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Assessment of drought impacts on vegetation health: a case study in Kedah

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Abstract. Prolonged drought in the early of 2014 has caused Malaysia to experience water supply shortage which directly affects both health and growth of vegetation. Thus this study aims to assess the risk vegetation areas that were impacted during 2014's drought by integrating the Standardized Precipitation Index (SPI) and Normalized Differentiation Vegetation Index (NDVI) methods. These two methods were able to assess the risk areas for the vegetation by measuring its health and classifying them according to its severity while considering the rainfall reduction at the specific time and location. The results obtained from this study shows that the central and north west of Kedah was vulnerable to the occurrence of drought. Kedah was more impacted by the dry event during the northeast monsoon. This study is significant as a fundamental input for further research and as an alternative approach by the application of space technology.

1. Introduction

In recent years, the increasing numbers of extreme weather had caused lots of damages to many sectors such as agricultures, fisheries and societies' development. One of the main concerns affecting Malaysia is the occurrence of drought events which lately happens with high intensity for a long duration of time. In early 2014, Malaysia has been hit by a prolonged drought. Malaysia is in the midst of three-month-long heat waves that has effected on the surrounding environment and communities [1] [2] [3]. In addition, the effects of the El Niño phenomenon was felt in Peninsular Malaysia at the end of 2014 and early 2015 [4]. During this period, vegetation will be more stress as it lack of water supply to store the moisture which usually reduces the length of the growing seasons.

Drought has been a big issue which can impact the society and economy as well. Therefore, the natural resources management in every country need rapid and continuous information about the changes of the variables. In a large scale, drought can cause death of animals, plants and even men when there is a shortfall of precipitation in a long time period that led to water shortage problems. Thus, monitoring and managing of this occurrence need a proper quantification economically and environmentally. The impacts of drought can be economic, social and environmental depending on how the surroundings reflect to the drought itself. There is a complex link between the drought events where the impact from the drought could be measure in the large scale and when experiencing a



physical drought. Drought can affect its target either directly or indirectly. The direct impacts of drought are forest fires, rangeland, reduced crop, reduced in water level, damage to fish habitat, and increased wildlife and livestock mortality rates. On the other hand, indirect impacts occurs as a consequence of direct impacts, for instance, a reduction in crop production and farmer's income, increase in market value of goods, migration, and others. In term of economic impact, Malaysia will face declination of 30% GDP if the drought continues for a long period after March [2]. In addition, the situation that happened in Malaysia during the prolonged drought impacted the oil palm production and followed by a decrease in the crude percentage if any long stretch of the hot weather continues a few months more. This is a challenging situation as water is a very important component to the palm oil growth [2].

There is no direct definition for droughts [4] and it is hard to measure as there are various ways and indices that can be used to define drought. Generally, drought can be classified into four groups that are meteorological drought, agriculture drought, hydrological drought and socio-economic drought. The first three types of drought are in respect of measuring the drought as a physical phenomenon and the last is about the supply and demand, in term of the impact of water shortage throughout the socio-economic system.

Table 1. Types of drought classified by the National Drought Mitigation Centre, University of Nebraska-Lincoln.

Types of drought	Explanation
Meteorological	Defined as related with the total of precipitations. It is comparing the precipitations at certain places and at certain period of times off the average precipitation for the places ("normal" or average amount). Thus, meteorological drought is regional-specific.
Hydrological	Hydrological drought is associated with the effect of the precipitation deficiency on surface or subsurface of water sources. Usually this type of drought is identified after meteorological drought.
Agriculture	This drought happens when there is lack of water for crops that links with several of characteristics of meteorological or hydrological droughts to agriculture impact such soil water deficits, reduced groundwater or water reservoir, precipitation deficiency and differences between actual and potential evapotranspiration.
Socio-economic	It is implies all the element of meteorological, hydrological and agricultural drought in term of the demand and supply aspect of economic goods. It happens when the demand of the economic goods exceeds it supply due to the drought event.

There are several indices that measure the distribution of precipitation in a period of time such as the Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI), Percent of Normal, Surface Water Supply Index (SWSI) and few more indices. Each of the indices works differently depending on the need that arises. PDSI was developed to measure the departure of the moisture supply [6] where the parameters needed are the precipitation and the temperature data. It is believed to be more complex than the Standardized Precipitation Index. However, PDSI held an advantage since it takes into account the basic effect of global warming through potential evapotranspiration. The index is roughly ranging from -4.0 to +4.0 and some researchers suggested that PDSI is suitable for agriculture but does not accurately represent the hydrological droughts [7]. This index however has many other problems related to the calibration and spatial comparability [8] [9] [10].

Standardized Precipitation Index or better known as SPI is an index that is simple and easy to be calculated and statistically relevant. This index is developed by McKee and others in 1993 to understand that the rainfall deficit has different impact of groundwater, reservoir storage, soil moisture, snowpack and stream flow. A historical monthly precipitation data of 30 years is needed in order to calculate the SPI [11]. The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought to the availability of different water sources. Soil moisture condition responds to the precipitation anomalies on a relatively short scale while groundwater, stream flow and reservoir storage reflect the longer term of precipitation anomalies. Thus, the SPI was calculated for 3-, 6-, 12-, 24- and 48- time scales originally [7]. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive and a wet event take place [7]. Each drought event therefore has a duration defined by its beginning and end, and the intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be defined as the drought's "magnitude". In this study, SPI is chosen as the index to measure the drought condition in Kedah based on ability and the suitability of the index.

