Mapping and Assessment of Burned Areas in Palawan, Philippines using SAR Burned and Vegetation Indices

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ABSTRACT

Palawan is considered "the last frontier" of the Philippines; in light of this, the province receives special attention from the national and international community. Despite this, there are still numerous issues that need to be addressed, including illegal burning activities. Based on reports and satellite image analyses, slash-and-burn (kaingin) farming is pervasive in Palawan. Burned areas are easily detected from optical satellite images using the Normalized Burn Ratio (NBR) or similar indices. However, the usefulness of optical imagery is severely limited by persistent cloud cover, especially in upland areas where kaingin is commonly practiced. This study focuses on the utilization of Sentinel-1 SAR data in monitoring the burned areas due to its ability to penetrate clouds, smoke, and haze. Radar burn and vegetation indices such as Radar Burn Difference (RBD), Radar Burn Ratio (RBR), Radar Vegetation Index (RVI), and Radar Forest Degradation Index (RFDI) were used to detect the burned areas. These were then cross-validated with the NBR layer. RBD index yielded better results compared to other radar burn and vegetation indices in mapping the burned areas. Additionally, the RBD using the VH polarization band provided detailed delineation of burned areas than that using the VV polarization band. In the operational monitoring of burned areas, the synergistic use of burned indices from optical and SAR images is recommended.

Keywords: Burned area mapping, Sentinel-1 SAR, Radar burn index, Radar vegetation index

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1. INTRODUCTION

Trees are valuable to humanity not only economically, environmentally, and industrially, but also spiritually, historically, and aesthetically because they maintain human health and life through direct and indirect gains by offering a diverse range of commodities for survival and success[1]. Trees also play a role in climate change mitigation by decreasing carbon dioxide and greenhouse gas emissions[2,3]. However, climate change and human-induced warming have already led to a global increase in the frequency and severity of fire weather, which makes trees and forests more vulnerable to fire[4,5,6,7].

Fires are causing an additional 3 million hectares of tree cover loss per year, with nearly 70% occurring in boreal regions. Fires are increasing at a 3% annual rate and are more frequent and severe. Deforestation and climate change have led to fires escaping into tropical rainforests, increasing by 5% per year since 2001[8].

The Philippines, with 7,100 islands, has a 30-million-hectare land area, with 52% classified as public forestlands and the rest as alienable and disposable. Most forestlands are in hilly, mountainous areas with 18% slopes[9]. The Global Forest Watch dataset revealed that the Philippines lost 1.31Mha of tree cover between 2001 and 2021, with fires accounting for 23.3kha or 1.7% of the loss. The year with the most tree cover loss due to fires during this period was 2016 with 2.95kha lost to fires — 2.3% of all tree cover loss for that year. The province of Palawan had the highest rate of tree cover loss due to fires with an average of 102 ha lost per year[8].

Based on the study, the Kaingin is the main driver of deforestation in the Philippines[10]. Presidential Decree No. 705 of the Philippine government defined the *Kaingin* as a portion of the forest land, whether occupied or not, which is subjected to shifting and/or permanent slash-and-burn cultivation having little or no provision to prevent soil erosion[11].

Several techniques have been employed for wildfire detection and estimation of burned areas; manual field measurement has always been the most common approach to measure the extent and severity of a wildfire. However, satellite imagery has emerged as an effective and practical method due to advancements in remote sensing satellite technologies[12]. Data from Landsat and Sentinel-2 is often utilized to map burn intensity and determine the post-fire extent, yet cloud cover makes these optical satellites less useful. The SAR satellite data offers the possibility to detect wildfires and assess their spatial extent and damage without being constrained by air conditions, unlike optical-range remote sensing imageries[13]. The study investigated the effectiveness of SAR burned indices in assessing the extent and severity of burn scars in Rizal, Palawan.

