HOTSPOT SPATIOTEMPORAL AND TREND ANALYSIS FOR NEAR REAL-TIME ACTIVE FIRE MONITORING USING MULTI-SATELLITE IMAGERY IN MALAYSIA

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ABSTRACT: Malaysia experienced severe forest fire episodes related to the peatland fire due to the prolonged dry season and the El- Niňo phenomenon. Thus, atmospheric pollution and haze remained a common problem throughout the dry period in this ASEAN region. Malaysian Space Agency (MYSA) has started the initiative to explore forest fire and haze monitoring activities since 2011 using various satellite imagery around the ASEAN region. Early detection of hotspot occurrence is crucial to minimize the impact and help authorities mitigate fire events as quickly as possible. Thus, this paper aims to show the study on spatiotemporal and trend analysis of fire occurrence from a wide range of fire detection sensors like VIIRS from SNPP as well as Terra and Aqua from MODIS. The spatial distribution of hotspots will become the early indicator of the characteristics of the fire event. This study used The Global Moran's I analysis to prove whether the hotspots are dispersed, random or clustered. Then, optimized hotspot analysis using Getis-Ord Gi* statistic is conducted to investigate trends over space and time of statistically significant hot and cold spot. The trend of historical hotspots recorded starting from 2012 until 2022 is further analysed to produce a fire-prone map. The results revealed that the hotspot pattern for states with high peatland cover is clustered within 95% to 99% significance level and classified as high fire-prone areas. In conclusion, this analysis effectively works as a decision support system in managing forest fire and haze since the actual condition of fire events can be obtained from the spatiotemporal of near real-time hotspots and fire-prone area information.

1. INTRODUCTION

Forest fires and haze are viewed as annual events in Malaysia that cause environmental impact. While Malaysia had a zero-burning policy to curb open/forest fire burning, there are still several incidents of open fire that occurred in Malaysia. To reduce their destructive impact, early fire detection is important for decision-makers to plan mitigation strategies as well as extinguishing efforts. Thus, Forest Fire Information System, (ForFIS) was designed and developed by the Malaysian Space Agency (MYSA) in 2011 to help the authorities in monitoring fire events in Malaysia using remote sensing active fire data. ForFIS had further enhanced the effectiveness of the information delivery system by using various sensors including VIIRS from SNPP for 375m resolution and 1-km resolution for Aqua and Terra from MODIS. The frequent number of acquisitions from multi-satellite will increase the potential of hotspot detection and the pattern distribution can be examined. Therefore, the objectives of this research are to perform the spatiotemporal of fire occurrences analysis using near real-time (NRT) historical hotspots from multi-sensors and to map the potential fire-prone area. Standard data products are an internally consistent, well-calibrated record of Earth's geophysical properties however the NRT fire products are generated more rapidly than the standard processing allows to meet the needs of the applications (Murphy et.al,2015).

In the context of active fire location, each hotspot represents the centroid of a 1km pixel that is flagged by the algorithm as containing one or more fires within the pixel. The algorithms compare the temperature of a potential fire with the temperature of the land cover around it. If the difference in temperature is above a given threshold, the potential fire is confirmed as an active fire or "hot spot". The MODIS active fire product detects fires in 1-km pixels while VIIRS in 375m pixel that are burning at the time of overpass under relatively cloud-free conditions using a contextual algorithm. The fire is often less than the size of the pixel. For MODIS and VIIRS, all confidence value ranges from low, nominal or high confidence are used in this study associated with the reflection from mid-infrared channel I4. In certain cases, the hotspot may not have been detected due to cloud cover, heavy smoke, or tree canopy may completely obscure a fire (Murphy et.al,2015).

In this study, several techniques of spatiotemporal analysis are adopted which are related to the clustering method in order to recognize the distribution pattern of the hotspot occurrence. The spatial autocorrelation and point density analysis are carried out to produce a fire-prone map. The Optimized Hot Spot Analysis gives incident points or weighted points that are statistically significant hot and cold spots using the Getis-Ord Gi* statistic. These methods, which have been tried to be used frequently in many areas in recent years, have also gained importance in determining the fire-prone area. All the hotspots will be validated using higher-resolution multispectral satellites to identify the smoke and burn scar feature.