The advancement of the technology to detect a slow disaster like drought is a very helpful solution and initiative that provide a meaningful data to deal with this kind of event. Therefore, with the help of environmental space sensors, drought can be detected 4-6 weeks earlier and delineated more accurately [12]. Geographic information system (GIS) and remote sensing (RS) have played an important role in studying different types of hazards [13]. Remote sensing techniques also provide variations of resolution for the image needed to be used. Satellite derived drought indicators calculated from satellite-derived surface parameters have been widely used to study drought such NDVI and VCI. The Normalized Difference Vegetation Index (NDVI) is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyse remote sensing measurements and assess whether the target being observed contains live green vegetation or not. The wavelength of visible lights are absorbed and reflected by the green plants on the Earth surface [14]. Generally, healthy vegetation will absorb most of the visible light that falls on it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. Bare soils on the other hand reflect moderately in both the red and infrared portion of the electromagnetic spectrum [15].

NDVI is a good indicator of green biomass, leaf area index and patterns of production [16] [17] and it is the most commonly used vegetation indices in the field previously mentioned. Theoretically, NDVI values are represented as a ratio ranging from -1 to 1. A low NDVI value usually shows the areas of barren rock, sand or snow (0.1 or less) while a moderately value of NDVI shows sparse vegetation like shrubs and grasslands (0.2 to 0.5). Dense vegetation like temperate and tropical forest will reflect a high NDVI value which approximately 0.6 to 0.9.

Several studies have been devoted towards drought with the aid of satellite-derived information. The relationship between NDVI and rainfall is known to vary spatially due to the effects of variation in properties such as vegetation type and soil background [18] [19], with the sensitivity of the NDVI values to fluctuations in rainfall, therefore they are varying regionally. There was a study related to the early detection of drought in East Asia was done previously where a standard NDVI and up-to-date NDVI were calculated to derive different NDVI image, of which the intensity and agricultural area damaged by drought was detected [20]. The difference image was used to create a drought risk maps. The study was successful in detecting and monitoring drought effects in agriculture. Previous research was able to utilize NDVI time series and gridded precipitation estimates at different spatial resolutions to investigate temporal and spatial patterns of vegetation greenness and was also able to explore the relationship between rainfall and vegetation dynamics. [21].

To fill this gap, this study aims to assess the vegetation health of Kedah in year 2014 by combining two types of drought assessment which are the meteorological part using SPI and the agricultural part using the NDVI. Integration of both indices was used to identify the exact vegetation areas that are at risk which help authorities in future plan and mitigation measures.

2. Methodology

2.1. Study area

Kedah is located at the northwestern part of Peninsular Malaysia which is 6.1184° N and 100.3685° E. It comprises of 12 districts with a total of geographical area of 9427 square kilometers and a total of over 2,000,000 populations. The landscape is dominated by paddy field and Kedah is the main rice producer of the country. There are dense rainforests on the highland, mangrove forest on the west coast of the state and practically two third of the state is forest area and some of it is reserved for legal lodging activities while few of it are opened to the public as a forest recreational park.

Based on Koppen-Geiger climate classification system, Kedah experienced a tropical climate and received a significantly rainfall that classified in the Af group (equatorial rainforest and fully humid) [22]. Even in a dry season the state is still experiencing rainfall. As other peninsular state of Malaysia, Kedah face the changes of the wind flow pattern that can be distinguished as Southwest (SW) monsoon, Northeast (NE) monsoon and inter-monsoon seasons. Because of some local topographic features, the rainfall distribution pattern in Kedah is affected and there was a previous study done showed that during NE monsoon, Kedah was one of the driest regions [23] in Malaysia. Figure 1 shows the rainfall station used in the study and information was obtained from the Department of Irrigation and Drainage Malaysia (DID).

