SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Integration of Early Warning Systems and Mobile Apps to Enhance Hot Spot Forest Fire Detection and Response

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ABSTRACT

A forest fire is a natural disaster that is caused by hot weather and a very dry landscape in a certain place. However, it also can be caused by human activity such as excessive logging activity, open burning that can cause thinning in the ozone layer and excessive use of chlorofluorocarbons (CFCs). Today, it appears that most people own smartphones and a variety of mobile applications are available to assist users in their daily lives. To identify the susceptibility of hotspot forest fires in Sungai Karang and Raja Muda Musa Forest Reserve, Selangor, Malaysia, this study investigates the causes that cause forest fires. The objective of this project is to develop an early warning phone application using Android Studio and Java programming languages. The method that will be used in this project is by using satellite images from LANDSAT 8 from the USGS website. To support this study, a variety of data or parameters, including LST, NDVI, NBR, NDMI and LULC have been gathered and compiled using a Geographical Information System (GIS). This information was taken from the shapefile of Landsat 8 after it underwent supervised classification. Then, all data taken will be used to develop a phone application using Android Studio and Java programming language. The result is all users can notify the condition of the landscape in Sungai Karang and Raja Muda Musa Forest Reserve which can start a forest fire in real time.

Keywords:

Forest fire; LULC; GIS; NDMI, NBR; LST; NDVI; early warning system; landsat 8

1. Introduction

An uncontrolled fire that starts in a wilderness area like a forest, meadow or grassland is known as a wildfire. Everywhere and at any moment, wildfires can start and are frequently sparked by human activity or a natural occurrence like lightning. Strong winds and extremely dry conditions, such as drought, both increase the risk of wildfires [1]. The issue with forest fires is that they frequently occur in remote, abandoned or poorly managed regions that are full of trees, timber that is dry and

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https://doi.org/10.37934/araset.XX.X.92109

parched, leaves and other materials that serve as fuel. A precise and thorough characterization of fuel is essential during wildfire events to forecast fire behaviour and guide suppression efforts [2].

In the study area, Sungai Karang and Raja Muda Musa Forest Reserve, Musri *et al.,* [3] stated that approximately 23,486 acres of peat swamp forest make up the Raja Musa Forest Reserve (RMFR), which is situated in Malaysia's Selangor State's Kuala Selangor District. About 1,000 ha near the southeast corner of the RMFR were found to be degraded peat swamp forest that had seen numerous forest fire incidents, depleting the seed bank embedded in the peat. The state of a particular location will be assessed using remote sensing and satellite pictures. With the development of remote sensing and GIS, academics have been more interested in modelling the locations of forest fires. Remote sensing data has been used to simulate forest fire danger zones at the local, regional and temporal scales. The process is rapid, non-invasive and offers vast coverage in comparison to the traditional field-based observation method [4].

To determine the likelihood of forest fires occurring, some parameters were taken into consideration. Let's start with land use and land cover (LULC). Alawamy *et al.,* [5] claimed that the rapid change in land use and land cover (LULC) brought on by an increase in anthropogenic activities because of the world's population growth has had a detrimental effect on the environment by causing forest degradation and the conversion of fertile land to urban development. The surface energy budget and regional microclimate have changed because of the conversion of naturally occurring land into impermeable areas [6]. Based on how the plant transmits light at wavelengths, the Normalized Difference Vegetation Index (NDVI) is typically used as a graphical indicator in the analysis of remote sensing to measure the status of plant health [7]. The spongy layer on the underside of the leaves reflects visible and near-infrared light, which is used to calculate the NDVI. When a plant is undernourished or stressed, the spongy layer fractures and the leaves reflect less NIR light but the same quantity of visible light.

Normalized Difference Moisture Index is referred to as NDMI. It is a vegetation index that is frequently used to evaluate the moisture content or water stress of vegetation in remote sensing and satellite image processing. The reflectance values of the near-infrared (NIR) and mid-infrared (MIR) wavelengths are used to calculate NDMI. Based on Rahman and Mesev [8] the normalized difference moisture index (NDMI) is a measure that is highly correlated with canopy water content. Normalized Burn Ratio (NBR) is to evaluate the severity and scope of burned areas following a fire event, it is a vegetation index that is frequently used in remote sensing and satellite imagery analysis. The effects of fire on plant reflectance are measured using NBR. As in Konkathi and Shetty [9] analysis of the burn severity is essential for the forest agencies to control fires and repair damaged areas after the fire season.

By promptly identifying wildfires using multispectral images, which are available from constantly orbiting satellites. Environmental satellites have a wide spatial coverage as well as great availability and timeliness. Applications for precise and trustworthy wildfire identification using deep learning for monitoring and mitigation. By examining the presented results, the author analyses strategies based on machine learning algorithms for forest fires prediction and detection systems reported in the recent literature and discusses their advantages and disadvantages [10].

