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Content list available at: www.benthamopen.com/TOCIEJ/

DOI: 10.2174/1874149501711010786

RESEARCH ARTICLE

Forest Fire Risk Assessment Using Hotspot Analysis in GIS

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Received: June 22, 2017 Revised: August 26, 2017 Accepted: September 16, 2017

Abstract:

Background:

Present intensifying forest fire incidents are becoming a major concern as they pose threats to the environment, economy and human's safety. This paper aims to identify forest fire hotspots using advanced hotspot analysis in the Geographical Information Systems (GIS), and suggest appropriate preventive measures.

Objective:

Brunei Darussalam is one of the Southeast Asian countries that is significantly affected by the increase in forest fire incidents in this region. Brunei Muara is the worst-hit district by forest fire in Brunei Darussalam, and hence it was selected as a case study for this research.

Results and Conclusion:

This research identified and prioritized forest fire hotspots, highlighted the shortage of fire stations within the identified hotspots and suggested the suitable locations for new fire stations in Brunei Muara district.

Keywords: Brunei, Forest, Fire, GIS, Risk, Hotspot.

1. INTRODUCTION

Forest is a valuable asset as it brings a wide range of benefits and services to human and ecosystem. It generates goods and services that benefit humankind such as timber and fuel, tourism, protection of watersheds and carbon storage [1], [2]. However, present intensifying forest fire activities are becoming a major concern as they pose threats to the environment, economy and human's safety. Pausas and Keeley [3] and Liu *et al.* [4] described fire as an extensive process in the earth system and one of the most important factors for natural ecosystems. Despite its role in earth processes, fire is also one of the disturbance factors in forests [5].

Forest ecosystems for years have been exposed and have had to adapt to disturbances that are affecting them. Disturbances in forest may include storms, snow breakage, snow avalanches, fire and animal activities [6], [7]. These disturbances help to form forest ecosystem by affecting their composition, structure and functional processes [6]. For instance, forest structure in 50 years old forest stands had changed after surviving snow avalanche. However, absence of soil disturbance and micro-climatic parameter for 20 years made the species composition in the area nearly similar to the pre-avalanche situation [7]. This shows that the presence of disturbances can affect the forest's ecosystem.

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Southeast Asian countries are under threat due to the increase in forest fire occurrence. It has damaged significant amount of forested area in the region annually. In Riau province, about 6,000 hectares of land and forest were damaged by fire in 2014. The fire incidents in the area had made the Pollutant Standard Index (PSI) to exceed to 100 and reach a dangerous level [8]. In 2015, a total of 2.6 million hectares of forest and farmland were reported affected by fire in Aceh [9]. Brunei as one of Southeast Asian's countries is significantly affected by the increasing forest fire activities in the country. Between 2007 and 2015, forest fire calls increased by 82%, for which, increased number of calls was received in recent years [10]. The intensifying forest fire activities affected Brunei's air quality. According to the JASTRe [11], Brunei's air quality got worsened and air pollution levels exceeded the standards in 2015.

In addition, forest fire can result in serious damage to the socio-economic, public property and potentially pose threat to human's lives [12 - 14]. Intense forest fire activities in the central and west Borneo in 2013 worsened Brunei's air quality, so that Brunei's Pollutant Standard Index (PSI) reached nearly 100. This PSI reading is categorised as 'moderate' and may result in minor health effects such as coughing, eye irritation and a running nose [15].

To further elaborate, Southeast Asian countries suffered extensive forest fire occurrences between 1997 and 1998, which eventually resulted in a devastating smoke-haze event that affected Singapore, Malaysia, Indonesia and Brunei. This incident damaged millions of hectares of forested area in the region. According to Someshwar *et al.* [16], 10 million hectares of land in Indonesia were damaged due to these forest fires, and this included 1.5 million hectares of peat swamp forests and 750,000 hectares of peat forest in Kalimantan provinces.

The widespread forest fires in Southeast Asia in 1997 caused serious economic impacts to the region. The effects were predicted to be $3.15 billion in 1997, while the Economy and Environment Programme for Southeast Asia (EEPSEA) estimated the total losses for the year 1997 and 1998 to be between $5 and $6 billion, respectively. Brunei, in particular, suffered the economic loss of $2 million due the 1998 forest fires and haze event [17].

This research focuses on the identification of forest fire hotspots and proposes mitigation measures to minimize the adverse impact of forest fire. A good understanding of forest fire risks is crucial in order to be able to properly manage forest fire. Guettouche and Derias [18] reported that forest fire risk management starts from its assessment. Many studies conducted have suggested that fire risk evaluation is a critical part and the foremost task in fire management [19 - 22]. Risk assessment involves the identification of risks and the reduction of frequency and magnitude of risks through preventive measures.

He *et al.* [23] identified three key requirements to manage forest fire risks namely (1) identification of hotspots (2) evaluation of the risk probability and (3) measures to reduce the risks. These key requirements are practically aligned with strategies proposed by some authors [12], [20] in evaluating forest fire risk using Geographical Information Systems (GIS). Most researchers studied the potential risks through the mapping of forest fire hotspots [20], [22], [24]. Identification of forest fire hotspots can be useful and helpful to improve the strength of current control and preventive measures of forest fire.

One of the tools that enables the identification of forest fire hotspots is GIS. The GIS provides means that can help to illustrate the spatial extension of forest fire hotspots. Due to this, GIS has been widely used by researchers for fire risk assessment [4], [12], [13], [20], [24], [25].

Kernel Density and Getis-Ord Gi* hotspot analysis are two types of GIS analyses that have been widely used in hotspot identification. The kernel is an estimator that is most commonly used and it functions by generalizing or smoothing discrete point data into a continuous surface area [26], [27]. In contrast, Getis-Ord Gi* utilizes Gi* statistics to measure the degree of correlation of weighted features within the specified distance threshold [28 - 30]. Gi* statistics was described by Getis and Ord and it can be used to identify clustering pattern with respect to the study area [28, 29].

Getis-Ord Gi* is a spatial autocorrelation method that enables the recognition and understanding of hot and cold spots. Spatial autocorrelation statistics is frequently used in evaluating the degree of clustering, randomness or fragmentation of a spatial pattern [31]. Getis-Ord Gi* is a spatial autocorrelation method that enables the recognition and understanding of hot and cold spots. According to Wubuli *et al* [31], spatial autocorrelation involves global and local spatial autocorrelation. The global spatial autocorrelation calculates the total degree of spatial autocorrelation for a dataset, while the local spatial autocorrelation identifies the location and types of clusters [31].

The local Getis-Ord Gi* statistics work by comparing the local sum for a feature and its neighbors is compared accordingly to the sums of all features. It calculates z-score and p-score of each feature in the study area, representing whether the differences between the local and global means are statistically significant or otherwise [32]. In addition, the statistics shows the extent of clustering pattern within the study area based on the calculated values [29]. Gi*statistics determines the clustering pattern of the hotspot and coldspot in a study area by indicating the statistical significance of the calculated z-score. A larger value of z score indicates a hot spot whereas, a lower value of z-score indicates the clustering of cold spots [32].

In addition, Gi* statistics were able to concurrently capture the frequency of the events, their corresponding values and spatial relationship [30]. According to Rosenshein [33], kernel density and getis-ord gi* are two different geospatial analyses, in which Kernel Density performs calculation by considering arbitrary search radius and the cell size while Getis-Ord Gi* considers the magnitude of each feature in the dataset in the context of its neighbours' values.