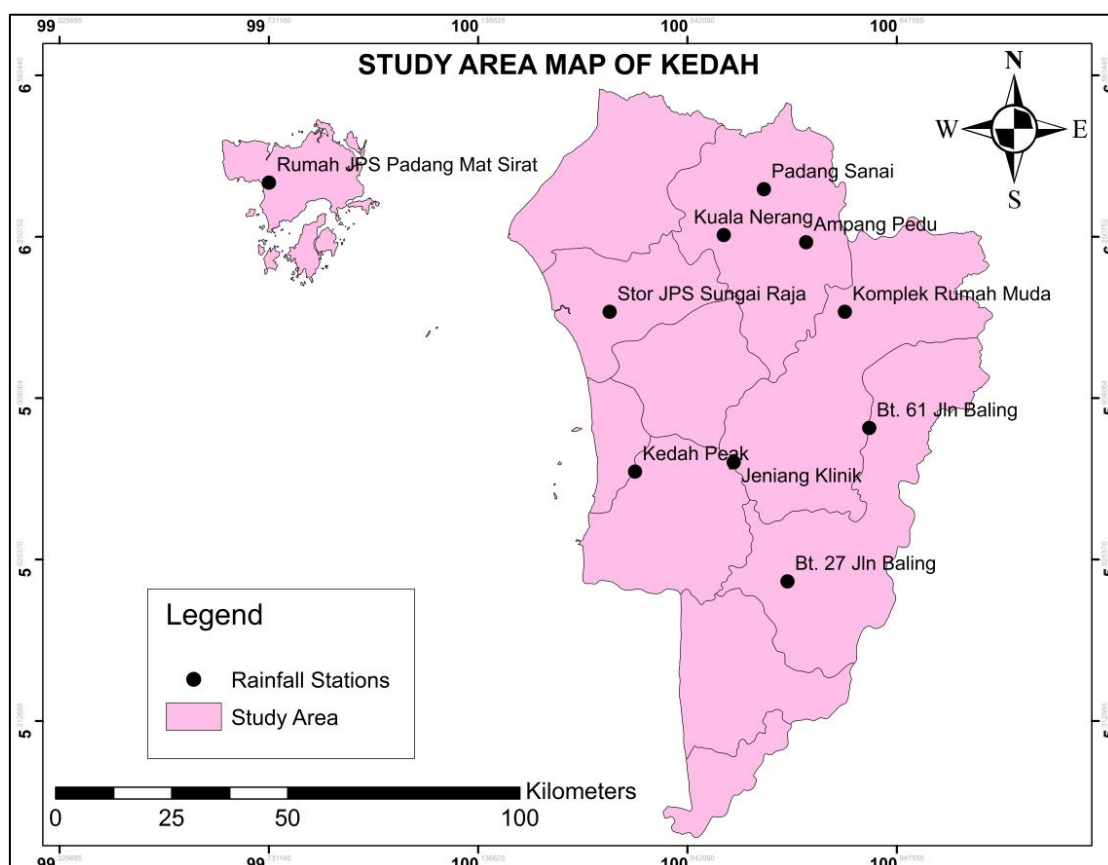


Figure 1. Map of the ground rainfall station at the study area.

2.2. Data acquisition

2.2.1 Meteorological data. Daily rainfall data for the period of 30 years from 1984 to 2014 for 10 stations was obtained from the DID Malaysia. Only ground rainfall station with 30 years of rainfall data was chosen in this study.

2.2.1 Satellite image. Landsat 8 OLI and TIRS data were obtained from the U.S. Geological Survey Earth Resources Observation and Science (EROS) Centre Landsat archive. The Landsat archive consists processed data of Level 1 Terrain corrected (L1T) level defined in the GeoTIFF file format in the Universal Transverse Mercator (UTM) map projection. Landsat 8 satellite has OLI and TIRS sensor on board to capture earth's surface with 16 days temporal resolution. Two images from February and July 2014 was selected from Landsat8 and the selection was based on the amount of the cloud coverage of the image and its consistency with the monsoon seasons that occurred in Malaysia.

2.3. Data processing

2.3.1. Meteorological data. The data has undergone statistical treatment due to some daily missing values. Even though the SPI program can be run with missing data however; it will affect the confidence level of the result obtained, depending on the distribution of the missing data [24]. Based on the SPI classification system a drought event will ends when a positive values start to appear, as negative values indicate dry spell while positive values indicate wet spell [7]. Interpreting a 3-month SPI provides a seasonal estimation of precipitation and reflects short-term and medium-term moisture conditions [24]. The SPI values are very helpful in obtaining the time and areas of interest of a dry spell occurrence. Interpolation method was then used to predict the values for areas that were far and not representable by the existing ground rainfall stations. Inverse Distance Weight (IDW) was chosen to predict the values by using the collected data points which was the monthly average of the SPI values.

2.3.2. Satellite image data. The image used in this study was corrected geometrically and atmospherically. The atmospheric correction was done to remove the cloud covers. Next procedure was to derive the NDVI values from the image by transforming the raw satellite data into NDVI values ranging from -1 to +1.

2.3.3. Vegetation health map. The last step in this study was to produce the drought vulnerability map by using the combination the SPI and the NDVI map. Co-kriging method was used due to its ability to take advantage of the covariance between two or more regionalized variables that were related and appropriate when the main attribute of interest is sparse, but related secondary information (seismic) is abundant. Ordinary co-kriging was similar to simple co-kriging in which the mean was assumed constant, but it differs in terms of the mean was estimated locally within each set of neighborhood control points, rather than being specified globally.

3. Results and discussion

3.1. Temporal variation of SPI -3

Drought risk area has been identified using SPI in Kedah for the year of 2014 by utilizing 30 years of historical rainfall data that was interpolated into the map for the identification process. SPI during the year of 2014 has been presented into two ways which were temporal and spatial pattern. Based on figure 2, the drought intensities can be determined by observing the values following the classification system by McKee and others in 1993 [7]. Due to high humidity in Malaysia climate [25], the modified classification system as shown in table 2 was referred during the process of classifying the SPI result

and all stations showed consistent variation with the driest peak on March and the wettest peak on December. A stockpile of values less than -1.0 were grouped together from January to April which indicate severe drought event while there were abundance of values that was more than $+1.0$ mostly from May to July and October to December that indicates severe wet seasons. Kedah Peak station have the lowest value of -1.56 which makes it the driest regions and Kuala Nerang station recorded the highest value of $+2.39$ in December which make it the wettest region among the entire part of the study area.

