Mapping small burned areas using high spatial resolution planetscope imagery: a case study of the wildfire in Da Lat city

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Giám sát cháy rừng quy mô nhỏ sử dụng ảnh vệ tinh độ phân giải cao planetscope tại thành phố Đà Lạt

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ABSTRACT

This study employed high spatial resolution PlanetScope imagery at 3 m resolution for mapping burned area and burn severity resulting from a wildfire that occurred from April 7-9, 2023 in the highland of Vietnam. The wildfire took place in a protection forest near the Prenn pass in Da Lat city, Lam Dong province, Vietnam. Pre- and post-fire Normalized Difference Vegetation Index (NDVI) maps were generated using no-cloud high-resolution images acquired on March 25 and April 23, 2023 by the PlanetScope's SuperDove satellites, respectively. The difference of NDVI (dNDVI) was then calculated, and thresholds, proposed by the author, were utilized to classify the study area into three different classes: unburned, low-to-moderate and high severity. The results showed that the total burned area was approximately 13.86 ha, with 8.19 ha classified as low-to-moderate severity, and 5.68 ha classified as high severity. Although there was no reference dataset to cross-validate the results, the estimated burned area is very close to the total affected area officially reported by the Forest Protection Department of Lam Dong province (about 13 ha). This study is one of the few that investigates the use of high-resolution PlanetScope imagery for environmental monitoring in Vietnam, and the first to focus on burned area and burn severity mapping in Vietnam. This work demonstrates the potential of PlanetScope images for mapping burned area and burn severity, particularly in small regions where other optical satellites, such as Sentinel-2 and Landsat, may not provide accurate results due to their spatial resolution limitations.

Từ khóa:
lập bản đồ khu vực cháy rừng, mức độ cháy rừng, Đà Lạt, PlanetScope.

TÓM TẮT

Nghiên cứu này sử dụng ảnh vệ tinh PlanetScope với độ phân giải không gian 3 m để giám sát khu vực bị tác động bởi cháy rừng và mức độ tác động của vụ cháy rừng xảy ra từ ngày 07/04/2023-9/04/2023, trong khu vực rừng phòng hộ gần đèo Prenn, thuộc địa phận thành phố Đà Lạt, tỉnh Lâm Đồng. Bản đồ chỉ số thực vật khác biệt chuẩn hóa (Normalized Difference Vegetation Index; NDVI) trước vào sau khi thời điểm cháy được xây dựng, sử dụng ảnh vệ tinh PlanetScope SuperDove chụp ngày 25/03/2023 và 23/04/2023, với mức độ mây phủ là 0%. Sự khác biệt của chỉ số NDVI trước và sau khi cháy (dNDVI) được sử dụng để phân loại khu vực nghiên cứu thành ba đối tượng: không bị tác động, tác động ít đến trung bình, và tác động cao, sử dụng các giá trị ngưỡng phân loại do tác giả đề xuất. Kết quả tính toán cho thấy tổng diện tích rừng bị tác động bởi vụ cháy là khoảng 13,86 ha, trong đó 8,19 ha bị tác động ít đến trung bình và 5,68 ha bị tác động cao. Tổng diện tích rừng bị tác động rất gần với con số ước tính do Chi cục Kiểm lâm tỉnh Lâm Đồng báo cáo chính thức (khoảng 13 ha). Bài báo này là một trong số ít các nghiên cứu ở Việt Nam sử *dụng ảnh vệ tinh độ phân giải cao PlanetScope trong giám sát biến động môi trường và là một trong những nghiên cứu đầu tiên tập trung vào giám sát diện tích và mức độ tác động của cháy rừng. Kết quả của nghiên cứu cho thấy tiềm năng của ảnh PlanetScope trong việc giám sát cháy rừng ở những khu vực có diện tích nhỏ mà các loại ảnh quang học khác như ảnh Sentinel-2 và Landsat không thể cung cấp các kết quả chính xác cao do giới hạn về độ phân giải không gian của những loại ảnh này.*

