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Forest Fire Incident Forecasting System In Permanent Reserved Forest In Peninsular Malaysia Using Big Data Analytics

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ABSTRACT
Purpose – This paper summarized the research project on the implementation of big data analytics to forecast the forest fire incident in Peninsular Malaysia.
Design/methodology/approach – The research project has developed a Forest Fire Incident Forecasting System in Permanent Reserves Forest (PRF) to forecast forest fire incidence in Peninsular Malaysia. This project was conducted for the Forestry Department Peninsular Malaysia (JPSM) in collaboration with the Ministry of Natural Resources, Environment and Climate Change (NRECC) using Big Data Analytics (BDA).
Findings – The results from the system have been summarized into four conclusions. Firstly, the forecast of areas with fire potential can be identified as early as 7 days; secondly, the location of relevant agencies to deal with forest fires close to the site of the fire incident can be identified. Third, the water source close to the fire scene can be located; and finally, the estimated cost of the extinguishing operation can be determined in advance.
Practical Implications - To overcome these obstacles and accomplish wise forest management, modern science, and technology must be improved. This research project has successfully implemented BDA via the Forest Fire Incident Forecasting System in PRF. It has improved the performance of the JPSM for its forest management system.
Originality – The project is originally conducted with collaborations between the JPSM and NRECC in the Malaysian federal government and has been successfully implemented by the forestry department.

Keywords: Forest Fire Incidents, Forecasting System, Big Data Analytics, Forestry Department Peninsular Malaysia (JPSM), Ministry of Natural Resources, Environment and Climate Change (NRECC)

1.0 Introduction

The Forest Fire Incident Forecasting System in Permanent Reserves Forest (PRF) in Peninsular Malaysia using Big Data Analytics (BDA) is initiated by Natural Resources, Environment and Climate Change (NRECC). This project implemented BDA analytics to assist JPSM, on analysing and forecasting forest fire incidents that occur in PRF of Peninsular Malaysia. Peninsular Malaysia's forests are an important resource supplying a variety of services and benefits, including timber and fuel, tourism, watershed protection, and carbon sequestration (Kamaruzaman & Dahlan, 2008). However, because they endanger the ecology, the economy, and public safety, forest fire operations are growing in importance. According to Vadrevu et al. (2010) and Sivrikaya et al. (2014), it is essential to recognise the dangers associated with forest fires in order to adequately manage forest fires. Forest fire prevention activities can be better planned with an improved understanding of forest fire risks and fire suppression resources that can be allocated in areas that have higher risks. Based on historical data, the Peninsular Malaysian forest fire phenomena has shown that natural, undisturbed forests very rarely burn, and even when they do, the damage is typically not

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extensive (Kamaruzaman & Dahlan, 2008). This is a result of the high plant diversity, humid conditions, and low fuel availability brought on by effective nutritional cycles. However, in disturbed or open conditions of forestland, which are drier and have plenty of wood debris that act as fuel, the forest may become more susceptible to fire.

In Peninsular Malaysia, burning by people (farmers and plantation owners) typically results in the majority of forest fires coming from outside the forest. Strong gusts and improper burning procedures could cause the fire to spread to surrounding woodlands. There have been instances where the fire started inside the forest, for example, from campfires lit by campers and hunters that were not properly put out. The El-Nino Southern Oscillation (ENSO) phenomenon occasionally causes extended dry circumstances that can cause water in wetland forests, especially the peat swamp forests, to dry up, making them extremely flammable. Such regions can burn for extended periods of time because the fire spreads underneath. In comparison to surface fires, burning also has a tendency to produce a greater quantity of smoke and contaminants into the environment. Every year, forest fires cause an environmental catastrophe. This results in a lack of national forest cover and indirectly reduces forest production. The production of optimum forest produce is essential to ensure economic growth for a country. As such, it is the responsibility of JPSM to maintain forest resources, ecological balance and environmental stability. Efficient planning, management and monitoring ensure that the forest area is managed and maintained sustainably. Historically, forest fires often occur in peat swamp areas which often take a long time to extinguish. As many as 12,000 hectares of 254,000 hectares of peat forest in Peninsular Malaysia have been exposed to forest fires that have resulted in significant losses, including the loss of flora and fauna found in this area. Hot weather and heat waves, particularly throughout dry times, are seen as the cause of forest fires in Peninsular Malaysia, especially in peat swamp areas. These events often have a devastating impact on the life of flora and fauna and the habitats. Continued incidents will also have a major impact on the air quality around the impacted area and could worsen throughout the country as a whole. The dry, hot weather and El Nino have become a major factor that is faced by the country which leads to prolonged drought conditions. This situation has caused several factors such as low soil moisture content and high potential fuel, thus causing forest fires, especially in the peat areas. The land opening is another factor by conducting open burning for agriculture purposes on private or government land near the boundary of the permanent reserved forests area, especially during dry and hot seasons that have led to a high number of forest fires incidents.