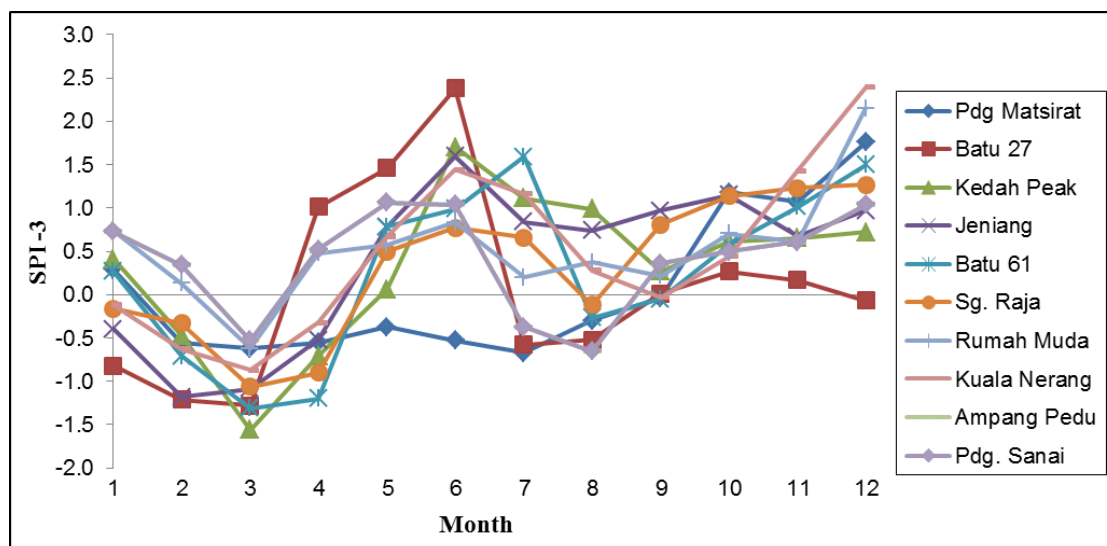


Figure 2. The monthly variation of the SPI -3 in 2014.

Table 2. Modified SPI classification system.

SPI value	Condition
More than 1.0	Severely wet
0.5 to 1.0	Moderately wet
0 to 0.49	Normal
-0.01 to -0.99	Moderately dry
Less than -1.0	Severely dry

3.2. Spatial variation of SPI -3 during Southwest (SW) monsoon

The interpolation of the SPI-3 variations for the study area in 2014 during SW monsoon season was shown in figure 3. SW monsoon was the driest season throughout the country and it experienced monthly minimum rainfall from late May to September [26] and it is a dry period with occasional short dry spells [27]. Result shows that Langkawi was the area with the most recurrent event of dry period compared to the other area in Kedah. Langkawi also experienced minimum rainfall received over the SW monsoon. Observations on the whole part of the study area shows that it experienced a wet season during May and June while certain area faces dry condition during July. The intensity of the dry period that occurs in July was high at the northern and southern part of Kedah. During August, the entire state of Kedah was in a moderate dry condition while the area represented by the Kedah Peak station recorded a moderately wet condition. Generally, the study area was not so affected by the SW monsoon and it was proven by a previous research where SW monsoon caused rainfall reduction on the western part of peninsular since all the rainfall indices that are tested were higher than other

parts of the Peninsular Malaysia [23]. Thus, the study area which is located in the northwest region of peninsular was considered to be the wettest region during this season.