2. DATA AND METHODS

2.1 Study Area

Palawan Province holds 23 municipalities, and one independent city[14]; one of which is Rizal municipality. Rizal is situated in the southwestern part of Palawan, bounded by a mountain range on the east and coastal terrain on the west. Its terrain has shaped its economic activities i.e., agriculture, tourism, trade, and fisheries[15]. Based on the NAMRIA land cover map of 2020, 35.7% of the municipal is shrub, 32.4% is open forest, 11.6% is perennial crop, 6.6% is annual crop, 5.2% is closed forest, 3.8% is grassland, 2.7% is mangrove forest, 1.1 is inland water, 1% is built-up, 0.01% is barren, and 0.03% is fishponds. Additionally, part of the municipality is the Mt. Mantalingahan Protected Landscape, and monitoring this area is essential considering ecological and environmental implications, biodiversity preservation, cultural and historical importance, and enrichment of its ecosystem services for socio-economic impacts[16].

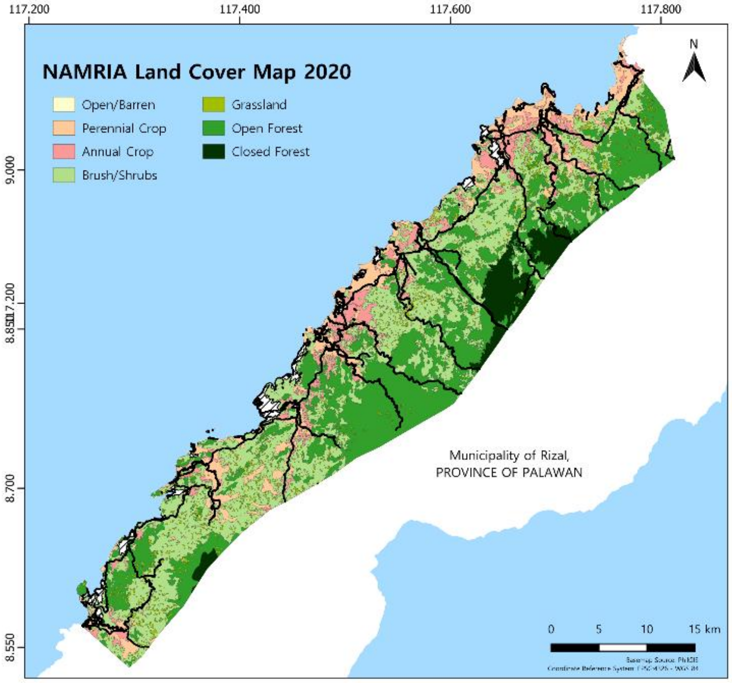

Figure 1. NAMRIA Land Cover Map (2020) of Rizal, Palawan, Philippines.

2.2 Data Used

The Ground Range Detected (GRD) dual-polarized (vertical-vertical and vertical-horizontal) images captured by the Sentinel-1 satellite data in interferometric swath mode are utilized to locate burnt regions[17]. The Sentinel-1 Synthetic Aperture Radar (SAR) data collected on March 2, 2020 (pre-fire) and March 26, 2020 (post-fire) were pre-processed using the widely used and standard workflow for pre-processing Sentinel-1 GRD data[18]. It includes steps such as removing thermal noise, border noise, radiometric calibration, speckle filtering, and terrain correction. These steps help to improve the quality of the data and make it more suitable for analysis.

The study assessed the burned area in Rizal, Palawan using the SAR burn indices and cross-referenced to optical burn index. The burned area indices used in this study are summarized in the Table 1.

Table 1. Optical and SAR-based Burn Indices

BURN INDEX	**DESCRIPTION**	**FORMULA**
Optical		
Normalized Burn Ratio (NBR)	It is a ratio between the near-infrared (NIR) and shortwave infrared (SWIR) values[19]. The high NBR value is indicative of healthy vegetation, while a low value indicates bare ground or recently burned areas.	$NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)}$
Normalized Burn Ratio + (NBR+)	An enhanced NBR that addresses misclassification in water utilizing SWIR, NIR, green, and blue bands. NBR+ values vary in a range between -1 and 1, where higher values represent burned areas[20].	$NBR+ = \frac{(SWIR - Red\ Edge - Green - Blue)}{(SWIR + Red\ Edge + Green + Blue)}$

