Mapping burned areas from landsat-8 imageries on mountainous region using reflectance changes

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Abstract. This research tried to detect a burned area that occurred in the mountainous region of Java Island. During this time, forest and land fires mostly occur in lowland areas in Sumatra and Kalimantan. However, it is possible that this phenomenon also occurs in mountainous regions, especially the mountainous regions of Java Island. The data used were Landsat-8, the latest generation of the Landsat series. The research location was on the Northeast slope of Mt. Ijen in East Java. The research methods include radiometric correction, data fusion, sample training retrieval, reflectance pattern analysis, Normalized Difference Vegetation Index (NDVI) and Normalized Burn Ratio (NBR) extraction, separability analysis, parameter selection for burned area detection, parameter test, and evaluation. The results show that ρ_5 and NBR_L parameter shows the highest values of D-values (most sensitive), to detect the burned area. Then, compared to ρ_5 , NDVI and NBR_S , Normalized Burn Ratio long (NBR_L) provide better results in detecting burned areas.

1 Introduction

During this time, forest and land fires mostly occur in lowland areas in Sumatra and Kalimantan. However, it is possible that this phenomenon also occurs in mountainous regions, especially the mountainous regions of Java Island. The data used were Landsat-8, the latest generation of the Landsat series. This satellite is the latest generation of the Landsat series and is designed to perfect the sensors on the Landsat-7 ETM + satellite. The satellite carries two simultaneously operated sensors, OLI (Operational Land Imager) sensors and TIRS [1]. Landsat-8 data has the ability and opportunity to be exploited in many applications, namely; 1) radiometric calibration and characterization, 2) surface reflectance, 3) surface albedo, 4) surface temperature, evapotranspiration, and drought, 5) agriculture, 6) land cover (conditions, disturbances and changes), 7) freshwater and coastal waters, and 8) ice and snow [2]. Table 1 shows the comparison between OLI and ETM+ spectral bands.

Landsat-8, the latest generation satellite of the Landsat series and previous generation Landsat, such as Landsat TM and Landsat ETM+, have been widely used to identified and mapped of forest and land fires [3-12]. But, most research took place in lowland regions, such as Eastern part of Sumatera and Southern part of Kalimantan in Indonesia regions. This research tried to detect the burned area that occurred in the mountainous region of Java Island using Landsat-8. The research location was on the Northeast slope of Mt. Ijen in East Java.

This research raises the topic of how remote sensing image data can be used in generating information on the distribution and extent of burned areas located on mineral soils in mountainous areas. This burned area information is important information for estimating carbon emissions from forest and land fires, impact and damage assessments, and for preparing the policy or mitigation programs to prevent forest and land fires.

2 The material and method

Figures and tables, as originals of good quality and well contrasted, are to be in their final form, ready for reproduction, pasted in the appropriate place in the text. Try to ensure that the size of the text in your figures is approximately the same size as the main text (10 points). Try to ensure that lines are no thinner than 0.25 point. The data used is a pair of multitemporal Landsat-8 imageries which cover Mt. Ijen areas (path 117 row 066), i.e the first was recorded data before the fires (pre-fires) and second was data recorded during or after the fires (post-fires). The first image dated August 28, 2015, and the second image dated November 16, 2015. The first image shows the condition before the fires of August 2015 and the second image shows the condition after the fires in November 2015 (Fig.1). Landsat-8 data were obtained from Remote Sensing Technology and Data Center of Indonesian National Institute of Aeronautics and Space (LAPAN) [13]. The data format is GeoTIFF. Level of Landsat-8 is level one terrain-corrected product (L1T).

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Table 1. OLI and ETM+ spectral bands [1]

OLI spectral bands			ETM+ spectral bands		
Bands	Band with (μm)	GSD (m)	Bands	A band with (μm)	GSD (m)
1	0.433 – 0.453	30			30
2	0.450 – 0.515	30	1	0.450 – 0.515	30
3	0.525 – 0.600	30	2	0.525 – 0.605	30
4	0.630 – 0.680	30	3	0.630 – 0.690	30
5	0.845 – 0.885	30	4	0.775 – 0.900	30
6	1.560 – 1.660	30	5	1.550 – 1.750	30
7	2.100 – 2.300	30	7	2.090 – 2.350	30
8	0.500 – 0.680	15	8	0.520 – 0.900	15
9	1.360 – 1.390	30

Fig. 1. Landsat-8 RGB 654 Mt. Ijen date of 28 August 2015 (pre-fires) and 16 November 2015 (post-fires)

The research methods include radiometric correction, data fusion, sample training retrieval, reflectance pattern analysis, Normalized Difference Vegetation Index (NDVI) and Normalized Burn Ratio (NBR) extraction, separability analysis, parameter selection for burned area detection, parameter test, and evaluation.

The following equation is used to convert DN values to TOA reflectance for OLI [14]:

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

where $\rho\lambda'$ is TOA planetary reflectance (without correction for solar angle). $M\rho$ is Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number), $A\rho$ is band-specific additive rescaling

factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number), and $Qcal$ is quantized and calibrated standard product pixel values (DN).

