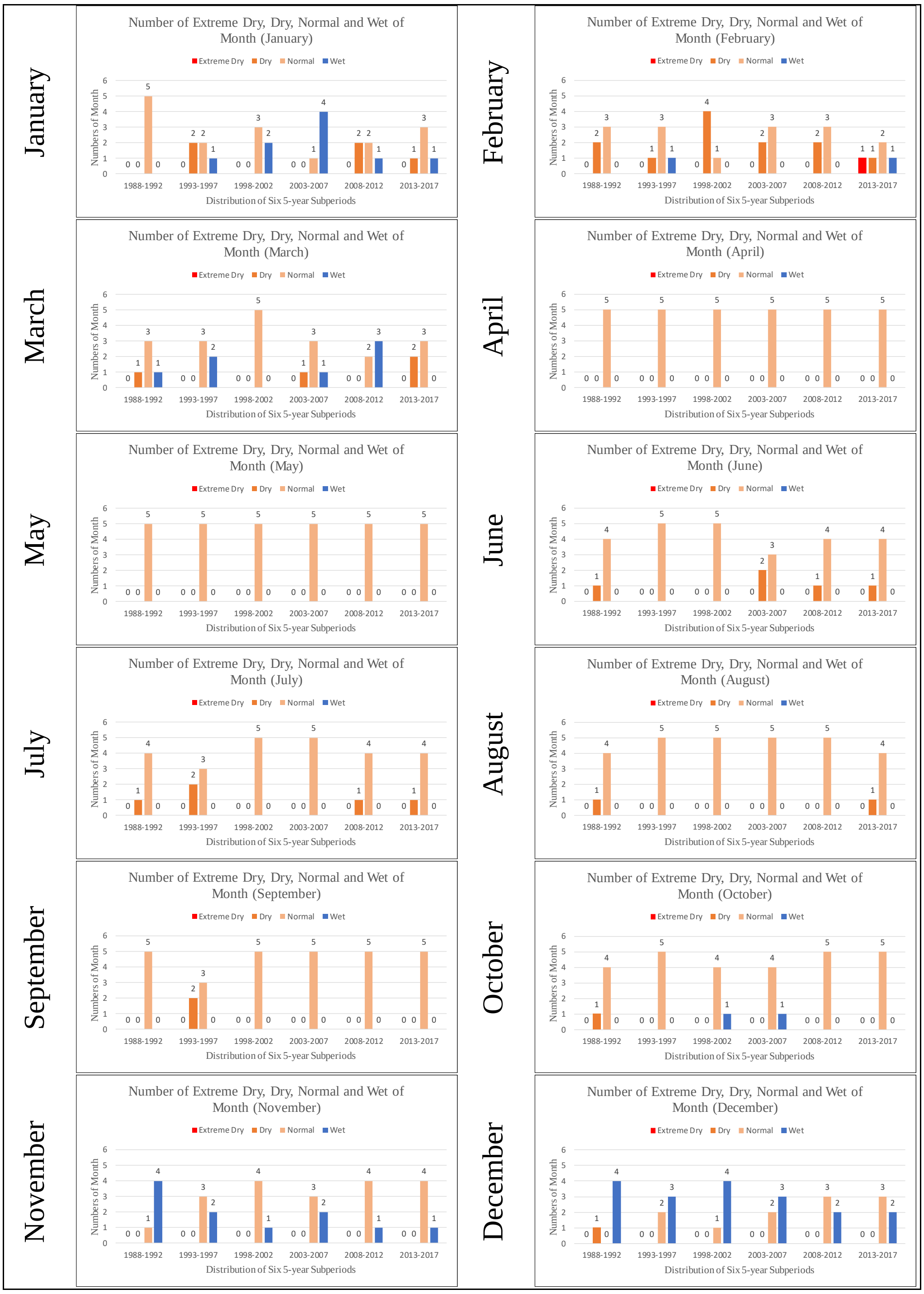


Figure A-10: Monthly RVI Frequency for Six 5-year Sub-periods in Southern Region.