Modern smartphones serve a multitude of purposes beyond just making calls and sending texts. They are equipped with various sensors such as accelerometers, gyroscopes, barometers and GPS, which can detect a wide range of activities and functions [11,12]. Hence, developing mobile applications can help people to have easy access to forest fire susceptibility in certain areas. It also helps multiple individuals such as the forest department to make prevention and helps the government and firefighters department to make early notification to evacuate the nearest people to a safe place. Based on the research by Qayum *et al.,* [13], the state has been able to prevent significant damage to biodiversity, flora and fauna, human life and public property thanks to the "eForestFire" initiative, which has not only increased public awareness but also allowed authorities to build fire lines, watch towers and other structures at the appropriate location and time to prevent a fire before it breaks out.

A hotspot susceptibility forest map is made using the Analytical Hierarchy Process (AHP). AHP will splitting down the complex Multi Criteria Decision Making (MCDM) into a hierarchy of connected parameters [14]. Satellite images from LANDSAT 8 were used to compute the Normalised Difference Vegetation Index (NDVI), Land Cover or Land Use (LULC), Land Surface Temperature (LST), Net Burn Ratio (NBR), Normalized Difference Moisture Index (NDMI) to evaluate the study's vulnerability [15]. These are all the elements that will be considered while developing the phone app for this study.

By promptly identifying wildfires using multispectral images, which are available from constantly orbiting satellites. Environmental satellites have a wide spatial coverage as well as great availability and timeliness. The development of precise and trustworthy wildfire identification methods using deep learning for applications in monitoring and suppression. Multiple layers in deep learning architectures, particularly deep neural networks, enable the collection of multispectral data in both temporal and spatial dimensions. It is feasible to create an early warning system with faster detection and accuracy using the previously collected data.

The objective of this research is to develop a mobile application that has an early warning system for forest fire in real-time by using Android Studio, Google Maps API and Java programming language.

2. Methodology

To assist and make the data gathering process for this project as simple and easy as feasible, the appropriate methodology should be used. Making sure the data collected for the study is pertinent to the research task is essential.

2.1 Material and Data Collection

ArcMap, Google Earth Pro and QGIS tools are utilised to create the map in the mobile applications. utilising Java programming language and the Google Maps API, we can construct an application that displays hotspot forest fires while utilising Microsoft Visual Studio as a tool to create mobile applications using C++ programming languages.

2.1.1 Study area

Raja Musa Forest and Sungai Karang in Selangor are the study locations. The study locations are located upper left (3°23'53.6"E and 101°30'36.3"N) and lower right (3°45'; 18.05"E and 101°30' 55.33"N), respectively as shown in Figure 1. Peat bogs with a total size of up to 23,486 ha and land encompassing more than 6,500 ha can be found in the Raja Musa Forest Reserve and Sungai Karang region. The reason for using this study area is Sungai Karang and Raja Musa Forest Reserve have LULC change since 1989 based on the previous research article. Therefore, it is suitable for developing a forest fire susceptibility map.

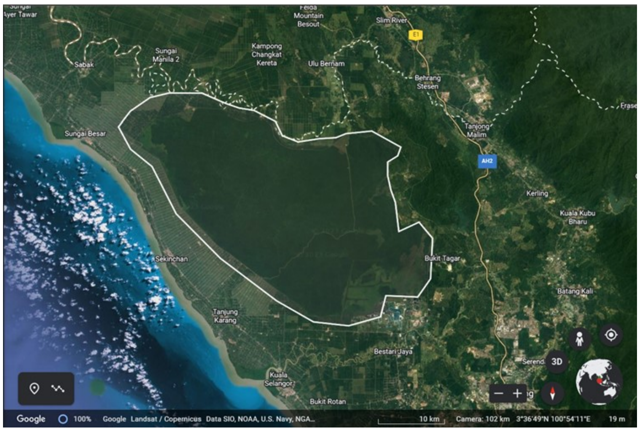

Fig. 1. Map of Raja Musa Forest reserve

Satellite images are obtained from the USGS website using satellite Landsat 8. It is compulsory to obtain satellite images with low cloud coverage to increase the accuracy of data. The images obtained on 24th March 2023 have the lowest cloud coverage. Then, the images used for extracted and classified. The obtained satellite image will be extracted and classified according to factors of forest fire used. After all the factors maps are produced, the Analytical Hierarchy method will be used to obtain a hotspot forest fire map of the study area. All these methods will be using raster calculators in ArcMap 10.8. Next, using Android Studio and Java programming language to produce early forest fire warning applications.

2.2 Method & Framework

The framework of this research as shown in Figure 2 starts with obtaining satellite images for each factor to require the susceptibility hotspot map in the study area. From satellite images, remote sensing can view the satellite images in many characteristics based on the satellite used. García-Berná *et al.,* [16] stated that it can be thought of as a subset of Earth observation, using sensors deployed on a variety of platforms, including satellites, aircraft or ground-based machinery, to collect and interpret data on crops and soil properties. Then, it can be used to classify and combine using raster calculations to obtain a specific factors map. By processing and analysing data using the AHP method the exposure hotspot map can be obtained. After all, data is obtained coding will be developed to create a mobile application.

