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MONITORING OF FOREST FIRE AREAS USING REMOTE SENSING TECHNOLOGY AND MULTITEMPORAL DIFFERENCE OF SPECTRAL INDICES

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ABSTRACT

This research aims to monitoring and classify forest fire areas in Chiang Dao Wildlife Sanctuary by using multitemporal difference of spectral indices based on the application of data from Landsat 8 OLI satellite during 2017-2021 and assess accuracy of obtained results. Research methodology consisted of: 1) data collection from Landsat 8 OLI satellite in March from 2017-2021; 2) analysis on multitemporal difference of spectral indices in 3 formats including Normalized Difference Vegetation Index (NDVI), Normalized Burned Ratio (NBR), and Soil-Adjusted Vegetation Index (SAVI); and 3) analysis on accuracy of results by comparing with data on reference points obtained from visual analysis and random points. The results revealed that, from 2017-2021, forest fire areas were calculated to be 3.59 km^2, 1.70 km^2, 130.21 km^2, 128.04 km^2, and 23.73 km^2, respectively.

Keywords: remote sensing, electromagnetic wave, forest fire, NDVI, NBR, SAVI.

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INTRODUCTION

Forest fire can be occurred and spread without control which may be caused by nature or humans' actions affecting to environment and living of humans. Forest fire occurred in mountains is considered to be more severe and rapid than those occurred on plains (Ruthamnong, 2019). Forest fire is a kind of disasters occurred with drought. There may be 2 causes of forest fire, i.e., nature and humans' actions. From statistical data on forest fire in Thailand during 2017-2021, it was found that all forest fire incidents were completely caused by humans and most of them were caused by forest products collection calculated to be 68.9% of all causes of forest fire (Department of Environmental Quality Promotion, 2020). Forest fire in Thailand that was caused by humans' acts can be found in drought from November to April and it was mostly found in March. Mostly, forest fire incidents are mainly occurred in deciduous forests, mixed forests, and forestry plantations (Urbancreature, 2021). As a result, acknowledgement on location, areas, formats, and distribution of forest fire areas after fire season is highly important for planning forest conservation, establishing related policies, and managing local fire (Panyakam & Pongsawat, 2021).

Chiang Dao District in Chiang Mai is considered as the area with the highest level of hotspot in Thailand (Tnnthailand, 2021) and most of forest fire incidents were occurred in Chiang Dao Wildlife Sanctuary because this area consists of limestone and stone courtyards hindering Doi Chiang Dao from retaining water. Consequently, has humidity in rainy season when it is raining only. However, it was recorded in the past that Doi Chiang Dao had no record on big forest fire. From measuring humidity of hill evergreen forests around it, humidity was in high level therefore forest fire occurred at Doi Chiang Dao has never spread to other areas. Subsequently, in 2015, forest fire situation in drought had been more severe due to several causes including climate change increasing drought level in drought season while lowering humidity accumulated in soil and piled dead leaves giving good fuel for forest fire. When villagers burned agricultural areas or some forest areas for collecting forest products in lower part of forests, they could not control fire so it spread to the top of the mountain. When there was no humidity as shield, fire spread rapidly from evergreen forest to meadow on the mountain. Strong wind made officers and villagers felt difficult to build firebreaks. In addition, big fire could spread through firebreaks causing terrifying forest fire in 2019 destroying over 50% of Doi Chiang Dao's area. This forest fire affected to many kinds of living creatures terrifying many conservationists that this forest fire may cause extinction of some types of vulnerable wildlife and plants (Ngthai, 2021).