2. MATERIAL AND METHOD

2.1 Study Area

The study area is located in Sarawak which is the largest state of Malaysia. The size of Sarawak is almost equal to that of Peninsular Malaysia. It is home to some of the world's most distinct flora and fauna. The total area of Sarawak is 12.4 million ha, with a population of 2.77 million. Sarawak consist of 12 administrative divisions which are Kuching, Kota Samarahan, Sri Aman, Betong, Sarikei, Sibu, Kapit, Bintulu, Mukah, Miri, Limbang and Serian. Based on the annual report from the Forest Department of Sarawak. 4.2 million ha are permanent forest estates and 712,012 ha are protected areas. Sarawak is selected as the study area due to the highest number of hotspots recorded almost every year. Sarawak also has the largest peat swamp forest with more that 70% distribution from estimated 1.54 million hectares that still remaining in Malaysia. (UNDP, 2006).

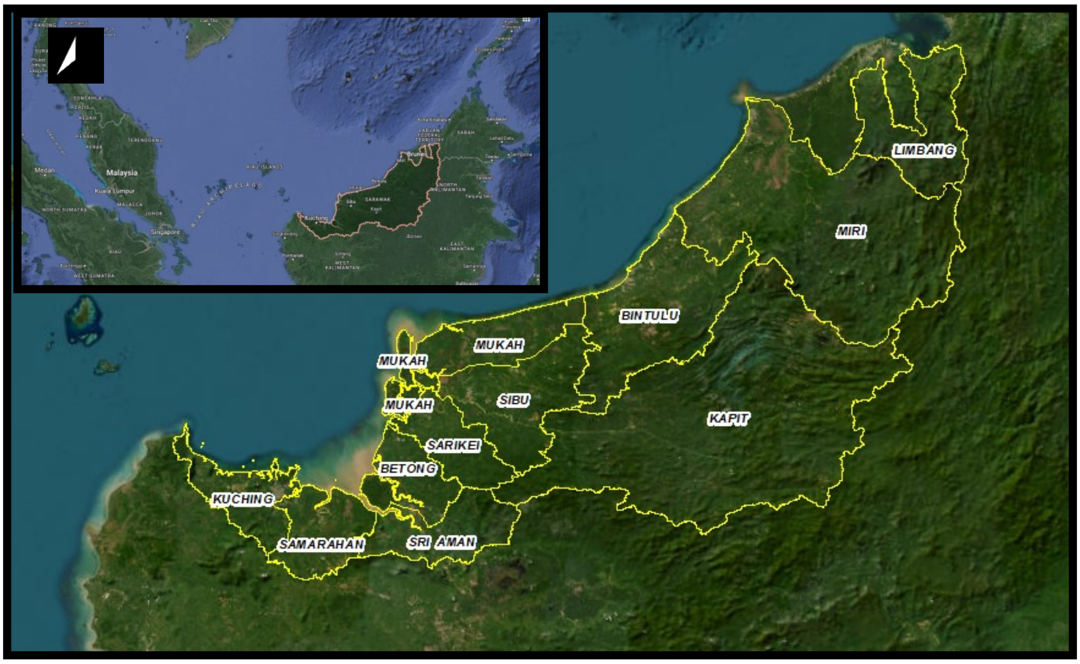


Figure 1. Location of study area in Sarawak, Malaysia

2.2 Satellite Imagery and Pre-Processing

In this study, we utilize active fire products from the Fire Information for Resource Management System (FIRMS) data catalogue. FIRMS generally makes the data available within 3 hours of a satellite observation. FIRMS distributes Near Real-Time (NRT) active fire data from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Aqua and Terra satellites, and the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi National Polar-orbiting Partnership (Suomi NPP). Combined (Terra and Aqua) MODIS NRT active fire products (MCD14DL) are processed using the standard MOD14/MYD14 Fire and Thermal Anomalies algorithm. VIIRS is the successor to MODIS for Earth science data product generation. The 375m I-band data complements the MODIS fire detections; they both show good agreement in hotspot detection but the improved spatial resolution of the 375m data provides a greater response over fires of relatively small areas and provides improved mapping of large fire perimeters (FIRMS,2023).

The nominal observation times for VIIRS S-NPP are 1:30pm and 1:30am. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon (FIRMS,2023). The differences on acquisition time for every sensor reflect to the existing and the expanding of the fire area. High-resolution imagery is used to validate the smoke and burn area from the active fire incident. In this study, The NRT data from these three sensors from 2012 to 2022 are used to populate the cumulative number of hotspots to present the hotspot distribution as shown in Figure 2.