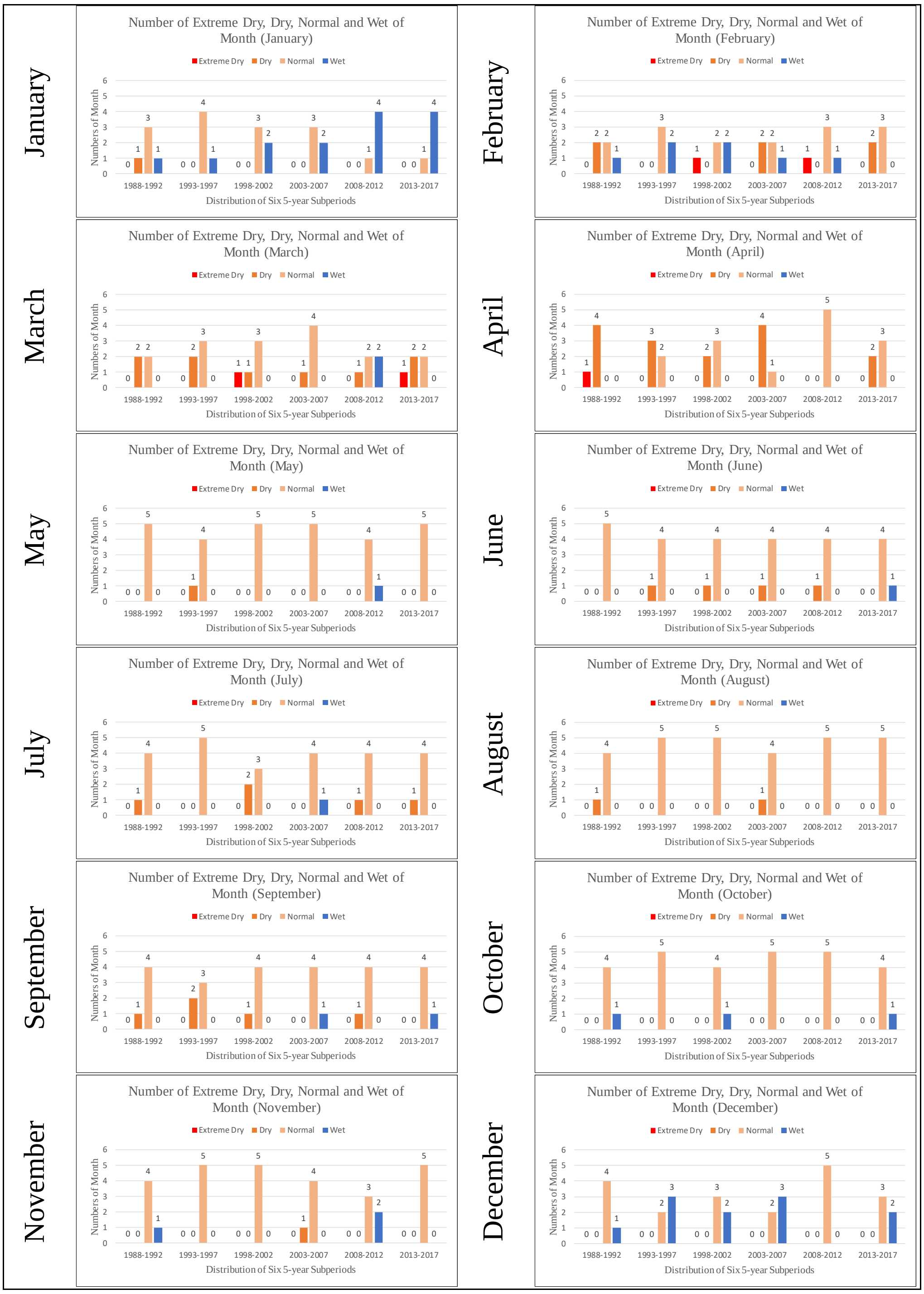


Figure A-11: Monthly RVI Frequency for Six 5-year Sub-periods in Region 1.