Chainey [34] compared Gi* to other hotspot mapping techniques, including Kernel Density, for crime hotspot mapping. Based on the prediction accuracy index (PAI), Gi* gave the best results in predicting the spatial extension of crime hotspots. Moreover Getis-Ord Gi* was the best mapping technique for capturing local clusters of crimes, and thus the identification of statistically significant crime hotspots.

Getis-Ord Gi* is also widely used in other disciplines essentially in health research, incident prevention and biodiversity distribution. Wubuli *et al.* [31], used Geits-Ord statistic in detecting spatial clustering of pulmonary Tuberculosis (TB) incidence in Xinjiang, China. They identified social and demographic predictors for TB incidence, and based on the studies, they were able to identify regions that should be prioritized by the government as an effort to control TB.

In addition, Getis-Ord statistics was used in identifying weather-crash pattern in Wisconsin county, the United States [35]. Using this method, they observed that weather was a contributor to higher number of crashes in some regions of the county. Thus, identification of locations for high weather-crash can be useful for the implementation of countermeasures in the affected area for road safety.

The following sections of this paper demonstrate the application of Getis-Ord Gi* GIS approach for the identification of forest fire hotspots in a study area in Brunei Darussalam. The adequacy of fire stations within the identified forest fire hotspots is evaluated, and the suitable locations for new fire stations are suggested.

2. MATERIALS AND METHODS

2.1. Study Area

2.1.1. Location

The region of interest in this study was Brunei-Muara District (Fig. **1**). It is one of the four districts in Brunei and it is located in the Northern part of Brunei between 4.913653° latitude and 114.919857° longitude. Brunei-Muara District is the smallest and the most populated district in Brunei with an area of 54,749 hectares and population of approximately 279,974 inhabitants [36]. The most of its population live in the centre of the district, wherein lies the capital city, Bandar Seri Begawan, and the Northern coastal area [37]. As of 2007, Brunei-Muara District comprises of 18 sub-districts and approximately 189 areas and villages.

2.1.2. Types of Forests

Large part of Brunei's land is still forested. Based on the studies conducted by Anderson and Marsden in 1988, the forest types in Brunei Muara District include Kerangas (Heath), Mangrove and secondary forests. Secondary forest is the most dominant forest in the district where it represents about 39.9% of the district [38]. On the contrary, mangrove and heath forests only represent a small proportion of the total forest covered in the district [39 - 41]. According to Bennett *et al.* [40], mangrove forest is distributed around the Brunei Bay and the capital area and a small proportion of Kerangas forest can be found at the northern part of the coastal area [39 - 41]. However, mangrove forests are claimed to be under threat due to the presence of human activities in the neighboring countries such as from the silt and debris produced by logging activity. In addition, mangrove forests in the vicinity of Kampong Ayer and industrial activities have also damaged because of the waste from Kampong Ayer and oil spills and industry at the mouth of Brunei River [40].

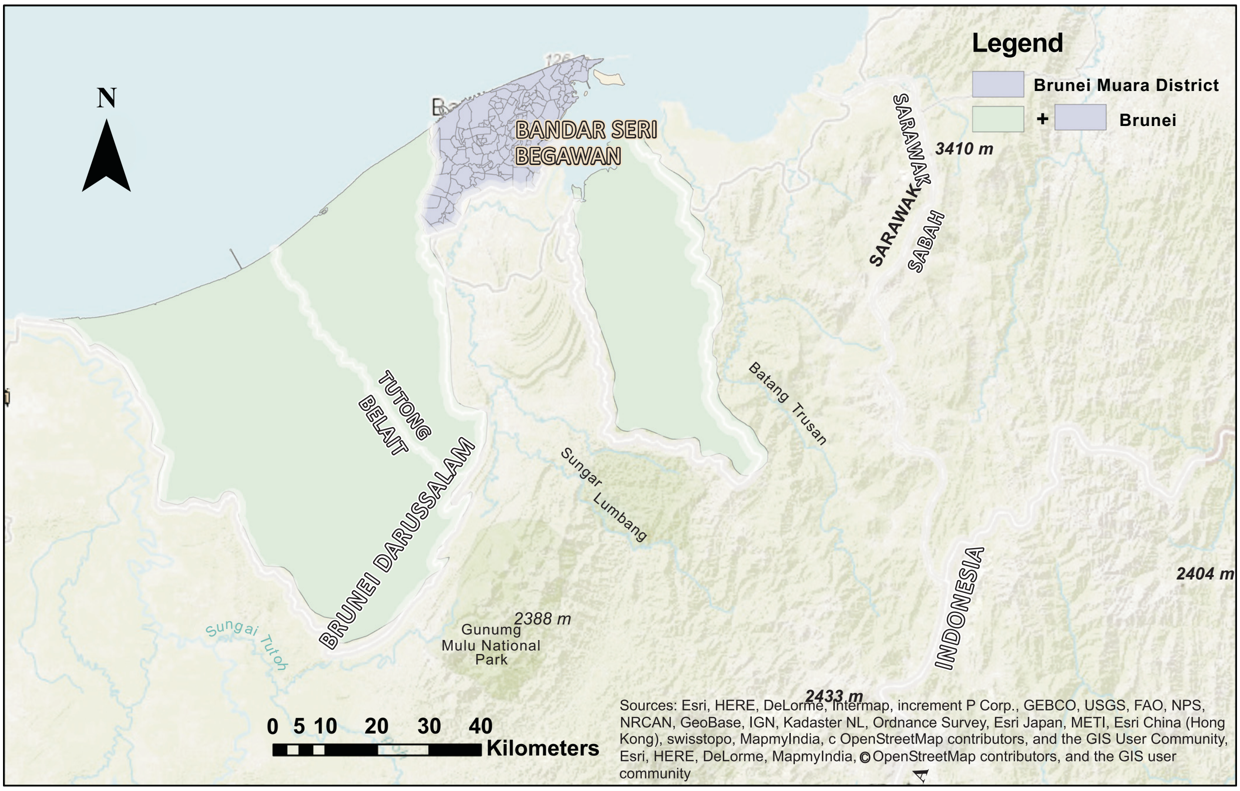

Fig. (1). Study Area: Brunei Muara District.

Secondary forest is a regenerating forest after significant removal and disturbance of the original forest [42]. This forest usually consists of the less developed canopy structure, smaller trees and less diversity. Due to its less developed canopy, this enables light to reach the floor, encouraging and supporting robust ground vegetation, and hence dense ground growth in this forest [43], [44]. According to Chua *et al.* [45], secondary forest can be found in portions in Sengkurong, Gadong, Mentiri and Serasa.

According to Dennis *et al* [46], studies showed that the increase in secondary forests in general shows increase in fire risk . This is because secondary forests get dried more quickly and hence, it catches fire more easily. Moreover, forests that have been previously disturbed are prone to fire because the forest canopy is opened and larger trees are scarred, this enables the light to reach and dry out the ground vegetation. Studies carried out on forests in Indonesia have shown that fire and damage due to fire are more intense in secondary forests than in the primary forests [46].

2.1.3. Climate

The studied area has humid tropical climate which is usually influenced by two monsoonal regimes, namely Northeast monsoon between mid-December and March, and the Southwest monsoon between mid-May and October. The temperature is low during the Northeast monsoon with maximum readings ranging between 29°C and 30°C which reach their highest in the transition period before the onset of the Southwest monsoon in May with average maximum reading of 33°C and 35°C [37].

2.1.4. Fire Stations

There are 14 fire stations located around the district. Fig. (**2**) shows the distribution of fire stations throughout the study area. It can be seen that the fire stations are most concentrated at the centre of the district. Based on the locations, the time taken by any fire engine to reach a fire incident, after an emergency call is received, usually takes approximately between 8 to 15 minutes [47].