Then, sun angle correction of TOA reflectance can be calculated by using the following equation [13]:

$$\rho\lambda = \frac{\rho\lambda'}{\cos(\theta_{sz})} = \frac{\rho\lambda'}{\sin(\theta_{se})} \quad (2)$$

Where $\rho\lambda$ is TOA planetary reflectance, θ_{se} is local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION). θ_{sz} is local solar zenith angle, $\theta_{sz} = 90^\circ - \theta_{se}$.

The following equation is used to extract the NDVI (modified from [14]):

$$NDVI = \frac{\rho_5 - \rho_4}{\rho_5 + \rho_4} \quad (3)$$

The following equation is used to extract the NBRs (modified from [3]):

$$NBRs = \frac{\rho_6 - \rho_5}{\rho_6 + \rho_5} \quad (4)$$

The following equation is used to extract the NBRL (modified from [3]):

$$NBRL = \frac{\rho_7 - \rho_5}{\rho_7 + \rho_5} \quad (5)$$

Where NBR_s is Normalized Burn Ratio (short), NBR_L is Normalized Burn Ratio (long) ρ_4 , ρ_5 , ρ_6 and ρ_7 are reflectance value of band 4, 5, 6 and 7 respectively.

The following equation is used to measure the separability [15]:

$$D = \frac{|\mu_2 - \mu_1|}{\sigma_2 + \sigma_1} \quad (6)$$

Where D is the Normalized Distance, μ_1 and μ_2 are mean values of samples before and after eruption respectively, σ_1 and σ_2 are the deviation standard of samples before and after eruption respectively.

3 Results and discussion

A pair of Landsat-8 date August 28, 2015, and November 16, 2015, showed the affected area due to fires on Mt. Ijen volcanic region. From the color composite band RGB 654, there can be identified the burned areas during that period. Burned areas show the purple color and look massive shape.

Several training areas of burned areas took in both derived reflectance corrected images. Then we measured the statistics of reflectance values from visible, Near Infra Red, and Short Wave Infra Red bands. In addition, measurements were made for NDVI, NBR_s and NBR_L images. Fig 2 and Table 2 showed the Landsat-8 OLI reflectance as well as index values of the burned area due to the fires between August 28, 2015, and November 16, 2015.

Before burning, the highest reflectance lied in the NIR channel (band 5). Whereas after burning, the highest reflectance lied in the SWIR channel (band 6 and 7) (Fig. 2). Based on the graph, however, generally, there can be understood that the fires will decrease reflectance on all channels, from visible, Near Infra Red, and Short Wave Infra Red bands. Among all band, band 5 has the greatest drop in reflectance value. The reflectance of band 5 decreased from 0.275 to 0.079 or decreased by 0.196. Table 2 shows the changes in reflectance and index values due to fires.

Fig. 2. The reflectance values of the burned area due to the fires between August 28, 2015, and November 16, 2015

When compared between forest and land fires in this mountainous regions with lowland regions in Riau Sumatra [16], burned areas in both regions have different reflectance patterns in the visible spectrum. Burned area in the mountainous regions, has a reflectance value toward the red spectrum will increase. Conversely, in lowland regions, the reflectance value toward the red spectrum is actually decreasing. Similarly, there is a difference between the pattern of reflectance changes. As mentioned earlier that fire events in the mountain region will decrease the reflectance value across the entire spectrum from the visible to the SWIR. While fires in lowland regions, the decrease in reflectance occurs only in visible spectrum up to NIR. In the SWIR spectrum, it will increase.

Fig. 3 show pre-fires and post-fires images of NDVI, NBR_s , and NBR_L derived from Landsat-8. Based on the measurement results it can be seen that the fires will cause a decrease in the value of NDVI, NBR_s , and NBR_L . The value of NDVI decreased from 0.606 to 0.327 (decreased by 0.280). the value of NBR_s decreased from 0.157 to -0.117 (decreased by 0.274). While the value of NBR_L decreased from 0.419 to -0.100 (changes 0.519).

The variables of ρ_4 , ρ_5 , ρ_6 , NDVI, NBR_s , and NBR_L showed the D -value > 1 , therefore they have good separability to discriminate burned and unburned areas (Table 3). This result is able to uncover the ability of ρ_4 , ρ_5 , ρ_6 , NDVI, NBR_s , and NBR_L in a separate area burned and unburned by the fires. One other important thing is that this result also showed that ρ_5 and NBR_L parameter has the highest of D -value compared with another parameter of a single band. Therefore, those variables were done as the threshold. The threshold based on the mean (μ) and deviation standard (σ) values (Table 2). Based on the normal distribution assumption, be chosen the values of $\mu \pm 1 \sigma$ as the threshold values for burned areas discrimination.