Figure 2. The cumulative number of hotspot from different sensor are quantify as the total number of hotspot per day

2.3 Statistical Analysis

Daily hotspot is downloaded and undergo automated pre-processing using Python script and ArcGIS software to extract their administrative boundary information like division, district and city. Then the basic statistical analysis is performed in order to view the trend of hotspots from 2012 until 2022. The graph of hotspots for every month was created in order to determine which month has the highest hot spots number in order to relate it with the surrounding environment such as meteorological factors. By using the graph, the trend of hot spots whether it increases or decreases over time can be determined.

2.4 Spatio-temporal Analysis

Spatial autocorrelation (Global Moran's *I*) measures spatial autocorrelation based on feature locations and feature values simultaneously. Given a set of features and an associated attribute, it evaluates whether the pattern expressed is clustered, dispersed, or random. It combines location proximity and attribute similarity into an index (Moran, 1950). Next, the space–time cube method is the analysis that can perform the specified analyses in one go, and it can detect hot and cold spots thanks to trend analysis (Esri, 2022). This tool identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots). It automatically aggregates incident data, identifies an appropriate scale of analysis, and corrects for both multiple testing and spatial dependence. (Esri,2022). Next, point density analysis is carried out to produce a fire-prone map. It calculates a magnitude-per-unit area from point features that fall within a neighbourhood around each cell. Only the points that fall within the neighbourhood are considered when calculating the density.

3. RESULT AND DISCUSSION

3.1 Statistical Analysis

Based on the 11-year trend of hotspot, Sarawak, Sabah and Pahang are ranked on the top three states that have the highest number of hotspot counts in Malaysia as shown in Figure 3. A sum of 68235 hotspots were recorded in Sarawak from 2012 to 2022 and Miri, Mukah and Kapit are among the division that shows the higher number of hotspot as shown in Figure 4. Every year the increasing hotspots in Sarawak occurred in May until September as shown in Figure 5. This is related to the southwest monsoon that is associated with the dry season in Malaysia which eventually affects the peatland water table. However, after some action and enforcement from the government, the trend of hotspots keeps decreasing over the years as a result of mitigation action from Malaysia via the National Haze and Dry Weather Committee and ASEAN Agreement on Transboundary Haze Pollution.