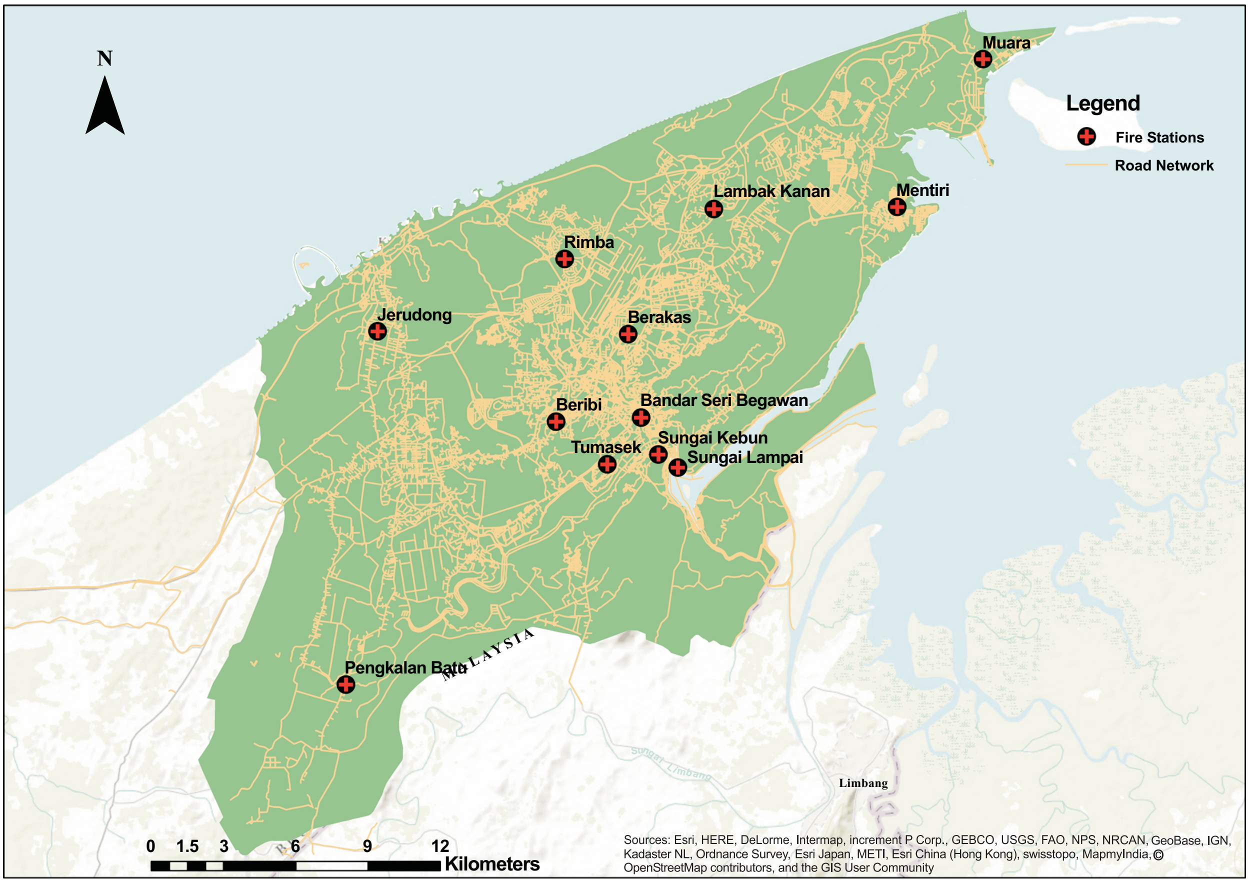

Fig. (2). Locations of fire station in Brunei Muara.

2.2. Data

This study was carried out systematically to identify the forest fire hotspots and determine 'who' and 'what' are vulnerable to forest fire. Fundamental data was collected from various sources. Forest fire calls from January to August 2016 were from Brunei fire and rescue department, and population census data was obtained from the Department of Statistics, Department of Economic Planning and Development.

Spatial data in this study were majorly obtained from *Google Earth* and *OpenStreetMap*. Layers produced using *Google Earth* include polygon of the study area, polygons of its villages and areas and locations of the fire station. The data was converted and loaded into ArcGIS software for analysis. Data gathered and produced were prepared and processed before being analysed for hotspots' identification. Data processing and hotspot analysis were performed using ArcGIS package.

ArcGIS package is a collection of GIS software that allows mapping, modelling, querying and analysing large quantity of data within a single database according to the location. It also allows the creation of maps for the visualization of scenarios [48]. Service coverage of each fire station in Brunei Muara District was determined and mapped in this study using the Network Analysis tool of ArcGIS and a shape file for road centrelines in Brunei Muara District. This is to evaluate the coverage of identified forest fire hotspots by the existing fire stations.

2.3. Methods

2.3.1. Data Preparation and Processing

Layers created and data obtained were prepared and transformed into a suitable format before it can be used for analysis. Data preparation is required as most data obtained were initially raw and cannot be directly used. The above Fig. (**3**) shows steps taken for preparing and analyzing data in this study.

