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COMPARISON OF LST, NDVI, AND LULC BETWEEN YEAR 2014 AND 2024 IN RELATION TO FOREST FIRE OCCURRENCE IN PERLIS

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ABSTRACT

Forest fires represent major hazards to ecosystems, biodiversity, and human communities. Several devastating forest fires have been recorded in Malaysia by the Fire and Rescue Department (FRD) due to human activity, drier conditions, and higher temperatures. From 2012 to 2024, 55% of wildfire incidents involving agricultural fields, woodlands, as well as shrub lands occurred in March, as confirmed by the Perlis State FRD. This study investigates the relationship between Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Land Use Land Cover (LULC) with forest fire occurrence in Perlis. Using remote sensing and Geographic Information Systems (GIS), we investigate how these factors interact to affect fire susceptibility. Satellite imagery used to extract the remote sensing indices, including LST, NDVI, and LULC, and the statistical data regarding the frequency and location of forest fire occurrences were obtained from Perlis State FRD. The correlation graph between each index with forest fire occurrence was obtained using ArcMap. The findings show that the number of forest fire incidents had doubled within 10 years and LST has positive relationship with forest fires, while NDVI is inversely related. These findings help to implement preventive strategies to mitigate the risks and effects of forest fires.

1. Introduction

Over the past decades, climate change has led to a higher intensity and frequency of extreme weather events all over the planet, inducing the occurrence of devastating forest fires. In addition to depleting natural resources and biodiversity, these fires also increase greenhouse gas emissions worldwide (Mohapatra & Trinh, 2022), which have an impact on public health and air quality. Chew et al. (2023) noted that the impacts of global climate change have resulted in elevated temperatures and decreased precipitation, creating a prolonged period of dry and warm conditions conducive to the ignition and rapid spread of wildfires.

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Several studies in different parts of the world revealed the connection between local climate change and forest fires. Moreno et al. (2023) found that changes in climatic conditions made the NDVI levels experience a sharp decrease during summer, increasing the flammability rate due to the lack of humidity in vegetation. Makumbura et al. (2024) also found a strong relationship between the forest fire index with monsoon patterns and wind patterns across Sri Lanka. Another study conducted by Talukdar et al. (2024) in Thailand reveals that the forest fire was found to be most active in March (46%) during the dry period. Hence, the detection, monitoring, and control of forest fires are critical economic and safety concerns in numerous countries worldwide.

The coordination of these variables with GIS technology facilitates spatial analysis of fire-prone areas, providing an effective method for fire prediction, planning, and prevention. To enhance wildfire risk assessment and environmental management, this study investigates the relationship between LST, NDVI, and LULC to forest fire occurrence. The assessment of wildfire risk is necessary to identify regions indicating the probability of forest fire incidents in Perlis, and the containment of wildfires holds significant importance in mitigating the extent of fire-related destruction.

2. Methodology

2.1 Study Area

The study covers the whole geographical area of Perlis, the smallest state located in the northernmost part of Malaysia. The study area includes the three political boundaries of Perlis that comprise all 22 mukims. Even though Perlis is relatively small, it has a variety of forest habitats, such as limestone hill forests, dipterocarp forests, and seasonal deciduous forests, especially inside the Perlis State Park and nearby forest reserves. These habitats are susceptible to seasonal droughts, rendering them prone to ignition during arid periods. Moreover, the state experiences a tropical monsoon climate; the dry season, typically from February to April, increases susceptibility to forest fires due to prolonged low precipitation and elevated temperatures, with a historical maximum of 40°C observed during this period in the year 2024. The vicinity of agricultural land and cross-border interactions with Thailand introduce anthropogenic factors like open burning and land clearing, which might elevate fire danger. Perlis is ideally suited for studies on forest fire detection due to its manageable scale, which facilitates comprehensive monitoring and data collection.

2.2 Software and Datasets Used

The software used in this study is ArcMap and Google Earth Pro. ArcMap was used to extract LST, NDVI, and classify LULC, and Google Earth Pro was used to georeference the location of the forest fire according to the data from the Perlis Fire and Rescue Department. The KML file of georeferenced data can then be converted into a shapefile using the ArcMap software. Landsat 9 satellite images were obtained during March 2014 and March 2024 with cloud coverage below 50% from the USGS website. Landsat 9 presents 11 spectral bands, including the visible, near-infrared, short-wave infrared, and thermal infrared spectrums.