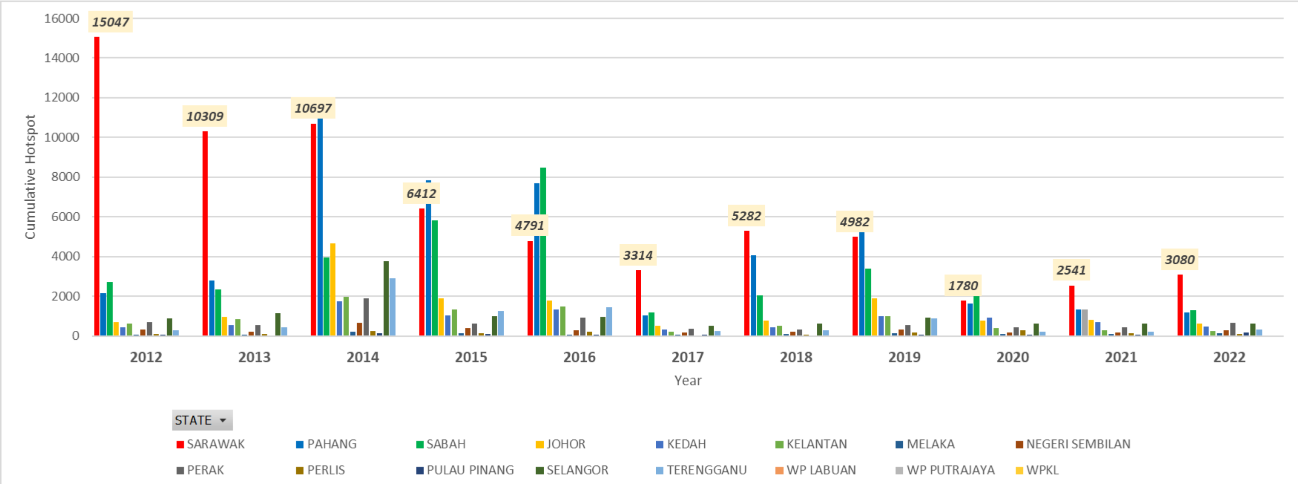


Figure 3. Total hotspot count by state in Malaysia 2012-2022

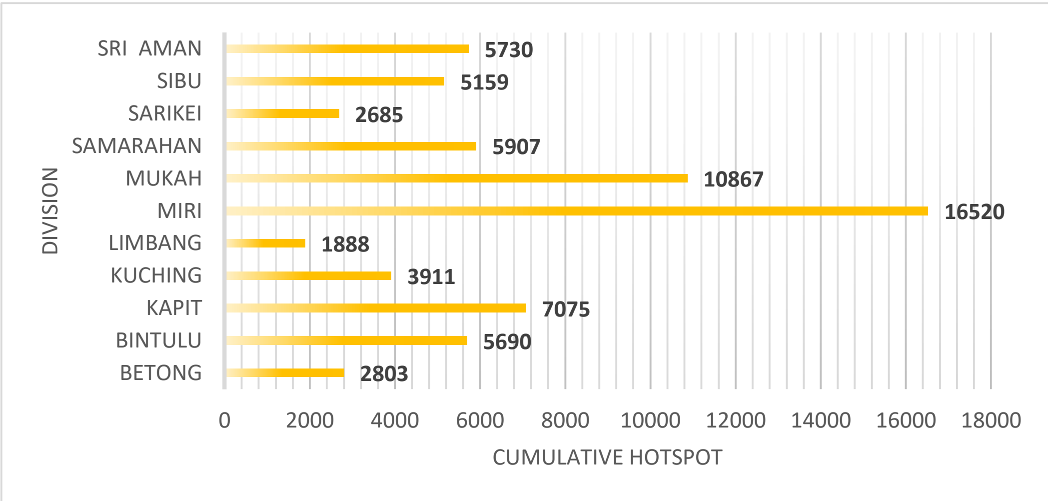


Figure 4. Total hotspot counts from 2012-2022 by Sarawak division

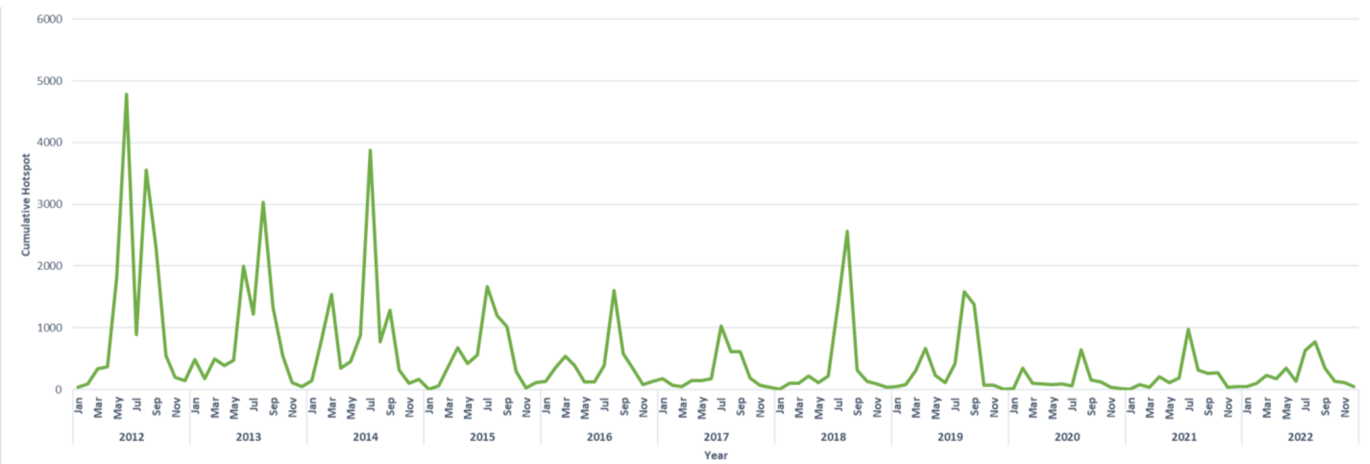


Figure 5. Hotspot count in Sarawak by month 2012-2022

3.2 Spatial-autocorrelation Analysis- Global Moran's I

The distributions of hotspots in Sarawak were divided into three different areas of tessellation which are 50 ha, 100 ha and 1000 ha, in order to observe the difference of pattern between them. From this analysis, it showed that in every area the hot spots are clustered as shown in Figure 6. The highest z-score value in Sarawak was at 50 ha with value 79.696894 and the lowest z-score was at 1000 ha with value 33.381989, these values show that there is less than 1% likelihood that this clustered pattern could be the results of randomness.