Synthetic Aperture Radar (SAR)		
Radar Burn Ratio (RBR)	RBR is defined as the average ratio of the backscatter coefficients between prefire and postfire for certain polarization[21]. The high RBR value is indicative of healthy vegetation, while a low value indicates bare ground or recently burned areas.	$RBR = \frac{Postfire\ backscatter}{Prefire\ backscatter}$
Radar Burn Difference (RBD)	RBD is defined as the difference of backscatter between pre-fire and postfire for a certain polarization[21]. The RBD positive values indicate healthy vegetation, while negative values indicate bare ground or recently burned areas[22].	$RBD = Postfire\ backscatter - Prefire\ backscatter$
Radar Vegetation Index (RVI)	RVI is a normalized ratio of cross-polarization power to the total polarization power. The RVI generally ranges from 0 to 1, with values closer to 0 indicating a smooth bare surface and values closer to 1 indicating dense vegetation. In some cases, the RVI may exceed 1 due to double scattering, which occurs when radar waves are scattered by two or more objects[23].	$RVI = \frac{(4 * VH)}{(VV + VH)}$
Radar Forest Degradation Index (RFDI)	RFDI measures the strength of the double-bounce term, is computed using the ratio between the power of the HH and HV polarizations[24]. The value varies between 0 to 1. The difference between the pre- and post-RFDI can be used to detect both loss of forest cover and its recovery after a disturbance.	$RFDI = \frac{(VV - VH)}{(VV + VH)}$

3. RESULTS AND DISCUSSION

3.1 Normalized Burn Index

Burnt area observed from an optical multispectral sensor has a distinct spectral signature compared to surrounding features such as vegetation, and water. Burned areas exhibit clear spectral distinction. Several indices have been used as indicators of change characterized by the fire incident. Normalized Difference Vegetation Index (NDVI) and burn indices such as Normalized Burn Ratio (NBR) are some of the established measures in burn mapping. These indices appropriately determine changes in vegetation and soil property due to the fire. Normalized Burn Ratio is utilized to highlight burnt areas; this exploits difference in spectral responses of vegetation to burnt area of SWIR and NIR. Areas affected by fire demonstrated low reflectance values in NIR while high reflectance values in SWIR. NBR uses the ratio of NIR and SWIR; yields high values indicative of healthy vegetation while low values indicate bare ground and burnt areas. Additionally, an enhanced version of this algorithm has been developed called NBR+. The index exploits the addition of green, and blue bands for omission of clouds and water[20]. NBR and NBR+ difference from pre and post fire image is also utilized and can be used to estimate burn severity; this also maps date-to-date changes[19]. While optical imagery is valuable for burn mapping, disadvantages and limitations can affect its usefulness and efficiency in certain cases such as presence and persistence of cloud, cloud shadow, smoke, and haze. Burn mapping in Rizal (Figure 2) is demonstrated using Sentinel-2 images acquired on February 15, 2020 (pre-image) and March 26, 2020 (post-image).