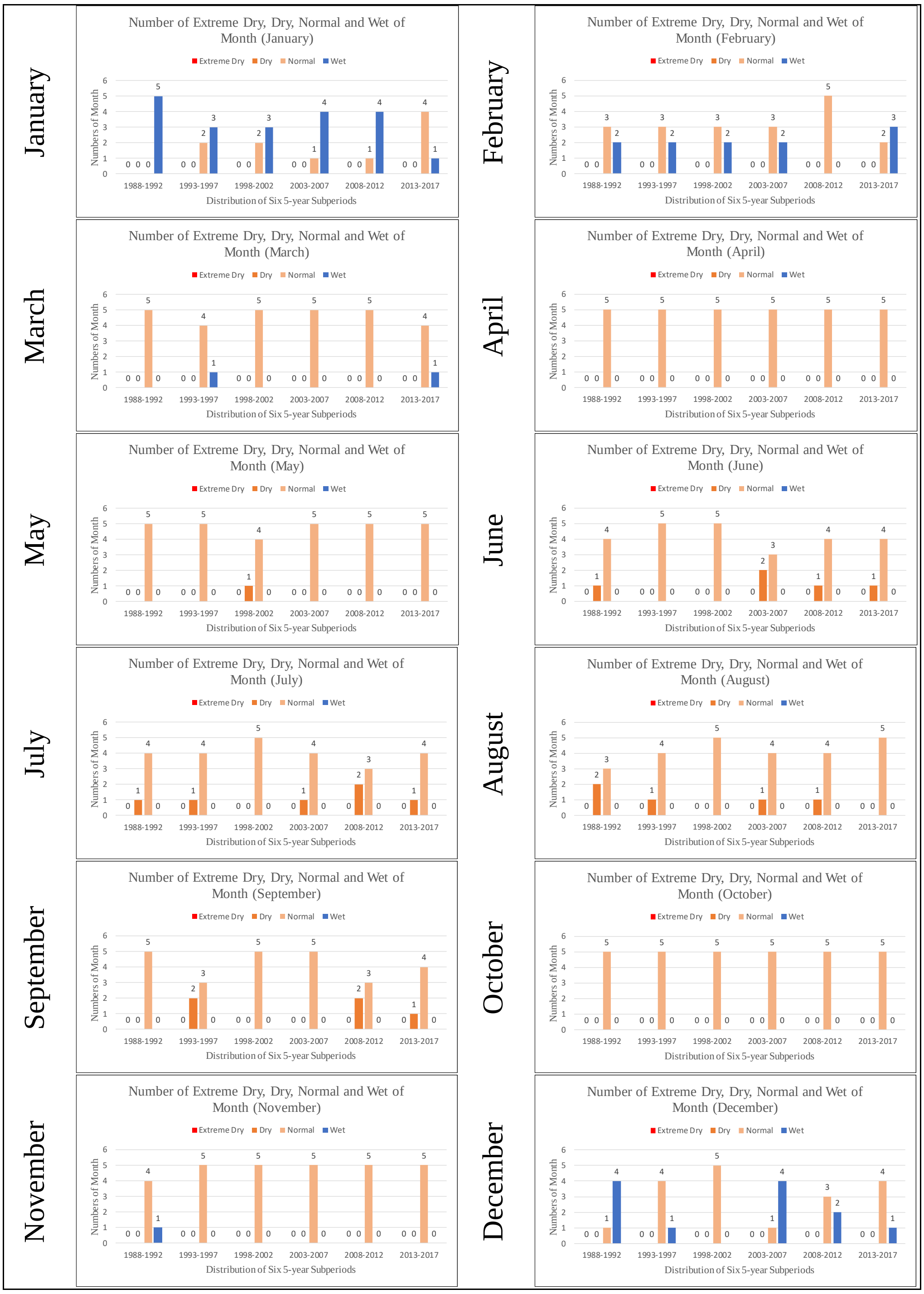


Figure A-12: Monthly RVI Frequency for Six 5-year Sub-periods in Region 2.