2.3 Forest Fire Frequency and Locality Extraction

In this study, the statistical data on fire occurrence in Perlis state were analysed, and fire cases related to forest and shrub lands were then extracted. The cases were arranged according to the date of incidents, and a graph was generated to compare the number of forest fire cases between the months in the year 2014 and the year 2024. The location of the forest fire incidents was then georeferenced in Google Earth Pro, and the forest fire frequency map was generated using ArcGIS Pro.

2.4 Selection of Spectral Indices

2.4.1 Normalized Difference Vegetation Index (NDVI)

NDVI is an index to quantify vegetation greenness by measuring the spectral reflectance of the ground surface feature (Mohd Jaafar et al., 2020) using near-infrared (NIR) and red spectral reflectance. The value of NDVI ranges from -1 to +1, where a negative value denotes no vegetated area and a positive value denotes vegetated area. The vegetation index is a valuable tool for evaluating fire risk, as persistently low NDVI values may suggest that the vegetation is more susceptible to ignition due to arid stress (Parvar et al., 2024).

2.5 Land Surface Temperature (LST) Extraction

LST is the temperature reflected by the Earth's surface. The LST uses thermal infrared (TIR) to retrieve the brightness temperature. Many algorithms have been developed to determine the LST, such as mono-window, split-window, single channel, temperature-emissivity separation, and land surface temperature algorithms (Junaidi et al., 2021). This study used land surface temperature algorithm to derive the LST value. LST is linked to fire hazard and helps in predicting forest fires as dry and hot surfaces increase the likelihood of ignite and fire spread. As surface temperatures rise, vegetation and soil moisture decrease, making forests more susceptible to fire.

$$LST = \frac{BT}{1+\left(\frac{\lambda \times BT}{\rho}\right) \times \ln e} - 273.15$$ Equation 1

2.6 Land Use Land Cover (LULC) Classification

Land Use and Land Cover (LULC) data is crucial for forecasting forest fires as it provides comprehensive information regarding various land types, including urban areas, agricultural fields, grasslands, and water bodies. Regions adjacent to residential zones exhibit an elevated likelihood of fire incidents (Parvar et al., 2024). There are two (2) most common approaches in LULC classification, which are supervised and unsupervised classification. In this study, a supervised classification approach was applied to identify the changes in land cover between the years 2014 and 2024.

3. Results and Analysis

The LST, NDVI, and LULC derived from satellite imagery have been utilized in this study. Figure 1 presents the comparison of the distribution of forest fire cases between the years 2014 and 2024 in Perlis. Comparing the two results, it can be seen that the frequency of forest fire occurrence had doubled within a decade. As shown in Figure 2, a positive correlation was found between LST and forest fire, whereas the relationship between NDVI and fire cases was inversely proportional. In Figure 2(a), there were significant fluctuations in LST in the year

2014, with temperatures peaking above 30°C on the 26th and 28th of March. The elevated temperatures correspond with a significant decline in NDVI readings throughout the same period, indicating a deterioration in plant health and coverage.

Contrariwise, in Figure 2(b), the LST values for the year 2024 were elevated during the observed period, ranging from approximately 25°C to 31°C. This increase in LST coincides with a notable decline in NDVI values, particularly between 21st and 25th March, when NDVI decreases from approximately 0.48 to 0.41. This pattern indicates an inverse correlation between LST and NDVI, signifying that elevated surface temperatures correspond to heightened heat stress in vegetation. This correlation may indicate the presence of conditions that increase the likelihood of forest fires, as elevated temperatures and compromised vegetation can enhance fire susceptibility.

The area changes in LULC between the year 2014 and the year 2024 can be observed in Figure 3. The built-up area and paddy field experienced the greatest significant shift, increasing approximately 77% and 46% respectively. The forest area diminished approximately 17% within a decade, probably due to deforestation caused by urbanization, agricultural development, or wildfires, as evidenced in prior documentation. Meanwhile, the shrub lands and vegetation area slightly decreased by only 4% from the year 2014 to the year 2024.