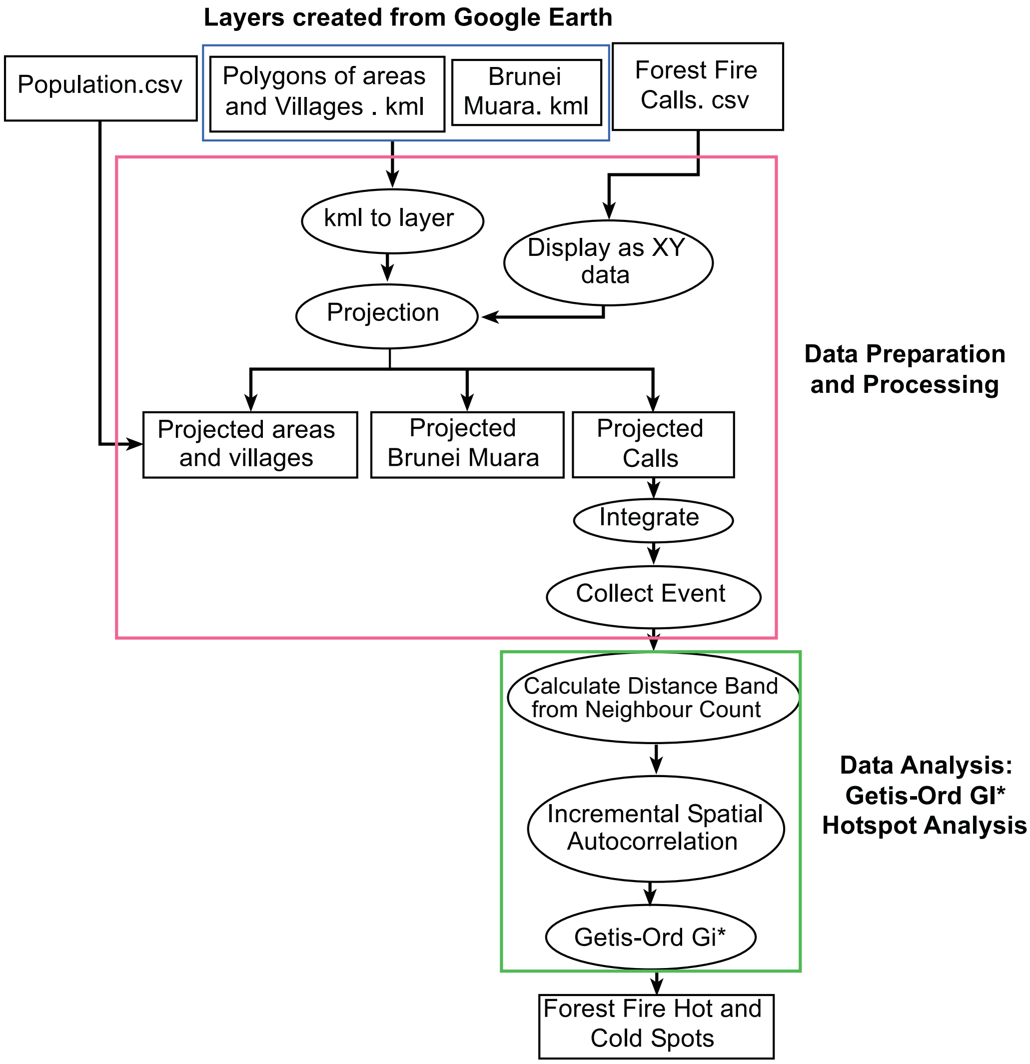

Fig. (3). Identification of forest fire hotspots.

2.3.1.1. Projection

Forest fire data obtained for Brunei Fire and Rescue Department was tabulated and GPS coordinates for each fire incident were determined and compiled. Tabulated forest fire calls were loaded into ArcMap software and displayed as XY data based on the latitude and longitude.

Layers and data loaded into ArcMap need to be projected to a suitable projection coordinate system for Brunei in order to assume that the data were plotted on a two-dimensional flat surface map instead of a three-dimensional spherical surface. Projection of data and layers could minimize the distortion of distance in the study.

2.3.1.2. Integration

Integrate tool helps to consider features that lie within the short distance of one another as identical and coincident [49]. GPS coordinates determined for each fire incident could be slightly inaccurate, therefore, integrate tool works by considering points lie within the selected distance to have the same location. Hence, they snapped together and were considered having the same location.

2.3.1.3. Collect Events

Collect events tool helps to transform forest fire calls into weighted points data. This tool combines the features and creates a new feature named ICOUNT (Fig. **4**). ICOUNT indicates the sums of all incidents at each unique location (X and Y centroid coordinates) [50]. This tool reflects the number of calls found at the location and combines them all. The sum of points combined at a particular location is recorded as ICOUNT.

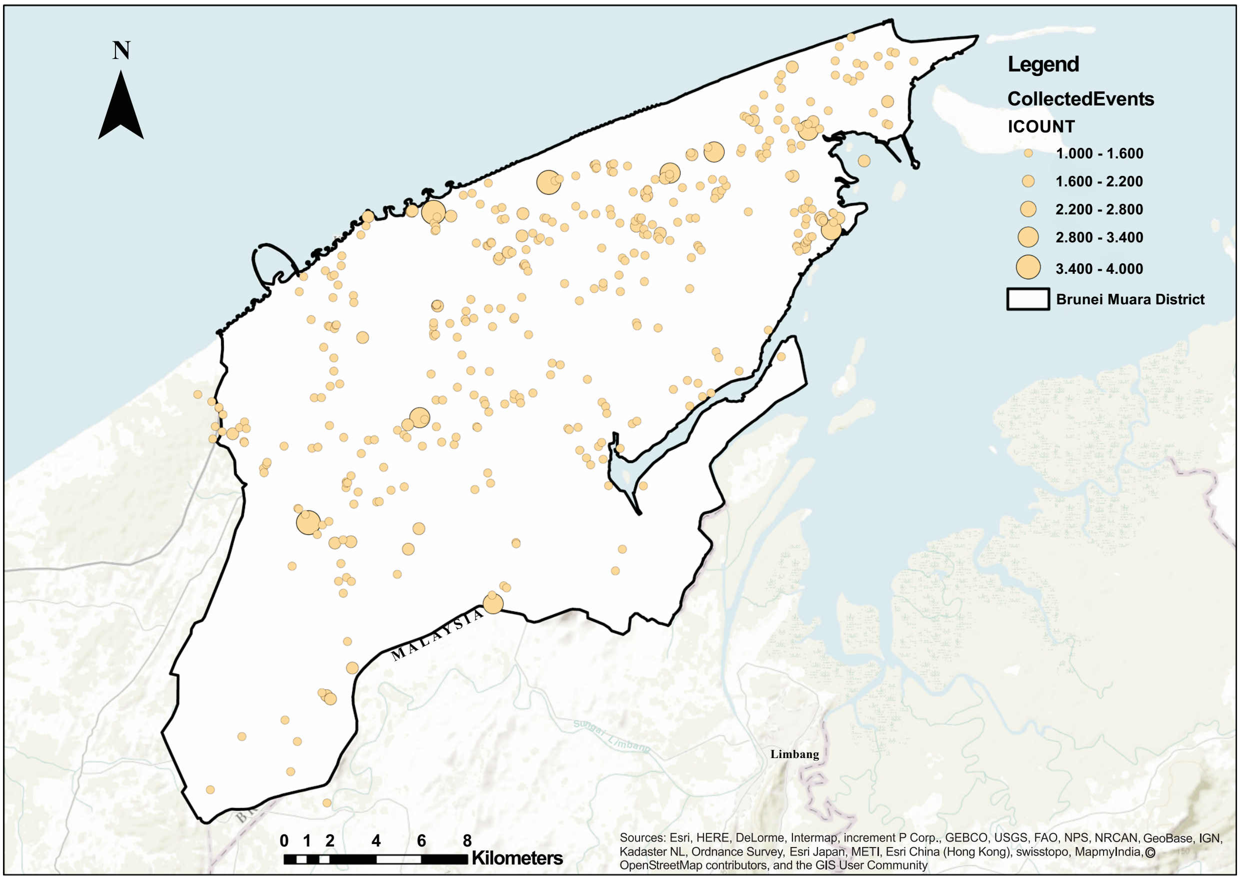

Fig. (4). Output of Collect Events Tool.

2.3.2. Data Analysis

After data were obtained and processed, they can be used for hotspot analysis. However, certain parameters are required to be set before the hotspot analysis tool can be run. Fig. (**3**) shows the stages in determining the parameter for hotspot analysis.

2.3.2.1. Calculate Distance Band from Neighbor Count

Before incremental spatial autocorrelation tool was run, beginning distance and distance increment need to be set. Calculate Distance Band from Neighbor Count tool was used to determine these parameters. This tool provides the minimum, average and maximum distance at which each point has at least one neighbor.

The tool provides maximum distance at which each feature has at least one neighbor to be 2702m. The resulted maximum distance of 2702m was used as the beginning distance. The average distance obtained from this tool is applied as distance increment. In this study, the increment distance was made smaller in an attempt to capture a more noticeable peak. Thus, distance at which points are most clustered can be determined. After several attempts of trial and error, distance increment of 300m was used in this study as distance increment.

2.3.2.2. Incremental Spatial Autocorrelation

Incremental spatial autocorrelation is a tool that measures the degree of clustering of data in space at increasing distance. This tool creates a graph that can be used as an appropriate scale of analysis (distance band) or radius because the peak indicates the distance at which the clustering is more pronounced [51, 52]. The maximum distance of 2702m was used as the beginning distance whereas the distance of 300m was set as distance increment.