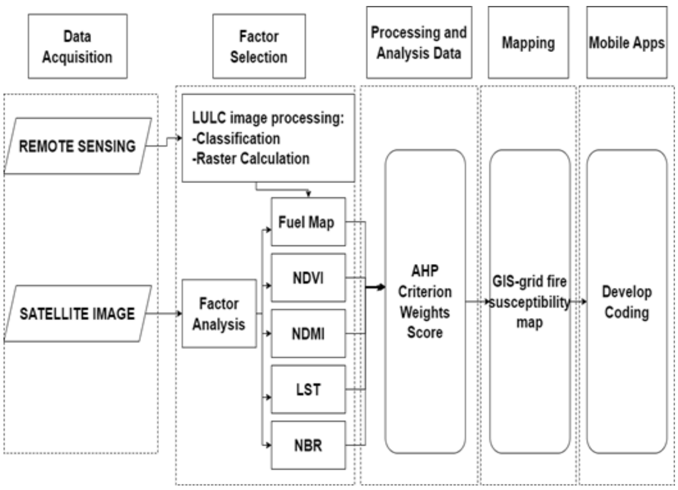

Fig. 2. Framework of research

2.2.1 Data acquisition

Firstly, data were collected by receiving satellite images from the Landsat satellite. The satellite image offers an aerial perspective of the research region that is not possible to see with the naked eye. Next, Google Earth Pro software will be used to obtain the shapefile of the study area in KML format as shown in Figure 3. Then, the shapefile will be used in ArcMap 10.8 to receive the study area attribute and location of geographic characteristic information, such as rivers, trees, roads and much more.

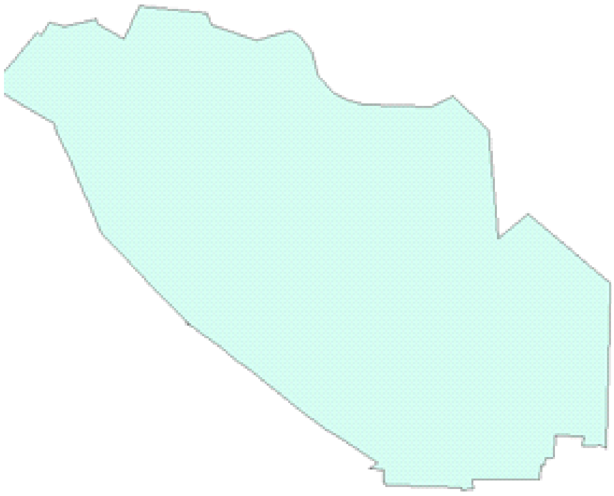

Fig. 3. The shapefile of Raja Musa Forest and Sungai Karang, Kuala Selangor in ArcMap 1

2.2.2 Factor selection

The fuel map is created by identifying the various vegetation types and the area's type using remote sensing technology. Because certain plants are significantly more hazardous than others, the fuel map is considered one of the considerations. Using the supervised classification technique, the fuel map is classified into four categories: agriculture, forest, water and bare soil. The description of those qualities pertinent to fire danger estimation and fire propagation research is based on classification schemes, which condense huge groupings of vegetation features because it is challenging to characterize all physical characteristics of all fuels in an area. Typically, these categories are known as fuel kinds. Fuel types are parameterized using fuel models in order to add fuel properties to fire behaviour and fire effect simulation models [17].

Using satellite imagery, NDVI is used to assess the state of the vegetation in each area. Due to plant leaves' ability to reflect near-infrared back to the receiver, it can measure how green the vegetation is. The NDVI is calculated using its formula by the raster calculator on ArcMap, just like the LST. The change in NDVI has been used to track the spatial-temporal fluctuations of plant cover and biomass production as well as to evaluate the effects of climate change on land surface phenology at a global or regional scale. NDVI is a valuable indicator for identifying above-ground vegetation conditions [18].

LST also affects the Bowen ratio (β = sensible heating/latent heating) and the rate of transmission. The area is significantly more vulnerable to forest fire if the transpiration rate declines while the Bowen ratio rises. One of the primary elements driving forest fire is the land surface temperature (LST). The geographic variance in LST was primarily caused by lower transpiration and was a result of fire-induced environmental changes [19]. The state and colour of the soil, the amount of fuel used, the amount of regrowth from burned plants, the blackening or blistering of trees, the depth of the burn in the soil and changes in fuel wetness are all factors used to evaluate the severity in the field. Estimating the severity of a burn is essential for rehabilitation and short-term mitigation measures [20].

When evaluating vegetative health, drought conditions and tracking changes in moisture content over time, NDMI is particularly helpful. To comprehend vegetation dynamics and make wise decisions about managing water resources and crop monitoring, it is used in many areas, including agriculture, forestry and environmental studies. The ratio between the difference and the sum of the refracted radiation in the NIR and SWIR is used to determine the NDMI, which describes the crop's level of water stress. It is feasible to identify the parts of a farm or field that have water stress issues by interpreting the absolute value of the NDMI [21].

2.2.3 Processing and analysis

The factor map is separated into a few categories, such as very low risk (1), low risk (2), moderate risk (3), high risk (4) and very high risk (5), that correlate to the parts of the map where there is a risk of fire. Using ArcMap's reclassification tool, the factor map is reclassified. These categories are then recorded in the common factor table, which is used to construct the fire hazard model using the Analytical Hierarchy Process (AHP) method. By multiplying all the score criteria by the weighting value derived from the AHP technique, a final fire risk assessment map can be created. For a pair-wise comparison process, the hierarchical topographical, climatic, environmental and anthropogenic factors were arranged [22].