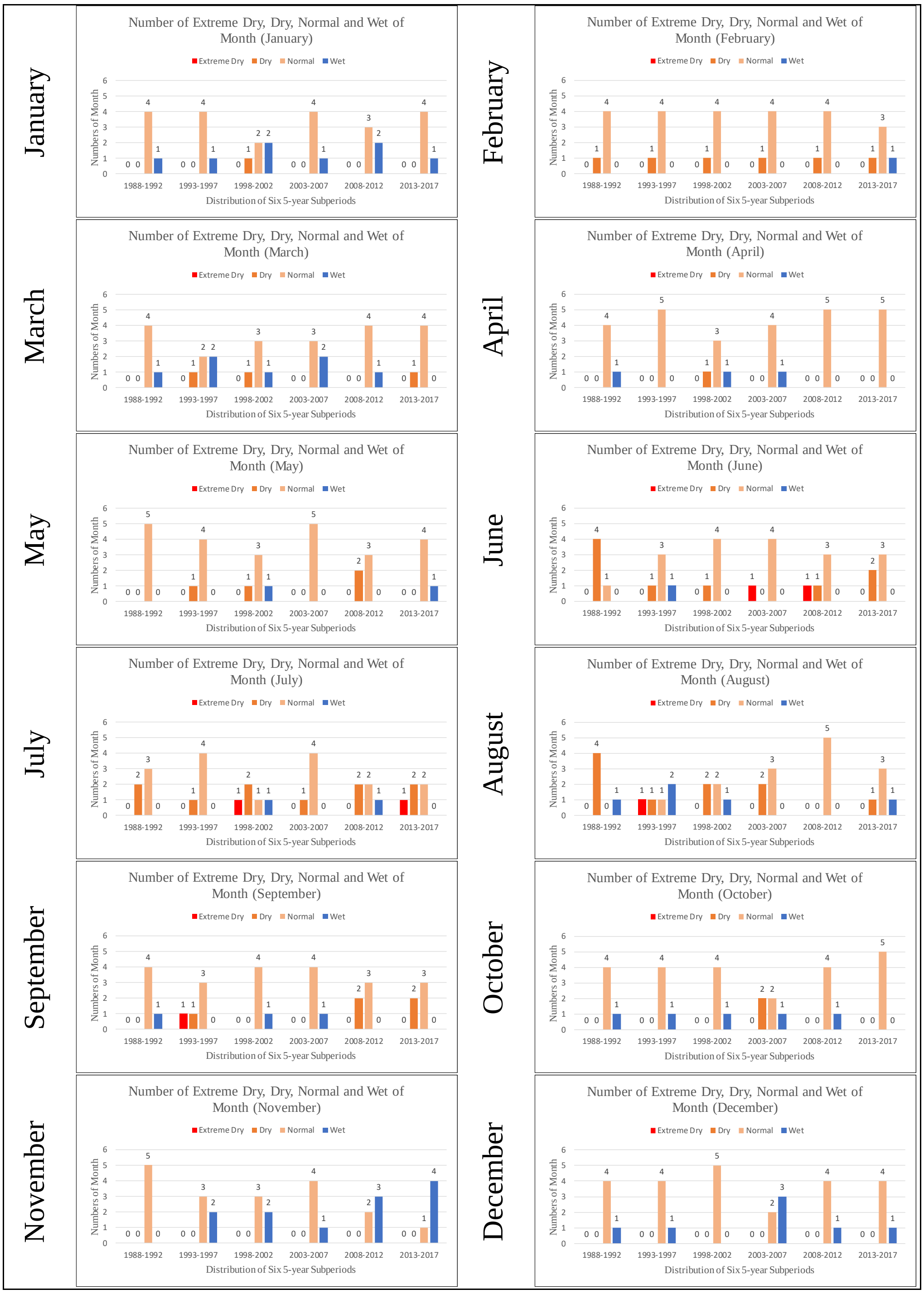


Figure A-13: Monthly RVI Frequency for Six 5-year Sub-periods in Region 3.

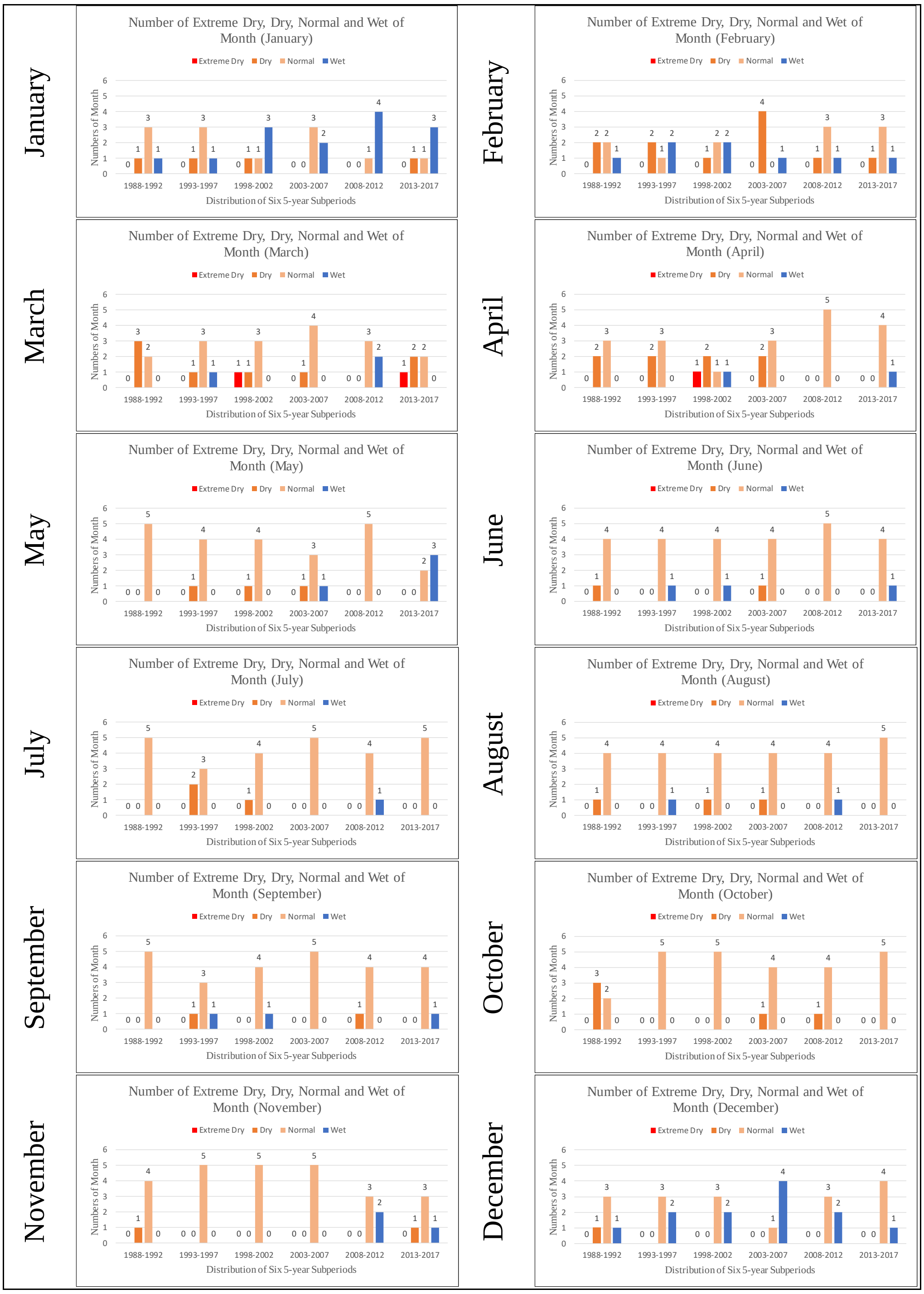


Figure A-14: Monthly RVI Frequency for Six 5-year Sub-periods in Region 4.