The output of this tool created a graph of incrementing distances against their corresponding z-score (Fig. **5**). The peak of the graph shown in Fig. (**5**) indicates the distance at which the clustering of the data is more affirmed. The clustering distance is then used in Getis-Ord Gi* analysis as distance band or radius

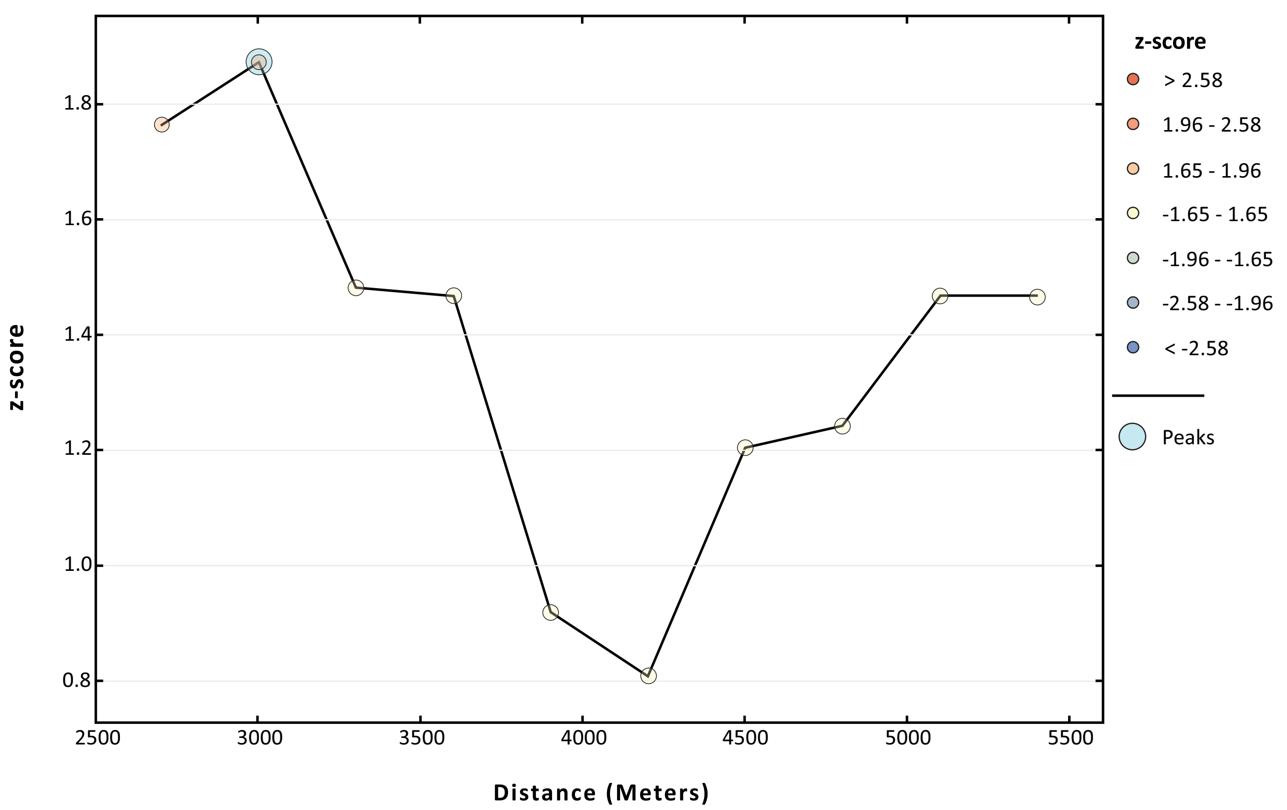

Fig. (5). Spatial Autocorrelation by Distance.

*2.3.2.3. Hotspot Analysis: Getis-Ord Gi**

Getis-Ord Gi* hotspot analysis method was used for the identification of forest fire hotspots in the study area, as shown in Fig. (**3**). This hotspot analysis utilizes Gi* statistics that can be calculated as follows:

$$G_i^{\ *} = \frac{\sum_{j=1}^{n} w_{ij} x_j}{\sum_{j=1}^{n} x_j} \quad \textbf{(1)}$$

Where, Gi* is the spatial autocorrelation (spatial dependency) statistics of an event i over n events, The term x_j defines the magnitude of variable x at events j over all n, and the term w_{ij} defines the weight value between the event i and j that represent their spatial interrelationship. Gi* statistics considers the magnitude of each feature in the dataset in the context of its neighbours' values. The local sum of a feature and its neighbours was compared accordingly to the sum of all features. If there is a significant difference between the local sum and the expected local sum, and that the difference is too large due to randomness, a statistically significant z score is the result [53].

To further elaborate, Getis-Ord Gi* hotspot analysis determines where the features with high and low z score and p value tend to form a cluster in the study area. The analysis tool calculates z score and p value for each feature which can help to indicate cold and hot spots of events. z score output represents the statistical significance of clustering for a specified distance, whereas p value indicates the probability that the observed spatial pattern was created by some random process.

Fig. (**6**) shows the overview of methods. Data gathered in the study were initially prepared and analysed for forest fire hotspot identification. Maps of fire stations service coverage were made to compare the current location of fire stations and the identified hotspots. Necessary improvement on the location of fire stations in particular can be determined based on this.

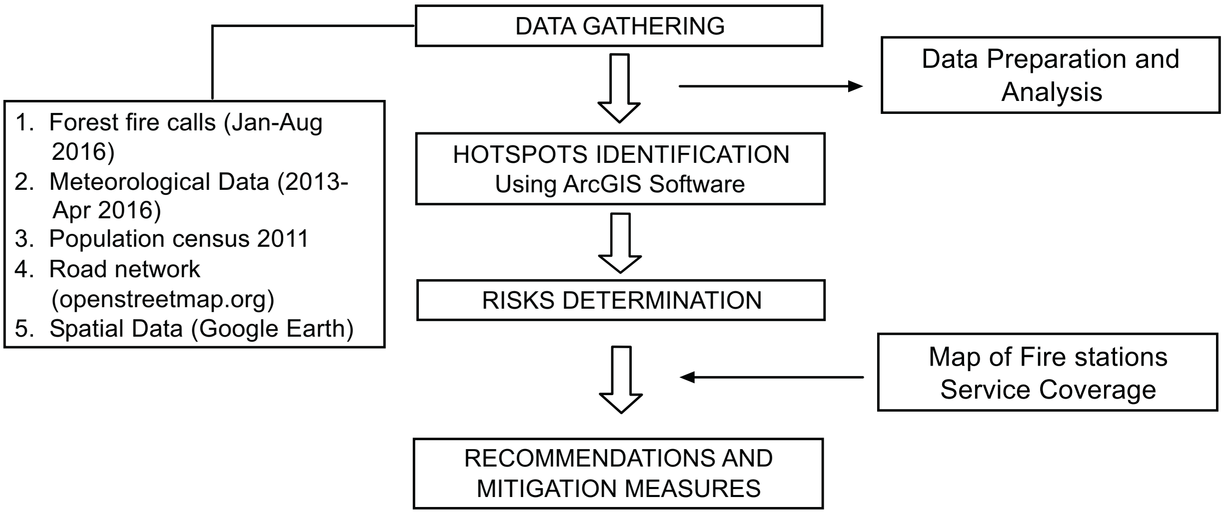

Fig. (6). Overview of Risk Assessment Process.

3. RESULTS AND DISCUSSION

3.1. Forest Fire Statistics

Increasing number of forest fire activities can be observed in Fig. (**7**). Number of calls in Brunei Darussalam increased by 80% from 2007 to April 2016 with intense forest fire occurrences in the recent years. Brunei-Muara District often recorded the highest number of forest fire incidents in comparison to the other districts. According to Brunei Fire and Rescue Department [47], between January and March 2016, a total of 332 forest fire calls were recorded in the district. This represents the highest number of total incidents compared to the other districts.