Remote Sensing Technology has basic principle on physics of electromagnetic wave that is used as media for obtaining data without direct contact with objects in 3 manners, i.e., 1) Spectral, 2) Spatial, and 3) Temporal (ESA, 2016; Elachi & Zyl, 2021; University of Lucknow, n.d.). For Remote Sensing Technology, satellite data can be used for surveying data in wide areas with lower cost than land survey. With this reason, it has been applied extensively in many studies on natural resources and environment (Rotjanakusol & Laosuwan, 2018; Rotjanakusol & Laosuwan, 2018; Rotjanakusol & Laosuwan, 2019; Prohmdirek *et al*., 2020; Chavarit *et al*., 2021; Jomsrekrayom *et al*., 2021; Suriya *et al*., 2021). In the past, inspection and classification of forest fire areas could be performed by using land survey. Subsequently, Remote Sensing Technology has been applied by using satellite data and spectral indices like Normalized Difference Vegetation Index (NDVI), Normalized Burned Ratio (NBR), Soil-Adjusted Vegetation Index (SAVI), Modified Soil Adjusted Vegetation Index (MSAVI), and Burned Area Index (BAI), etc., to study on forest fire areas (Burapapol & Nagasawa, 2016; Kim *et al*., 2021; Al-hasn & Almuhammad, 2022; Pompa-García *et al*., 2022; Uttaruk *et al*., 2022). With the aforementioned importance, the objective of this research is to minitoring and classify forest fire areas in Chiang Dao Wildlife Sanctuary by using multitemporal difference of spectral indices, i.e., NDVI, NBR, and SAVI based on application of data obtained from Landsat 8 OLI satellite during 2017-2021.

STUDY AREA

Chiang Dao Wildlife Sanctuary (Figure-1) is a wildlife sanctuary in Thailand located in Chiang Dao District, Chiang Mai Province, with the approximate area of 521 km^2 covering the areas of Mueang Hang District, Wieng Hang District, Mueang Ngai Sub-district, Mueang Khong Sub-district, Chiang Dao Sub-district, and Mae Na Sub-district. The interesting point is that Doi Chiang Dao that is the highest limestone mountain in Thailand with the height of 2,275 m that is tanked as one of Top 3 Mountains in Thailand after Doi Inthanon and Doi Pa Hom Pok. It was registered as a wildlife sanctuary on August 24th, 1978. Climate of Doi Chiang Dao is continental climate or tropical monsoon with rainy season switching with drought. Climate of this area can be divided into 3 seasons including summer from February to May with average highest temperature of 29.1°C and the highest temperature was in April, rainy season from May to October with temperature ranged from 26.1-27.1 °C, winter from November to January with average lowest temperature from the mid of December to the mid of January at 6.7 °C. In some years, the lowest temperature would be lower than 0 °C causing frost in the morning.

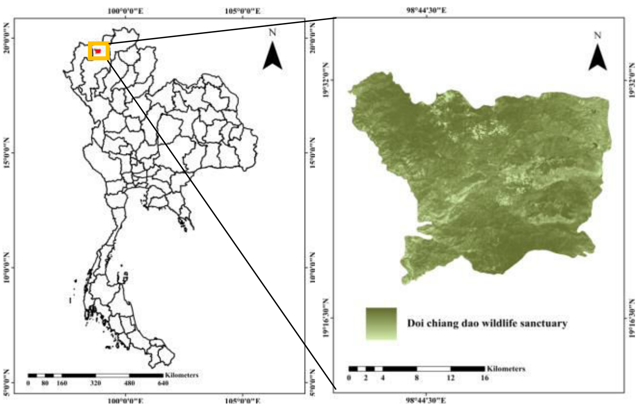


Figure-1. Chiang Dao wildlife sanctuary.

MATERIALS AND METHODS

Data Collection

Landsat 8 OLI is a U.S. earth observation satellite under the cooperation between National Aeronautics and Space Administration (NASA) and United States Geological Survey (USGS) and it was launched to orbit on February 11th, 2013. It has Sun Synchronous Orbit and repeats orbit at the same area every 16 days. Landsat 8 OLI/TIRS consists of sensors including Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) with 11 bands (Loyd, 2013). In this research, data obtained from Landsat 8 OLI satellite during March 2017-2021 were used.

