Forest and Land Fire Severity Analysis in 2022-2023 in Hulu Sungai Selatan Regency Using the NBR (Normalized Burn Ratio) Method

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Abstract. Forest and land fires are recurring disasters in Indonesia that cause environmental, health, and socio-economic losses. Hulu Sungai Selatan Regency, South Kalimantan, is among the affected regions, particularly during 2022–2023 when the El Niño phenomenon and flammable peatlands increased fire risk. This study analyzes the spatial extent and severity of fires and their potential impact on local communities by integrating remote sensing and demographic data. The Normalized Burn Ratio (NBR) and Difference Normalized Burn Ratio (dNBR) derived from Landsat 8 and 9 imagery (2021–2023) were used to map fire severity, supported by hotspot data from the Ministry of Environment and Forestry and settlement data from the Geospatial Information Agency. Population data from the Central Bureau of Statistics (BPS) were incorporated to develop a Fire Vulnerability Index (FVI) representing community exposure to fire-prone areas. The results show that burned areas in 2023 expanded compared to 2022, with increasing low to moderate severity classes. Subdistricts with dense populations, such as Kandangan and Angkinang, showed higher fire vulnerability values, indicating potential socio-environmental risks. These findings emphasize the importance of integrating remote sensing and statistical data to support effective fire mitigation and risk reduction in vulnerable regions.

Keyword: dNBR (Differenced Normalized Burn Ratio), Forest and Land Fires, Hulu Sungai Selatan, Landsat, NBR (Normalized Burn Ratio).

1. Introduction

Indonesia is one of the countries with the largest forest areas in the world. According to the World Bank [1], Indonesia ranks 8th with a forest area of 909,221.3 km². Forests are invaluable natural resources because they contain a rich biodiversity, regulate water systems, prevent floods and landslides, and maintain soil fertility [2]. Forests are not only beneficial for animal species, plants, or specific ethnic groups that inhabit them. However, forests also play an important role in maintaining the balance of the global ecosystem [3].

In recent years, Indonesia has continuously faced the threat of forest and land fires (karhutla), which occur almost every year, especially during the dry season. Over the last five years, 2023 became the year with the largest fire after 2019, with a total area of 1,161,192.90 Ha [4]. Forest fires are often caused by irresponsible individuals who damage forests through illegal logging without replanting and by deliberately burning forests to convert them into palm oil plantations [5]. About 99% of forest fires in Indonesia are caused by human activities, either intentional or unintentional [6]. In addition to human factors, the El Niño phenomenon is also often a major cause of forest fires in Indonesia [7]. El Niño can cause prolonged droughts, thereby increasing the potential for forest and land fires. In recent years, South Kalimantan has become one of the provinces with frequent forest fire incidents. This is a serious concern because the province faces a major threat from forest and land fires.

South Kalimantan is one of the regions that most frequently experiences forest and land fires. Fires are common in Kalimantan, Sumatra, and Papua because these areas are located on peatlands [8]. Peat originates from the accumulation of organic material over a long period of time with characteristics that make it highly flammable, especially when dry [9]. In 2023, South Kalimantan recorded the largest area of forest and land fires in Indonesia, with 190,394.58 Ha, followed by Central Kalimantan (165,896.44 Ha), South Papua (150,813.34 Ha), South Sumatra (132,082.86 Ha), and West Kalimantan (111,848.43 Ha) [4]. Forest and land fires remain a serious threat in South Kalimantan, which is vulnerable due to the presence of easily flammable peatlands. Studies show that peat fires in Kalimantan contribute up to 76% of $PM_{2.5}$ emissions from fires. Even during the 2023 El Niño dry season, peat fires in Central Kalimantan contributed about 90 $\mu g/m^3$ to the outdoor average $PM_{2.5}$ concentration of 136 $\mu g/m^3$, with more than 1.62 million people exposed to hazardous air [10]. High air pollution disrupts educational activities and harms the agricultural sector due to significant reductions in sunlight [11]. This condition makes South Kalimantan highly prone to fires, which can damage ecosystems, threaten settlements, reduce soil fertility, and endanger public health due to smoke. Therefore, this region is important to study through hotspot mapping, air monitoring, and geospatial-based risk analysis for effective prevention strategies.

Forest and land fires are disasters that have significant impacts on the environment, public health, and the regional economy [12]. Therefore, understanding the severity and extent of the fires is very important to support decision-making in disaster management and ecosystem recovery. However, field monitoring is often constrained by limited access, human resources, and costs [13]. In this case, remote sensing technology serves as a solution to overcome these limitations. By utilizing satellite imagery, fire analysis can be carried out periodically without conducting direct surveys across the entire area. One widely used approach is the Normalized Burn Ratio (NBR).

Various previous studies have utilized remote sensing to analyze the distribution and severity of forest and land fires. A study in [14] used Landsat-8 OLI satellite imagery from 2019 before and after fires with the NBR method to map the spatial pattern of forest and land fires in Mount Merbabu National Park, showing that this algorithm has high potential to be applied in other landscapes in future studies. Another study in [15] determined the severity of forest and land fires in Lamandau Regency, Central Kalimantan, using Difference Normalized Burn Ratio (dNBR) values on Sentinel-2 imagery, showing a decrease in the severity of forest and land fires that occurred in 2021 and 2022. Meanwhile, study in [16] compared commonly used fire indices such as the Normalized Burn Ratio (NBR), Burned Area Index for Sentinel-2 (BAIS2), Mid-Infrared Burned Index (MIRBI), and vegetation indices such as the Normalized Difference Vegetation Index (NDVI) on Sentinel-2A satellite imagery in Mount Merbabu National Park, showing that NBR has better quality than BAIS2, MIRBI, and NDVI in detecting forest and land fire areas.

Nevertheless, most of these studies are still limited to the spatial identification of fire severity without overlaying social vulnerability variables such as proximity to settlements. On the other hand, not all studies conducted validation, either through direct field surveys or the use of official fire hotspot data from agencies, which causes the classification results of burned areas to remain unvalidated. In addition, dNBR results were only used to distinguish burned and unburned areas without classification of fire severity and its extent. Based on these limitations, this study offers a new approach by integrating remote sensing data and official demographic statistics to assess the level of fire vulnerability at the subdistrict level. The integration of population density data from the Central Statistics Agency (BPS) enables the development of a Fire Vulnerability Index (FVI) that measures the level of population exposure to fire-prone areas. Through this approach, it is possible to identify which subdistricts are highly vulnerable and potentially affected by forest fires.

This study focuses on Hulu Sungai Selatan Regency, which has not been extensively studied in terms of the severity and vulnerability of the community to fires. By combining the NBR method with residential zone overlay, integration with demographic data, and hotspot validation from the Ministry of Environment and Forestry (KLHK), this research can contribute to environmental monitoring with socio-economic risk assessment, thereby producing information that can be used for fire mitigation planning and data-based policy formulation.

2. Research Method

2.1. Study Area

The research location analyzed is in Hulu Sungai Selatan Regency, South Kalimantan. Figure 1 presents the research location map from the national to the regency scale. Figure 1a shows the overall territory of Indonesia with a red box marking the island of Kalimantan. In figure 1b, the map is focused on Kalimantan Island so that the position of South Kalimantan can be seen more clearly. Figure 1c shows the area of South Kalimantan Province, while figure 1d shows the administrative boundaries of Hulu Sungai Selatan Regency as the research area.