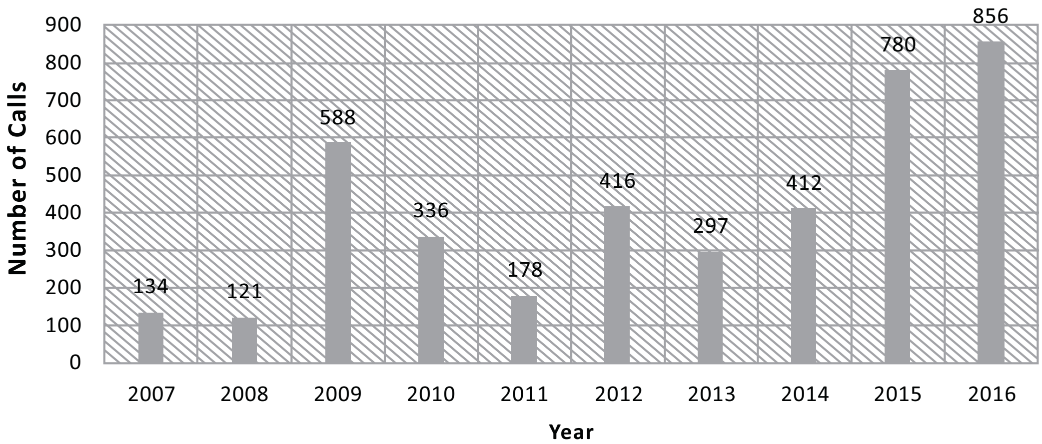

Fig. (7). Forest Fire Statistics in Brunei Darussalam (2007-2016) [47].

3.2. Forest Fire Hotspots

Fig. (**8a**) shows the forest fire calls in Brunei before Getis-Ord Gi* tool was applied, and Fig. (**8b**) shows the output of Getis-Ord Gi* tool. This tool provides output in terms of GIZScore map that indicates the hot and cold spots in the study area. In addition, it generates point features that indicate hot and cold spots in the study area (Fig. **8b**). This tool derived output named GiZScore which generates z-score value for each feature that helps to indicate the statistical significance of feature clusters, and eventually the hot and cold spots. In Fig. (**8b**), it can be seen that hotspots and coldspots are presented by points where the values were $1.576269>z>0.303554$ (red) and $-1.209978<z<-0.203445$

(blue) standard deviations, respectively. In addition, Fig. (**8b**) shows that features with high positive value of z score are specified as the hotspots (red), whereas features with low value of z score are specified as the cold spots (blue). The z score helps to indicate whether the features show a random pattern or they show statistically significant clustering or dispersion, which presents that there is an underlying spatial processes at work. Therefore, for statistically significant positive z score, the higher the value, the intense the clustering of the hotspot. For statistically significant negative z score, the lower the value, the stronger the clustering of cold spots [51], [54].

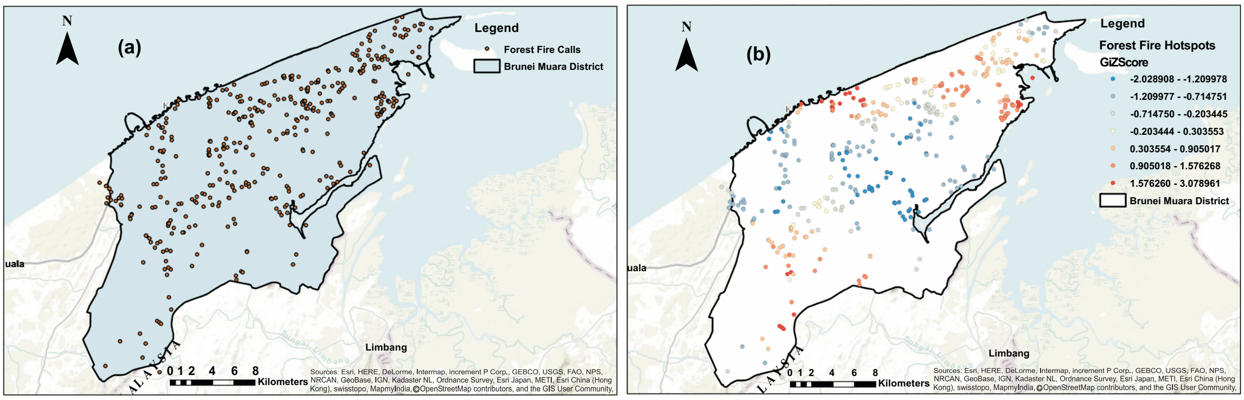

Fig. (8). (a) Forest Fire calls in Brunei Muara District (b) GIZScore Maps of Geti-Ord Gi* Hotspot Analysis.

Inversed Distance Weighted (IDW) is applied to the hotspot map generated using Getis-Ord Gi* analysis for the visualization of hotspots. IDW is one of many interpolation techniques that is widely used for mapping the spatial extension of hotspots. It creates smooth continuous surface on the forest fire hotspots distributed across the study area. The continuous smooth surface is classified into 5 different classes of hotspots, as shown in Fig. (**9**). The Very High (red) areas reflect that the areas require more attention from the local government and fire and rescue Ddepartments in managing the forest fire incidence as forest fire are more congregated with a high value of z-score in those areas. In contrast, the very low areas (blue) show the statistically significant clustering pattern of negative z-score. These areas require the least attention as they are considered as the cold spots. Whereas, the areas that are characterized high, moderate and low require a different level of attention depending on the areas.

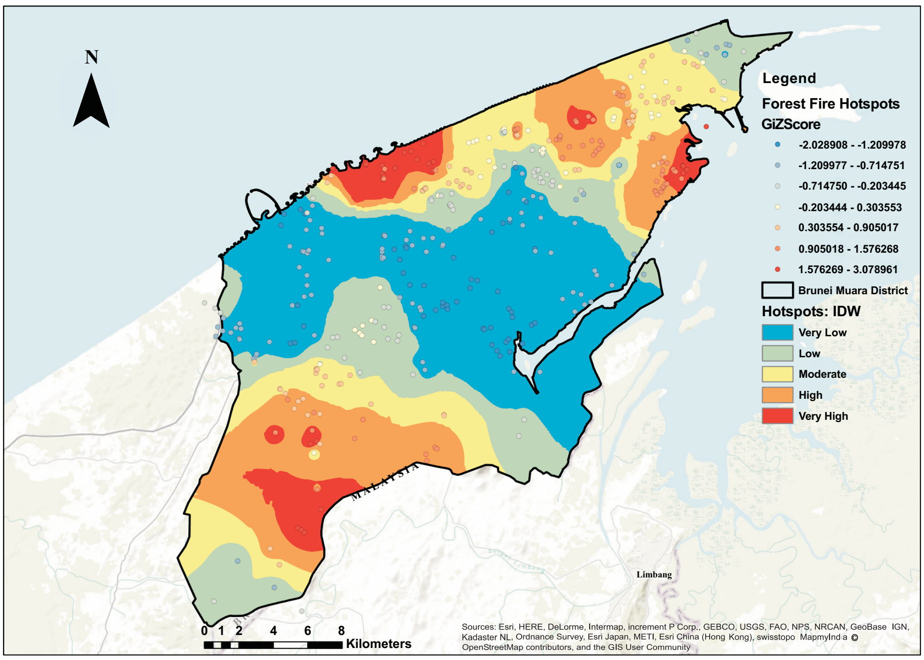

Fig. (9). IDW of GIZScore map.