Conversion of Digital Number (DN)

This procedure is important and it must be performed before analyzing satellite data with indices. In this research, DN was converted as Reflectance by using Equation 1. Subsequently, obtained data were calculated to find adjustment with sun elevation as shown in Equation 2 (Yale University, 2022).

$$\rho\lambda' = M\rho * Qcal + A\rho \qquad (1)$$

Where;

$\rho\lambda'$ = TOA planetary reflectance, without correction for solar angle

$M\rho$ = Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_ MULT_BAND_x, where x is the band number)

$A\rho$ = Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_ BAND_x, where x is the band number)

Qcal = Quantized and calibrated standard product pixel values (DN)

$$\rho\lambda = (\rho\lambda'/\cos(\theta SZ)) = (\rho\lambda'/\sin(\theta SE)) \qquad (2)$$

Where;

$\rho\lambda$ = TOA planetary reflectance

θSE = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION).

θSZ = Local solar zenith angle; $\theta SZ = 90^\circ - \theta SE$ (RADIANCE_ADD_BAND_x, where x is the band number)

Qcal = Quantized and calibrated standard product pixel values (DN)

Analysis on Multitemporal Difference of Spectral Indices

In this research, the following spectral indices were used:

- Normalized Difference Vegetation Index (NDVI): NDVI (Tucker, 1979; Laosuwan *et al*., 2016;

Rotjanakusol, & Laosuwan, 2019) is a kind of index indicating proportion of plants covering soil surface. It can be calculated by making proportion based on wavelength related to plants. It was making of proportion based on difference of reflection of surface between Near-infrared (NIR) and Red wavelength with sum of both wavelengths for adjusting as normal distribution (Equation 3). Results of NDVI were ranged from -1 to 1 and value that was close to 1 indicated high density of plants, for example, forest areas. On the other hand, if value was close to 0 or negative indicating low density of plants or none. Impact of occurred forest fire occurred is degeneration of forest areas, for example, NDVI of forest fire area may be low or negative.

$$NDVI = (NIR-RED) / (NIR+RED) \quad (3)$$

Where;
NIR = reflected value in the near-infrared spectrum
RED = reflected value in the red range of the spectrum

- Normalized Burn Ratio (NBR): NBR (Keeley, 2009) is a kind of index that is designed to find burning areas and evaluate severity of fire. NBR is the use of wavelength of Near Infrared (NIR) and Short Wave Infrared (SWIR) as shown in Equation 4. Plants will have high Reflectance in Near Infrared (NIR) and low Reflectance in Short Wave Infrared (SWIR). On the other hand, forest fire area will have low Reflectance in Near Infrared (NIR) and high Reflectance in Short Wave Infrared (SWIR). Generally, high NBR indicates small quantity of plants, empty spaces, and forest fire areas.

$$NBR = (NIR-SWIR) / (NIR + SWIR) \quad (4)$$

Where;
NIR = reflected value in the near-infrared spectrum
SWIR = reflected value in the shortwave infrared spectrum

- Soil-Adjusted Vegetation Index (SAVI): SAVI (Huete, 1988) is a kind of index that is designed to find forest fire areas and assess severity of fire. This method is similar to Normalized Difference Vegetation Index (NDVI), i.e., making proportion based on difference of reflection of surface between Near-infrared (NIR) and Red wavelength with sum of both wavelengths or adjusting as normal distribution by adding L factor (plants coverage value) Value of L factor was 0 for areas with high level of density of plants and 1 for areas with low level of density of plants. Calculation of SAVI is shown in Equation 5.

$$SAVI = ((NIR-RED) / (NIR-RED + L)) * (L) \quad (5)$$

Where;
NIR = reflected value in the near-infrared spectrum
RED = reflected value in the red range of the spectrum
L = amount of green vegetation cover

False Color Composite (FCC)

In this research, FCC was created for inspecting accuracy of forest fire areas by using data obtained from Landsat 8 satellite (7(R), 5(G), 4(B)) whereas FCC can show forest fire areas clearly through various color shades as follows (Liu *et al*., 2020, Uttaruk *et al*., 2022): Forest fire areas were shown with purple color to dark purple color, active fire areas were shown with orange color to red color, forest areas were shown with green color to dark green color, areas of deciduous forest were shown with light purple color, pink color, and white color, open lands were shown with white color, pink color, and light orange color, agricultural areas were shown with white color, light green color and dark green color, and water sources were shown with dark blue color.