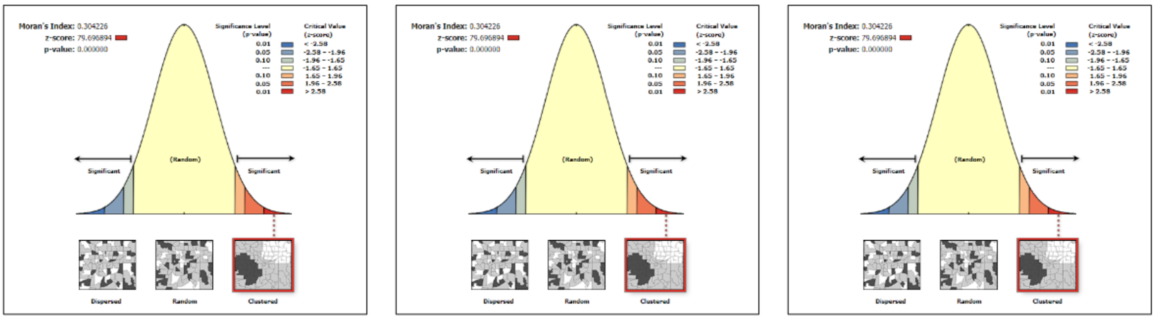


Figure 6. Result of Spatial autocorrelation (global Moran's *I*)