In BDA, there are three types of data analytics:

a) Descriptive Analytics are the conventional forms of Business Intelligence and data analysis.

It aims to offer a clear description or summary view of facts and data. It reports historical events using two main techniques: data aggregation and data mining. The validity of results is easier to apply because this type of analytics typically only goes beyond surface analysis. Observations, case studies, and surveys are a few popular methodologies used in descriptive analytics (Bayyurt & Baday, 2022).

b) Predictive Analytics are used to make predictions about unknown future events.

Predictive analytical models record links between several risk assessment factors under a shared set of criteria for calculating a score or weighting. Businesses may effectively analyse big data to their advantage by using predictive analytics. To forecast future events, history and present data are analysed using methods from artificial intelligence, machine learning, statistics, modelling, and data mining. It appears that machine learning has not been widely utilised to investigate forest fires in Malaysia, as mentioned by Chew et al., (2022), but similar approaches have been successfully used in many other countries since they have been receiving greater scrutiny now. Therefore, it is suggested that using machine learning methods will assist Malaysia with the issue of predicting or detecting fires.

c) Prescriptive Analytics provides organisations with recommendations around optimal actions to achieve business objectives.

Prescriptive analytics also refers to the factors that deliver information on possible outcomes or scenarios and suggests a course of action or strategy. In other words, prescriptive analytics anticipates what, when and why it happened and thus suggests options to diminish further threats. Furthermore, prescriptive analytics can improve prediction accuracy after adjusting with the new data that has been inserted (Lepenioti et al., 2020).

Based on this project, users have decided to implement Descriptive Analytics for Problem Statement 1, 2, 3 and 4. Implementation of Predictive Analytics is for Problem Statement 1 and 3, while Prescriptive Analytics is for Problem Statement 2, 3 and 4.

1.1 Research Objectives

The objectives of this research are to:
1.1.1 Develop a prediction model identifying the location of potential forest fire hotspots;
1.1.2 Identify the other related agencies in dealing with forest fire;
1.1.3 Identify the cost needed during forest fire operations; and
1.1.4 Identify the nearest available water source location to the hotspots.

1.2 Scope of the project

The scope of the project includes developing dashboards, visualisations and relevant analytics. The scope also covered on inputs used, describing the processes involved (data acquisition, data cleansing, data exploration and data automation) and visualised the outputs including dashboard and analytics for business case in analysing and forecasting forest fire incidences for JPSM. This project covered all of the PRF in Peninsular Malaysia and the proximity (adjacent) area up to 1km outside of its border.