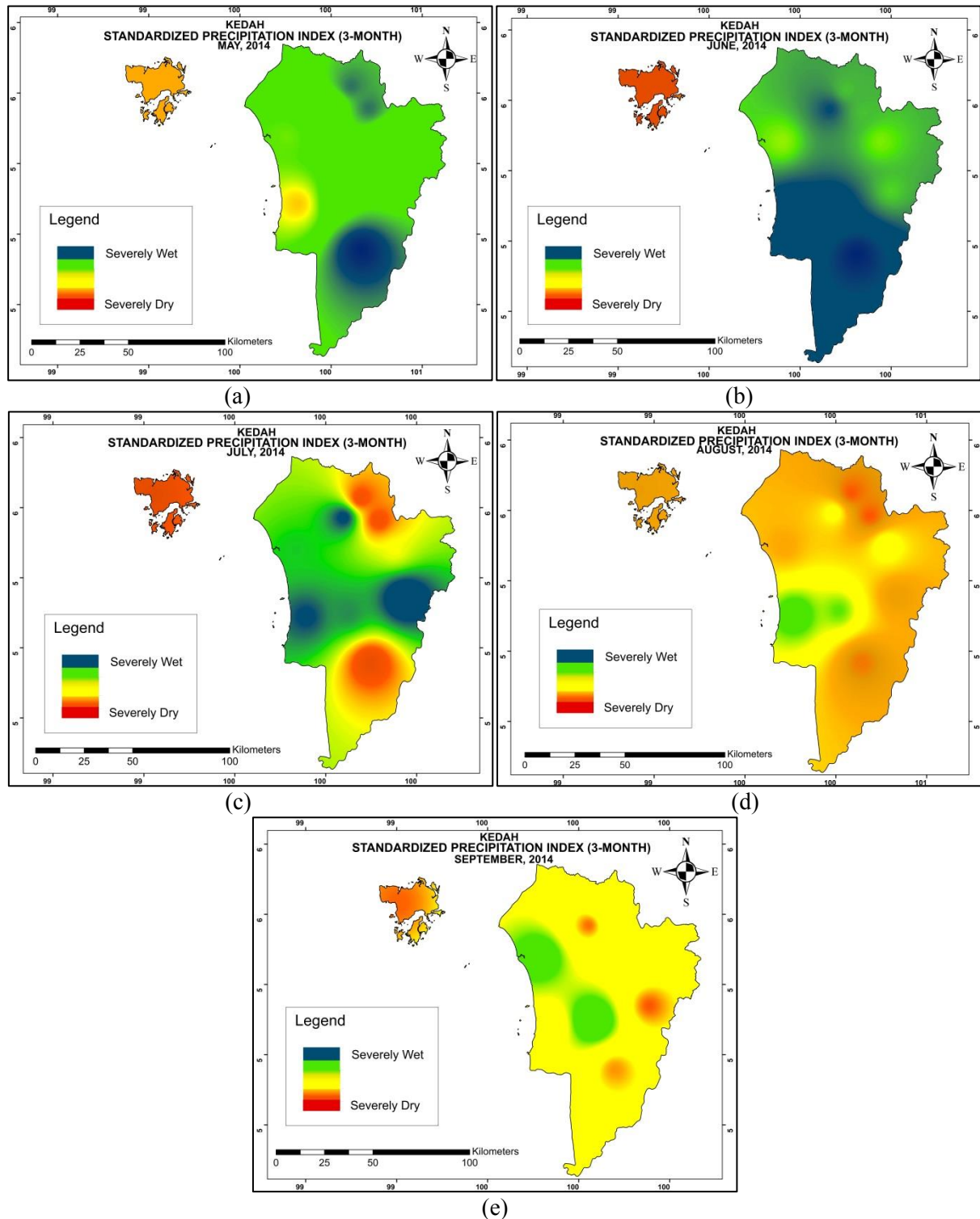
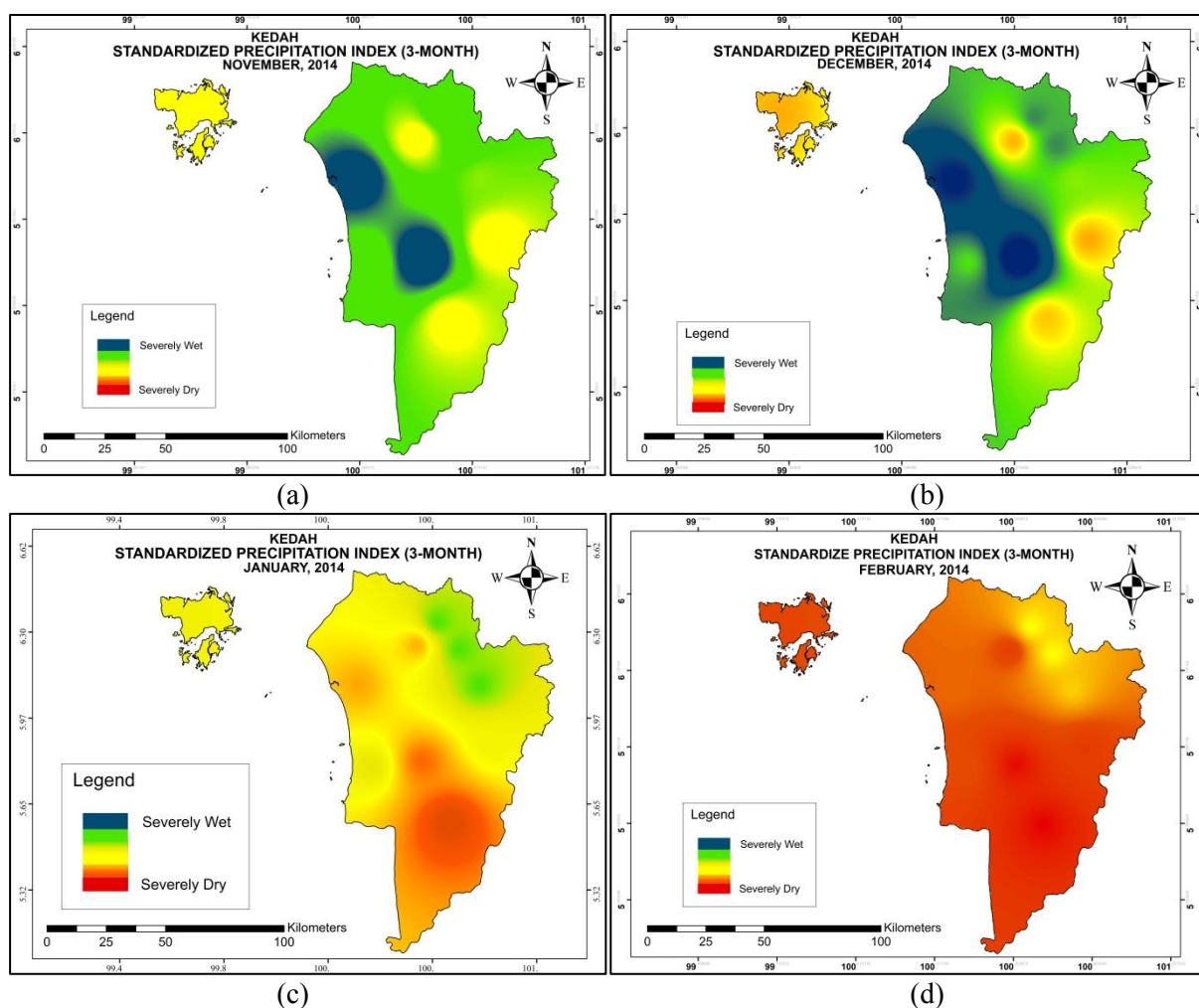