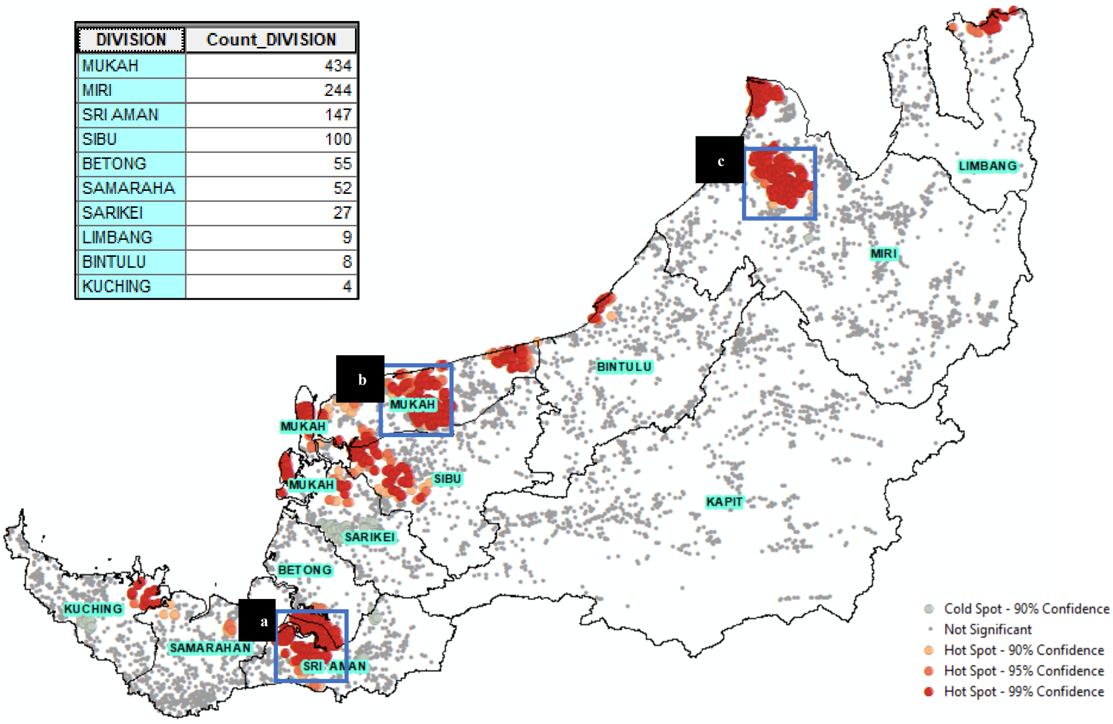
3.3 Optimized Hotspot Analysis

This analysis investigates the trends of hot spots over space and over time and indicates the high value or low value of hotspots and their relationship with peatland cover. The high value is displayed and classed based on hotspot trends of statistical significance where hot spots have 99%, 95% and 90% confidence while cold spots represent the low value with 99%, 95% and 90%. Not significant that shows no patterns indicate that the area has <90% confidence. Based on the results, red output features represent hot spots where high incident counts cluster while blue output features represent cold spots where low incident counts cluster. 5346 clusters were formed from the total of 68,235 hotspots, while 1435 is defined as high value of hot spots which range from 90%-99% confidence as shown in Figure 7. According to the location of the high-value hotspot, the highest cluster which is 434 clusters is situated in Mukah while 244 clusters in Miri, 147 clusters in Sri Aman,100 clusters in Sibu and certain cluster in other divison as shown in Table 1.

The intersecting of hotspots with the peatland area is carried out as shown in Figure 7 and the result shows that 75% of the hotspot cluster are dominated by peatland fires while the rest is the fire from slash and burn activities from plantation and agricultural site or solar flare from industrial area. Peatland is subjected to fire incidents as it has a high probability of fire recurrence due to the unburnt biomass, direct sunlight due to the removal of canopy shading and fire-prone secondary vegetation which will provide more fuel to ignitions (Posa et al., 2011 and Siegart et al., 2001)

Table 1. Total Number of cluster by Sarawak Divison

DIVISION	Count_DIVISION
MUKAH	434
MIRI	244
SRI AMAN	147
SIBU	100
BETONG	55
SAMARAHA	52
SARIKEI	27
LIMBANG	9
BINTULU	8
KUCHING	4



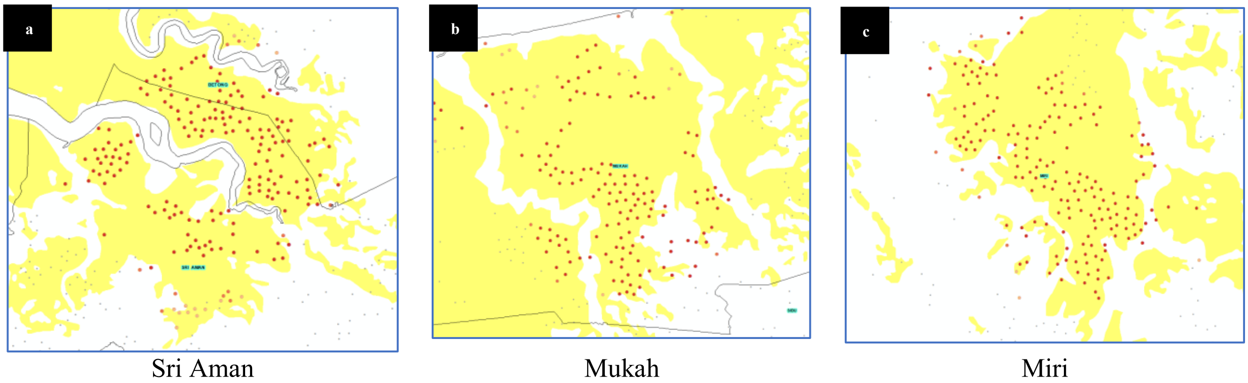


Figure 7. Distribution of hot spot and cold spot clusters based and the overlaying peatland cover

3.4 Point Density Analysis for fire-prone map

The hotspot dataset is divided into two categories fire-prone map (a) and(b) which(a) is the earlier episodes from 2012 to 2017 and the (b) is latest hotspot 2018-2022 based on the hotspot trend in Sarawak that was discussed previously. By doing this comparison, any changes in the fire-prone area over time can be relate. According to the density map in Figure 8, due to the decrease of hotspot count in 2018-2022, the intensity of hotspot is also reduced from very high fire-prone areas during 2012-2017 to moderate and low level especially in Miri, Mukah and Sri Aman. The maximum value of density for map (a) is 1.00 while 0.23 for map (b).