2.0 Research Design

The project adopted Big Data Analytics (BDA) to develop the Forest Fire Incident Forecasting System in Permanent Reserves Forest (PRF) to improve the forest management system. The BDA adoption technique is increasingly in demand and have been implemented by recent studies on forest management and SMEs (Maroufkhani et al., 2023; Hasan et al., 2019). One of the disruptions in the ecosystems of forests around globally is forest fire incidences. It influences the forest ecosystem processes by affecting the ecological succession and nutrient availability in the forest soils. In the evergreen tropical forest ecosystem, during the ENSO-induced drought, forest fire occurrences can be very damaging since the trees are not adapted to the high temperature from fire and will deteriorate the forest ecosystem, leading to habitat destruction and biodiversity (Musri et al., 2020; Nuruddin, 2019). Forest fire in tropical forest is mainly caused by human induced activities. Fire has been used to burn trees in forested areas and convert the burnt areas into agriculture spaces. During this activity, some of the fire became uncontrolled and burnt adjacent forest reserved areas. In 1982/83 several thousand hectares of forest areas were burnt in Sabah due to prolonged drought brought by El Niño-Southern Oscillation (ENSO) in the Pacific Ocean. ENSO comes in every 5 to 7-year cycle and in 1992/93, Malaysia and neighbouring countries experienced forest fire incidences which lead to environmental impacts such as heavy haze and biodiversity destruction. The haze has caused a steep increase in respiratory illness among the high-risk population such as the elderly (Musri et al., 2020).

Based on the current practice, a forest fire incident can only be known when someone makes a report after an observation. By the time agencies arrive at the scene, the fire may have become huge and sometimes catastrophic, which will cost a lot of resources in fighting the fire. To reduce the required resources that need to be borne by the government and other parties, early preventive measures should be adopted so that actions can be taken to prevent the forest fire from happening or spreading to a larger area.

Generally, a fire can be detected as a hotspot from the satellite that will be marked as red in colour. If a hotspot is found in a forest, it means that a forest fire is happening in a particular area (Kumar & Kumar, 2022; Yukili et al., 2016). With the help of the satellite, a forest fire can be detected if the hotspot has fallen into a PRF. This capability to detect fire makes forest fire prediction an essential function in preventing or minimising the impact of the forest fires (Sitanggang et al., 2013; Wijayanto et al., 2017).

As a result of the forest fire incidents, the estimated cost of the damage in Malaysia is about RM816.47 million a year which leads to negative implications on the socio-economic, health and well-being of the human. Therefore, this will result in global problems such as deforestation, global warming, or desertification. The impacts of forest fire can be minimised by having a good forest fire management and early detection system. The essence of a good early detection system is the quick detection of forest fire and the response of the forest fire suppression team to put out the forest fire. The deployment of geographic information systems and remote sensing, extensive weather observation systems and big data analysis can help in the development of early detection systems for forest fires (Feng & Zhou, 2023; Sewak, Vashisth & Gupta, 2021). Currently, in Malaysia, there is no such system available that integrates all these technologies for detecting forest fires. It is recommended that this system be developed to support the effort currently implemented by JPSM. This system will further enhance and complement the capability of JPSM to suppress forest fire more effectively using the state-of-art technology.

When a forest fire prediction can be implemented, resources of the agencies can be planned in mitigating the process of suppressing and curbing the fire from getting into an uncontrollable size. Many factors, such as meteorological conditions, land use, settlements, types of forests and others can be used for the analysis of forest fires prediction (Feng & Zhou, 2023; Pourtaghi et al., 2016). At the same time, the cost of the fire operation can be predicted depending on the area of the location. Finally, the water source can be planned for arrangements before going to a site for a forest fire operation.

In order to develop the system, four (4) problem statements have been identified as below:

Problem Statement 1
Where is the potential location for forest fires? What is the relationship between environmental factors (weather, soil, land use, settlements) and forest fire?

Issue
Forest fire occurrences are posing serious risks to the ecology, the economy, and public safety. It takes a lot of effort to analyse manually by humans as it involves a lot of analysis from the input dataset from a few environmental factors. The strength of existing forest fire management and prevention efforts can be strengthened by identifying hotspots for forest fires (Chew et al., 2022).

Expectation
1. To identify of affected PRF;
2. To identify current and predicted hotspot location;
3. To generate the FWI data; and
4. o display all environmental factors leading to forest fire incidents.