Figure 3. Maps show the spatial distributions of SPI-3 interpolation during SW monsoon in Kedah for year 2014 in the month of (a) May, (b) June, (c) July, (d) August and (e) September respectively

3.3. Spatial variation of SPI -3 during Northeast (NE) monsoon

The observation made during NE monsoon shows an increasing trend of dry areas in the first three months; January, February and March. NE monsoon occurred from November to March which was the major rainy season with a maximum rainfall received in Malaysia [26]. It is usually known as the wettest period every year. However according to the maps in the figure 4 (c), (d) and (e), the study area experienced a dry condition during those three months and the phenomenon was proven by a previous finding done in 2009, indicated that the northwest region could be classified as the driest area during NE monsoon [23]. This might be due to the existence of Titiwangsa range. This is also consistent with the Drought Report of Kedah that stated, Kedah had experienced a prolonged drought from January to March and faced a great loss in the rice production during this period [28].



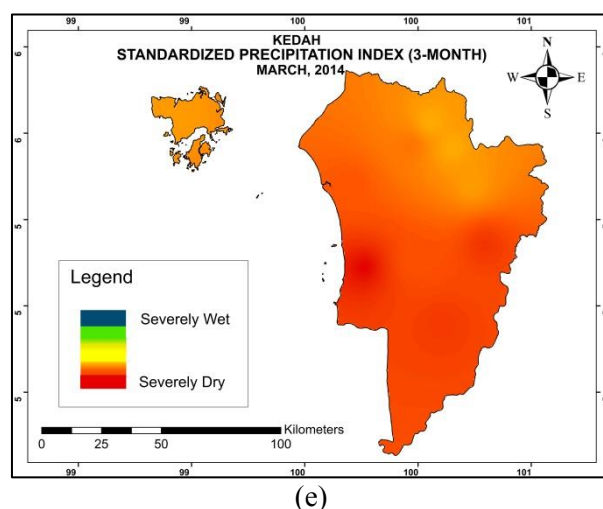


Figure 4. Maps show the spatial distribution of SPI-3 interpolation during NE monsoon in Kedah for year 2014 in the month of (a) November, (b) December, (c) January, (d) February and (e) March respectively.

3.4. Spatial pattern of vegetation health

Figure 5 (a) and (b) depicts the spatial pattern of NDVI of February and July respectively in 2014. Based on figure 5 (a) the west part of the study area shows red colour that indicate low NDVI values which means less vegetation or greenness. On the other hand, in figure 5 (b) the north part of the study area were dominated by low NDVI values and this might be caused by the problem of cloud coverage on that area that was treated before processing. From figure 5 (a) and (b) we can interpret that compare to July, February records low greenness value which indicate the deteriorating health of the vegetation in that particular area. The finding is in line with the report from DOA that recorded from January until March in 2014, where the yield encountered losses due to the drought event that last during those three months [28]. The deterioration of vegetation health during this period might be contributed by the insufficient amount of rainfall received.

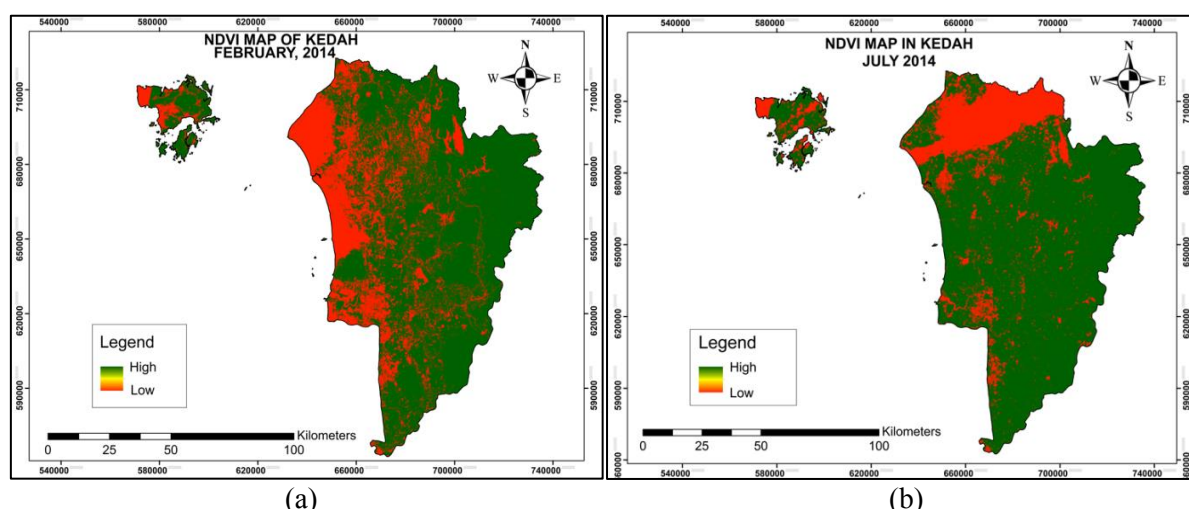


Figure 5. The spatial pattern of NDVI in Kedah for (a) NE monsoon and (b) SW monsoon.