Fig. 3. Pre-fires and post-fires images of NDVI, NBR_s, and NBR_L derived from Landsat-8

Table 2. The changes in reflectance and index values due to fires

Pre-fires										
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	NDVI	NBR _s	NBR _L
Min	0.013	0.016	0.030	0.029	0.197	0.127	0.064	0.395	-0.076	0.148
Max	0.045	0.050	0.088	0.103	0.430	0.267	0.159	0.873	0.510	0.740
Mean	0.030	0.035	0.058	0.067	0.275	0.199	0.112	0.606	0.157	0.419
Sdev	0.005	0.006	0.009	0.014	0.036	0.023	0.016	0.084	0.085	0.091

Post-fires										
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	NDVI	NBR _s	NBR _L
Min	0.013	0.010	0.008	0.012	0.026	0.023	0.022	0.197	-0.330	-0.377
Max	0.041	0.043	0.051	0.068	0.148	0.190	0.159	0.535	0.174	0.374
Mean	0.024	0.025	0.029	0.039	0.079	0.099	0.096	0.327	-0.117	-0.100
Sdev	0.005	0.005	0.006	0.008	0.020	0.024	0.023	0.048	0.071	0.113

Changes										
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	NDVI	NBR _s	NBR _L
Min	-0.009	-0.008	0.003	-0.019	0.064	-0.018	-0.066	0.072	-0.026	0.094
Max	0.030	0.034	0.058	0.065	0.363	0.185	0.085	0.547	0.747	0.986
Mean	0.006	0.010	0.029	0.027	0.196	0.100	0.015	0.280	0.274	0.519
Sdev	0.005	0.006	0.009	0.015	0.043	0.034	0.029	0.090	0.120	0.157

Table 3. Normalized Distance For Spectral Bands and Indexes of Landsat-8

ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	NDVI	NBR _s	NBR _L
0.533	0.882	1.879	1.262	3.456	2.099	0.396	2.129	1.755	2.541

Burned areas pixels are extracted by applying the thresholds of post and changes of the variables. The pixel was defined as burned areas if meet the following criteria:

$$BA(\rho_5)_{ij} = \begin{cases} d\rho_{5ij} \geq 0.153 \\ \rho_{5postij} \leq 0.099 \end{cases} \quad (7)$$

$$BA(NDVI)_{ij} = \begin{cases} dNDVI_{ij} \geq 0.189 \\ NDVI_{postij} \leq 0.374 \end{cases} \quad (8)$$

$$BA(NBR_s)_{ij} = \begin{cases} dNBR_{sij} \geq 0.153 \\ NBR_{spostij} \leq -0.046 \end{cases} \quad (9)$$

$$BA(NBR_L)_{ij} = \begin{cases} dNBR_{Lij} \geq 0.362 \\ NBR_{Lpostij} \leq 0.013 \end{cases} \quad (10)$$

Whereas BA_{ij} is burned area pixel. $BA(\rho_5)_{ij}$ is burned area pixel based on reflectance band 5, $BA(NDVI)_{ij}$ is burned area pixel based on NDVI, $BA(NBR_s)_{ij}$ is burned area pixel based on NBR_s, and $BA(NBR_L)_{ij}$ is burned area pixel based on NBR_L. $d\rho_{5ij} = \rho_{5(pre-fires)_{ij}} - \rho_{5(post-fires)_{ij}}$. $dNDVI_{ij} = NDVI_{(pre-fires)_{ij}} - NDVI_{(post-fires)_{ij}}$. $dNBR_{sij} = NBR_{s(pre-fires)_{ij}} - NBR_{s(post-fires)_{ij}}$. $dNBR_{Lij} = NBR_{L(pre-fires)_{ij}} - NBR_{L(post-fires)_{ij}}$.

The result of the implementation of this formula can be seen in Fig.4. When the results were compared with the appearance of the Landsat-8 RGB color composite image 654 (Fig 1), then visually can be seen that the results of parameter estimation using NBR_L already provides a good overview of the results.

4 Conclusion

On the mountainous regions, based on Landsat-8, burned area shows the highest reflectance lied in the SWIR channel (band 6 and 7). The fires will decrease reflectance on all channels, from visible, Near Infra Red, and Short Wave Infra Red bands, whereas band 5 has the greatest drop in reflectance value. The fires also will cause a decrease in the value of NDVI, NBR_s, and NBR_L. ρ_5 and NBR_L parameter shows the highest values of D-values (most sensitive), to detect the burned area. The results show that, compared to ρ_5 , NDVI and NBR_s, Normalized Burn Ratio long (NBR_L) provides better results in detecting burned areas. The analysis for other cases in Indonesia is needed to give the better and more comprehensive results, in the context of the use of Landsat 8 for observation of the burned areas on mountainous regions in Indonesia.

This paper is a part of the remote sensing data application research for forest/land fires conducted at Remote Sensing Application Center, Indonesian National Institute of Aeronautics and Space (LAPAN), the fiscal year 2018. Remote Sensing Technology and Data Center of LAPAN has provided the data access to Landsat-8.

Fig. 4. Burned area (BA) derived from Landsat-8 based on $\rho 5$, NDVI, NBR_s , NBR_L

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