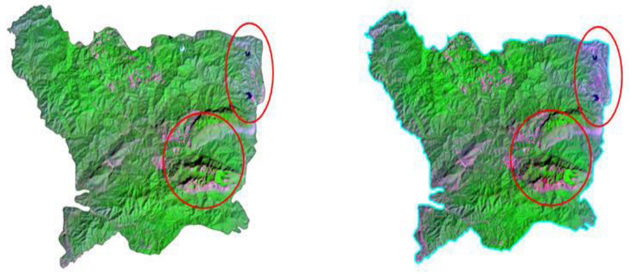
Accuracy Test

In this research, the accuracy test was performed by using Kappa statistic. Results obtained from analysis through FCC of data obtained from Landsat 8 satellite (7(R), 5(G), 4(B)) were compared by using visual interpretation (point by point) with results obtained from analysis on Multitemporal Difference of Spectral Indices (NDVI, NBR, SAVI) from 2017 to 2021. In this research, 60 reference points were determined classified into: 1) 20 points with severe forest fire, 2) 20 points with minor forest fire; and 3) 20 points without forest by creating random points in ArcGIS program.

RESULTS AND DISCUSSIONS

Analysis Results

Data obtained from Landsat 8 OLI satellite during 2017-2021 used for creating False Color Composite (FCC) with wavelength of SWIR-NIR-Red (RGB: 754) revealed that it could show forest fire areas clearly. Areas with severe forest fire were shown with purple color to dark purple color whereas forest areas were shown with green color and light green color or dark green color based on types of plants, appearance of plants and density of cover crops. The example of forest fire area based on data obtained from Landsat 8 OLI satellite in 2018 showing prefire and postfire areas is show in Figure-2.



(a) (b)

Figure-2. False Color Composite (a) prefire and (b) postfire.

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Subsequently, results obtained from False Color Composite (FCC) process with wavelength of SWIR-NIR-Red (RGB:754) during 2017-2021 were analyzed and compared to inspect forest fire areas with results of analysis on spectral indices consisted of NDVI, NBR, SAVI by determining 60 reference points as mentioned above. Results of analysis and comparison for inspecting forest fire areas of 5 years are shown from Figure-3 to Figure-7.

Figure-3, in 2017, results of analysis and comparison between FCC(RGB:754) and NDVI revealed that there were 27 points of forest fire areas whereas results of analysis and comparison between FCC(RGB:754) and NBR revealed that there were 38 points of forest fire areas. Results of analysis and comparison between FCC(RGB:754) and SAVI revealed that there were 35 points of forest fire areas.

Figure-4, in 2018, results of analysis and comparison between FCC(RGB:754) and NDVI revealed that there were 32 points of forest fire areas whereas results of analysis and comparison between FCC(RGB:754) and NBR revealed that there were 34 points of forest fire areas. Results of analysis and comparison between FCC(RGB:754) and SAVI revealed that there were 27 points of forest fire areas.

Figure-5, in 2019, results of analysis and comparison between FCC(RGB:754) and NDVI revealed that there were 31 points of forest fire areas whereas results of analysis and comparison between FCC(RGB:754) and NBR revealed that there were 39 points of forest fire areas. Results of analysis and comparison between FCC(RGB:754) and SAVI revealed that there were 26 points of forest fire areas.