In addition, Fig. (**9**) reveals that forest fire hotspots are most intensified at the Northern part of Brunei Muara District and towards the shoreline. Whereas, the cold spots are more concentrated at the centre of the district. The red zones indicate areas with significant spatial clustering that have a very high value of z score.

Regions and villages interfering with the very high hotspots marked in red are summarized in Table **1**.

Table 1. Areas and villages interfering with the very high hotspots.

Affected Area and Villages	Population	Interference Area (km^2)	Percentage (%)
Hutan Simpan	0	0.56298942	1.44
Kg Batong	1026	1.52132682	3.90
Kg Batu Ampar	690	1.217671087	3.13
Kg Batu Marang	1026	0.469313332	1.20
Kg Jerudong	3938	0.715165718	1.84
Kg Junjongan	1992	6.452455605	16.56
Kg Limau Manis	834	0.935296634	2.40
Kg Masin	2606	1.0272253	2.64
Kg Mentiri	1488	2.931044815	7.52
Kg Panchor Murai	605	1.27319762	3.27
Kg Pangkalan Batu	1196	4.117440664	10.57
Kg Pangkalan Sibabau	592	0.809976807	2.08
Kg Parit (Pengkalan Batu)	716	0.844232339	2.17
Kg Salambigar	1883	1.04955105	2.69
Kg Tanah Jambu	2348	0.377645155	0.97
Kg Tungku	1134	9.88299272	25.37
Kg Wasan	334	0.370816078	0.95
Perkhemahan Berakas	3634	0.250843157	0.64
Perumahan Negara Mentiri Kawasan A	2685	2.530165011	6.49
Perumahan Negara Mentiri Kawasan B	3136	0.126035743	0.32
Perumahan Negara Rimba Kawasan 1	1914	0.002661555	0.01
Perumahan Negara Rimba Kawasan 5	4543	0.896353147	2.30
STKRJ Lambak Kiri	2832	0.597952488	1.53

Table **1** reveals that Kg Tungku has the largest potential affected area by forest fires in comparison to other affected villages and regions. It accounted to 25.37% of the total area interfering with the very high forest fire hotspots, followed by Kg Junjongan with a percentage of 16.56%.

3.3. Fire Stations Service Area Coverage

Service area map can be useful in determining the effectiveness of the current locations of fire stations in the district. According to Fire and Rescue Department, the speed of fire pumper truck varies and depends on the road and traffic conditions. In addition, safety and surroundings also need to be taken into consideration. Speeds of 56km/h and 80km/h were, therefore, selected for this study. Speed of 56 km/h was selected based on the studies conducted by RAND [55] on average speed of fire pumper truck. This speed is the average speed of fire pumper truck considering the average terrain, average traffic, weather and interruptions at intersections. Another service area map was generated for the speed of 80 km/h. Both speeds were selected to determine the coverage area of each fire station in the study area. 5-minute and 8-minute drive-time were selected to evaluate and compare the extent of the fire stations coverage areas for the two drive-time scenarios. The service area maps produced were then integrated with the identified hotspots for evaluation, as shown in Figs. (**10** and **11**).

The green points in Fig. (**10**) reveal distant regions where it is impossible to reach within 8 minutes from any fire station in the study area at an average driving speed of 56 km/h. Kg Masin, Kg Bebatik, Kg Mulaut, Kg Kulapis and Perumahan Tanah Jambu are represented by the green points in Fig. (**10**), which indicate that these villages are the farthest locations from any fire stations in the study area. These villages and regions were also found to be located within the high and moderate forest fire hotspots. Fig. (**11**) shows that the whole study area can be covered within 8-minute drive-time at a speed of 80km/h. Figs. (**10** and **11**) also show that although a few fire stations are close to the very high hotspots, the majority of fire stations in the study area are concentrated at the very low hotspots.

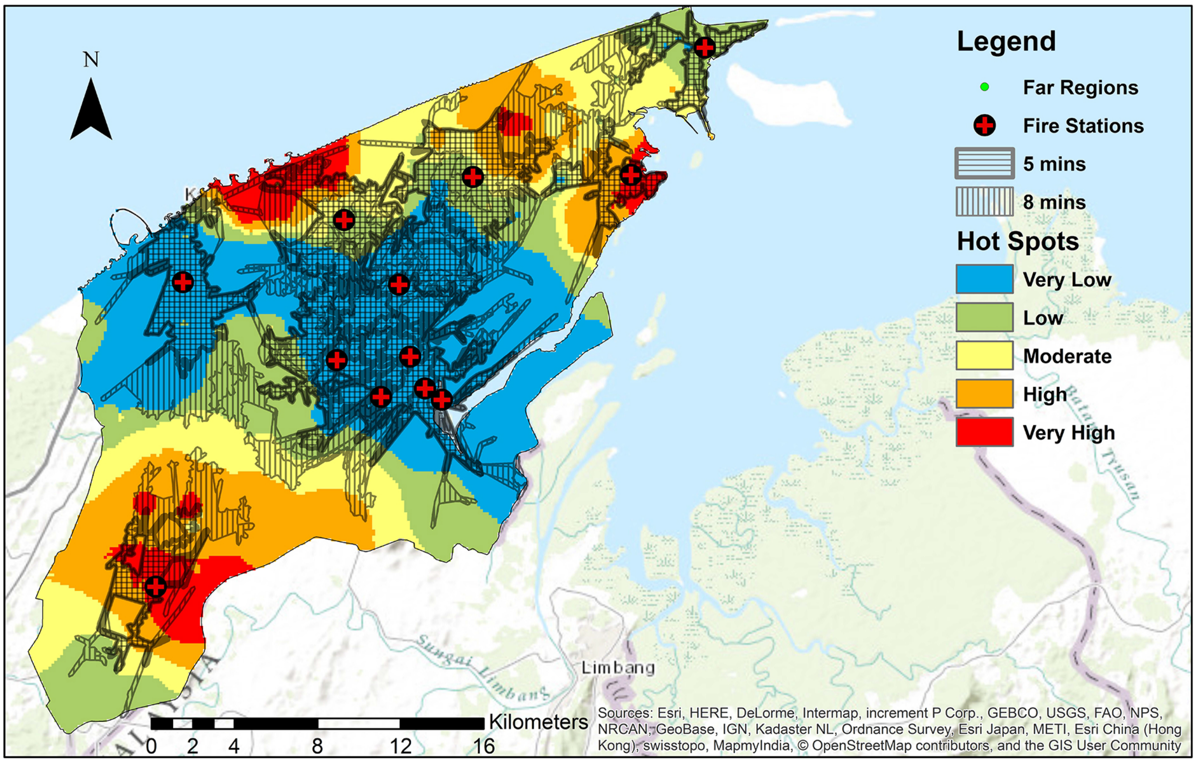

Fig. (10). Service Coverage Area of Fire Pumper Truck (56km/h).