2.2.4 Mapping

The AHP method commences using the ArcMap raster calculator. The raster calculator will consider the NDVI, LST, fuel map, NBR and NDMI. Based on research conducted by Venkatesh *et al.,* [23], all fire-related factors, including slope, elevation, aspect, terrain ruggedness, precipitation, evapotranspiration, wind speed, temperature, fuel type, roads, settlements and water bodies, were classed and combined to create a fire susceptibility map. The final map is subsequently produced and can be compared to an actual fire hazard map to ensure its accuracy.

2.3 Calculation

Every factor which are LST, NDVI, NDMI, NBR, AHP has their own equation. The equations were mentioned below.

2.3.1 Land Surface Temperature (LST) classification

One of the crucial variables that affect energy transfers between the land and atmosphere, climatic patterns, heat fluxes and ecological modelling is LST, which stands for the surface temperature of the Earth [24]. The Landsat satellite image is used for the LST analysis. Since the satellite image is initially digital, it cannot calculate the values needed for image processing. Using the following formula, the thermal band is first transformed into spectral radiance as in Eq. (1):

$$L\lambda = (ML) \times Qcal + AL \tag{1}$$

Where:
$L\lambda$ = Spectral radiance
ML = Radiance multiplicative scaling factor for the band
AL = Radiance additive scaling factor for the band
$Qcal$ = Digital number of thermal bands

Then, the top of the atmospheric brightness temperature is then calculated from the spectral radiance using the constant values from the metadata file. The following is the formula as in Eq. (2):

$$BT = \frac{K_2}{\ln\left(\frac{K_1}{L\lambda + 1}\right)} - 273.15 \tag{2}$$

Where:
BT = At-satellite brightness temperature
Lλ = TOA spectral radiance
K1 = Band-specific thermal conversion constant from the metadata
K2 = Band-specific thermal conversion constant from the metadata

The BT is converted from Celsius (°C) to Kelvin (K), hence, minus 273.15.
The percentage of vegetation (PV) is calculated next. The PV equation is as follows in Eq. (3):

$$PV = \left(\frac{NDVI - NDVI\ minimum}{NDVI\ maximum - NDVI\ minimum}\right)^2 \tag{3}$$

The flow of LST as in Figure 4:

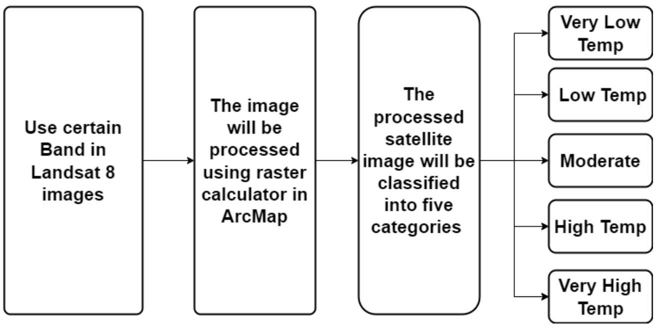

Fig. 4. LST flow

2.3.2 NDVI classification

By assessing the greenness of the vegetation, NDVI shows the state of plant health or the density of the vegetation. Landsat's satellite images NDVI is determined as follows in Eq. (4):

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4} \tag{4}$$

The NDVI value is between 1 and -1. If the value is 1, the vegetation is healthy; if it is between -1 and 0, there is no vegetation. Red denotes a lack of vegetation and green denotes a high density of vegetation. The flow of NDVI is in Figure 5.

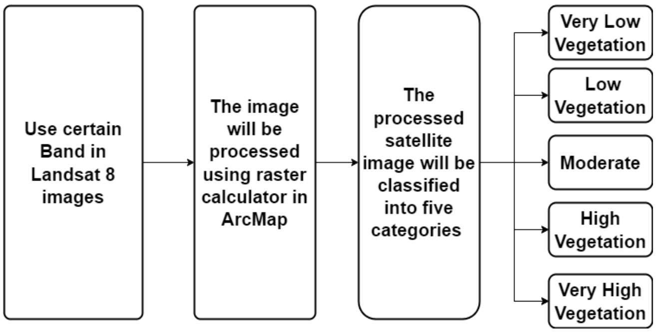

Fig. 5. NDVI flow

In general, its values are near zero for rocks, sand or concrete surfaces, negative for bodies of water and positive for vegetation, such as crops, shrubs, grasses and woods [25].

2.3.3 Fuel map classification

The carefully supervised classification map was based on earlier research on the peat-swamp map, the Raja Musa Forest Fire map and the Sungai Karang map. The Interactive Supervised Tool can be used to classify satellite images as well. The flow of the fuel map is shown in Figure 6.