The result of SPI and NDVI were consistent with each other in term of areas affected by the rainfall reduction and that indicate the rainfall variation can be applied to detect the drought event in the study area. Severity map shows the level of the drought intensities and its strength for a certain period of time. Figure 6 (a) is the severity of drought in February which represents the condition during NE monsoon. Meanwhile figure 6 (b) is the condition during the SW monsoon. Condition during NE monsoon was much severe compared to the condition during the SW monsoon. This result was in line with the SPI result obtained in figure 3 and 4 that shows dry condition was much more intense during the NE monsoon.

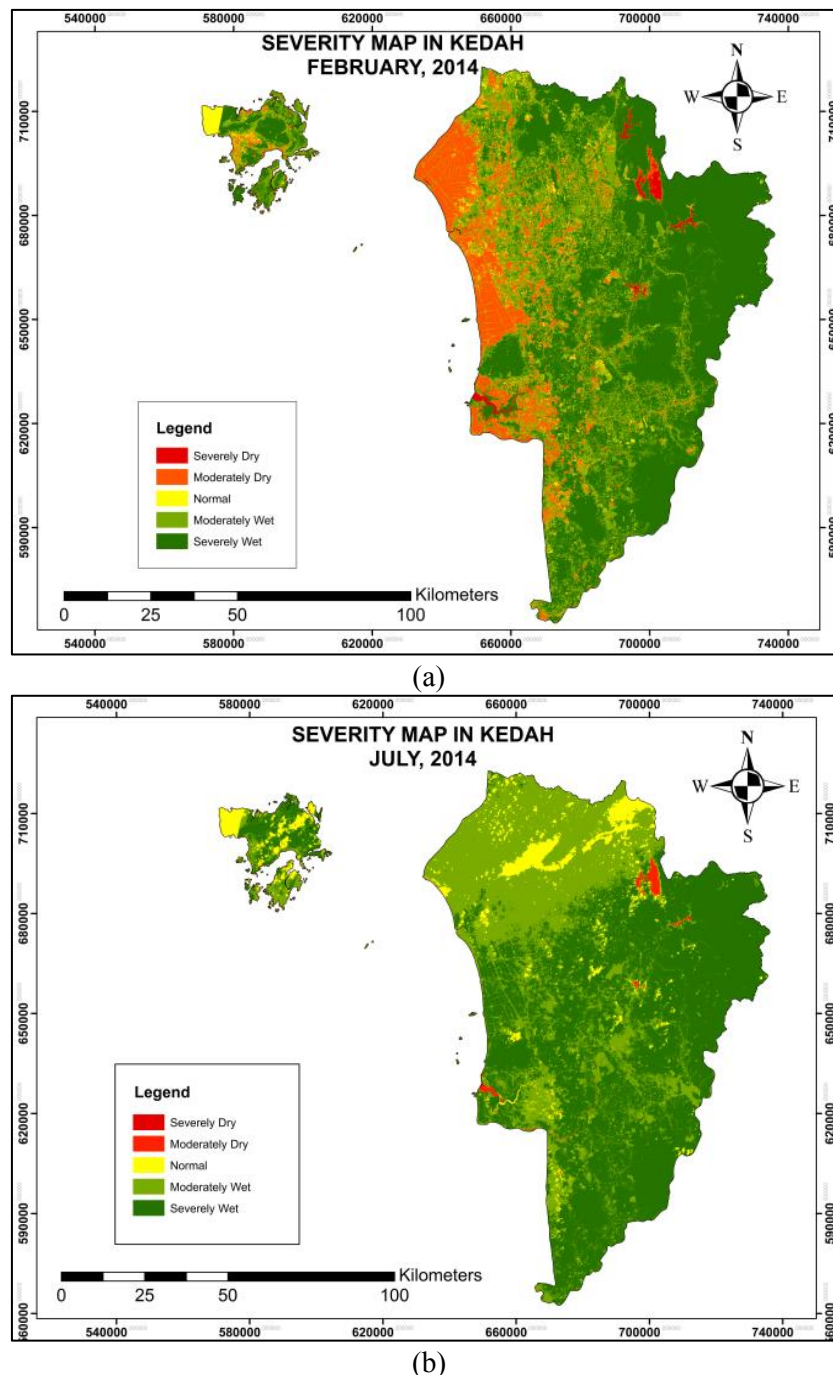


Figure 6. The severity map of Kedah during (a) NE monsoon and (b) SW monsoon.