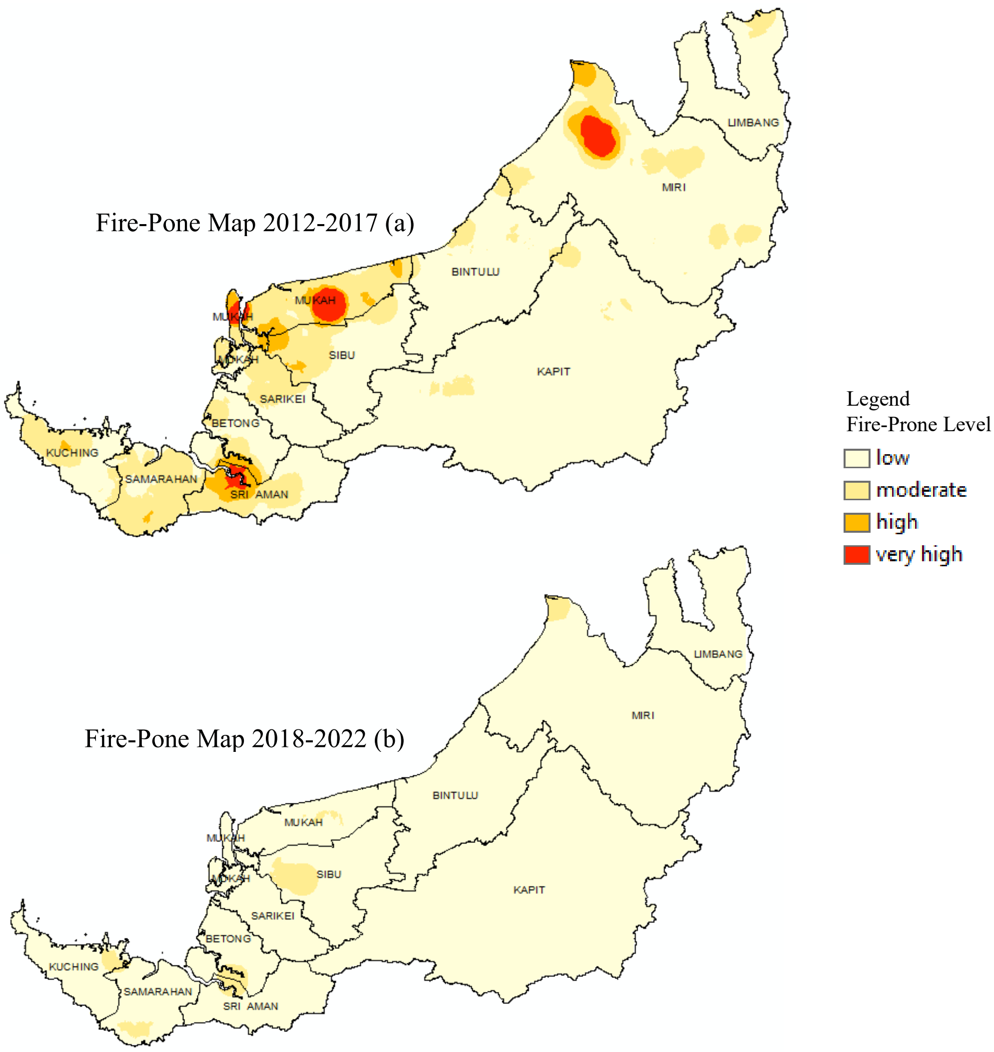
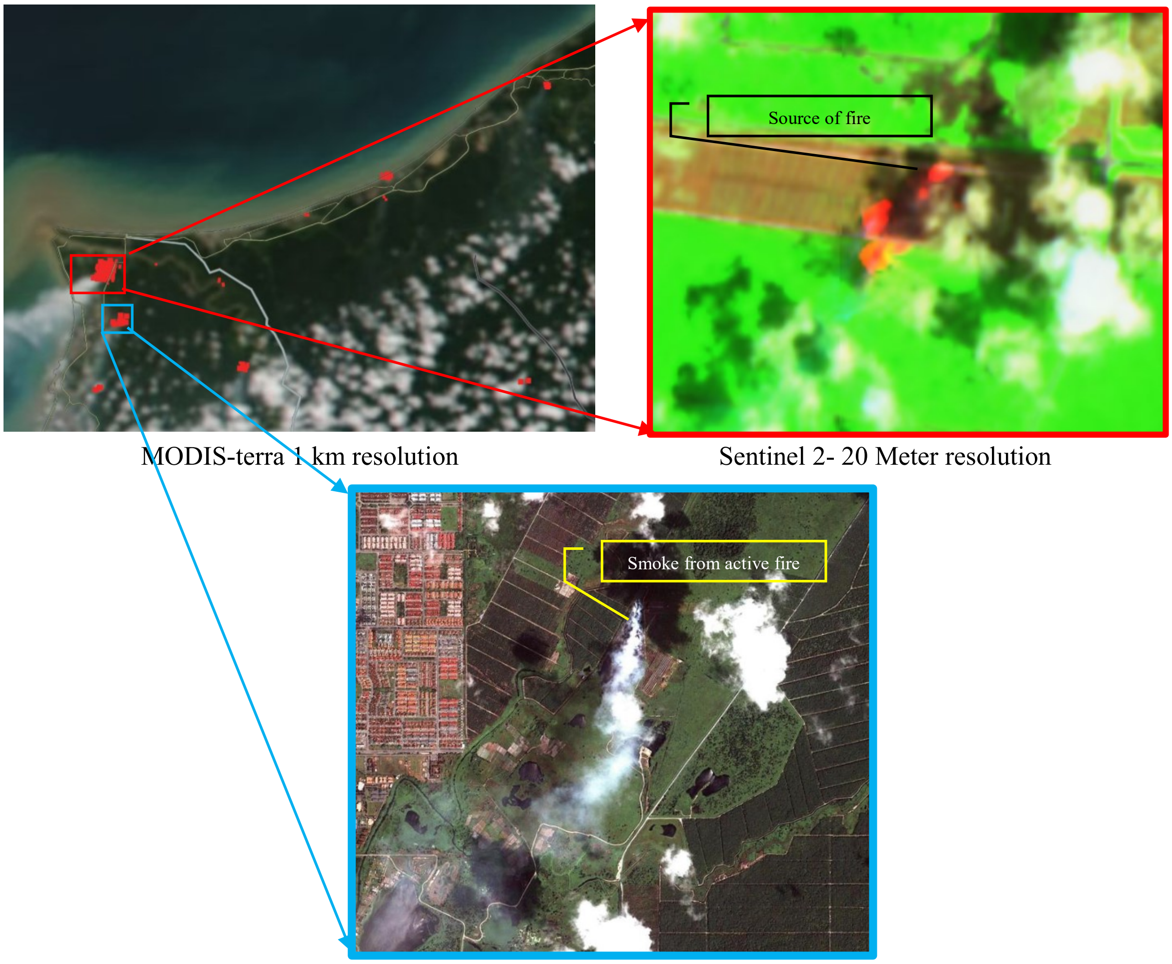