1. INTRODUCTION

Wildfires are defined as unplanned fires that spread quickly over woodland or brush. These fires can be extremely destructive, causing significant damage to ecosystems, as well as social and economic disruptions at local and global scales. In recent decades, under the effect of anthropogenic and natural factors, including global warming and climate change, the frequency and intensity of wildfires has significantly increased [1]. Estimating the damage caused by wildfires has become crucial as it not only helps in understanding the impact of these disasters on the environment, ecosystems and human communities, but also assists in developing effective strategies for prevention and mitigation. While traditional field surveying methods are slow, costly, and impractical for large or remote areas [2], remote sensing satellite observations provide a faster and cost-effective solution [3]. Satellite observations with coarse spatial resolutions such as the Moderate Resolution Imaging Spectroradiometer (MODIS) products are suitable for mapping wildfire damage in large areas [4, 5]. Medium spatial resolution optical imagery acquired from Sentinel-2 and Landsat platforms are used most frequently for wildfire burn mapping [6-8]. Very high-resolution (VHR) observations captured by commercial satellites, such as Worldview-2, QuickBird-2, and Geoeye-1, provide detailed information at sub-meter spatial resolution but at a higher cost and lower temporal resolution [9-11].

Among different techniques for wildfire damage mapping using optical satellite observations, spectral indices are used the most due to their efficiency and simplicity [12, 13]. Among these indices, the Normalized Burn Ratio (NBR) [14] has been traditionally considered the most popular choice for mapping wildfire damage [15]. The NBR is calculated as the ratio between the near-infrared (NIR) and the short-wavelength infrared (SWIR) bands. These two bands are used because the differences of surface reflectance from vegetation and non-vegetation surfaces (including burned area) are maximum in these wavelengths. However, in situations when satellite sensors do not capture information in SWIR wavelengths, the Normalize Difference Vegetation Index (NDVI) may be used as an alternative for mapping burn severity [16]. These spectral indices have proven to be effective in mapping burned area and burn severity to support wildfire management.

The primary goal of this study is to explore the use of high spatial resolution PlanetScope imagery for mapping burned area and burn severity, particularly for small areas where the spatial resolutions of Sentinel-2 and Landsat satellites are inadequate to differentiate between burned and unburned areas. PlanetScope observations were chosen for this study because it is the only high-resolution dataset available in the study area that the author can access free-of-charge. For detailed technical review of PlanetScope satellites and its three generations, readers can refer to the work of [17]. Section 2 describes the study area and details of PlanetScope observations employed in this study. Section 3 outlines the methodology utilized in this study. Section 4 presents and discusses the obtained results. Finally, Section 5 concludes this study.

2. RESEARCH METHODOLOGY

2.1. Study area

The study area (approximately 1.45 km^2) is located in a protection forest located near the Prenn pass of Da Lat city, Lam Dong province, Vietnam (Figure 1). Da Lat city is a popular tourist destination situated on the Lam Vien plateau at an altitude of approximately 1,500 m above the sea level. As of 2022, Da Lat city spans an area of over 393 km^2, with a population of more than 237,000 people. The city has more than 20,000 ha of forests, with natural forests accounting for about 14,460 ha [18].

On 7 April, 2023, a wildfire was detected in the study area at around 15 p.m. local time [19]. While the wildfire was largely under control by 23 p.m. local time, some large fire spots continued to smolder until 9 April [20]. According to the Forest Protection Department of Lam Dong province, the wildfire was reported to have destroyed around 13 ha of forests, mainly grass, shrubs, and pine leaves, while mature pines were not seriously affected due to their height [18]. Figure 2 illustrates true color and false color composite maps of the study area using high-resolution PlanetScope images acquired before and after the wildfire, on 25 March and 23 April, 2023, respectively. The main burned area are clearly visible in the images as they appear red in the true color composite map (Figure 2c), and green in the false color composite map (Figure 2d).