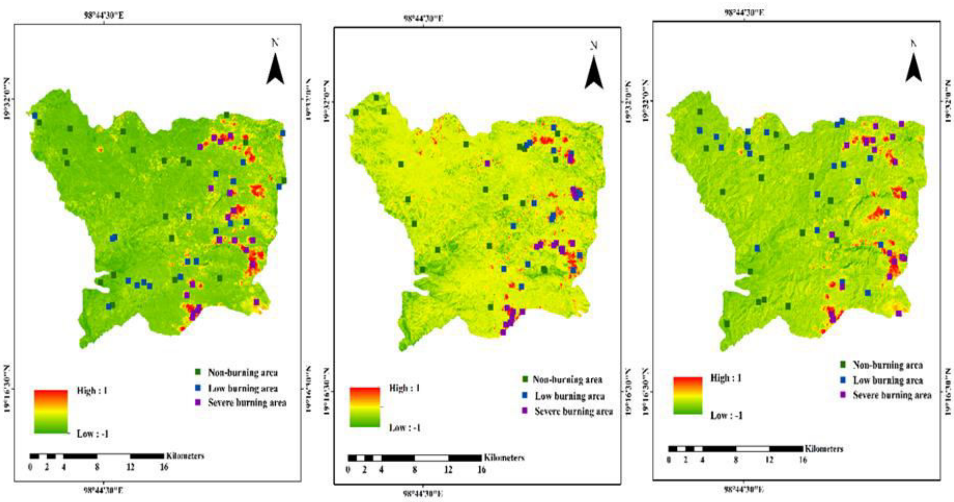
Figure-6, in 2020, results of analysis and comparison between FCC(RGB:754) and NDVI revealed that there were 23 points of forest fire areas whereas results of analysis and comparison between FCC(RGB:754) and NBR revealed that there were 28 points of forest fire areas. Results of analysis and comparison between FCC(RGB:754) and SAVI revealed that there were 32 points of forest fire areas.

Figure-7, in 2021, results of analysis and comparison between FCC(RGB:754) and NDVI revealed that there were 29 points of forest fire areas whereas results of analysis and comparison between FCC(RGB:754) and NBR revealed that there were 34 points of forest fire areas. Results of analysis and comparison between FCC(RGB:754) and SAVI revealed that there were 33 points of forest fire areas.

Accuracy Assessment

In this research, results of analysis on data obtained from Landsat 8 OLI satellite were assessed on accuracy by using Kappa statistics with results obtained from analysis on False Color Composite (FCC) with wavelength of SWIR-NIR-Red (RGB:754) during 2017-2021 and results obtained from analysis on spectral indices consisted of NDVI, NBR, and SAVI with 60 reference points in ArcGIS program. Those 60 random points were divided into 20 points with severe forest fire, 20 points with minor forest fire, and 20 points without forest fire. Results of accuracy assessment would be shown yearly started from 2017-2021 as follows:

- For 2017, results of accuracy assessment of NDVI revealed that there were 13 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 78.33% with Kappa statistics of consistency at 0.68. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer's accuracy was 84.62% and 100% with omission error of 15.38% and non-omission error. User's accuracy was 55% and 80% with commission error of 45% and 20%, respectively.



(a) (b) (c)

Figure-3. FCC with (a) NDVI, (b) NBR and (c) SAVI in 2017.