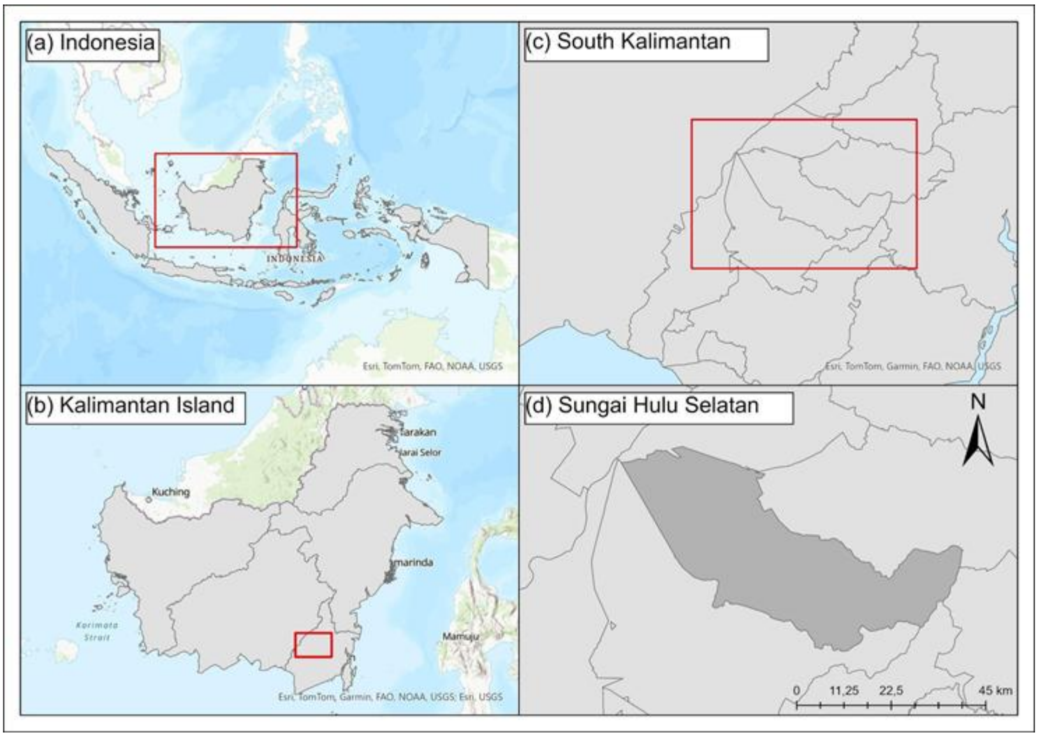

Figure 1. Study area (a) Indonesia, (b) Kalimantan Island, (c) South Kalimantan, (d) Hulu Sungai Selatan.

ICDSOS
The 3rd International Conference on Data Science and Official Statistics
November 27 - 28, 2025

This research is focused on Hulu Sungai Selatan Regency, South Kalimantan Province, Indonesia. This regency has a land area of about 1,804.94 km². Geographically, the regency is located between 2°26' S - 3°01' S and 114°48' E - 115°26' E. South Kalimantan Province is one of Indonesia's regions most frequently affected by forest and land fires. This condition was influenced by the El Niño phenomenon, which caused a drier than usual dry season and triggering fires [17]. According to the National Disaster Management Agency (BNPB), South Kalimantan was among the provinces with the highest number of fire incidents in August 2023. This data can be seen in figure 2. Data from Sipongi [4] recorded a total burned area of more than 190 thousand hectares, making it the province with the largest fire extent in Indonesia that year. These fires are strongly associated with the presence of peatland ecosystems, which are highly flammable during prolonged dry seasons [9]. This reflects a broader fire pattern commonly found in Kalimantan, Sumatra, and Papua as regions dominated by peat and agricultural expansion zones prone to burning [8], [9].

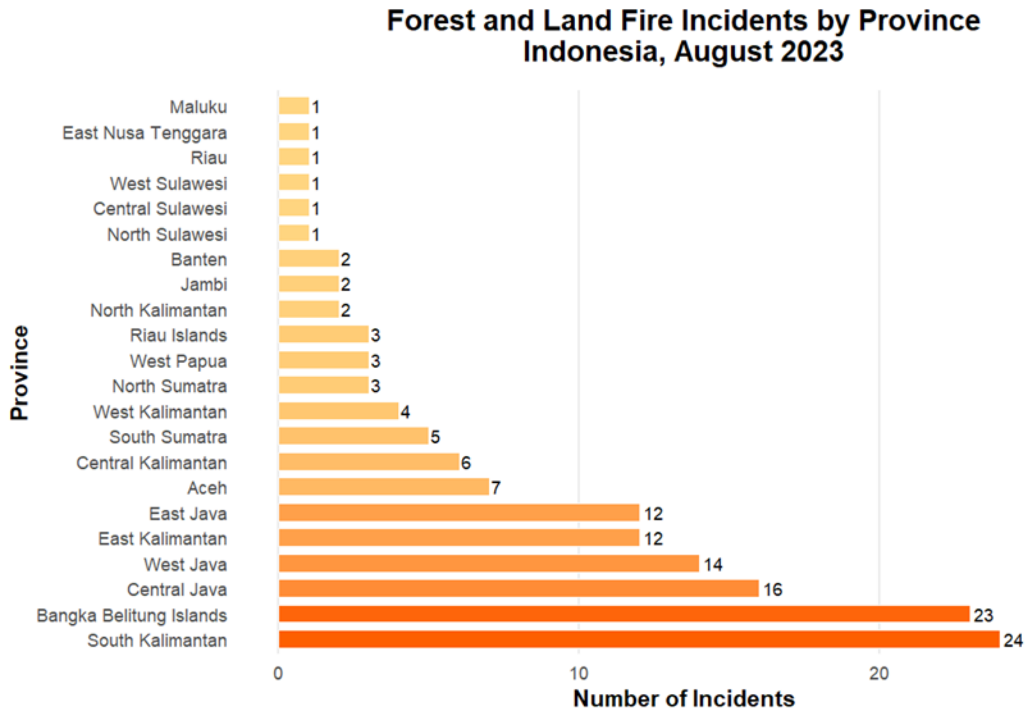

Figure 2. Forest and land fire incidents by province Indonesia, August 2023. Modified from BNPB [17].

Hulu Sungai Selatan Regency is one of the most affected areas and is an important focal point for analyzing the severity of fires. This regency has ecological vulnerabilities with socio-economic characteristics that increase its exposure to fire risk. Based on data from the South Hulu Sungai Regency Central Statistics Agency [18], around 41.34% of the workforce is employed in the agricultural sector, while the population density reaches around 129 people per km², which is the fifth highest population density in South Kalimantan. These figures indicate that most of the population depends on land-based livelihoods that can be directly threatened by forest and land fires. In addition, data from Global Forest Watch [19] shows that Hulu Sungai Selatan has consistently lost forest cover associated with fire events between 2021 and 2024, albeit with fluctuating intensity. It was recorded that 29 ha of forest cover was lost due to fires in 2023. This data can be seen in figure 3. The combination of fairly dense settlements, a large number of workers employed in the agricultural sector, and repeated loss of vegetation makes Hulu Sungai Selatan a representative and strategic area for assessing the severity of fires and their implications for social and environmental conditions. This condition confirms that Hulu Sungai Selatan is one of the priority areas for monitoring and research related to the severity of forest and land fires. Therefore, this region is very suitable to be used as a study area to examine the impacts of fires and the mitigation strategies needed to reduce environmental and social losses due to forest and land fires.