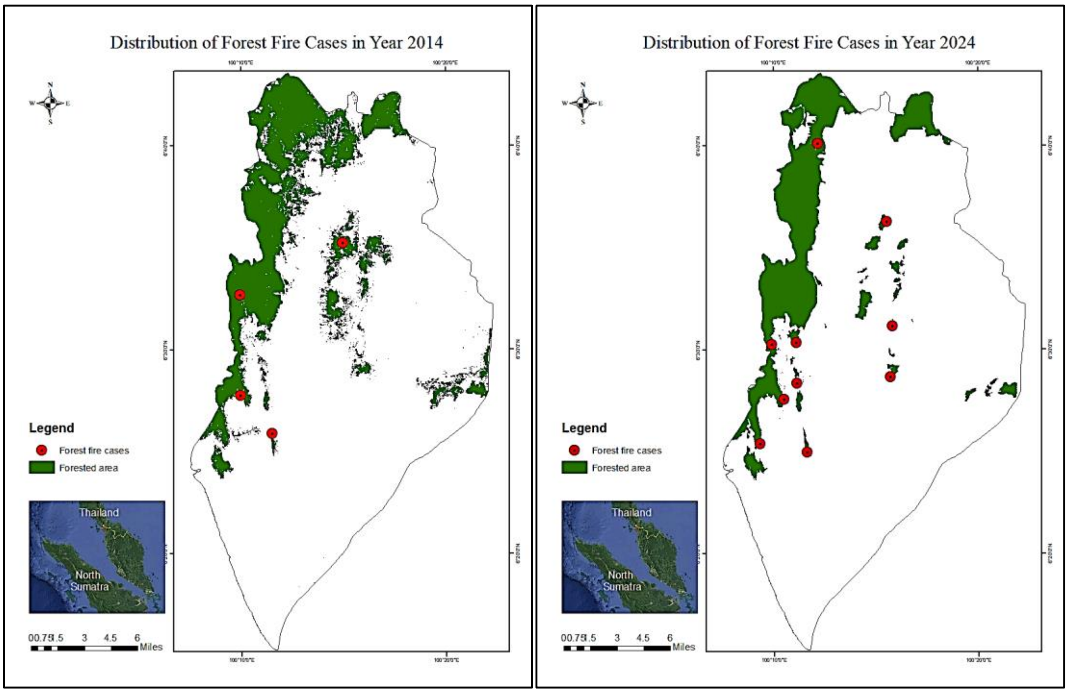

Figure 1. Comparison of the distribution of forest fire cases between the years 2014 and 2024 in Perlis.

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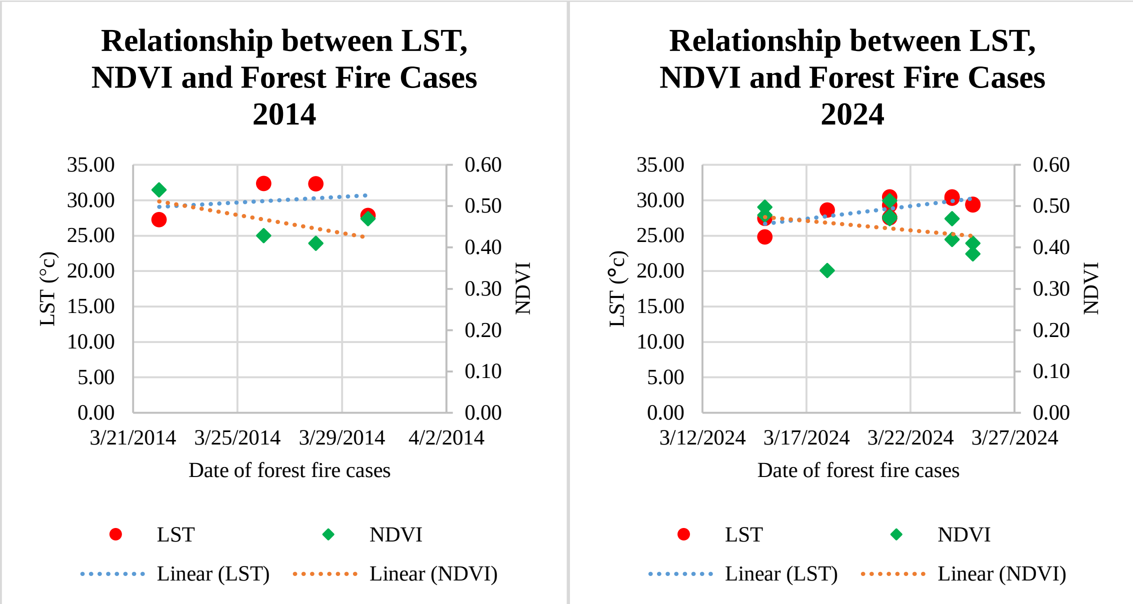

Figure 2. LST, NDVI, and fire cases comparison between the year 2014 and the year 2024 in Perlis.