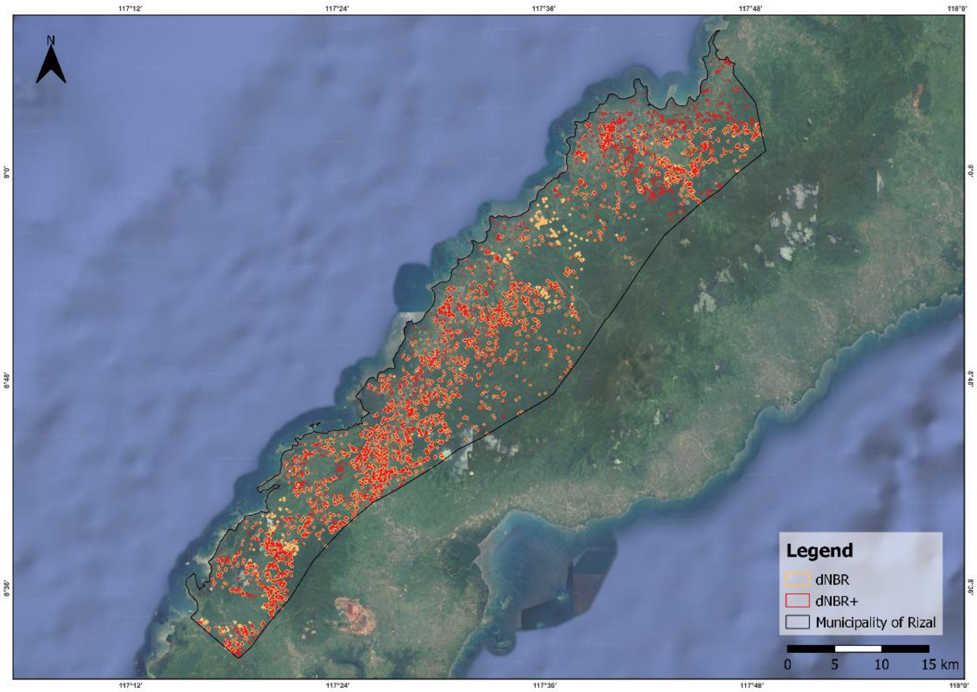

Figure 2. Burned area in Rizal, Palawan between the period of February 15, 2020 and March 26, 2020. The burned areas are identified using the difference between pre- and post- NBR and NBR+ values.

NBR measured burned areas as follows: 2.837 sq km (open forest), 0.011 sq km (closed forest), 2.427 sq km (annual crop), 0.74 sq km (perennial crop), 7.573 sq km (shrub), and 1.383 sq km (grassland). Burned areas being present in various vegetation types suggests fire-related activities, e.g., deforestation and clearing, slash-and-burn agriculture, or prescribed fires. Detected burnt areas using NBR is used to cross-validate those from SAR-based burn indices.

SAR Indices

The use of radar imagery can fill in the gaps left by optical imagery, spatially and temporally, in areas covered with clouds, smoke, and haze. SAR also has advantages such as its all-weather capability, day and night imaging, and penetration in vegetation. SAR-based burned area and vegetation indices, namely, RBR, RBD, RVI, and RFDI, are examined in comparison with the optical-based NBR. Evaluation of detection per index is shown in Figure 3. The study found that the RBR values for VH and VV polarizations were not significantly different. This suggests that the polarization combination of the SAR data does not have a significant impact on the RBR values. The study also found that high values of RBR, which are indicative of healthy vegetation, are not consistent with the burnt areas of dNBR. This suggests that the RBR might not be useful to map burn areas accurately. On the other hand, RBD demonstrates good agreement with the dNBR result. The visual comparison highlights VH polarization exhibiting high contrast between burned and unburned areas. Between the RBR and RBD that utilizes single polarization detection, and simple ratio, and difference, respectively; VH polarization, and difference of post and pre fire detects burn more effectively than VV and ratio index. The RVI and RFDI utilize cross polarization modes, in ratio and difference. The results of pre-fire and post-fire values for both indices were similar. This suggests that no significant change has been detected in the image scene. This is also true for the resulting difference of both indices, which were also similar. Among the four SAR-based burn index, the RBD shows sensitivity in detecting burned areas in the Philippine setting. These burned areas (Figure 3) are situated in open forests, shrublands, and grasslands.