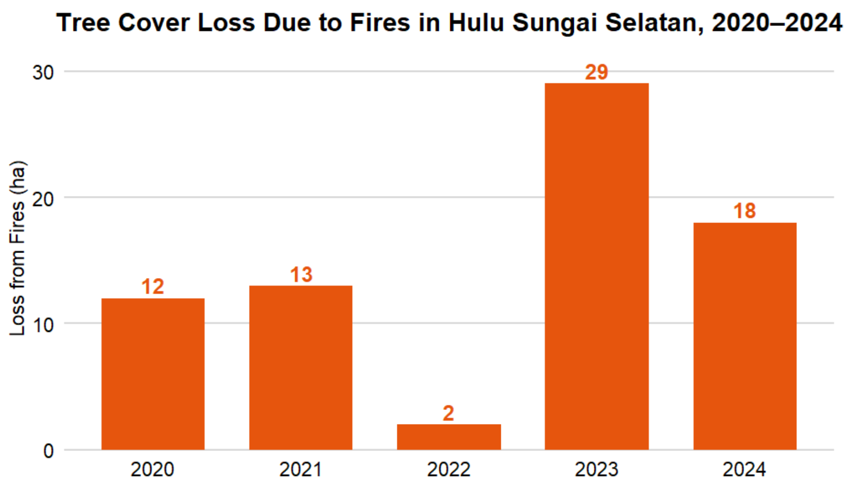

Figure 3. Tree Cover Loss Due to Fires in Hulu Sungai Selatan, 2020-2024. Modified from Global Forest Watch [19].

2.2. Data

In supporting the analysis process, the availability of appropriate data is an important aspect. The data used in this study were selected based on their relevance to the identification of burned areas. This study uses several data types, as shown in table 1. These data include vector data of administrative boundaries, vector data of settlement zones, hotspot distribution data, Landsat 8 imagery, and Landsat 9 imagery.

Table 1. Data used in this study.

No	Data	Type	Spatial Resolution	Temporal	Reference
1	Administrative Data	Vector	City/1:50.000	2024	(BIG, n.d.)
2	Residential Area Zones	Vector	City/1:50.000	2024	(BIG, n.d.)
3	Hotspots	Tabular	Province	2022-2023	(KLHK, n.d.)
4	Population Density	Tabular	Subdistrict	2022-2023	(BPS, n.d.)
5	Landsat-8 OLI	Raster	30x30 m	2021	(USGS, 2013)
6	Landsat-9 OLI	Raster	30x30 m	2022-2023	(USGS, 2021)

The main research data comes from Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) satellite imagery for 2022 and 2023, downloaded through the USGS EarthExplorer platform. This imagery was chosen because it has a combination of Near Infrared (NIR) and Shortwave Infrared (SWIR) spectral bands that allow the calculation of Normalized Burn Ratio (NBR) and Difference Normalized Burn Ratio (dNBR) to detect and measure fire severity [20]. The spatial resolution of this imagery is 30 meters for multispectral bands and 100 meters for thermal bands, with a temporal resolution of 16 days. This data is freely available and has a high level of reliability for medium-scale analysis.

Hotspot data were obtained from the Ministry of Environment and Forestry (KLHK), which uses MODIS (Moderate Resolution Imaging Spectroradiometer) and VIIRS (Visible Infrared Imaging Radiometer Suite) sensors. This data contains coordinates, dates, and times of detected forest and land fire indications. The spatial resolution of MODIS is 1 km and VIIRS is 375 meters, with a daily temporal resolution [21]. These hotspots were used as preliminary validation data to ensure that the areas identified as burned through satellite image analysis indeed had indications of fire activity on the ground.

Administrative boundary data were obtained from the Geospatial Information Agency (BIG) in shapefile (.shp) format. This data has a mapping scale of 1:50,000 with a spatial resolution of ±25 meters. Administrative boundaries were used to clip the analysis area so that image processing was only focused on the relevant study area. This study also used settlement data obtained from the Geospatial Information Agency (BIG) to identify the relationship between the distribution of settlement areas and fire severity levels.

Additionally, demographic data in the form of population density (people per square kilometer) for each subdistrict were obtained from the Central Bureau of Statistics (BPS) This data was used to represent the exposure component in the Fire Vulnerability Index (FVI) analysis, which integrates population distribution with average dNBR values per subdistrict. The inclusion of this dataset enables the assessment of community vulnerability to forest and land fires from both spatial and socio-demographic perspectives.

2.3. Method

In order to obtain results related to the extent and severity of forest and land fires, a structured methodological approach is required. The selection of appropriate methods is an important foundation so that each stage of analysis can address the research problems and objectives. This study combines remote sensing and geographic information system techniques to identify and measure the extent of fire severity. For this purpose, the steps in the analysis are arranged sequentially, starting from data collection, satellite image processing, to result interpretation. Data processing was carried out using ArcGIS Pro software developed by the Environmental Science & Research Institute (ESRI). In general, the research flowchart can be seen in figure 4.

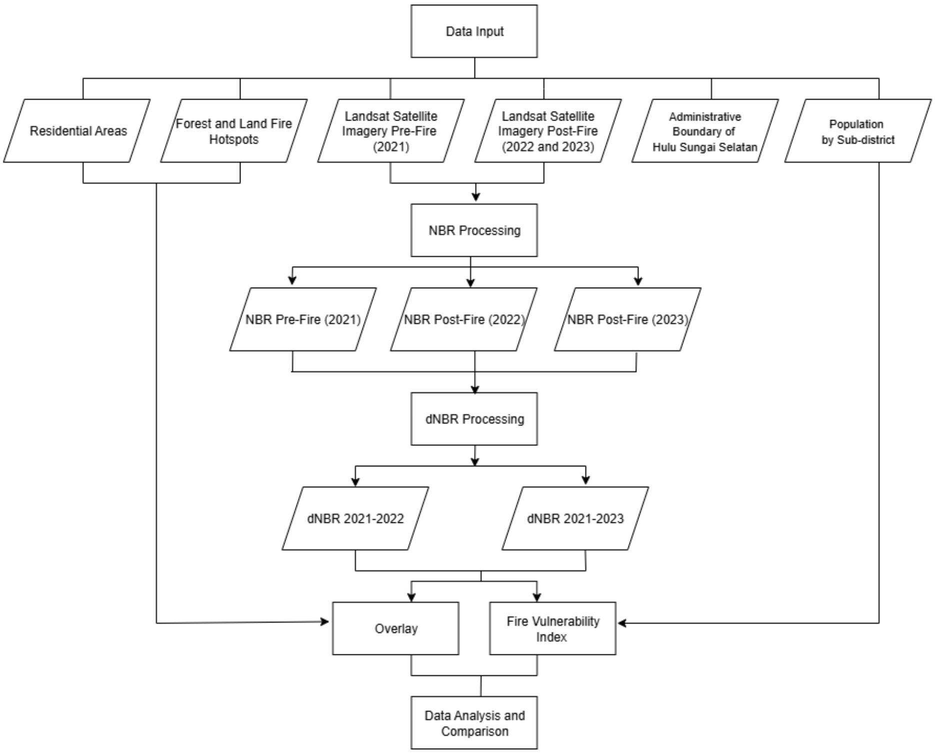

Figure 4. Flowchart in this study.

2.3.1. NBR (Normalized Burn Ratio). The NBR method is an algorithm designed to detect burned areas through the comparison of Near Infrared (NIR) and Shortwave Infrared (SWIR) channels [22]. NBR is used to identify burned areas and estimate the severity of forest or land fires [23]. In Landsat 8 and 9 imagery, the NIR wavelength is represented by band 5, while the SWIR wavelength is represented by band 7. The NIR channel is sensitive to healthy vegetation that reflects high light, while the SWIR channel is sensitive to water content and surface conditions after a fire [24]. High NBR values indicate good vegetation conditions, while low NBR values represent bare soil and newly burned areas [25]. The difference in reflectance values allows NBR to identify the severity of fire spatially, thus facilitating the analysis of forest and land fires. The equation used in the calculation of the Normalized Burn Ratio (NBR) algorithm is written in equation (1):

$$\mathrm{NBR} = \frac{\mathrm{NIR} - \mathrm{SWIR}}{\mathrm{NIR} + \mathrm{SWIR}} \tag{1}$$

Description:

NBR = Normalized Burn Ratio

NIR = Near Infrared

SWIR= Short Wave Infrared

Compared to other methods, NBR has a high level of accuracy and better capability in detecting fires [17]. Through the NBR method, further processes will be carried out to determine the severity level of forest and land fires in Hulu Sungai Selatan Regency.