Output
Modelling:
1. Predicted Hotspots
2. FWI (Fire Weather Index)

Visualisations:
1. Map layer of PRF consist of types of forests (Descriptive)
2. Current and predicted hotspot location (Predictive)
3. FWI map layer (Descriptive)
4. To display all environmental factors leading to forest fire incidents
a. Location of historical forest fire incidents
b. Location of settlement (Villages & Residential) (Descriptive)
c. Location of land use (Descriptive)
d. Location of Eko Rimba (Descriptive)
e. Location of Commercial Plantation (Descriptive)
f. Map layer of road (Descriptive)

Data Required
1. Historical and current hotspot
2. Forest fire incidents history

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3. Weather condition: wind speed, rainfall, temperature, humidity
4. Location of PRF
5. Settlement (Villages & Residential)
6. Land use
7. Road
8. Taman Eko Rimba
9. Commercial Plantation

Problem Statement 2
What is the level of availability of resources and related agencies to deal with forest fire?

Issue
It is difficult to get in contact with fire extinguishers control agencies when a forest fire happens. Theoretically, it is unknown how resource availability affects fire suppression costs. In one way, having more resources available might enable quicker and more effective fire line construction, resulting in lower unit costs. Due to a management incentive mechanism that promotes risk-averse behaviour and raises unit prices, it is possible that the availability of resources will encourage excessive resource consumption (Shuaib, Parsa, & Zehra, 2023; Solutions, 2022). On the other hand, a dearth of resources can force a revised, less-aggressive suppression strategy in some parts of the fire zone, leading to a bigger fire area and a reduction in unit costs.

Expectation
1. To show the location of related agencies; and
2. To show the route and distance agencies from predicted hotspots.

Output
Modelling: Route and distance

Visualisations:
1. Location of related agencies from predicted hotspots:
a. Location of observation towers (Descriptive);
b. Location of Fire stations (JBPM) (Descriptive)
c. Location of Pejabat Hutan Daerah and ranger's office (Descriptive); and
d. Location of Angkatan Pertahanan Awam Malaysia (APM) (Descriptive).
2. Route and distance of agency to the hotspot (Prescriptive)

Data Required
1. Location of observation tower;
2. Location of fire stations (JBPM);
3. Location of Pejabat Hutan Daerah and ranger's office; and
4. Location of Angkatan Pertahanan Awam Malaysia (APM).

Problem Statement 3
What is the cost of a forest fire operation?

Issue
According to Zhang, Lim and Sharples (2016) as cited by Shekede, Gwitira and Mamvura (2019), it is hard to allocate funds for the cost of fire extinguishing operation as it may vary. Due to the high expense of battling forest fires, the nation's budgetary and policy discussions now prioritise fire suppression spending. Considering that large flames account for the majority of fire suppression costs, it is crucial for both strategic fire planning and onsite fire management decisions to understand the fire characteristics that affect costs. For use in forest fire decision support or after-fire reviews, these features can then be utilised to provide estimates of suppression costs for significant forest fires.

Expectation
To visualise an expected costs that will be incurred for the forest fires operation on the predicted hotspot.

Output
Modelling: Costing

Visualisations:
Visualisations of expected costs:
a. Number of days taken (Predictive, Prescriptive);
b. Burned Area (Descriptive, Predictive, Prescriptive); and
c. Total cost (Descriptive, Predictive, Prescriptive).

Data Required
Total cost of forest fire operation:
1. Number of days of taken;
2. Total cost (RM); and
3. Burned area (ha).

Problem Statement 4
Does the forest fire have a water source for forest fire operation?

Issue
Maintaining a sufficient supply of water through appropriate water transportation is an essential requirement for the quick localization and extinguishment of a forest fire. Transporting water to put out forest fires, particularly in terrain that is highly tough, is a challenging problem in firefighting strategies. The effectiveness of the intervention depends on how many extinguishing agents are available during the fire (Musri et al., 2020).

Expectation
1. To display water source locations near the predicted hotspot;
2. To display the distance of the available water sources to the predicted hotspot; and
3. To display the straight line distance of water source to the predicted hotspots.

Output
Modelling:
1. Route and distance; and
2. Distance of straight line.

Visualisations:
1. Water source locations near the predicted hotspot (Descriptive);
2. Distance of the available water sources to the predicted hotspot (Prescriptive); and
3. Straight-line distance from water source to the hotspot (Prescriptive).