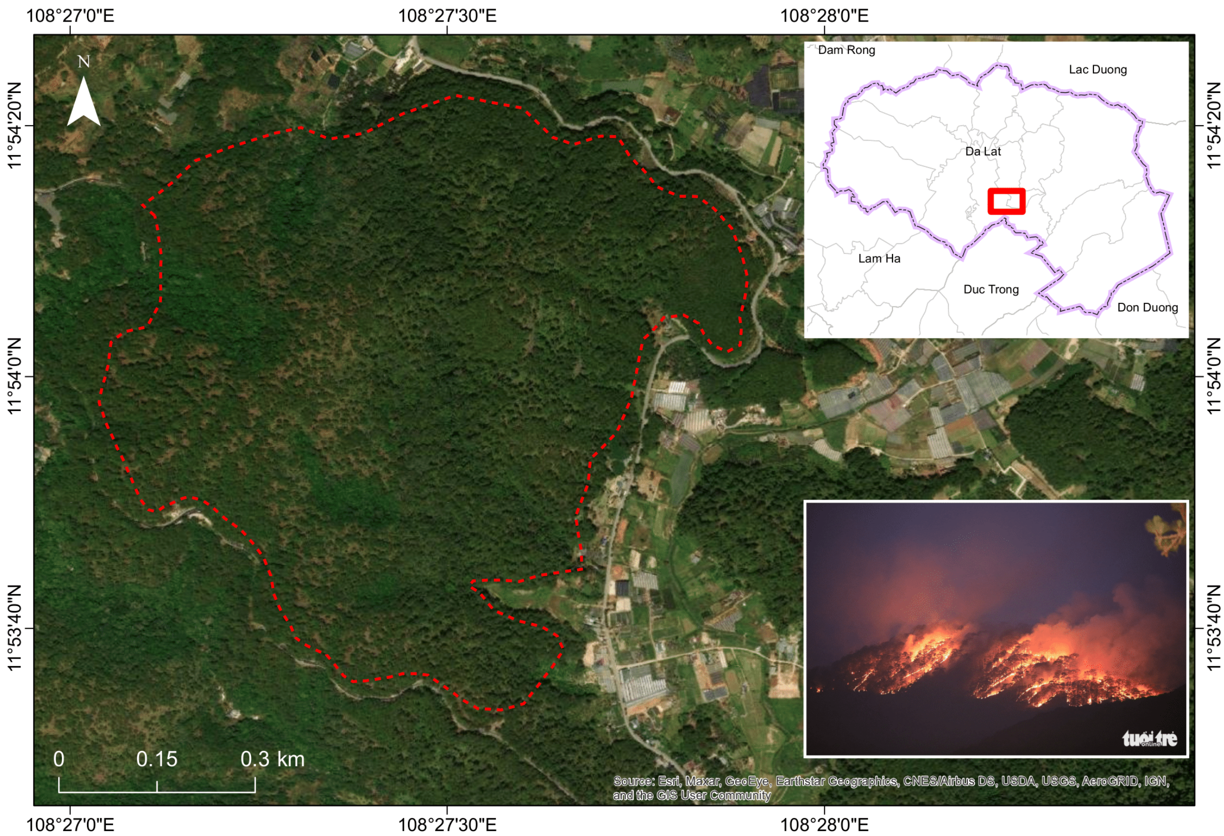

Figure 1. Location of the study area which is a protection forest (inside the dashed red polygon) located about 10 km from Da Lat city, Lam Dong province. The small photo was taken at the scene on the evening of April 7, 2023

(Source: [20])