2.3.2. dNBR (Difference Normalized Burn ratio). The dNBR is often used to determine the severity of forest and land fires [20]. dNBR can be defined as the difference between pre-fire NBR and post-fire NBR [26]. In applying this method, image data before and after the fire is certainly required. High dNBR values indicate severe damage, while low dNBR values indicate high vegetation regrowth after fire [25]. The calculation of dNBR can be formulated in equation (2):

$$\mathrm{dNBR} = \mathrm{NBR}_{\mathrm{Pre-fire}} - \mathrm{NBR}_{\mathrm{Post-fire}} \quad (2)$$

Description:

dNBR = Difference between pre-fire NBR and post-fire NBR

NBR Pre-Fire = NBR before the fire

NBR Post Fire = NBR after the fire

The classification of forest and land fire severity is based on the classification obtained from a journal written by Que et al. [23]. The severity of forest and land fires is classified into 7 classes. The classification of severity is presented in table 2.

Table 2. Fire severity levels.

No	dNBR	Fire severity levels
1	< -0.25	High Post-fire Regrowth
2	-0.25 - -0.1	Low Post-fire Regrowth
3	-0.1 - +0.1	Unburned
4	0.1 - 0.27	Low-Severity Fire
5	0.27 - 0.44	Moderate-Low Severity Fire
6	0.44 - 0.66	Moderate-High Severity Fire
7	> 0.66	High-Severity Fire

2.3.3. Overlay Analysis. The dNBR results were then overlaid with several other data, namely hotspot distribution and settlement zones. Overlay is a spatial analysis technique that combines several data layers to generate new information [27]. In the context of this study, the overlay between dNBR results and hotspot distribution data aims to validate areas identified as burned areas based on satellite imagery with the actual hotspot presence detected by satellite sensors. This helps improve the accuracy in identifying burned areas. In addition, the overlay with settlement zones was carried out to determine the relationship between fire areas and the location of residential settlements. This analysis is important to assess the potential risks faced by communities, especially if fires occur near settlement areas. By combining these layers, the study can produce thematic maps depicting the distribution of burned areas validated with hotspots as well as their proximity to settlement areas.

2.3.4. Fire Vulnerability Index (FVI). To determine the level of exposure of the population to fire-affected areas, the Fire Vulnerability Index (FVI) was calculated by integrating the average dNBR value and population density per subdistrict. The average dNBR value is obtained from the results of zonal statistical analysis representing the severity of the fire (hazard), while population density data (people/km^2) from the Central Statistics Agency (BPS) is used to represent the exposure component. Both variables are normalized to a range of 0–1 using the min–max normalization method. The formula can be seen in equation (3):

$$Xnorm = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (3)$$

Description:

Xnorm = Normalized Value

X= Original Value of Variable (dNBR or Population Density)

Xmin and Xmax = Minimum and Maximum Values of Variable

The FVI value is then calculated using the weighting formula as stated in equation (4):

$$FVI = (0.6 \times dNBR_{norm}) + (0.4 \times Pop_{norm}) \quad (4)$$

A weight of 0.6 was given to the severity of the fire component because this aspect was considered more dominant in determining the level of risk, while a weight of 0.4 was given to population density as an exposure factor.

The FVI results were classified into three classes to identify the level of vulnerability of each subdistrict to the impact of fire, as shown in table 3.

Table 3. Fire severity levels.

Vulnerability Category	FVI Range	Description
Low	0.00-0.30	Low level of population exposure to fires
Moderate	0.31-0.60	Moderate level of population exposure to fires
High	0.61-0.80	High level of population exposure to fires

This approach allows for the integration of remote sensing data and official statistics, so that FVI results not only represent the physical aspects of fires, but also provide spatial information on social vulnerability. Thus, FVI can be used as a basis for planning forest and land fire mitigation policies.

3. Result and Discussion

3.1. NBR Pre-Fire (2021), Post Fire (2022) and Post Fire (2023)

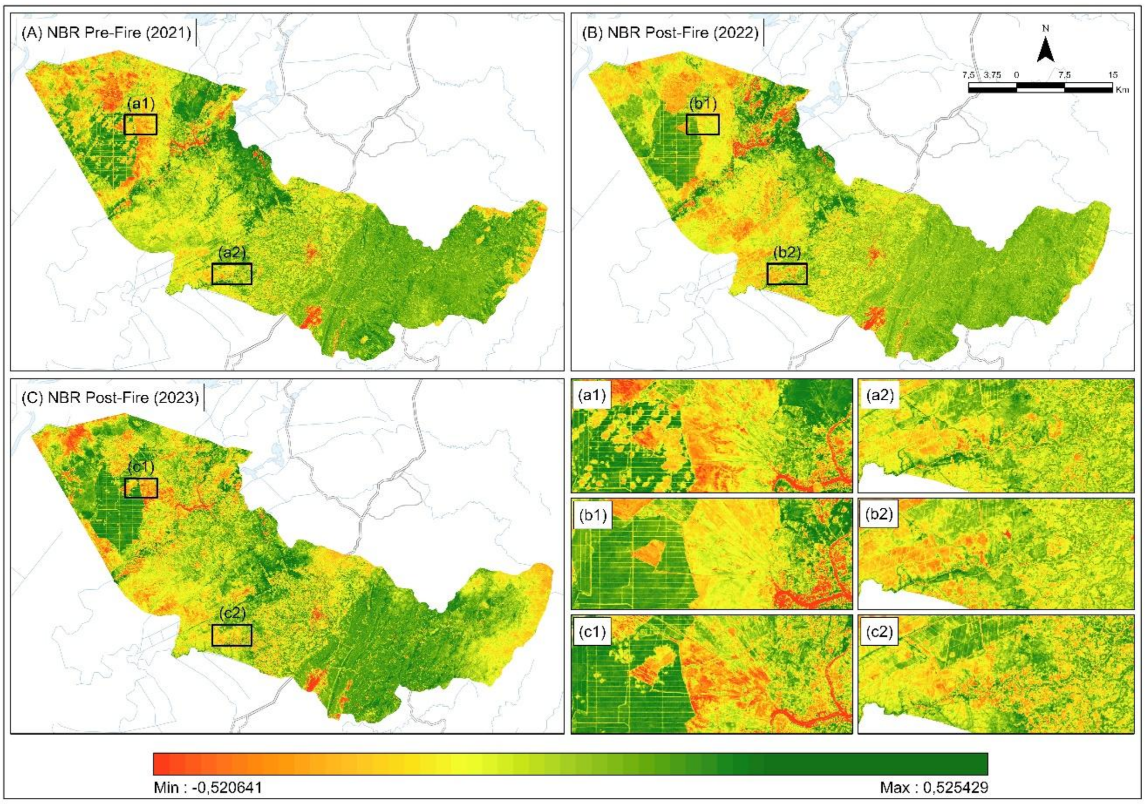

Figure 5. NBR (a) pre-fire, (b) post-fire (2022), (c) post-fire (2023).

Figure 5 illustrates the burned areas in the research site. NBR Pre-Fire uses 2021 image data as an illustration before the fire occurred. Meanwhile, for NBR Post-Fire, 2022 and 2023 image data were used as comparisons. Low NBR values approaching -1 indicate burned areas, while high NBR values approaching 1 indicate good vegetation conditions. In figure 5, the lowest NBR value in 2022 was -0.220140, while in the 2023 NBR Post-Fire, the lowest NBR value was -0.520641. This indicates that in 2023, there were wider burned areas compared to 2022. This is further supported by the highest NBR value in the 2022 results, which was 0.525129, while in 2023, the highest NBR value was 0.5013. This indicates a reduction in vegetation in 2023 due to fires. To observe more detailed changes, two observation areas (extents) were selected, namely extent 1, which is the area with the highest concentration of hotspots, and extent 2, which is located in the settlement area.