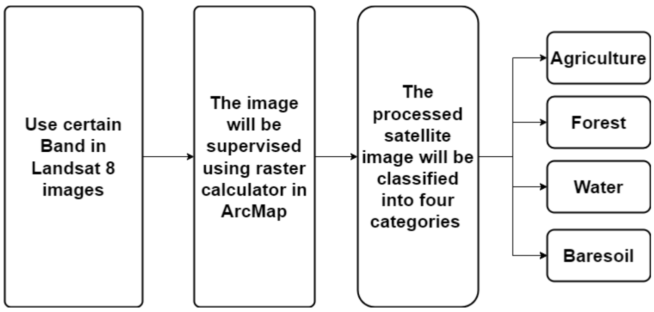

Fig. 6. Flow of fuel map

The distribution of fuel types and their attributes must be understood for fire models and fire management systems. This is because it may be used to determine the behaviour, risk and effects of fires [26].

2.3.4 NDMI classification

NDMI is a vegetation index that is often used in the processing of satellite images and remote sensing data to assess the moisture content or water stress of vegetation. Additionally, the normalized differential moisture index (NDMI), which is capable of accurately measuring the water content of a canopy of vegetation, was used [27].

To calculate the NDMI, Eq. (5) is used to determine the moisture content in the study area:

$$NDMI = \frac{Band\ 5 - Band\ 6}{Band\ 5 + Band\ 6} \quad (5)$$

The flow of NDMI as in Figure 7:

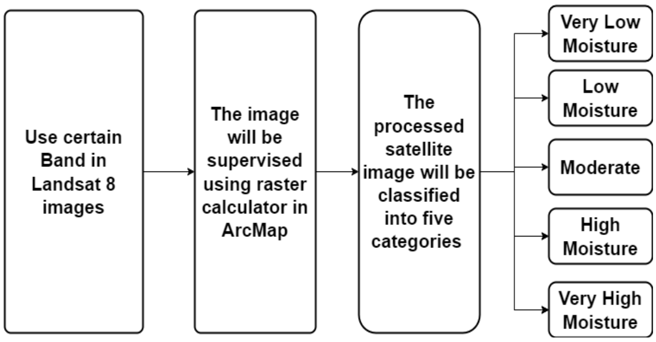

Fig. 1. Flow of NDMI

2.3.5 NBR classification

The Normalized Burn Ratio (NBR), a vegetation ratio that is often used in remote sensing and satellite imaging analysis, is used to assess the severity and scope of burned areas following a fire occurrence.

Research by Ammar *et al.,* [28] stated that to identify burned regions and gauge the severity of the fire, which has a significant impact on how vulnerable forest and land fires are, the burn rating was normalized. Normalized Burn Ratio has a significant impact on how vulnerable forest and land fires are.

The NBR is calculated using Eq. (6):

$$NBR = \frac{Band\ 5 - Band\ 7}{Band\ 5 + Band\ 7} \tag{6}$$

The classification of NBR also has been classified into 5 categories. The flow of NBR is stated in Figure 8.

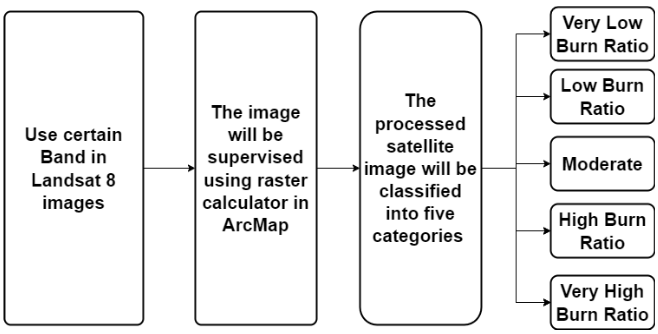

Fig. 8. NBR flow

2.3.6 Hotspot map

Classifications for the factors map were obtained using LULC. The AHP technique had been utilized to obtain the fire hazard modelling and mapping by finding the sum of weight values. In the standard AHP technique, we should provide a specific number within a range of 1 to 9 so that weights can be generated for pair-wise comparisons [29].

The summation weight values can be found using the AHP tool calculator in GIS Spatial Analyst. The formula for mapping fire dangers in Eq. (7) is as follows:

$$FR = \sum_{i=1}^{n} (W_i X_i) \tag{7}$$

Where:
X = the vulnerability criterion score of factors I
W = weights of the components
FR = the risk of forest fire

The fire danger mapping can also be created by combining all factor maps using ArcMap's raster calculator tool. The flow of developing hotspot map as in Figure 9.

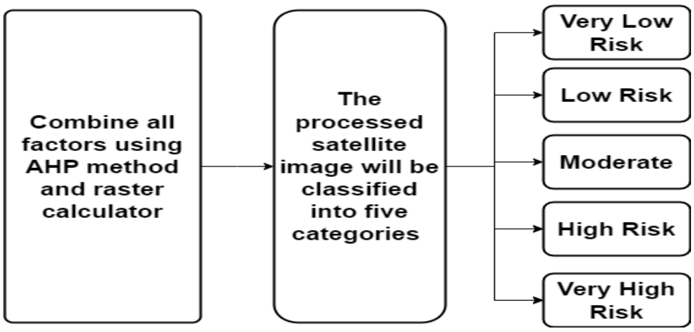

Fig. 9. Hotspot map flow

2.4 Apps Development

Android Studio software was used to develop the early warning apps and the programming language used was Java. Firebase is used as the assistant tool in the Android Studio to allow developers to store and synchronize data in real-time across multiple clients. It enables real-time data updates, offline capabilities and automatic synchronization across devices.