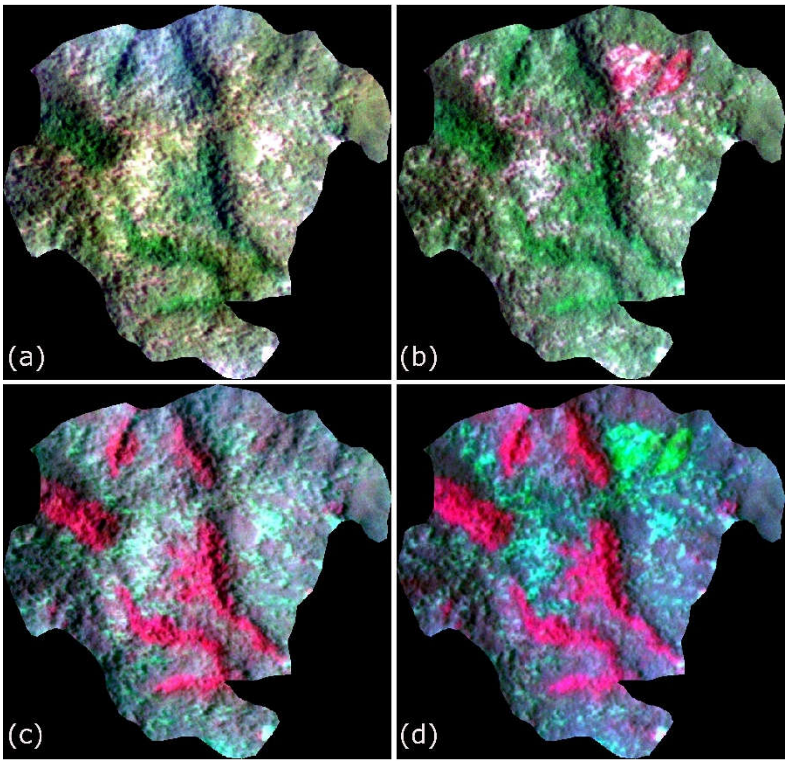

Figure 2. True color (top) and false color composite maps (bottom) of the study area, acquired by PlanetScope satellites before (left) and after the wildfire (right), on March 25 and April 23, 2023, respectively

2.2. PlanetScope imagery

The study area is quite small; therefore, Sentinel-2 and Landsat observations could not provide accurate results due to limitations of their medium spatial resolutions. To map small burned areas, two free-cloud PlanetScope Level 3B Ortho Analytic surface reflectance images at 3 m spatial resolution were used. The pre-fire image was acquired on March 25, 2023 at 02:20:38 UTC, and the post-fire image was acquired nearly one month after on April 23, 2023, when the wildfire was over. The two images were selected based on area coverage, cloud cover, sun zenith angle, and overall scene quality. The two images were both taken by the Planet's SuperDove satellites, and were geometrically and radiometrically corrected before being distributed to end-users for further processing. SuperDoves is the third generation of Planet's satellites, started being launched from 2018. Until now, the constellation has nearly 200 satellites, orbiting in sun-synchronous orbits at an attitude of approximately 475 km, with an inclination of 98^0 [17]. Details of these two images are shown in Table 1. PlanetScope images were provided through the Planet's Education and Research program [21], which can be registered at: https://www.planet.com/markets/education-and-research/.

Table 1. Characteristics of the two PlanetScope imagery used in this study

	Acquisition Date	Area Coverage (%)	Cloud Cover (%)	Pixel Resolution (m)	Instrument	Band wavelengths (nm)
Pre-fire Imagery	25/03/2023 (02:20:38 UTC)	100	0	3	SuperDove (PSB.SD)	Blue (465 - 515) Green (547 - 585) Red (650 - 680) NIR (845 - 885)
Post-fire Imagery	23/04/2023 (02:54:43 UTC)	100	0	3	SuperDove (PSB.SD)	

Source: [22]

2.3. Methodology

The workflow used in this study is illustrated in Figure 3. Initially, the original pre- and post-fire images were spatially subset to cover the entire study area using a shapefile created by the author. Next, the NDVI maps were generated for both pre- and post-fire images using Equation (1), where NIR and RED are surface reflectance in the near-infrared (band 4) and red (band 3) wavelengths, respectively. To merge the two pre- and post-fire NDVI images into a single product with the same dimensions and projection, the Layer Stacking tool of ENVI version 5.0 was used. The difference in NDVI (dNDVI) between pre- and post-fire NDVI was then calculated using Equation (2). Subsequently, thresholds were applied to the dNDVI values to classify the study area into three severity levels. Pixels with dNDVI values less than 0.09 were classified as unburned area, while those with dNDVI values ranging from 0.09 to 0.15 were classified as having low-to-moderate severity. Finally, pixels with dNDVI values greater than 0.15 were classified as having high severity. It is important to note that no standard exists for classifying wildfire burn severity using dNDVI, and the intervals used in Table 2 can vary depending on various factors [23]. Therefore these criterions were proposed by the author after referring to the criterions suggested by United States Geological Survey (USGS) [24] and careful manual interpretation of the dNDVI map in ENVI. The final classification map was post-processed for correction, and then exported to a kmz file for being displayed in Google Earth for better visualization.