Extent 1 (figure 5a1, 5b1, and 5c1) was selected because this area was identified as the center of the fire with many hotspots, thus showing the dynamics of forest fires and their changes. In 2021 (a1), green areas still appeared, indicating healthy vegetation before the fire occurred. However, in 2022 (b1), changes began with the dominance of orange and red colors, indicating the start of vegetation damage due to fire. In 2023 (c1), the area completely turned into yellow and red colors. This indicates that the forest fire expanded in 2023.

Extent 2 (figure 5a2, 5b2, and 5c2) was selected because it includes settlement areas that are important to analyze regarding the impact of fires and land cover changes due to human activities. In 2021 (a2), green areas still appeared, indicating healthy vegetation around settlements. However, in 2022 (b2), changes appeared with the emergence of yellow, orange, and red colors, indicating vegetation decline. This condition continued in 2023 (c2), where yellow expanded, green areas decreased, and even small red areas emerged. This indicates an increase in burned areas that could potentially increase the vulnerability of settlements to future fires.

3.2. The dNBR Model in 2021-2022 and 2021-2023

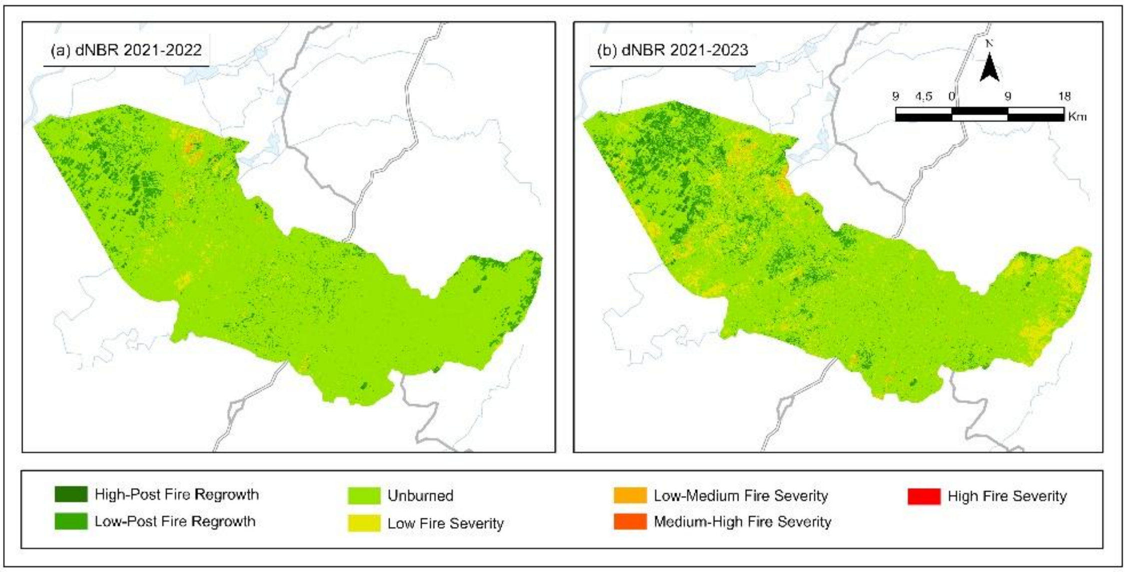

Figure 6. The dNBR model (a) 2021-2022, (b) 2021-2023.

Figure 6 illustrates the level of damage caused by forest or land fires. The higher the dNBR value, the more severe the fire damage. Area calculations were performed on the dNBR model to determine the area in more detail. A comparison of the severity of fires in 2022 and 2023 is presented in table 4.

Table 4. Burn severity areas in 2022 and 2023.

Burn Severity Areas	Area in 2022 (Ha)	Area in 2023 (Ha)
High Post-fire Regrowth	503.0004648	1111.216109
Low Post-fire Regrowth	12677.39548	17581.04225
Unburned	151449.1949	130697.4249
Low-Severity Fire	4506.149529	19162.75665
Moderate-Low Severity Fire	591.1403139	1167.82621
Moderate-High Severity Fire	0.061622229	0.45
High-Severity Fire	0	0.09

Based on the chart in table 4, unburned areas in 2022 were larger compared to 2023. This indicates that forest fires were more extensive in 2023. This indication is also reinforced by the larger extent of low-to-high severity fire levels in 2023. A graph is also provided to illustrate the comparison of burned area severity levels between 2022 and 2023. The illustration is presented in figure 7.

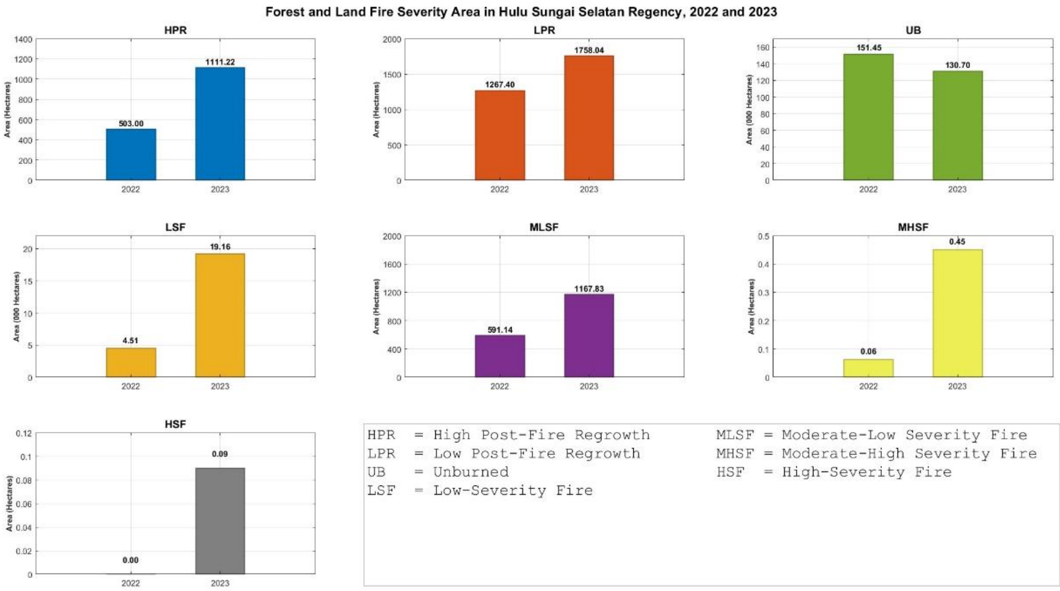

Figure 7. Burn severity area chart of forest and land fires in 2022 and 2023.

3.3. The dNBR impact in Settlement Area Analysis to Assess Fire Risk to Residential Areas

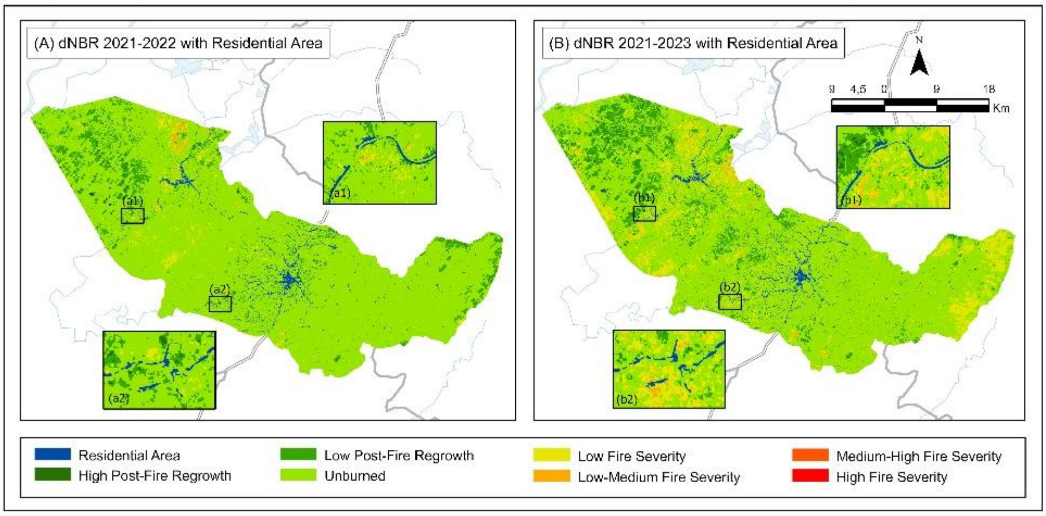

Figure 8. dNBR impact with settlement areas.