2.4.1 Mobile apps

The apps will have a registration, login, factors interface and Google Map of the study area. To have access to Google Maps, the coding requires a Google API key that gives access to this application to use Google Maps in this programming language. Figure 10 shows a flowchart on how the apps developed in Android Studio.

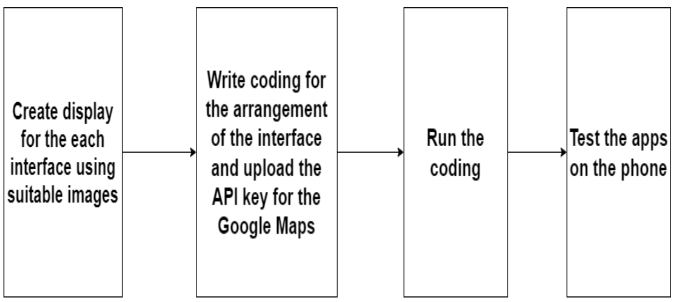

Fig. 10 Flow of the app’s development

2.4.2 Integrating of image processing & mobile APPS

The flowchart of the apps starts with login, if the user is a first-time user, they need to register first. The register consists of name, email, date of birth, gender, phone number and password creation. After the user is done with registration, it will be directly brought to the dashboard of the application which consists of buttons for factors of forest fire and hotspot maps that will bring the user to Google map as shown in Figure 11.

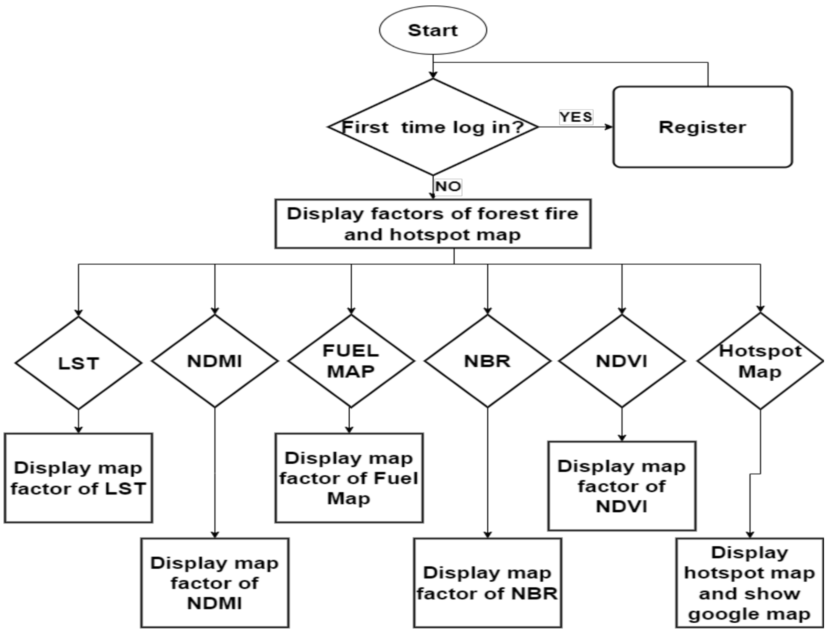

Fig. 11. Flowchart of the apps

3. Results
3.1 Process Satellite Images

After the satellite images from each factor and hotspot map have been processed using the raster calculator. The results will be classified into a few categories according to factors of suitability.

3.1.1 Classification of forest fire factors

The area of red colour as shown in Figure 12 is an area that is close to human activity areas such as roads and housing areas. The land in that area is hotter compared to the area in the reserve forest.

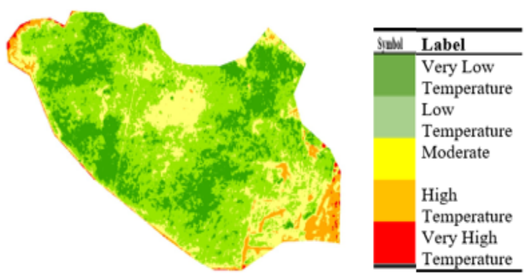

Fig. 12. Classification of LST

The area of red colour and yellow colour in Figure 13 shows low trees in the area. The lower the trees in the area, the higher the possibility of forest fires occurring.

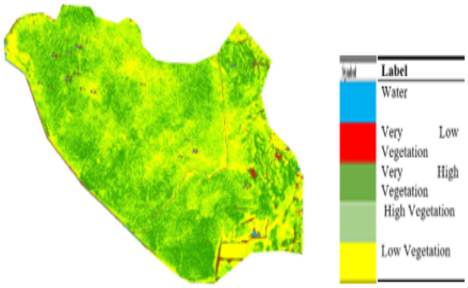

Fig. 13. Classification of LST

There are four categories of fuel maps as in Figure 14. Agriculture for brown colour, green for forest areas, blue colour for water and yellow colour for bare soil. Agriculture has a high risk of forest fire due to exposure to substances the plant that might burn the trees.