3.5. Vulnerability map for vegetation in Kedah

In this study, the application of SPI identified the area that faced drought while the NDVI result showed the area that record the health of the vegetation and the combination of these two indices showed vegetation health that was affected by rainfall reduction or occurrence of drought event. Referring to figure 7, the northern part of the map that governed by the unhealthy vegetation condition was at Kuala Nerang. Predominantly, the villager's economic source for this area is derived from the paddy and mango plantation. Based on the previous SPI result in figure 3 and 4, Kuala Nerang mainly experienced moderate rainfall during the early SW monsoon and ranged between moderately to severely dry during the NE monsoon. Another unhealthy vegetation area was at Pendang which was also a paddy production area. Langkawi Island was one of the areas that face risk of moderately dry condition resulting in unhealthy vegetation in that area.

Since the lack of water can affect the soil moisture and the reservoir storage, scientific analysis can help to point out the exact area that need attention and at the same time improve the level of society's awareness prior to this intense issue. In this regard, early planning and action could be taken as a proper step in connection with the water shortage problem.

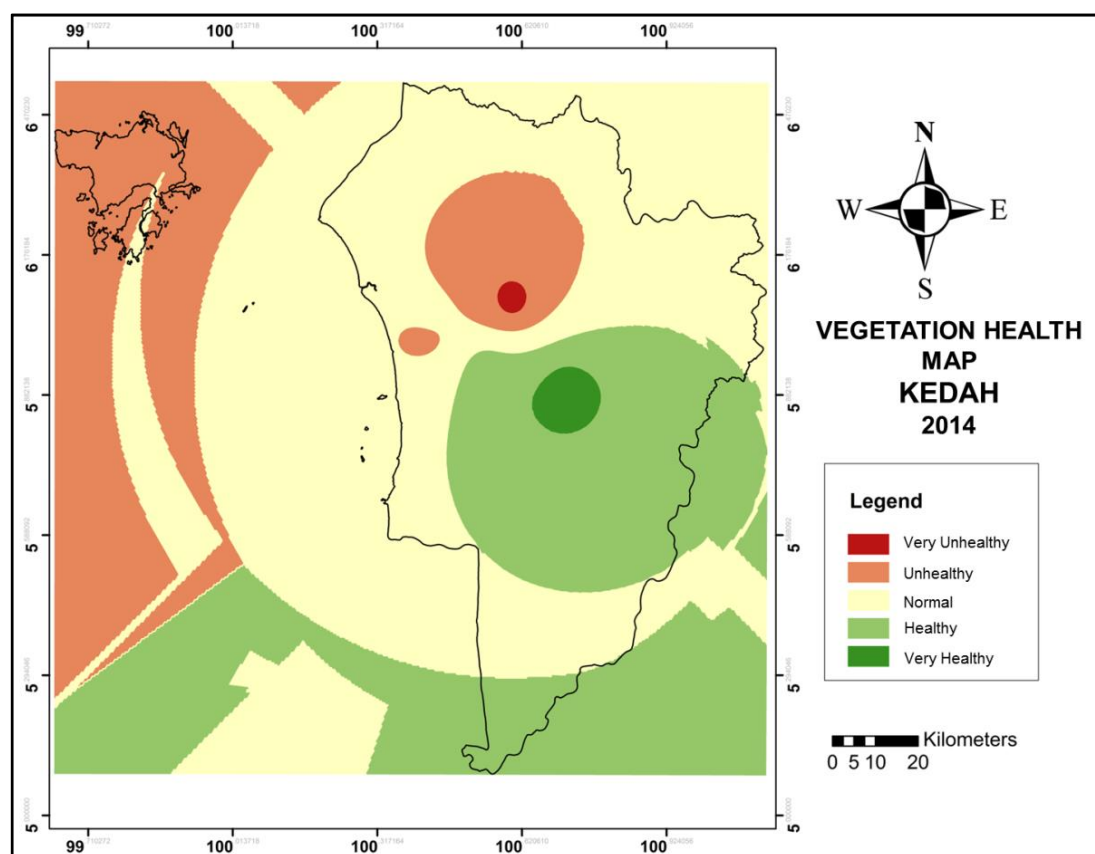


Figure 7. Vegetation health map in Kedah for year 2014.

4. Summary

Kedah was affected by the two main monsoons in Malaysia which were the NE monsoon that brings dry condition to Kedah especially at Kedah Peak station and SW monsoon that shows result in a wet condition throughout the state. Generally, Kedah's weather fluctuates all along the year. Kuala Nerang, Pendang and Langkawi Island were the areas with its vegetation's health affected by the rain reduction. This study was done to help the authorities and farmer to take action based on drought event

that occurs in 2014 resulting in economic losses to the state. The result has shown areas that were more prominent to the drought occurrence and by identifying the specific area, extra precaution will be easier. The main limitation in this study was due to the rainfall station that was distributed sparsely. Resulting in some of the area was not exactly represented by its exact condition which led to errors in the vegetation health map.

The overall outcome showed that the risk identification process can be done by integrating many methods and sources with the benefit of minimizing time and cost taken for the process. The finding of this study can help the authorities and even the farmers in preparing the mitigation measures. The findings of this study will definitely contribute in identifying the risk area of Malaysia which is in the process of researching at the moment.

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