Figure 8 presents the dNBR map for the periods 2021–2022 (A) and 2021–2023 (B), combined with settlement area information. In extent (a1), there are variations of yellow and orange, indicating low to moderate fire severity. No dominance of red is found, suggesting that high-severity fires had not yet occurred widely during this period. Meanwhile, in extent (b1), the burned areas expanded.

This result is also supported by extent (a2), which shows that low-severity fire areas were only a few, while other areas were unburned. This shows that vegetation in the area was still preserved. Conversely, in extent (b2), the burned area had expanded with low to moderate severity fire levels. These results show that the choice of extents provides stronger evidence of fire dynamics and their impacts on settlements. These findings emphasize the importance of fire mitigation strategies to prevent fire impacts from spreading to residential areas.

Settlement areas were then buffered to determine the reach of settlement zones in areas affected by fire. In this study, distances of 200, 400, and 600 meters were used to analyze the reach of settlements in burned areas. The results of the analysis are shown in table 5 and table 6.

Table 5. Burn severity areas in 2022 within buffer zones.

Fire severity levels	200 m	400 m	600 m
High Post-fire Regrowth	0.001779%	0.002507%	0.001614%
Low Post-fire Regrowth	0.052258%	0.063631%	0.049057%
Unburned	0.923777%	0.904666%	0.922703%
Low-Severity Fire	0.019986%	0.025757%	0.024271%
Moderate-Low Severity Fire	0.0022%	0.003438%	0.002356%
Moderate-High Severity Fire	0%	0%	0%

Based on the analysis results in table 5, unburned areas dominated across all buffer area. At a 200 m radius, unburned areas reached 0.92%, while low-severity fires only accounted for 0.020% and moderate-low severity fires accounted for 0.0022%. Post-fire regrowth in the low category was 0.05%, and in the high category, only 0.0018%.

As the radius increased to 400 m, the extent of unburned areas slightly decreased to 0.90%, although there was an increase in low-severity fires to 0.026% and moderate-low severity fires to 0.0034%. At a 600 m radius, the dominance of unburned areas remained with 0.92%, while low-severity fires were 0.024% and moderate-low severity fires were 0.0024%.

Table 6. Burn severity areas in 2023 within buffer zones.

Fire severity levels	200 m	400 m	600 m
High Post-fire Regrowth	0.001093%	0.001822%	0.00231%
Low Post-fire Regrowth	0.034836%	0.04902%	0.052231%
Unburned	0.883298%	0.835169%	0.835656%
Low-Severity Fire	0.077879%	0.107192%	0.101394%
Moderate-Low Severity Fire	0.002895%	0.006797%	0.008408%
Moderate-High Severity Fire	0%	0%	0%
High-Severity Fire	0%	0%	0%

The results in 2023, shown in table 6, demonstrate a relatively similar pattern. At a 200 m radius, unburned areas reached 0.88%, while low-severity fires were 0.078% and moderate-low severity fires were 0.0029%. Low-category post-fire regrowth was larger compared to 2022, at 0.035%, while the high category was only 0.0011%. At a 400 m radius, unburned areas decreased to 0.835%, with an increase in low-severity fires to 0.107% and moderate-low severity fires to 0.0068%. At a 600 m radius, the proportion of unburned areas rose again to 0.836%, followed by low-severity fires at 0.10% and moderate-low severity fires at 0.0084%. A graph is also included to illustrate the proportion of forest and land fire severity in 2022 and 2023 in the buffer area. The illustration is presented in figure 9.

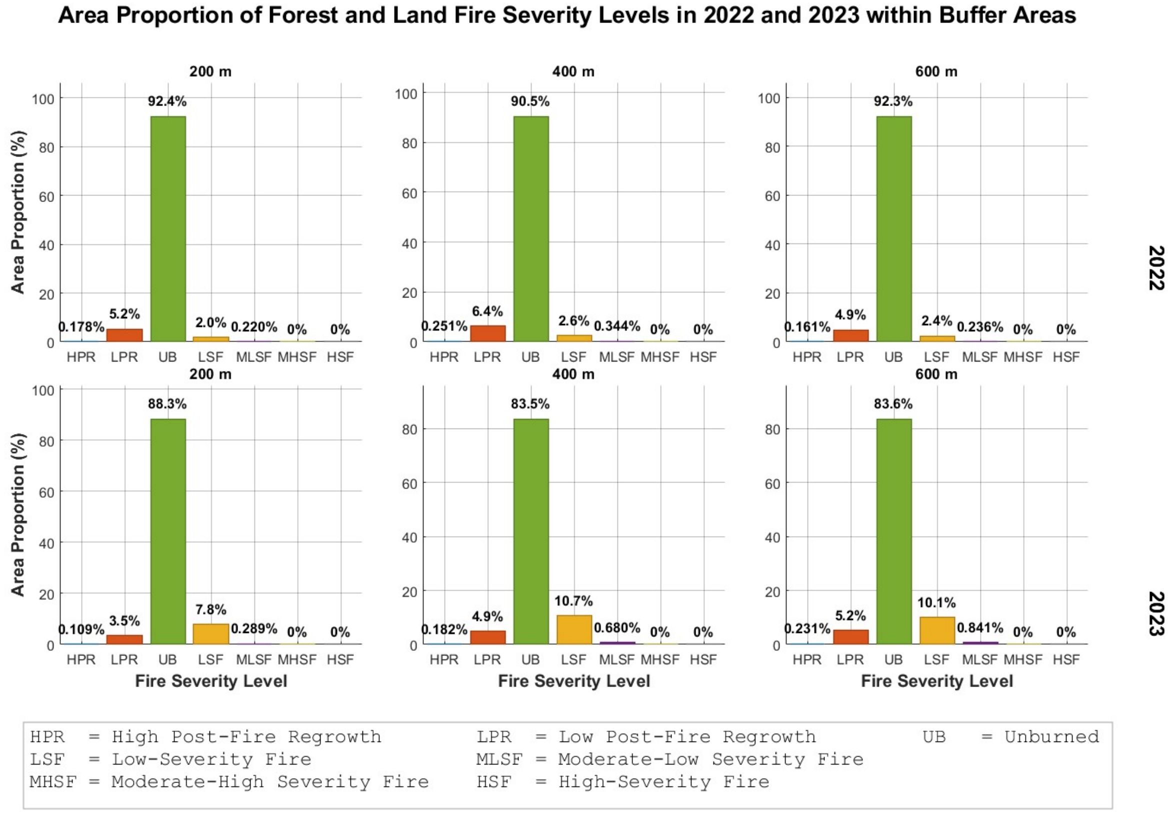

Figure 9. Area proportion of forest and land fire severity levels in 2022 and 2023 within buffer areas.

In general, these results show that unburned areas continued to dominate both in 2022 and 2023. However, there was an increase in burned areas with low to moderate-low severity in 2023 compared to 2022. In addition, the proportion of low and high post-fire regrowth also decreased in 2023, although at the 600 m radius, low and high post-fire regrowth actually increased in 2023. This indicates that the process of vegetation regeneration after fire had begun to appear in 2023, although the fire severity was relatively higher compared to 2022.