$$NDVI = \frac{NIR \quad RED}{NIR + RED} = \frac{BAND\,4 \quad BAND\,3}{BAND\,4 + BAND\,3} \tag{1}$$

$$dNDVI = NDVI_{pre-fire} \quad NDVI_{post-fire} \tag{2}$$

Table 2. Threshold values used for mapping wildfire burn severity using dNDVI in this study

dNDVI Interval	Burn Severity
< 0.09	Unburned
0.09 to 0.15	Low-to-moderate Severity
> 0.15	High Severity

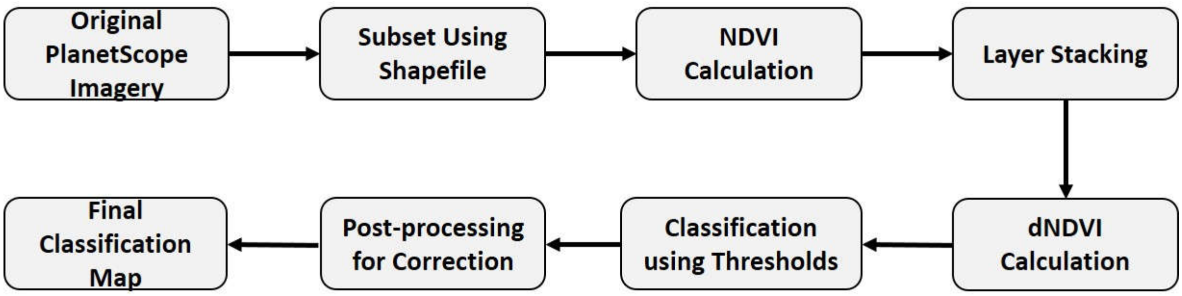

Figure 3. The processing framework applied in this study

3. RESULTS AND DISCUSSIONS

3.1. Generation of pre- and post-fire NDVI maps and dNDVI map

The pre- and post-fire NDVI maps of the study area, obtained from the two PlanetScope images are shown in Figure 4. The study area, which is a protection forest, had high NDVI values before the wildfire, ranging from 0.533 to 0.923, indicating that the pine forest was in a very good condition. However, the wildfire caused partial to total destruction of vegetation cover on the ground in some regions, resulting a reduction in their NDVI to below 0.4. Mature pines were not seriously destroyed by the wildfire thank to its height; therefore, NDVI in these regions did not decrease too much. The

NDVI of unburned area exhibited minimal variations, with the highest NDVI being 0.912. As depicted in Figure 4 (right), the primary fires occurred in the northeast of the protection forest.

The dNDVI map of the study area is shown in Figure 5, with the values ranging from -0.10 to 0.34. Since the cloud cover of both pre- and post-fire images was 0%; therefore, there was no need to apply a cloud mask to the dNDVI map. The burned regions are more visible in Figure 5 compared to the post-fire NDVI map, and are depicted as red regions where dNDVI values exceed 0.09. By implementing the threshold criteria specified in Table 2, a burn severity map can be generated promptly.