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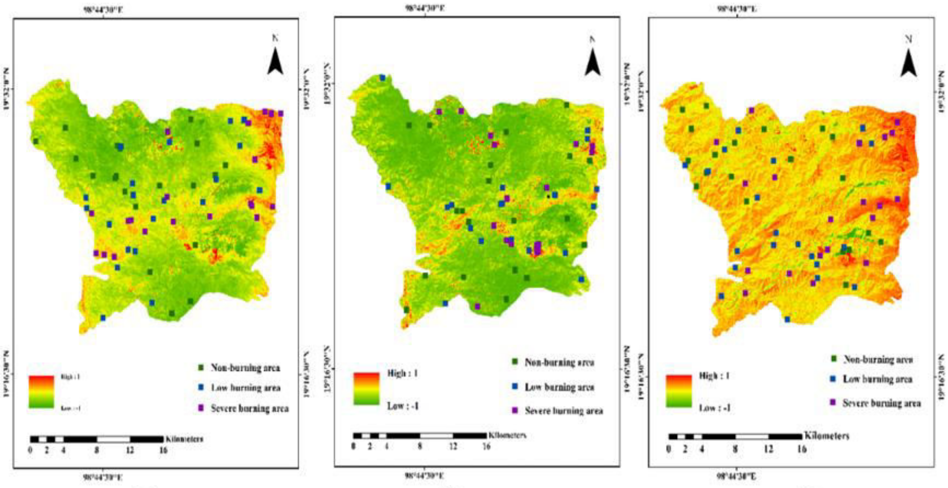
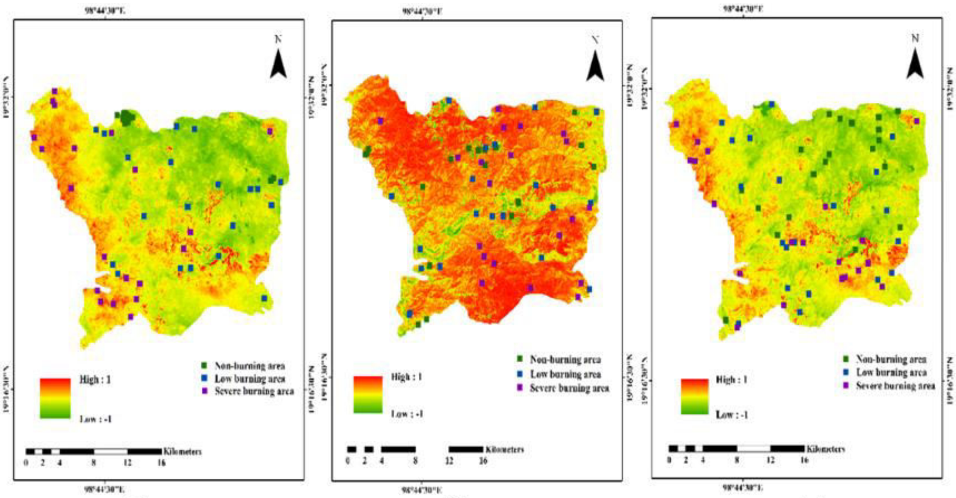


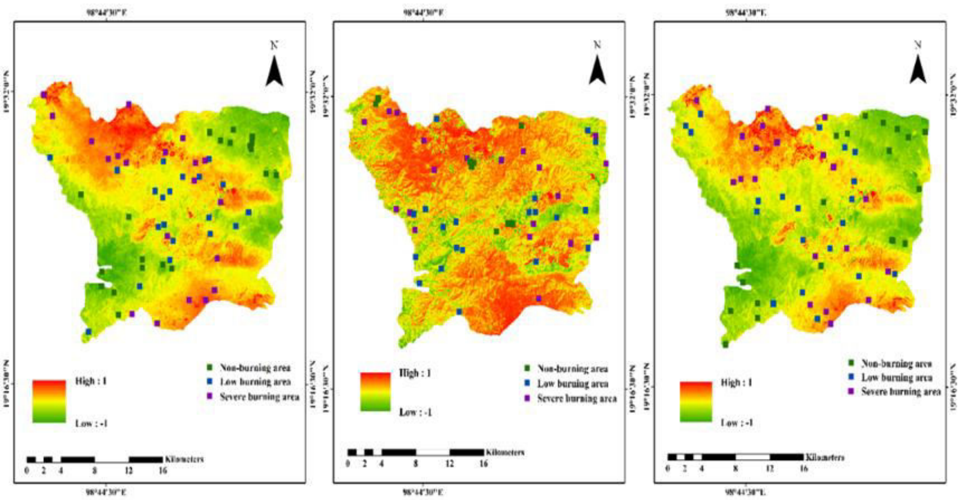
(a) (b) (c)

Figure-4. FCC with (a) NDVI, (b) NBR and (c) SAVI in 2018.