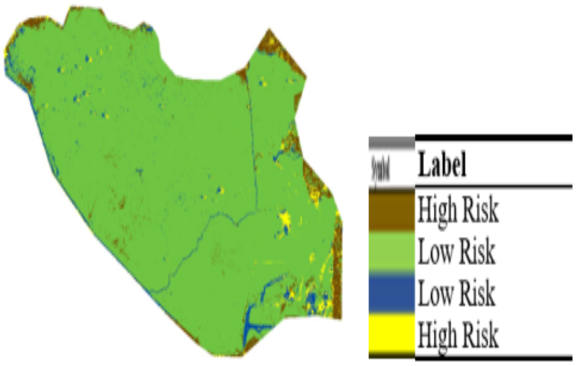

Fig. 14. Classification of fuel map

The low moisture areas as in Figure 15 consist of human activity areas such as agriculture and near roads. It can be low trees which make it less exposed to sunlight which can make the land dry.

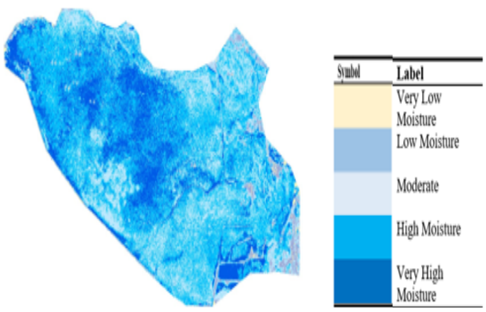

Fig. 15 Classification of NDMI

The areas of red colour and orange colour as in Figure 16 have a high possibility of burning due to high temperatures and near human activity areas.

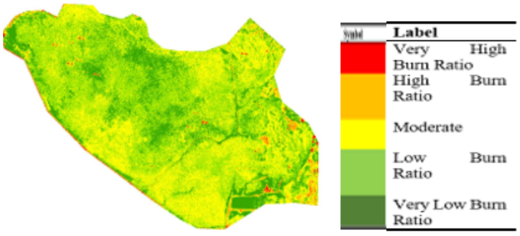

Fig. 16. Classification of NBR

Figure 17 shows the highest possible forest fire occurrences from the most factors combined in the red colour area.

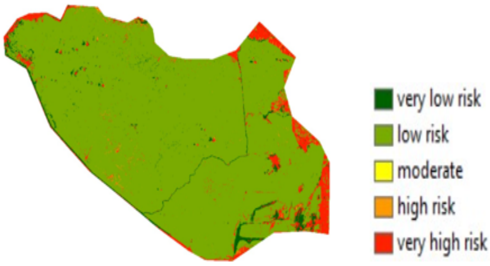

Fig. 17. Final hotspot map

3.1.2 Forest fire apps

After all classified images are done. The processed satellite images will be transferred into the apps for the interface of the apps. Firstly, the application begins with logging in and signing in for users. It required an email and password for the user to have access to the apps as shown in Figure 18.

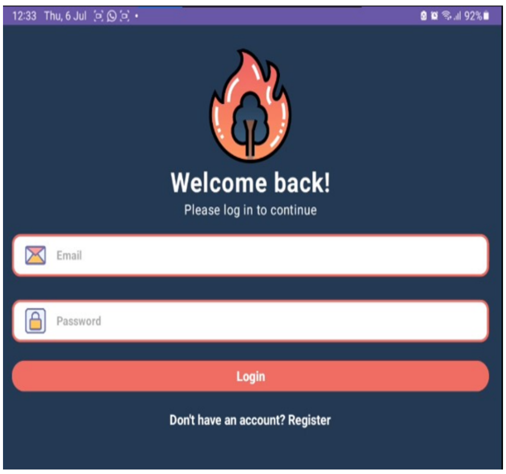

Fig. 18. Log in and sign in interface

If the user is the first time using the application, then they need to register so that their information can be saved in the real-time database. It required their email, name, date of birth, gender, phone number, password and password confirmation as in Figure 19.

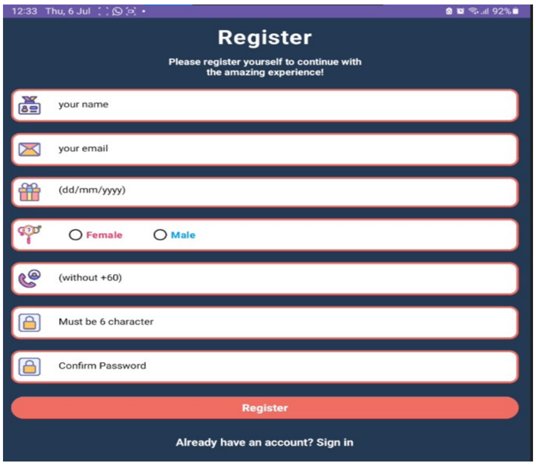

Fig. 19. Register Apps

After that, the apps will bring the user to the first interface that has buttons for the factor of the forest fire and hotspot forest fire map as in Figure 20.