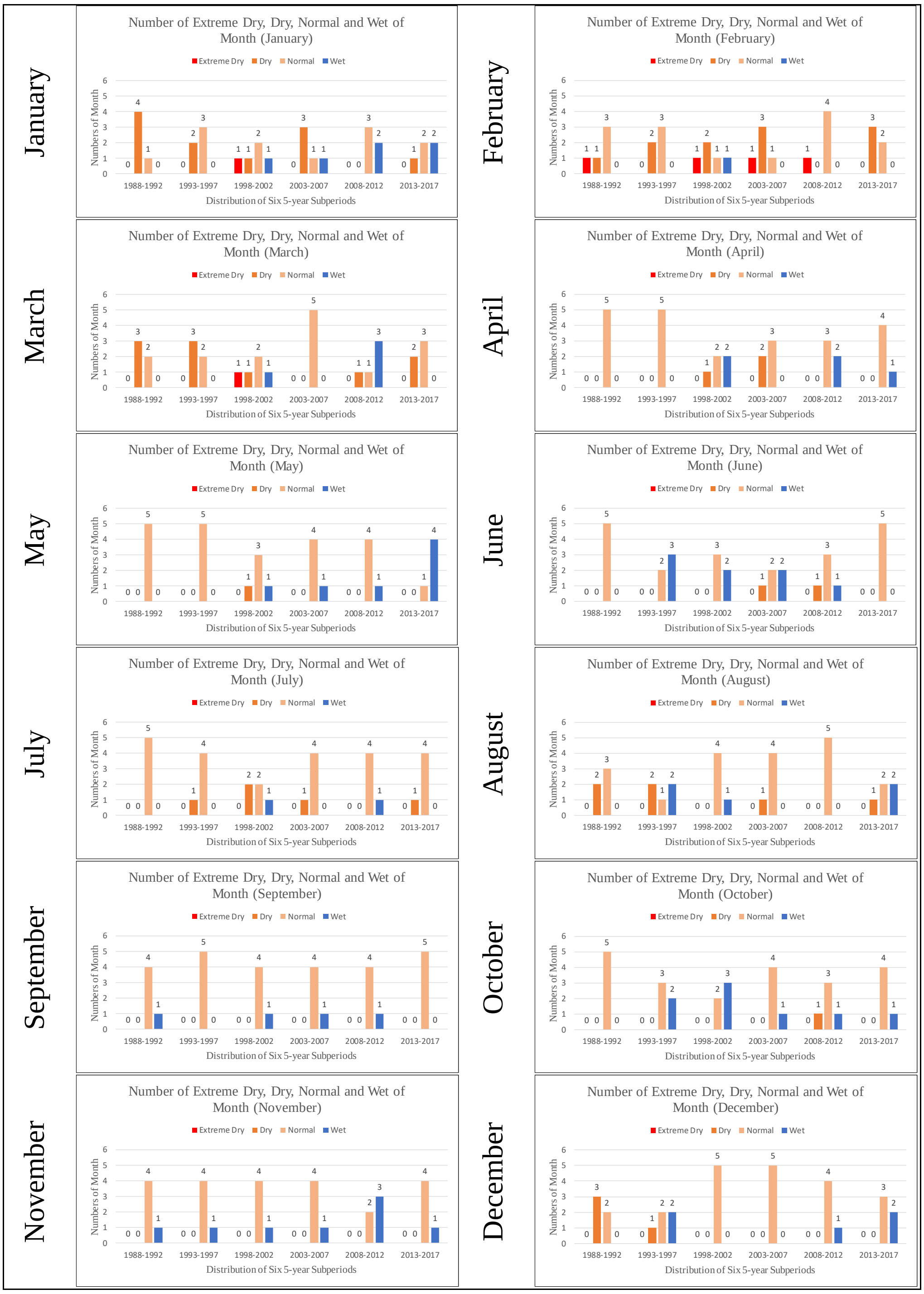


Figure A-15: Monthly RVI Frequency for Six 5-year Sub-periods in Region 5.