(a) (b) (c)

Figure-5. FCC with (a) NDVI, (b) NBR and (c) SAVI in 2019.



(a) (b) (c)

Figure-6. FCC with (a) NDVI, (b) NBR and (c) SAVI in 2020.

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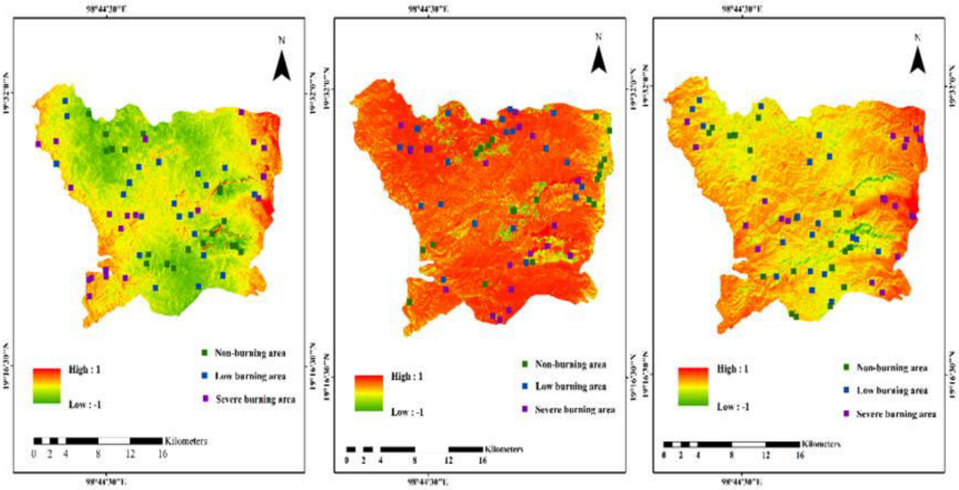

(a) (b) (c)

Figure-7. FCC with (a) NDVI, (b) NBR and (c) SAVI in 2021.

Results of accuracy assessment of NBR revealed that there were 3 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 95% with Kappa statistics of consistency at 0.93. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer’s accuracy was 90.48% and 95% with omission error of 9.52% and 5%. User’s accuracy was 95% and 95% with commission error of 5% and 5%, respectively.

Results of the accuracy assessment of SAVI revealed that there were 6 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 90% with Kappa statistics of consistency at 0.85. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer’s accuracy was 85% and 100% with omission error of 15% and non-omission error. User’s accuracy was 85% and 90% with commission error of 15% and 10%, respectively.

- For 2018, results of the accuracy assessment of NDVI revealed that there were 10 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 83.33% with Kappa statistics of consistency at 0.75. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer’s accuracy was 77.78% and 100% with omission error of 22.22% and non-omission error. User’s accuracy was 70% and 90% with commission error of 30% and 10%, respectively.

Results of the accuracy assessment of NBR revealed that there were 12 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 80% with Kappa statistics of consistency at 0.67. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer’s accuracy was 47.37% and 88.89% with omission error of 52.63% and 11.11%. User’s accuracy was 90% and 80% with commission error of 10% and 20%, respectively.

Results of the accuracy assessment of SAVI revealed that there were 15 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 78% with Kappa statistics of consistency at 0.63. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer’s accuracy was 72.72% and 100% with omission error of 27.28% and non-omission error. User’s accuracy was 80% and 55% with commission error of 20% and 45%, respectively.

- For 2019, results of the accuracy assessment of NDVI revealed that there were 10 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 83.33% with Kappa statistics of consistency at 0.75. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer’s accuracy was 77.78% and 100% with omission error of 22.22% and non-omission error. User’s accuracy was 70% and 90% with commission error of 30% and 10%, respectively.

Results of the accuracy assessment of NBR revealed that there were 14 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 76.67% with Kappa statistics of consistency at 0.65. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer’s accuracy was 66.67% and 83.33% with omission error of 33.33% and 16.67 %. User’s accuracy was 70% and 75% with commission errors of 30% and 25%, respectively.