The analysis results in both years show that fire severity is not linear with distance but may be influenced by other factors such as vegetation conditions, topography, and fire spread direction. Overall, these results show that unburned areas continue to dominate the entire buffer zone in both 2022 and 2023, while the proportion of burned areas around settlements is very small, less than 1% of the total area. Although this percentage seems small, these results are still significant in the context of fire risk to communities. The existence of areas with low to moderate fire severity within the 200–600 meter buffer zone indicates that fire activity continues to occur around residential areas, albeit on a limited scale. This condition may not cause direct damage to homes or infrastructure, but it still poses indirect risks to the community, mainly through the spread of smoke, reduced air quality, and reduced visibility. These indirect impacts can affect public health, particularly by increasing the risk of respiratory disorders during prolonged dry seasons.

The case in Hulu Sungai Selatan Regency shows similar conditions. Based on local media reports such as Bisnis.com [28], haze from forest and land fires can affect daily community activities, reduce air quality, and lead to an increase in the number of acute respiratory infection (ARI) cases. This shows that even though the burned area around residential areas is less than 1%, the impact felt by the community is still significant, especially in terms of the environment and health. Thus, the results of this buffer zone analysis provide important insights into the proximity between burned areas and residential areas. These findings confirm that fire management strategies need to focus not only on direct land loss, but also on indirect social and environmental risks, such as exposure to smoke and air pollution. Efforts such as raising public awareness, monitoring land burning, and conducting regular air quality monitoring are important steps in reducing the risk of fires in areas such as Hulu Sungai Selatan, where even small-scale fires can have an impact on the health and safety of the community.

3.4. Fire Vulnerability Index (FVI) and Population Exposure

The Fire Vulnerability Index (FVI) is used to describe the level of community vulnerability to the impacts of forest and land fires in each sub-district in Hulu Sungai Selatan Regency. This index is calculated based on a combination of the average dNBR value, which represents the severity of fires, and population density data, which represents the level of exposure of communities in each sub-district in Hulu Sungai Selatan Regency. The FVI calculation results for 2022 and 2023 are presented in table 7.

Table 7. Fire Vulnerability Index (FVI) by Subdistrict in Hulu Sungai Selatan Regency, 2022–2023.

Subdistrict	FVI 2022	Category 2022	FVI 2023	Category 2023
Loksado	0,12	Low	0,60	Moderate
Kalumpang	0,62	High	0,36	Moderate
Daha Barat	0,03	Low	0,22	Low
Padang Batung	0,44	Moderate	0,25	Low
Daha Selatan	0,60	Moderate	0,59	Moderate
Telaga Langsat	0,49	Moderate	0,54	Moderate
Simpur	0,40	Moderate	0,21	Low
Sungai Raya	0,54	Moderate	0,54	Moderate
Angkinang	0,29	Low	0,61	High
Kandangan	0,75	High	0,76	High
Daha Utara	0,16	Low	0,09	Low

Based on the results of the 2022 and 2023 FVI calculations presented in table 7, it can be seen that the level of fire vulnerability in Hulu Sungai Selatan is uneven across subdistricts and has changed between 2022 and 2023. In 2022, the subdistricts with high vulnerability were Kandangan (0.75) and Kalumpang (0.62), indicating a combination of high fire intensity and high population density. Most other subdistricts, such as Padang Batung, Daha Selatan, Telaga Langsat, Simpur, and Sungai Raya, were classified as moderate, while areas such as Loksado, Angkinang, Daha Barat, and Daha Utara were classified as low.

In 2023, there were changes in vulnerability patterns in several areas. Kandangan continued to show the highest FVI value (0.76), indicating that this area remained the most vulnerable to forest and land fires in the district. Meanwhile, Angkinang experienced a drastic increase from the low category (0.29) to high (0.61), indicating an increase in exposure or intensity of fires in the area. Loksado also experienced a jump from the low category (0.12) to moderate (0.60), indicating that areas that were previously low risk are now beginning to show an increase in the potential impact of fires. Conversely, Kalumpang and Padang Batung experienced a decrease in vulnerability category. Kalumpang dropped from high (0.62) to moderate (0.36), and Padang Batung from moderate (0.44) to low (0.25). Simpur also showed a significant decrease from 0.40 to 0.21. This condition indicates that fires in these areas tend to decrease or are no longer centered in areas with high population density. On the other hand, Telaga Langsat, Daha Selatan, and Sungai Raya remained stable in the moderate category, indicating no significant changes in the vulnerability conditions in these subdistricts.

Overall, the subdistricts with high vulnerability in 2023 are Kandangan and Angkinang, which need to be the top priority in fire mitigation. Areas with moderate vulnerability include Loksado, Telaga Langsat, Daha Selatan, and Sungai Raya, which have the potential to be affected if the fires spread. Meanwhile, areas with low vulnerability such as Daha Barat, Daha Utara, Padang Batung, and Simpur still need to be monitored to prevent an increase in risk in the future. These results can be used as a basis for local governments to determine priority areas for action based on their respective risk levels.

Based on the results of the fire severity analysis (dNBR), residential exposure, and vulnerability level (FVI), mitigation measures are needed to reduce the risk of fires in the future. Key measures that can be taken include strengthening the monitoring and early warning systems in subdistricts with high FVI such as Kandangan and Angkinang, restricting land burning practices, and implementing buffer zones around settlements. In addition, the use of FVI results can help local governments set spatial priorities for fire intervention, for example in the placement of fire stations and land rehabilitation. Public education is also important to increase preparedness and participation in fire prevention.

3.5. The comparison between dNBR with hotspot data

Figure 10 shows a comparison between the results of dNBR processing and hotspots at each fire severity level in two different periods, namely 2021–2022 and 2021–2023. Figure 10a illustrates the condition in 2021–2022, where most of the study area was still in the unburned and low fire severity classes, although there were some points with higher severity. Meanwhile, figure 10b depicts the condition in 2021–2023, which shows a wider fire pattern, with the appearance of medium-high fire severity to high fire severity classes in several locations. This analysis aims to examine the relationship between fire severity levels based on dNBR and hotspot distribution as an indicator of fire activity. The selection of the two extents (a1/b1 and a2/b2) was based on the fact that in 2022 and 2023 both had hotspots, but with different intensity or number of hotspots.

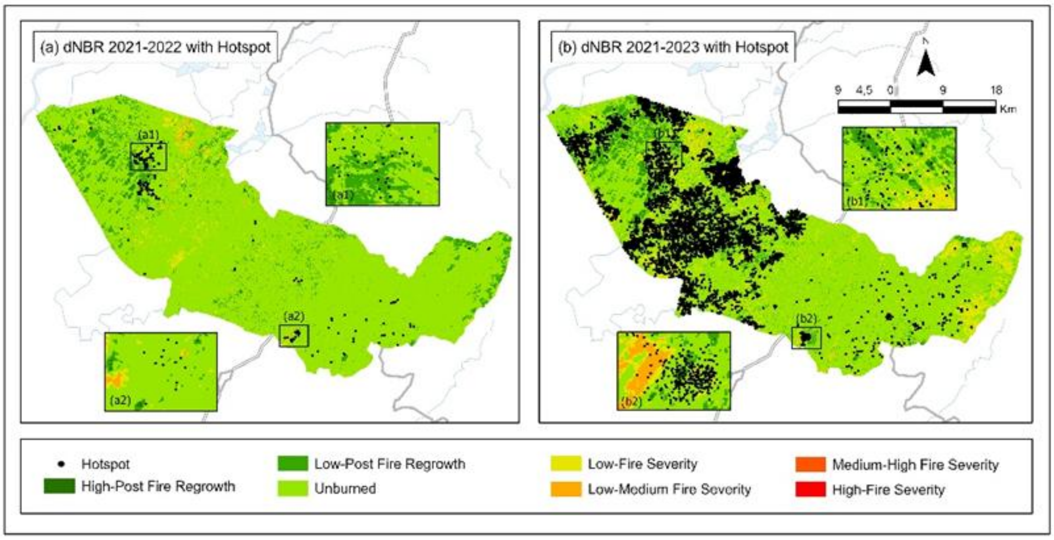

Figure 10. dNBR comparison with hotspots.