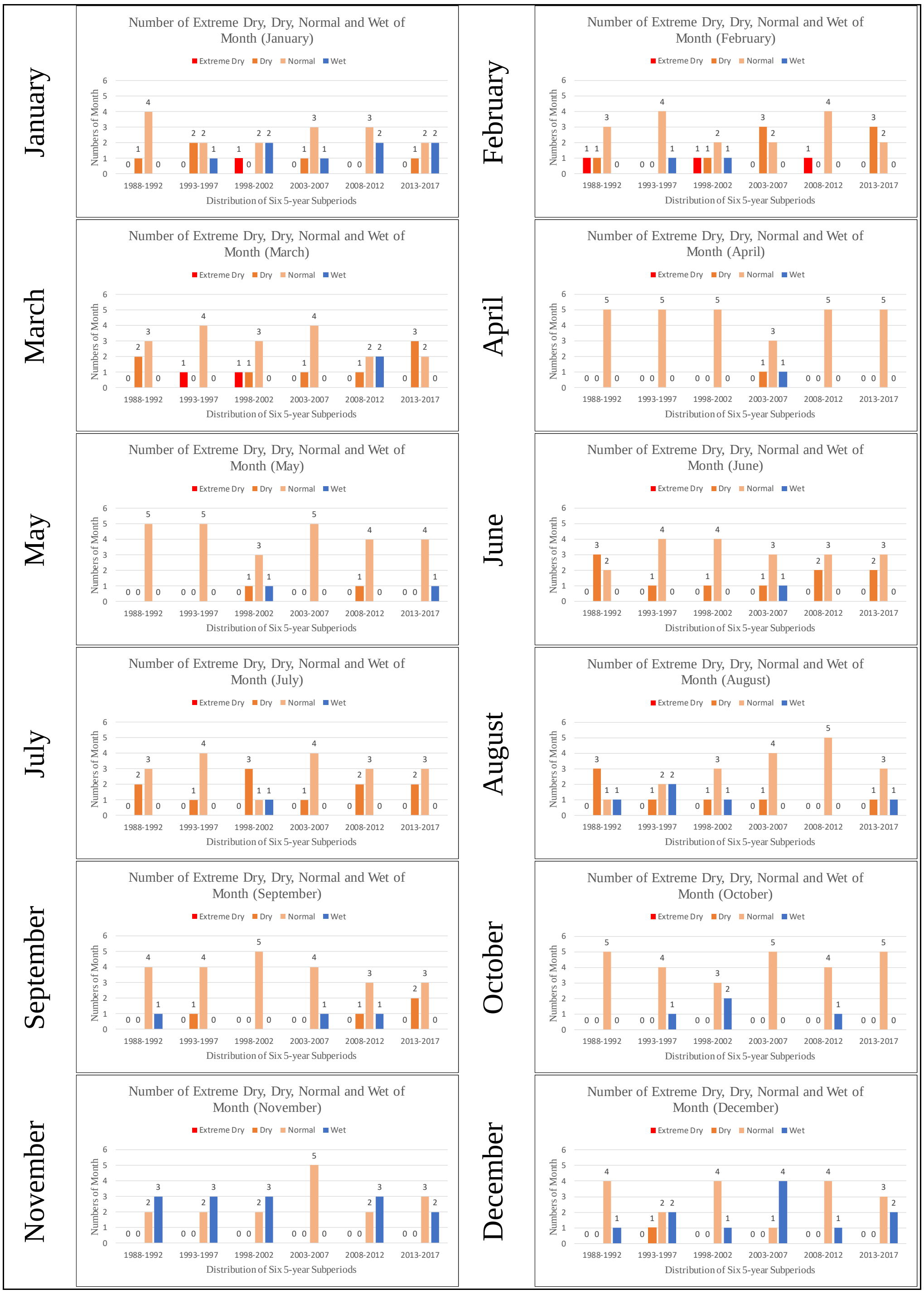


Figure A-16: Monthly RVI Frequency for Six 5-year Sub-periods in Region 6.