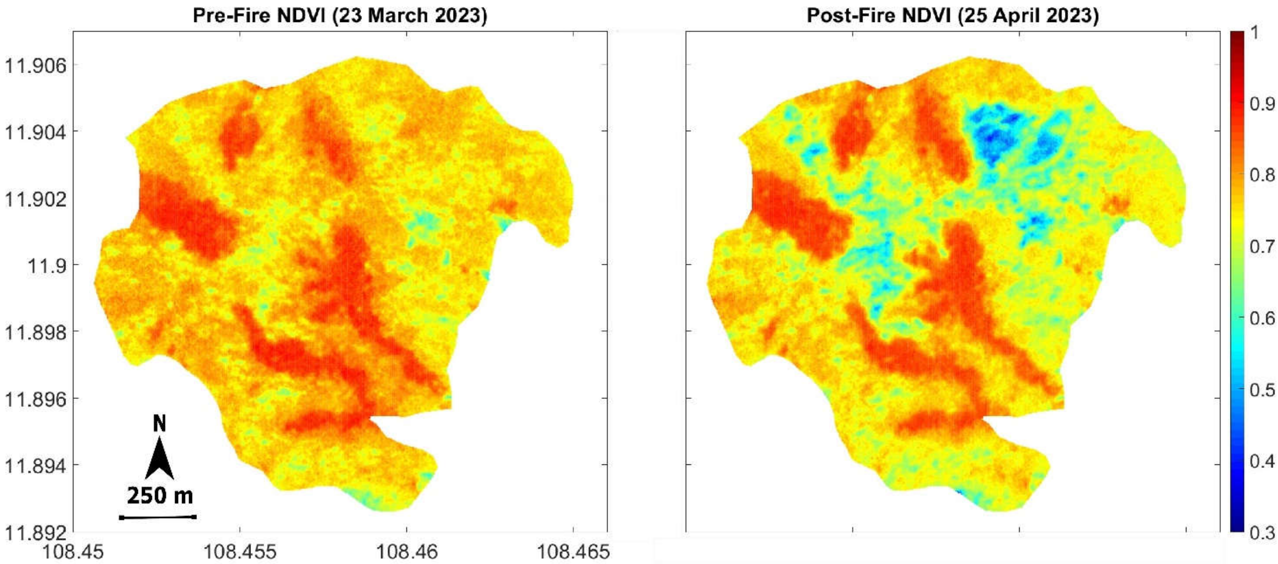

Figure 4. Pre- and post-fire NDVI maps of the study area derived from PlanetScope images

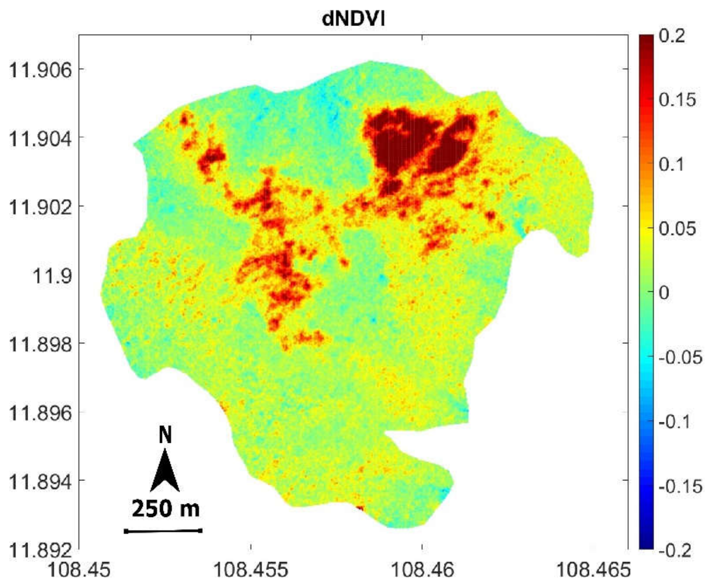

Figure 5. The dNDVI map of the study area

3.2. Wildfire damage assessment: Burn severity mapping

The burn severity map of the study area is illustrated in Figure 6 with three levels of severity, unburned area displayed in green, low-to-moderate severity in red, and high severity in black. The spatial resolution of PlanetScope images used in this study is 3 m, and based on this, the author estimated the total area affected by the wildfire to be 13.87 ha, with 8.19 ha being low-to-moderate affected and 5.68 ha being highly affected. While lacking a reference dataset for precise accuracy assessment, these results are in close agreement with the estimation provided by the Forest Protection Department of Lam Dong province, which reported an area of about 13 ha [20], thus suggesting that the methodology used in this study is reliable and accurate, and can be useful to map burned area in near real-time. In comparison with previous work focusing on burned area mapping using deep learning techniques trained on PlanetScope observations [25, 26], or the fusion of PlanetScope with other optical satellite observations (i.e., Landsat-8 and Sentinel-2) [2, 27], the proposed method is faster and less complicated. This method is suitable for local managers to rapidly generate burned area maps; therefore, it is very useful for emergency response of forest fires, particularly in rural areas. For better visualization, the burned area map was exported to a kmz file, with the unburned area removed, for being displayed on Google Earth as depicted in Figure 7.