Results of the accuracy assessment of SAVI revealed that there were 15 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 78% with Kappa statistics of consistency at 0.63. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer’s accuracy was 72.72% and 100%

with omission error of 27.28% and non-omission error. User's accuracy was 80% and 55% with commission error of 20% and 45%, respectively.

- For 2020, results of the accuracy assessment of NDVI revealed that there were 20 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 66.67% with Kappa statistics of consistency at 0.50. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer's accuracy was 81.25% and 83.33% with omission error of 18.75% and 16.67. User's accuracy was 65% and 50% with commission error of 35% and 50%, respectively.

Results of the accuracy assessment of NBR revealed that there were 19 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 68.33% with Kappa statistics of consistency at 0.53. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer's accuracy was 65.22% and 72.22% with omission error of 34.78% and 27.78 %. User's accuracy was 75% and 65% with commission error of 25% and 35%, respectively.

Results of the accuracy assessment of SAVI revealed that there were 12 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 80% with Kappa statistics of consistency at 0.70. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer's accuracy was 78.95% and 80.95% with omission error of 21.05% and 19.05. User's accuracy was 75% and 85% with commission error of 25% and 15%, respectively.

- For 2021, results of the accuracy assessment of NDVI revealed that there were 13 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 78.33% with Kappa statistics of consistency at 0.68. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer's accuracy was 66.67% and 100% with omission error of 33.33% and non-omission error. User's accuracy was 70% and 75% with commission error of 30% and 25%, respectively.

Results of the accuracy assessment of NBR revealed that there were 10 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 83.33% with Kappa statistics of consistency at 0.75. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer's accuracy was 72.72% and 90% with omission error of 27.28% and non-omission error. User's accuracy was 80% and 90% with commission error of 20% and 10%, respectively.

Results of accuracy assessment of SAVI revealed that there were 13 points that did not meet with research results. When calculating overall accuracy, it was found that overall accuracy was 78.33% with Kappa statistics of consistency at 0.68. When considering on class of minor forest fire areas and severe forest fire areas, it was found that producer's accuracy was 72.00% and 92.30% with omission error of 28.00% and 7.70. User's accuracy was 90% and 60% with commission errors of 10% and 40%, respectively.

CONCLUSIONS

Forest fire is another kind of disaster that can cause huge damages. Forest fire can be caused by nature like lightning, volcanic eruption, boiling hot weather and drought, and humans' actions like forest products collection, farm burning, animals hunting, livestock, forest burning for teasing, and negligence, etc. However, most forest fire incidents were caused by humans' actions. This research aims to inspect and classify forest fire areas in Chiang Dao Wildlife Sanctuary by using multitemporal difference of spectral indices based on application of data from Landsat 8 OLI satellite during 2017-2021 and assess accuracy of obtained results. From obtained results, it could be concluded that, from 2017-2021, forest fire areas were calculated to be 3.59 km^2, 1.70 km^2, 130.21 km^2, 128.04 km^2, and 23.73 km^2, respectively.

Moreover, results of the accuracy assessment based on 60 reference points classified into 20 points with severe forest fire, 20 points with minor forest fire, and 20 points without forest using Kappa statistics revealed that NBR showed the highest level of overall accuracy at 95.00% with Kappa statistics at 0.93 in 2017. In 2018, NDVI showed the highest level of overall accuracy at 83.33% with Kappa statistics at 0.75. In 2019, NBR showed the highest level of overall accuracy at 78.33% with Kappa statistics at 0.68. In 2020, SAVI showed the highest level of overall accuracy at 80.00% with Kappa statistics at 0.70. In 2021, NBR showed the highest level of overall accuracy at 83.33% with Kappa statistics at 0.75. Upon examining the results of the analysis and the accuracy assessment, it can be concluded that spectral indices such as NDVI, NBR and SAVI are used for monitoring and classification of forest fire areas in the study together with satellite data can identify forest fire locations very well.

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