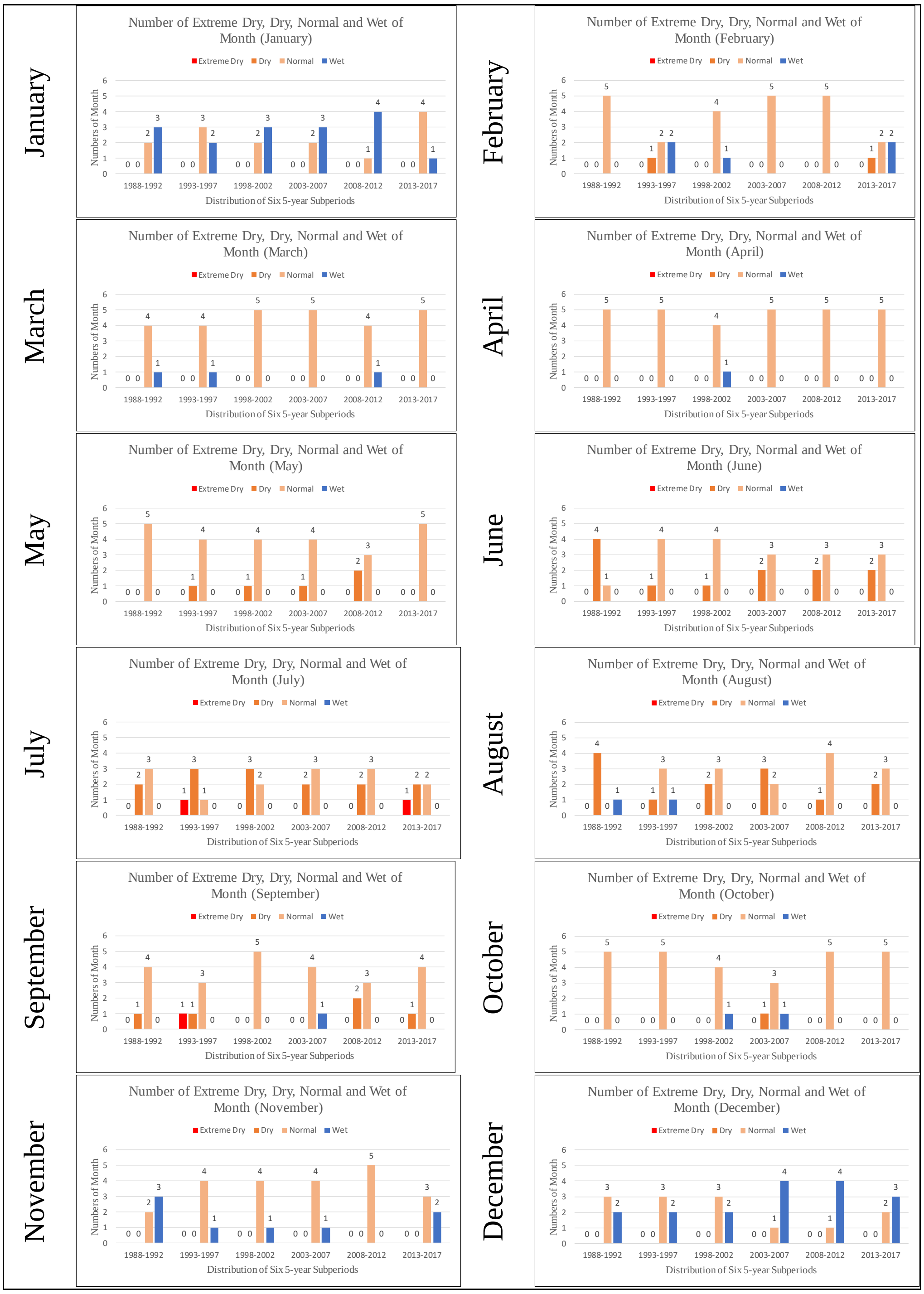


Figure A-17: Monthly RVI Frequency for Six 5-year Sub-periods in Region 7.