Data Required
1. Location of tube well;
2. Location of lake;
3. Location of river;
4. Location of dam; and
5. Location of canal.

3.0 Results

3.1 Predicted the forest fire hazard potential area in PRF

The forest fire hazard potential area in PRF will be plotted into a map. This is based on the Fire Danger Rating System (FDRS) that provides information to support fire management. FDRS will predict fire behaviour that will facilitate FDPM to make decisions on fire mitigation and smoke haze pollution. Colour coding was used as shown in Table 1.

Forest fire - prone area

Land cover	Slope	Aspect	Settlement	Road	Elevation
Forest	< 2.25	Flat/South	<500	<1000	<100
Agriculture land	2.25 - 4.73	East/South-East/South-West	500 - 1000	1000 - 2000	100 - 200
Bare Land	4.74 - 8.10	West/North-East/North-West	1000 - 2000	2000 - 3000	200 - 300
Built-up	8.11 - 14.17	North	2000 - 3000	3000 - 4000	300 - 400
Water bodies	>14.17		>3000	>4000	>400

Table 1 (Enoh, Okeke, and Narinua, 2021)

Sustainable Energy and Environment Review
Volume 1, issue 1
DOI: 10.59762/seer924712041120231103143053

The current forest fire hazard potential in PRF areas will show the real-time map that is considered as happening now (present day) whilst prediction Map has shown present day of hotspot in PRF areas in Peninsular Malaysia can be calculated up to 7 days. The prediction forest fire hazard potential in PRF areas consists of required data that are essential for further processing that includes previous forest fire hazard potential in PRF areas, forest fires history and previous weather conditions. Fire Weather Index (FWI) works as one of the inputs alongside other data such as meteorological data, settlements, land

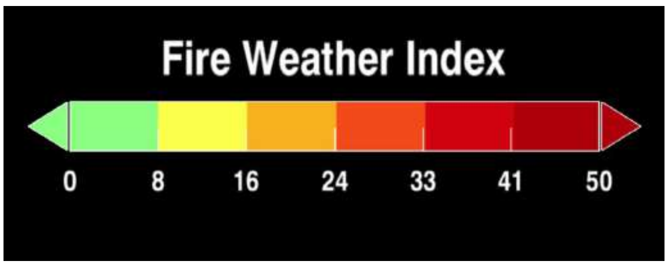

Figure 1 Svs, 2023

use and roads. If an area has a red FWI indicator, it is likely that the probability of the hotspot occurring is high. By having this indicator, this will assist in increasing the accuracy of forest fire hazard potential prediction together with other data. Figure 1 shows the predicted forest fire forest fire hazard potential area in PRF on map.

3.2 Identification nearby firefighting agency (location and distance)

BDA can also calculate and identify the route and distance from the current forest fire hazard potential in the PRF area to the nearby firefighting agency facilities such as JBPM, APM, Forest District Office, Forest Ranger's office and Forest Fire Observation Tower. The route and distance will be displayed in the mouse-over box on a map. At the right-side panel, a histogram of the nearest agencies to the current forest fire hazard potential in the PRF area will be displayed. The input data for these tasks are the location of JBPM, APM, Forest District Office, Forest Ranger's office and Forest Fire Observation Tower. At the processing stage, the acquired data will be tabulated on the map so that distance and routing calculation is performed using the map's application. Figure 2 shows the route and distance from the nearby firefighting agency to the current forest fire hazard potential in PRF areas.