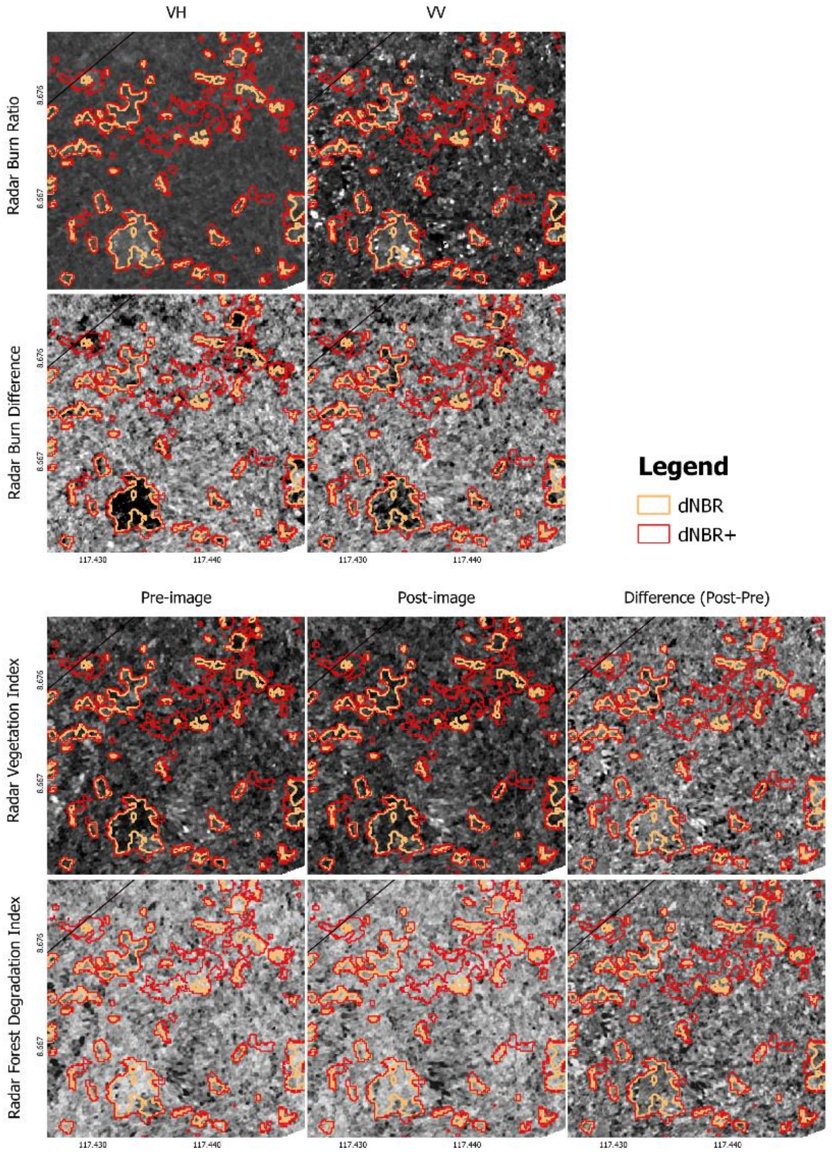

Figure 3. SAR-based burn indices layers overlaid with dNBR and dNBR+ delineated burned areas (orange).

The burned areas detected from the RBD in dNBR extent were sampled per vegetation type and its value ranges were examined; shown in Table 2 are the minimum, maximum, average, and standard deviation per type. Mean RBD ranges from -1.763 to -1.514 , indicating burned areas in open forests, grasslands, shrubs, annual and perennial croplands. As for closed forest, there was none to minimal burn detection mapped; this agrees with NBR results.

Table 2. RBD burned values using the dNBR extent.

	BURNED AREA RANGE VALUES IN SAR			
	Maximum	**Mean**	**Minimum**	**Standard Deviation**
RBD in dNBR extent	8.586	-1.720	-10.098	2.455
OPEN FOREST	6.767	-1.514	-8.754	2.543
CLOSED FOREST	0.266	0.266	0.266	0
GRASSLAND	5.904	-1.481	-9.419	2.705
BRUSH-SHRUBS	4.715	-1.727	-7.923	2.256

ANNUAL CROP	3.796	-1.763	-9.170	2.513
PERENNIAL CROP	2.267	-1.707	-5.858	1.948

Burned areas derived from RBD VH and VV were delineated using thresholding, wherein negative values indicate bare ground or recently burned areas. The selection of threshold value was conservative to certain burned areas in reference to the dNBR extent, RBD VH, RBD VV < -6; otherwise it would result in delineated areas highly influenced by speckle and artifacts inherent in a SAR image.

The burned areas derived from RBD were compared with dNBR and dNBR+ to test its accuracy; shown in Table 3 is the matrix showing the overlap pixels of SAR-derived and optical-derived burned areas as reference. Even with low overlap areas, identification of locations and extent of burned areas is still suggested. This can determine burned area locations and complements in cloud-covered areas in optical images.

Table 3. RBD burned areas overlapping with dNBR and dNBR+.

	RBD VH	RBD VV
dNBR	5,038 pixels (16% overlap)	2,022 pixels (10%)
dNBR+	6,870 pixels (22%)	3,031 pixels (15%)

4. CONCLUSION

The open forests of Rizal, Palawan were the most affected by the fire during the period of the study. The RBD in VH polarization showed patterns that were very similar to the optical-based burn index, NBR. This suggests that the RBD in VH polarization can be used to assess the spatial extent and severity of fire. The other SAR burn and vegetation indices used in the study is ineffective in the Philippines, especially in the mountainous areas. This also demonstrates that the synergistic use of burned indices from optical and SAR images leverages on the strengths of both datasets. This can lead to more complete and accurate burn area mapping. This approach contributes to better-informed decision making for improved emergency response, and ecological and environmental resource monitoring.

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