Figure 8. The hotspot density map that represent the potential fire-prone map for 2012-2017 and 2018-2022

3.5 Verification using Multi-Spectral Higher Resolution Satellite

In order to validate whether the hotspot is an actual fire event, moderate-resolution satellites like Sentinel-2 or Landsat-8 are also utilized to analyze the land cover and burn scar at clustering hotspot and as an example the fire episodes on February 2020 in Miri as shown in Figure 9. At this point, the multispectral SWIR and NIR band combination is very important to visualize the fire characteristic and burned area especially for the location that lacks access to the ground. The Near Infrared (NIR) and Shortwave Infrared (SWIR) spectral regions are relevant for detecting burned areas. The NIR reflectance after a fire sharply declines due to the loss of vegetation, whereas the SWIR reflectance rises as a result of the removal of water-retention from plant. In addition, image acquisition using the very-high resolution of imagery like SPOT-6 with 1.5 meter resolution also important to provide information such as water sources, land use types and accessibility for firefighting agency especially for large scale event.



SPOT6-1.5 Meter resolution

Figure 9: Snapshot of active fire in Kuala Baram, Miri, Sarawak 23 February 2020 using Terra, Sentinel-2 and SPOT 6

4. CONCLUSION

This study showed that the hotspot occurrences in Sarawak are clustered and 75% of the clusters are associated with peatland. The results have also proven that there are increments of hotspot trends towards the hot seasons in the middle of year starting from may every year until September. At this point, GIS-based hotspot mapping analysis has provided convenience especially in determining the risky areas of forest fires. The study revealed that the very high fire-prone area within periods 2012-2017 located in Mukah, Miri, Sri Aman and Sibu division had much improved after 2018-2022 due to mitigation action taken by the authorities. For future studies, site verification need to be conducted as well in order to enhance the information on the severity of the fire-prone area since it plays an active role in making more critical evaluations to protect the forest.

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