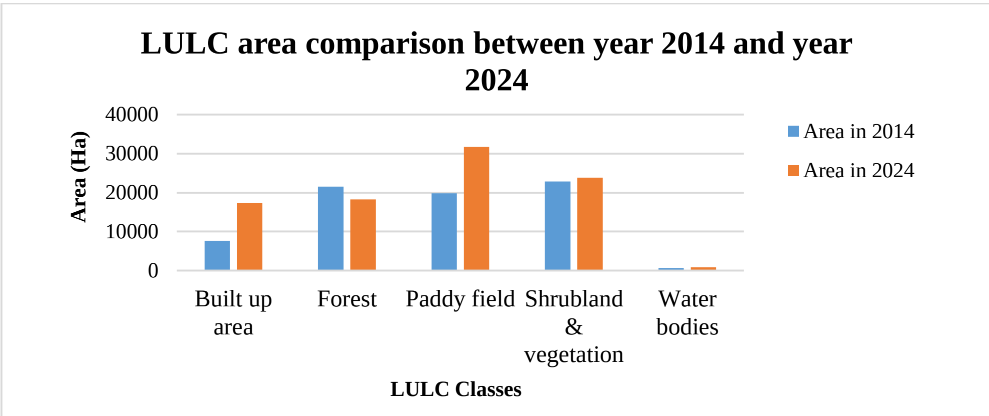

Figure 3. Comparison of the area of LULC between the year 2014 and the year 2024 in Perlis.

4. Discussion

The results obtained in this study only revealed the sampling data conducted in March and does not explicitly state impact on annual trends. The analysis found that the mean LST exhibited a peak in March for both years, indicating a strong correlation with forest fire occurrences. The elevated surface temperatures may be associated with prolonged droughts and increased solar radiation during the El Niño event that accelerate moisture loss in plants and soil. The likelihood of ignition increased when surface temperatures remain elevated for extended periods, particularly during arid seasons or droughts. Supporting this view, Parajuli et al. (2020) write that LST is a significant weather parameter influencing fire behaviour, and according to existing studies, as temperature increases, the risk of forest fires will also escalate. The results in this study are consistent with the study conducted by

Chew et al. (2023) in Pahang, where the study found that the temperature progressively rose from January 2021, with peak values of 32-34°C in many areas by March 2021 during the fire season. Likewise, Talukdar et al. (2024) also hold the view that most forest fire risk zones experience elevated temperatures one month before the fire outbreaks.

Consequently, these climatic circumstances lead to a significant decline in NDVI levels, indicating plants are experiencing dryness, due to elevated temperatures and reduced soil moisture. This indicates environmental stress increases the likelihood of fire propagation, as arid or scant flora serves as fuel for fire ignition. Moreover, the findings of this study clarify a negative correlation between NDVI and forest fire occurrence, as a low NDVI value indicates dehydrated vegetation and thus increases the probability of ignition. Moreno et al. (2023) make a similar point in their study of decreased NDVI levels during dry weather, heightening flammability due to the absence of humidity in plants. Parvar et al. (2024) also noted that NDVI functions as a reliable measure of the greenness and overall health of the vegetation, crucial factors in predicting the occurrence of forest fires.

The spatial distribution of LST was considerably influenced by the increment of built-up areas in the study area. Swift urbanization and deforestation in the study area have led to a reduction in forested areas, leaving ground surfaces exposed to sunlight, hence increasing the monthly mean temperature. LULC classification demonstrates the alterations humans have made to the landscape, such as deforestation, agricultural expansion, and residential construction. These alterations may initiate and propagate fire incidents. The results were consistent with Ullah et al. (2023), who noted that the alterations in LULC have elevated the LST in an urban setting, and artificial features exhibit a higher LST than natural features.

5. Conclusion

The relationship between LST, NDVI, LULC, and forest fires demonstrates the complexity of climatic factors and human activities. Higher LST indicates a hotter and drier climate, making fires easier to ignite and spread. Reduced NDVI levels, on the other hand, indicate that there is less vegetation moisture and a higher level of combustion fuel. Deforestation, urbanization, and agricultural development have altered the supply of fuel and introduced new sources of forest fire ignition. Changes in land cover and vegetation, combined with increased surface temperatures, can influence how quickly forest fires spread. Understanding these interactions is essential for improving wildfire prediction models and early warning systems.

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