3.3 Identification of the water location sources and other facilities for the Forest Fire Operation

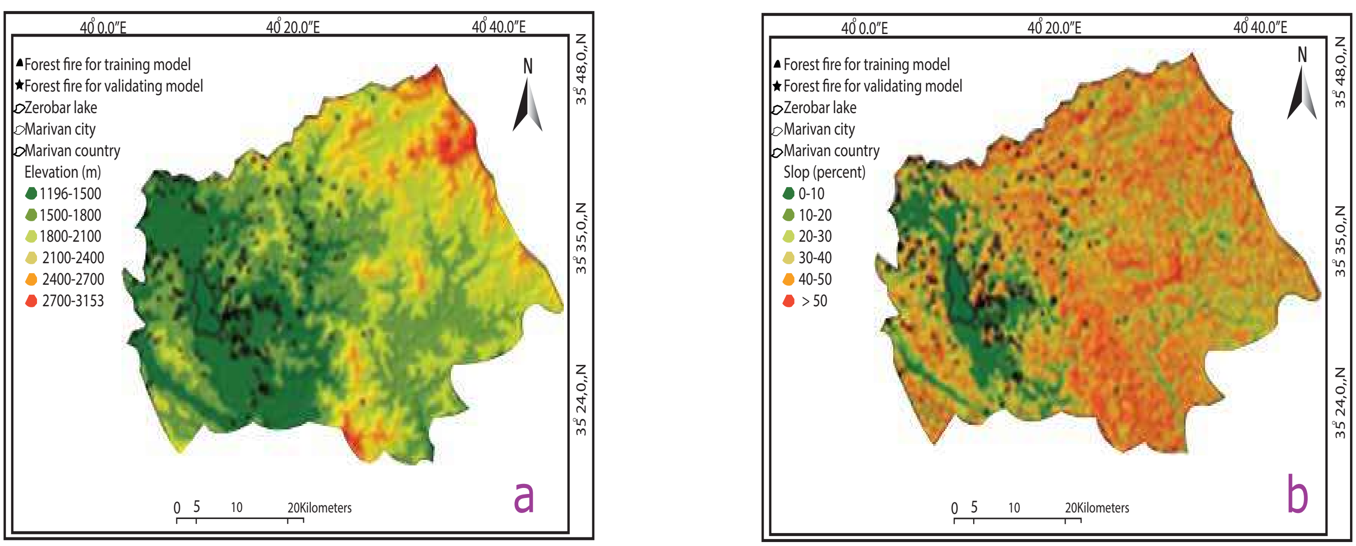

Figure 2 shows the route and distance from the nearby firefighting agency to the current forest fire hazard potential in PRF areas.

Sustainable Energy and Environment Review
Volume 1, issue 1
DOI: 10.59762/seer924712041120231103143053

The system was set to locate the nearest water sources such as river, canal and lake nearby and other facilities such as tube well, check dam available and also Watch Tower that was built to the nearest predicted hotspot location. This will provide an adequate supply of water for suppressing forest fire activities, particularly in exceptionally rough terrain, which represents an obstacle in fire suppression methods. Figure 3 showed some of the water sources and other facilities that the system managed to locate.

Figure 3

3.4 Calculation of the estimation cost of firefighting operation

BDA can do the calculation for estimation of the cost of firefighting operation. The expected output would be the overall cost that will be incurred for a forest fires operation. At this stage, a correlation between area sizes and the duration of the firefighting operation cost will be used. The value of the expected cost will be displayed at the side panel of the screen on the selected hotspot as can be seen in Figure 4.

4.0 Conclusion, Implications And Future Research

With the development of technology such as big data, mitigating techniques can be devised to address one of the country's most pressing environmental problems: forest fires. The predominant aim of this research is to develop a prediction model that could identify the location of potential forest fire hotspots, the cost involved during forest fire operations; and determine the location of the nearest available water source by applying big data. In this study, the development of a Forest Fire Incident Forecasting System in Permanent Forest Reserves in Peninsular Malaysia by involving Big Data Analytics (BDA) has been proven to help JPSM to implement an effective monitoring on forest fire. This definitely should reduce the spread of forest fires and minimize the cost of forest fire fighting operations. Apart from that, BDA system can help JPSM preserve forest biodiversity from being lost due to forest fire incidents.