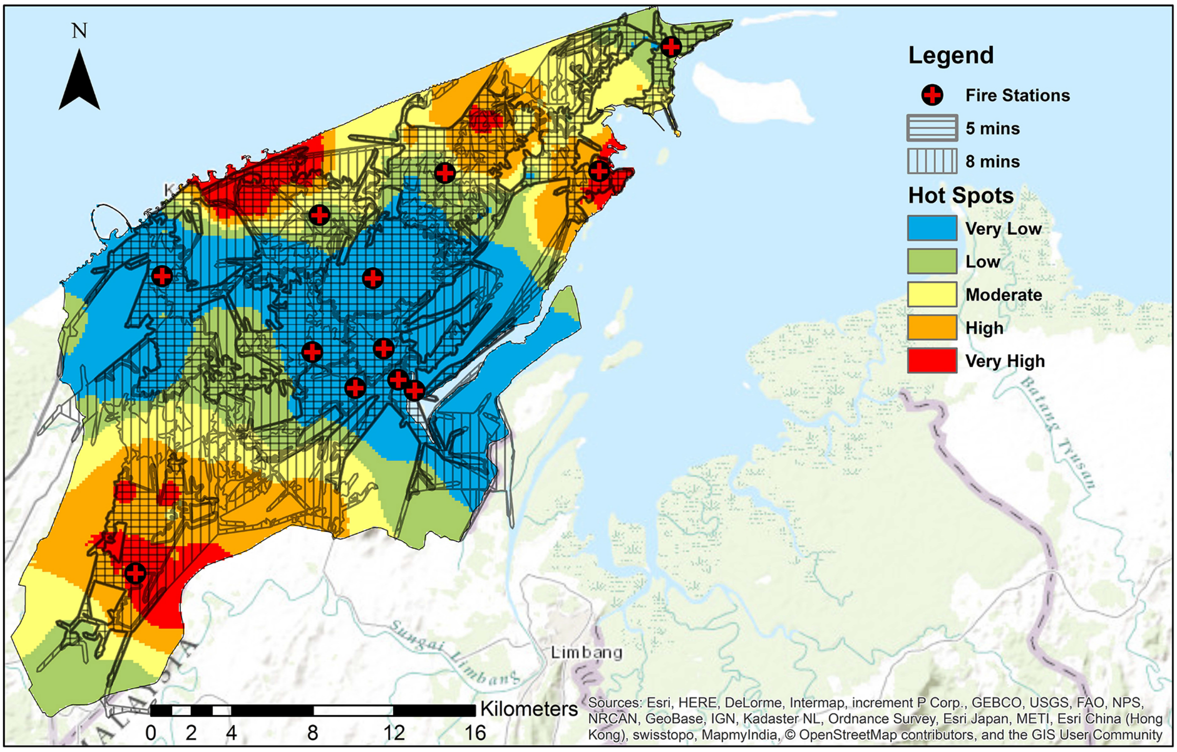

Fig. (11). Service Coverage Area of Fire Pumper Truck (80km/h).

Suitability analysis was applied on the identified hotspot to determine the most suitable location for a new fire station. The suitability analysis used [56] was to identify a suitable site for the development of new fire stations in the district. A new fire station could improve the emergency services of Fire and Rescue Department in the District. Therefore, the suitable location for new fire stations was determined based on factors shown in Fig. (**12**).

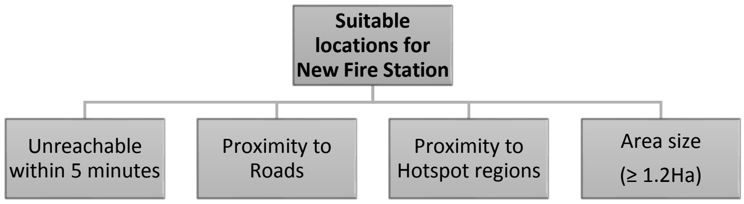

Fig. (12). Factors considered in Suitability Analysis.

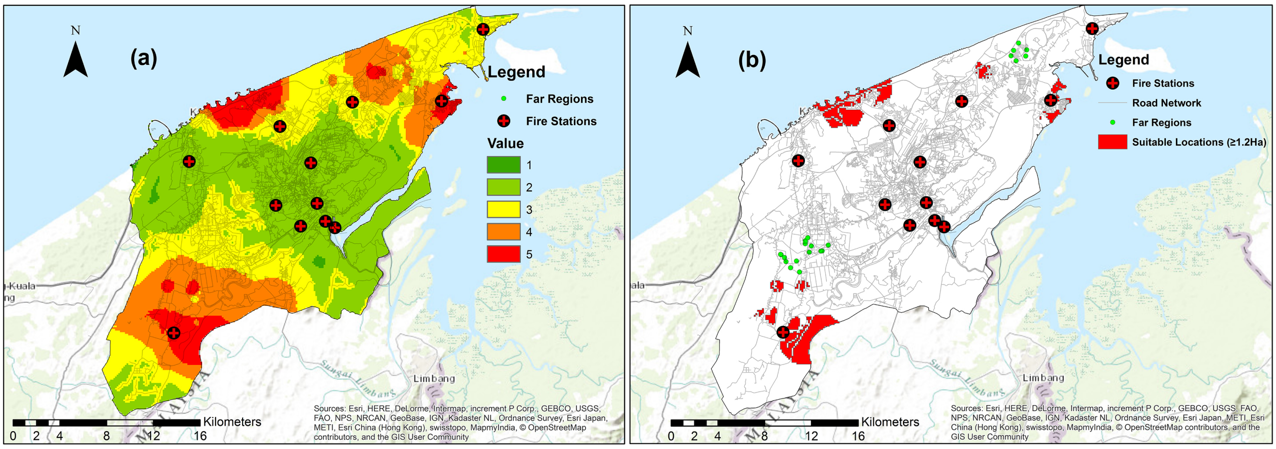

Fig. (13). (a) Suitable regions: 5 - Most Suitable; 1 - Least Suitable (b) Suitable location with area size of ≥ 1.2Ha.

Fire and Rescue Department needs a good access to road for the pumper truck. Therefore, a good potential site should be close to the main road and the hotspot regions. In addition, the new site for fire station needs to be placed in areas that are unreachable within 5 minutes by the current available fire stations in the district. Fig. (**13a**) shows the potential suitable locations for new fire station in the district. Value 5 (red) in Fig. (**13a**) indicates that the areas are the most suitable area as they lie in the vicinity of the main road and the Very High hotspot and in addition, they are away from 5 minutes' drive-time. Whereas, value 1 (green) represents the least suitable location for the fire station as it is closer to the cold spots and reachable within 5 minutes.

The newest fire station in the district was built in 2012 on an area with the size of about 1.2Ha. Therefore, in an attempt to narrow down the suitable locations, areas with size of at least 1.2Ha were identified and potential suitable location can be seen in Fig. (**13b**).

CONCLUSION AND RECOMMENDATIONS

The increasing forest fire occurrence in Brunei has damaged and affected forests in the area. Every year, hundreds of hectares of forested areas are damaged due to the increase in forest fire activities. The Getis-Ord Gi* hotspot analysis GIS approach successfully identified the forest fire hotspots at the Northern Part of Brunei Muara District and towards its shoreline. However, the locations of fire stations in this area are mostly concentrated at the core of the district, and are mostly located outside the critical forest fire hotspots. Therefore, the use of Getis-Ord Gi* hotspot analysis in the GIS for forest fire risk assessment was extremely useful for spotting the shortage of fire stations, and suggesting the suitable locations for new fire stations in Brunei Muara District. Suitability analysis for new fire station was also conducted by considering several important factors. The identified areas are, therefore, the suitable locations for building new fire stations that can help to effectively improve the emergency services of Brunei Fire and Rescue Department.

This study can be further improved by taking into consideration different parameters that affect the occurrences of forest fire such as forest type and topography. The accuracy of the identification of the forest fire hotspots can be further improved using data of forest fire calls for more than 10 years. Further study is recommended to effectively identify the service area of fire stations in the district. Road and traffic conditions need to be taken into account to determine the accurate coverage area of each fire station.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

The authors would like to thank Brunei Fire and Rescue Department, Department of Statistics (JPKE), Brunei Darussalam Meteorological Department (BDMD), and Survey Department, for providing the data needed for this study.

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