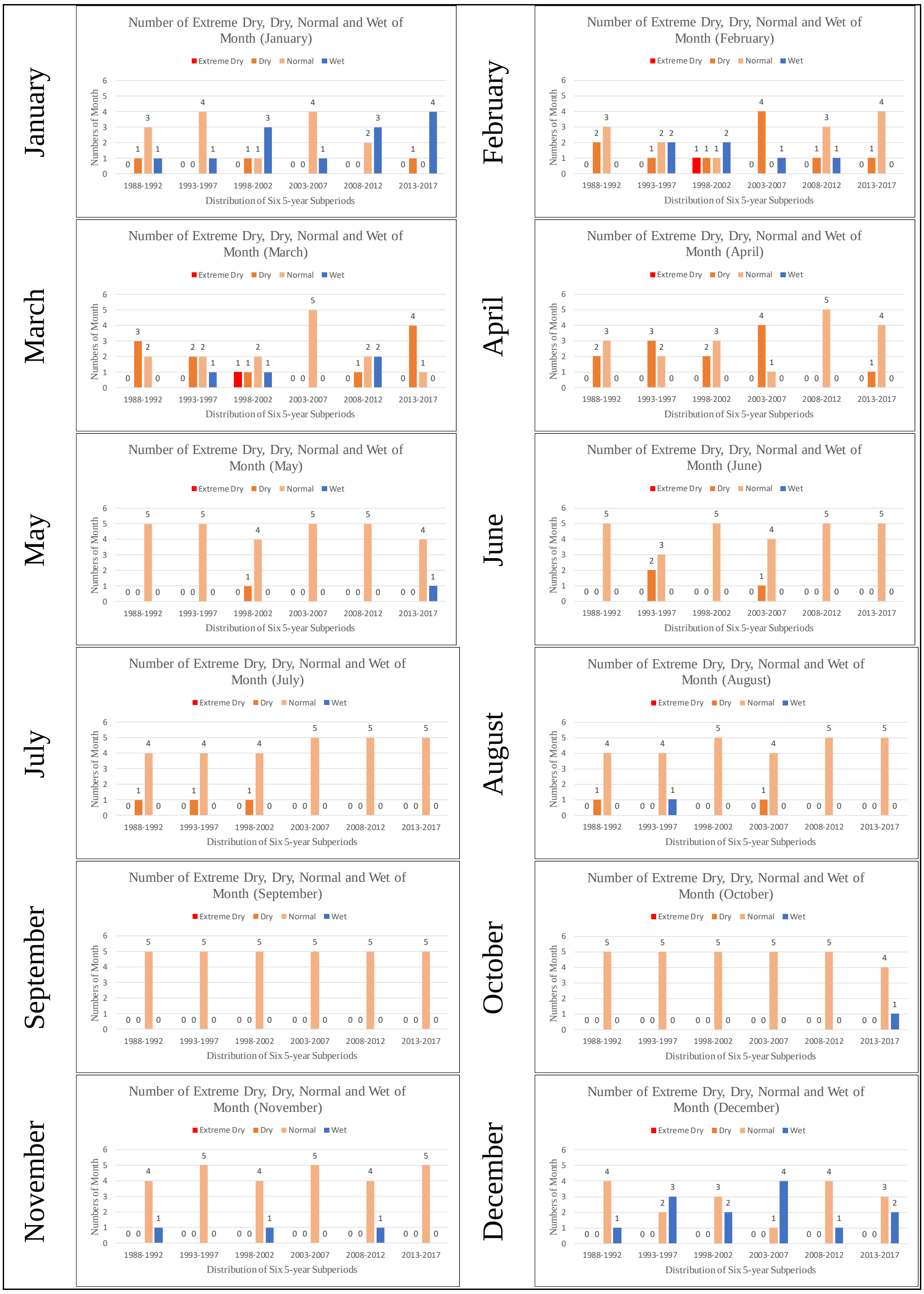


Figure A-18: Monthly RVI Frequency for Six 5-year Sub-periods in Region 8.

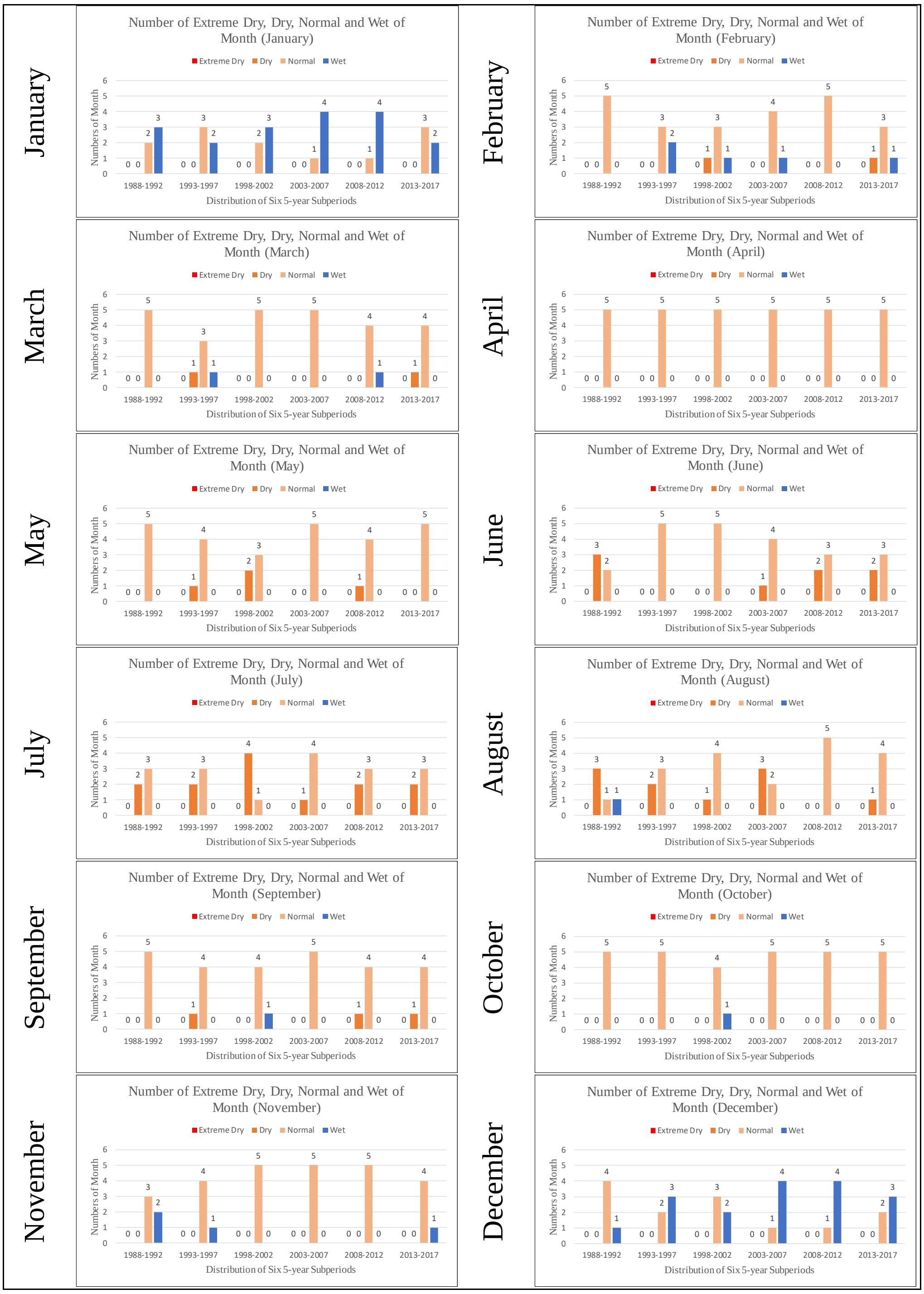


Figure A-19: Monthly RVI Frequency for Six 5-year Sub-periods in Region 9.