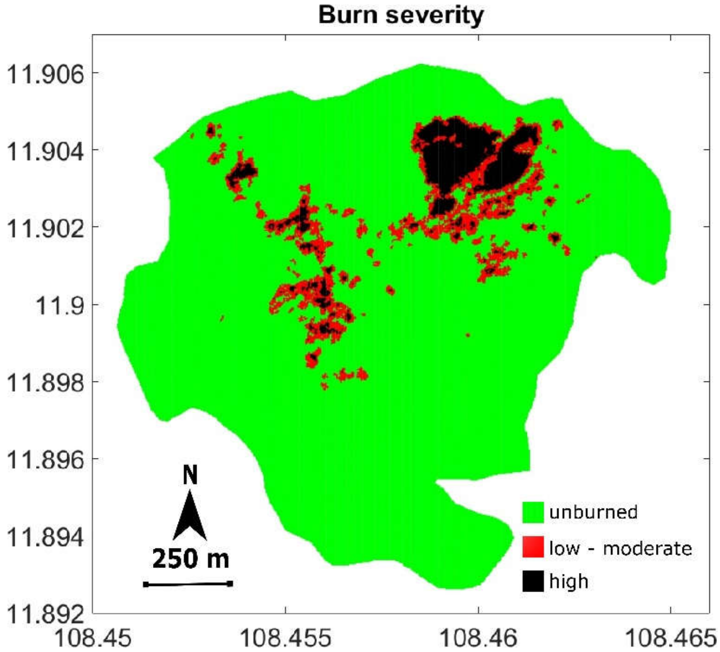

Figure 6. Burn severity map of the study area

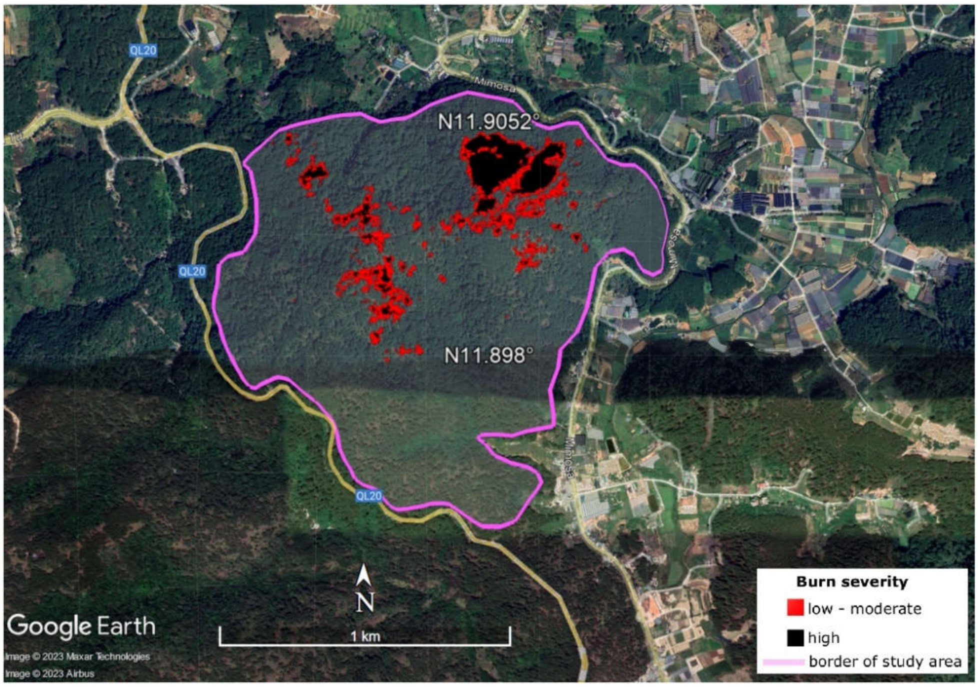

Figure 7. Burn severity map of the study area, being displayed on Google Earth Pro

3.3. Advantages and limitations of PlanetScope compared to other optical satellites

Compared to other popular optical satellites managed by big space agencies, PlanetScope satellites offer several advantages for environmental monitoring applications. Firstly, PlanetScope images have high spatial resolution imagery up to 3 m, enabling detailed mapping of small changes on Earth's surface, particularly for disaster monitoring and management. Secondly, the constellation of nearly 200 satellites ensures a much higher revisit time compared to other platforms, allowing the same location to be captured multiple times in a day compared to every 5 days with Sentinel-2 and every 16 days with Landsat. This feature is especially useful for monitoring rapidly changing conditions such as floods and wildfires. Thirdly, Plantscope images are rapidly delivered to end-users within hours of capture, making them ideal for emergency response and military applications.