The color variations on the map indicate differences in severity levels, ranging from unburned areas to severely affected areas. The number of hotspots in 2022 for each level of fire severity can be seen in table 8.

Table 8. Number of hotspots in 2022 at each fire severity level.

Fire severity levels	Hotspot data in 2022	Percent
High Post-fire Regrowth	2	1.18
Low Post-fire Regrowth	31	18.34
Unburned	133	78.70
Low-Severity Fire	3	1.78
Moderate-Low Severity Fire	0	0.00
Moderate-High Severity Fire	0	0.00

Based on table 8, which shows the number of hotspots in 2022 at each fire severity level, there were 169 hotspots distributed in Hulu Sungai Selatan Regency. For the high post-fire regrowth level, there were 2 points or 1.18%. For the low post-fire regrowth level, there were 33 points or 18.34%. The unburned level had the highest number of points, namely 133 points or 78.70%. At the low fire severity level, there were 2 points with a percentage of 1.78%. Based on figure 10 and table 8, it can be seen that the majority of hotspots were at the unburned fire severity level, with hotspots clustered in the northern region. Only 3 points indicated the occurrence of fires with low severity. An analysis of the number of hotspots at each level of fire severity was also conducted for 2023. An illustration of the number of hotspots in 2023 at each level of fire severity can be seen in table 9.

Table 9. Number of hotspots in 2023 at each fire severity level.

Fire severity levels	Hotspot data in 2023	Percent
High Post-fire Regrowth	47	0.83
Low Post-fire Regrowth	778	13.79
Unburned	3548	62.87
Low-Severity Fire	1064	18.86
Moderate-Low Severity Fire	206	3.65
Moderate-High Severity Fire	0	0.00
High-Severity Fire	0	0.00

Based on table 9, which shows the number of hotspots in 2023 at each fire severity level, there was a very significant increase in hotspots from 2022 to 2023, with a total of 5,643 hotspots concentrated in the northern and western parts. The overall increase in hotspots was 5,474 points. At the high post-fire regrowth severity level, there were 47 points with a percentage of 0.83%. At the low post-fire regrowth severity level, there were 778 points or 13.79%. At the unburned severity level, there were 3,548 points or 62.87%. At the low severity level, there were 1,064 points or 18.86%, and at the medium-low fire severity level, there were 206 points or 3.65%. Overall, in 2023 there were 1,270 points that experienced fires with severity levels ranging from low to medium. The comparison between the number of fires in

2022 and 2023 shows a very large difference, indicating a forest and land fire phenomenon with a larger extent in 2023.

As a form of validation of the results of fire severity classification based on dNBR values, an accuracy assessment analysis was conducted using a confusion matrix. This analysis aimed to measure the level of conformity between the dNBR classification results and MODIS hotspot data based on confidence levels, namely low, medium, and high. The high confidence level is assumed to indicate large-scale fire occurrences, as larger fire points are more easily detected by satellite imagery, thereby resulting in higher confidence values. Conversely, smaller or less intense fires are more likely to have lower confidence levels due to reduced detectability. The dNBR reclassification raster, which originally consisted of seven classes (High Post-fire Regrowth, Low Post-fire Regrowth, Unburned, Low, Moderate-Low, Moderate-High, and High Severity Fire), was simplified into three main categories, namely class 1 as low severity fire covering classes 1–4 (High/Low Post-fire Regrowth, Unburned, and Low Severity Fire), class 2 as moderate fires covering classes 5–6 (Moderate-Low and Moderate-High Severity Fire), and class 3 as high fires representing class 7 (High-Severity Fire). Each hotspot point is then extracted to obtain a prediction value. The extraction results are then compiled into a comparison table between the actual class (hotspot confidence) and the predicted class (dNBR reclass). From these results, a suitability matrix is obtained, as shown in table 10.

Table 10. Fire Vulnerability Index (FVI) by Subdistrict in Hulu Sungai Selatan Regency, 2022–2023.

	Pred Low	Pred Medium	Pred High	Total Ref
Ref Low	149	1	0	150
Ref Medium	196	3	0	199
Ref High	147	4	0	151
Total Pred	492	8	0	500

Based on the matrix in table 10, the overall accuracy is 30.4% with a kappa coefficient of 0.0034. As cited in [29], Viera and Garrett stated that Kappa value falls into the category of slight agreement. The Low class has a procedure accuracy of 99.3% with a user accuracy of 30.3%, the Medium class has a procedure accuracy of 1.5% with a user accuracy of 37.5%, while the High class has a value of 0% for both procedure accuracy and user accuracy. Procedural accuracy indicates the model's ability to identify areas that should belong to a class, while user accuracy indicates the likelihood that an area classified into a class actually belongs to that class based on reference data. The low accuracy results may be due to differences in spatial resolution between Landsat imagery (30 m) and MODIS hotspot data (1 km), which cause discrepancies in the detection of burned areas. This is also a limitation in this study because it only uses MODIS hotspot data as comparative data due to the limited availability of validation data for more accurate fire verification.

As an additional form of validation, this study sought to validate its results using data obtained from publicly available news reports. The burned area generated from the dNBR analysis was then compared with reports of forest and land fires (karhutla) in 2023 published by several news sources. According to Jagosatu [30], forest and land fires in Hulu Sungai Selatan affected seven districts, including Daha Barat, Daha Selatan, Daha Utara, Kalumpang, Telaga Langsat, Simpur, and Sungai Raya. This finding is also supported by reports from Bakabar.com [31] and the Health Crisis Center of the Ministry of Health of the Republic of Indonesia [32], which recorded fire occurrences in Daha Barat, Daha Selatan, Daha Utara, Kalumpang, Sungai Raya, and Angkinang. These areas correspond to the 2023 dNBR analysis results, where the aforementioned districts, particularly Daha Barat, Daha Selatan, Daha Utara, and Kalumpang, were among the top five regions with the largest burned areas in Hulu Sungai Selatan, ranging from low to high fire severity levels.

These findings indicate that the dNBR results used in this study show consistency with field-reported fire events from multiple news sources. Therefore, the dNBR analysis can be considered a reliable basis for mapping the spatial distribution of burned areas and providing additional support for interpreting fire risk and vulnerability in Hulu Sungai Selatan.

4. Conclusion

This study aims to analyze the extent and severity of forest and land fires in Hulu Sungai Selatan District in 2022 and 2023 using the NBR and dNBR methods, overlaying them with residential zones, developing a Fire Vulnerability Index (FVI), and validating them using hotspot data. The analysis results show that in 2023, the area affected by fires was larger than in 2022, with an increase in the area in the low to moderate severity category. The FVI shows that the subdistricts with high vulnerability are Kandangan and Angkinang. Overlaying with residential zones shows areas that are potentially directly affected by fires, especially within a 400-meter radius of residential areas. Validation using hotspot data from the Ministry of Environment and Forestry reinforced the fire classification results, with a significant increase in the number of hotspots from 2022 to 2023. This study is useful for providing spatial information related to forest and land fire patterns and community vulnerability to fires.

Acknowledgement

The author would like to express his deepest gratitude to the Ministry of Environment and Forestry for providing hotspot data to support our analysis, the Central Statistics Agency for providing population density data, and to all those who have assisted in the completion of this research.

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