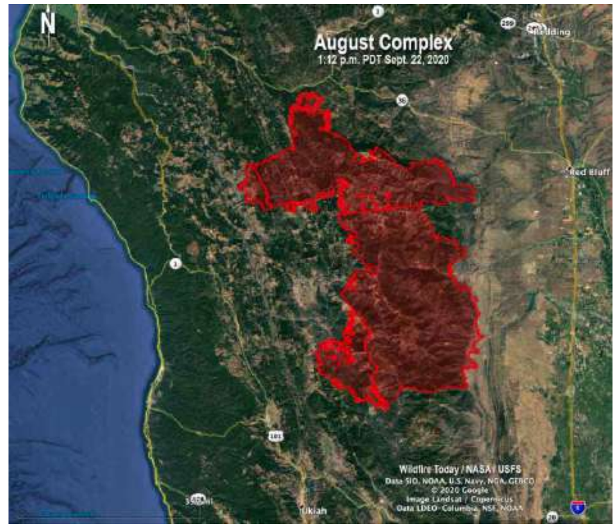

Figure 4 Wildfiretoday, 2020

4.1 Theoretical Implications

In past studies, most of the researchers have focused on one specific area or locality a lack of independent methodology settings has made it difficult for others to replicate the study. According to Chew et al., (2022), there were no previously published studies that applied machine learning for forest fire management in Malaysia. Hence, this study which covered the whole Peninsular Malaysia's PFR to identify hotspots for forest fire using big data provides a more inclusive understanding with higher applicability on a global scale. Moreover, it is believed that this study paves the way for An innovative approach for employing big data infrastructures not just for commercialization purposes by companies but also proved to be useful in nationwide planning and management. Theoretically, the popularity of machine learning and artificial intelligence may encourage academics to use large data to their advantage and create algorithms to address the problem of forest fires. In retrospect, unlike the BDA system, conventional computing platforms might not be able to process and analyse massive and complicated data. Since fire incidents may occur differentially depending on the geographical topologies, local climates, and forest conditions, The topographic risk index, weather danger index, and fuel danger index were only a few of the various indices that previous researchers took into account while creating their forest fire risk index model. These indices were generated utilising the slope, aspect, and elevation factors. Yet the accuracy of these calculations are often impeded by the lack of complete weather information (Chew et al., 2022). Hence, the BDA system in forest fire prediction offers a more superior approach.

4.2 Practical Implications

There are a few main practical implications that can be achieved by using this system. Firstly, the developed fire potential prediction model can be used by the monitoring team to make preparations before the fire incident occurs. With this, relevant government agencies in dealing with forest fires can be identified in a short time as a preventive measure. Specifically, the management of JPSM can monitor the occurrence of forest fires to formulate policies, work plans and mitigation measures in forest fire management to reduce forest loss and destruction and its consequences. Moreover, the costs required during forest fire operations can be estimated by using the BDA system. For the government departments such as the Department of Environment (DOE) and the forest rangers, the BDA system enables better environmental quality control and local population management in case a fire breaks out. Secondly, for researchers from public and private higher education institutions, this study enables the use of certain data for further investigation purposes to improve the existing policies and operations in an effort to help control the frequency that forest fires occur. In addition, this study acts as a source of reference in providing insights on some strategies in overcoming the impact To be a source of reference to other agencies in overcoming the impact of illegal logging and forest exploration incidents as well as to make environmental land use development plans. Lastly, for the public, particularly the local community, such disclosure of certain data from the BDA system may be a source of reference in educating the public about the causes of forest fires. Apart from that, it also helps the public to always be vigilant about fires that will occur if they are in the vicinity of an area that has the potential to burn. Early preventive actions can be undertaken to evacuate the area before any bodily harm takes place.

4.3 Limitation and Future Research

This research gives many benefits to various stakeholders that are related to the PRF in Peninsular Malaysia. However, this research has its limitations. Firstly, this research is only focusing on PRF in Peninsular Malaysia. It is suggested that for future research, this research should be done in other locations outside Peninsular Malaysia such as Sabah and Sarawak to tackle this issue widely. According to Chew et al. (2022), a number of fire occurrences have recently been documented in Sabah and as a result, the selected places are thought to be ideal for future experimental investigations on forest fires. The second limitation is this research is mainly using BDA for forecasting the forest fire incident. To support the findings based on the method used in this research, future research may extend this research by using other additional methods or techniques in forecasting the forest fire incident. This will allow for comparison and improvement to be made in order to obtain a more accurate forecasting result.

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