However, when compared to other platforms, PlanetScope satellites also have some limitations. Firstly, as a private company, Planet's data is not totally free as Sentinel-2 and Landsat observations. PlanetScope images used in this study were provided through the Planet's Education and Research program, which is limited to 5000 km^2 of data monthly for education purposes only [21]. This limitation hinders the ability to monitor changes of large areas for extended periods, and thus limits the use of PlanetScope data for scientific research. Secondly, PlanetScope's SuperDove satellites have a smaller coverage area (32.5 x 19.6 km) compared to Sentinel-2 and Landsat, which restricts their applications to small areas located within the satellite's constellation's swath. Thirdly, PlanetScope has limited historical data as the first satellites were launched only in 2016, making long-term analysis and monitoring impossible [28]. Fourthly, PlanetScope sensors capture images in only four spectral bands, including red, green, blue and near-infrared, while Sentinel-2 and Landsat capture images in 13 and 11 spectral bands, respectively. Without having a short-wave infrared band, it limits the types of analysis that can be performed with PlanetScope images compared to the other platforms. Fifthly, PlanetScope images are acquired using many small satellites, belonging to difference generations, rather than a single large platform like Sentinel-2 and Landsat. Therefore, radiometric and geometric corrections of these products are not always compatible across generations of satellites, and does not always match the standard requirements expected by the remote sensing community [29, 30]. Last but not least, similar to other optical satellite platforms, cloud cover can be a significant problem with PlanetScope satellites, especially over tropical regions where cloud contamination is normally very high during several months in a year [31].

It is worth noting that these limitations do not significantly affect the quality of this study. The author was able to ensure the reliability of the results by selecting pre- and post-fire images that met specific criteria, such as zero cloud cover, the study area lies within one PlanetScope's scene and captured by similar instruments. The pre-fire image was acquired at 02:20:38 UTC, and the post-fire image was acquired at 02:54:43 UTC. This helps to reduce differences in illumination conditions. Moreover, the absence of a short-wave infrared wavelength does not impact the classification results since the NDVI, which has been widely used for wildfire damage assessment [2], was utilized in this study.

4. CONCLUSIONS

This study utilized high spatial resolution PlanetScope images at 3 m resolution to map the burned area and burn severity caused by a wildfire that occurred in April 2023, in a protection forest near the Prenn pass in Da Lat city, Lam Dong province in the highland of Vietnam. The pre- and post-fire NDVI maps were generated using cloud-free images acquired on March 25 and April 23, 2023, respectively, followed by dNDVI calculation. As there is no standard threshold criterions exist for burned area and burn severity mapping based on dNDVI values, the author proposed classification threshold values for this case by manually interpreting the dNDVI image. The results estimated that the total burned area to be 13.87 ha, with 8.19 classified as low-to-moderate severity and 5.68 ha classified as high severity. Although no reference dataset was available for precise accuracy assessment, these numbers closely match the total affected area, officially reported by the Forest Protection Department of Lam Dong province (about 13 ha). According to the author's best knowledge, this work is among the few studies investigating on the use of high-resolution PlanetScope observations for environmental monitoring in Vietnam, such as [32-37], and is the first one focusing on burned area and burn severity mapping.

This study highlights the potential of high-resolution PlanetScope observations for mapping burned area and burn severity, especially for small regions where other optical satellites (i.e. Sentinel-2 and Landsat) might not provide good results due to the limitation of their spatial resolutions. Future work might focus on two directions: (1) Applying similar processes to map burned area and burn severity caused by other wildfires to identify a better threshold criterions for wildfire burned area mapping; and (2) For regions where free-cloud Sentinel-2 observations are available and can be used, data fusion of Sentinel-2 and PlanetScope images will be investigated to benefit the short-wave infrared wavelength of Sentinel-2 satellite for better mapping burned area and burn severity.

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