Fig. 20. Buttons to display factors and hotspot map

If the user presses the LST button, the interface as in Figure 21 will be displayed. If the user presses the NDVI button, the interface as in Figure 22 will be displayed. If the user presses the LULC button, the interface as in Figure 23 will be displayed. Interface as in Figure 24 will be displayed if the user presses the NBR buttons. The interface as in Figure 25 will be displayed if the user presses the NDMI button. If the user presses the Map Hotspot Forest Fire, it will display as in Figure 26 to show a real-life map to the user.

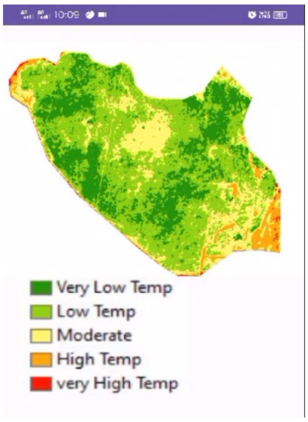

Fig. 21. LST interface

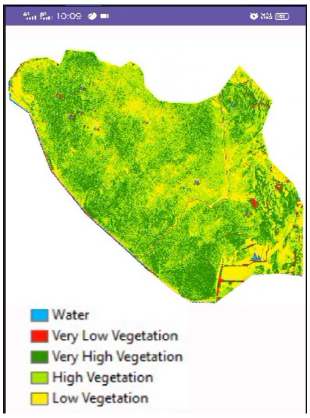

Fig. 22. NDVI interface

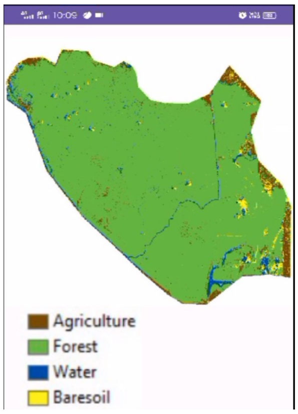

Fig. 23. LULC interface

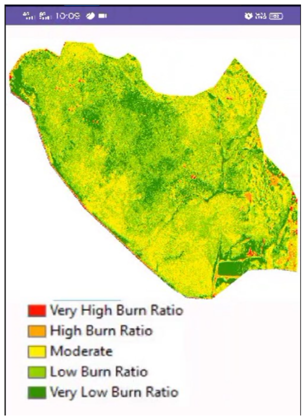

Fig. 24. NBR interface

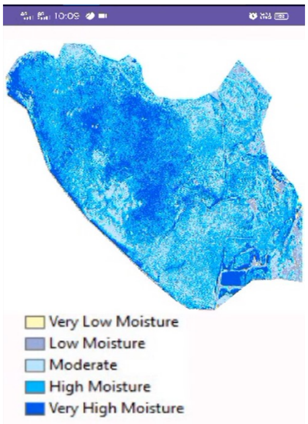

Fig. 25. NDMI interface

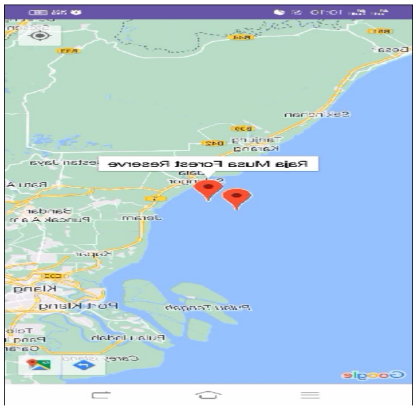

Fig. 26. NDMI interface

4. Conclusions

In conclusion, the goal of this research is to develop the mobile application's early warning system for forest fires. It is particularly appropriate for this research to identify forest fire threats and give an early warning to the people who live nearby as the Raja Musa Forest Reserve and Sungai Karang area has a history of changing land use/land cover over time. As the Forest Reserve Department, we may take preventative measures to ensure that this forest and all of its flora and species are saved.

All the software programmes used to get the forest fire hazard map, like ArcMap and the USGS website, are beneficial and teach a lot about how remote sensing and GIS function. This study also mentions the AHP approach as an alternative method for calculating the weight requirements. Remote sensing and GIS tools can be used to study the geographical and temporal dynamics of forest fires [40].

By developing the mobile application for this early warning system, it should help not just for public, also for government departments such as forest department and fire fighter to do early prevention. This will make safety precautions for all communities in the study area. They can open the apps to see the area that have high possibility for a forest fire to occur and do some prevention activity. The development of forest fire early warning systems that have an emphasis on community involvement and social aspects in general is crucial. Finally, this research may aid all communities worldwide in ensuring future safety.

As for recommendations, this research can be improved by further the development of the mapping and the apps. For the mapping, it could be improved by adding some model according to temperature and weather conditions in Malaysia [30]. For instance, during the rainy season, the temperature might a bit lower, so the range value for LST might be change and from this a new mapping range value for LST factor can be processed. For the app's development, it can be improved by adding advanced interface for the user easier to understand [31].

Acknowledgement
The author acknowledges the Universiti Teknologi MARA for funding under the Grant LESTARI (600-IRMI 5/3/LESTARI (035/2019). The authors also would like to thank the School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, Selangor for their valuable support.

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