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Designing a Multitemporal Analysis of Land Use Changes and Vegetation Indices to Assess the Impacts of Severe Forest Fires Before Applying Control Measures

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Abstract: Forest fires represent a significant intersection between nature and society, often leading to the loss of natural resources, soil nutrients, and economic opportunities, as well as causing desertification and the displacement of communities. Therefore, the objective of this work is to analyze the multitemporal conditions of a sixth-generation forest fire through the use and implementation of tools such as remote sensing, photointerpretation with geographic information systems (GISs), thematic information on land use, and the use of spatial indices such as the Normalized Difference Vegetation Index (NDVI), the Normalized Burned Ratio (NBR), and its difference (dNBR) with satellite images from Sentinel-2. To improve our understanding of the dynamics and changes that occurred due to the devastating forest fire in Los Guájares, Granada, Spain, in September 2022, which affected 5194 hectares and had a perimeter of 150 km, we found that the main land use in the study area was forest, followed by agricultural areas which decreased from 1956 to 2003. We also observed the severity of burning, shown with the dNBR, reflecting moderate–low and moderate–high levels of severity. Health and part of the post-fire recovery process, as indicated by the NDVI, were also observed. This study provides valuable information on the spatial and temporal dimensions of forest fires, which will favor informed decision making and the development of effective prevention strategies.

Keywords: forest fire; remote sensing; spatiotemporal indicators; regional issues; land use changes

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1. Introduction

Climate change is a crucial factor to consider in the occurrence of large-scale fires. In Spain, information about fifth- and sixth-generation forest fires, or "megafires", is relatively recent, due to their increased frequency in recent years. A recent literature review confirmed the ambiguous nature of these terms, with size thresholds ranging from >100 to 100,000 hectares, with averages of >10,000 hectares being the most common [1].

According to the guideline "Prevention of Large Wildfires using Fire Types Concept" by Costa et al. [2], fire generations are defined by scenarios with factors limiting firefighting capacity. They identify five generations of fires, with the sixth generation encompassing those that have emerged in recent years. These fires are characterized by their immense size, high intensity, and rapid spread, making their behavior difficult to predict. As Inazio Martínez de Arano, Director of the Regional Office for the Mediterranean of the European Forest Institute (EFI), explained to the Science Media Centre Spain (SMC) [3], "sixth-generation" fires generate intense heat that disrupts the dynamics of the upper atmospheric layers, creating winds which defy accurate modeling. This makes forecasting their behavior even more challenging. A prime example of such a fire is highlighted in the Preliminary Report by the Junta de Andalucía of the Fire in Los Guájares, which occurred in September 2022 in the rural region of Los Guájares, Granada, Spain, where 5194 hectares were affected within a 150 km perimeter [4].

An increase in fire intensity over time, particularly in sixth-generation fires with pyroconvection activity, poses a major threat to life and property due to these fires' intensity and erratic behavior [5]. This trend is exacerbated by rising temperatures, which can lead to drought conditions, especially when combined with shifts in precipitation patterns that become more intense but less frequent. Additionally, increased fuel flammability resulting from warmer and drier conditions is a direct response of fire to climate change [6].

This combination of factors increases the risk of forest fires, significantly impacting land degradation neutrality. Al Sayah's study [7] highlights the importance of a land use plan based on land degradation neutrality (LDN) as a tool to mitigate hazards such as fires. Their research emphasizes this point using wildfire and landslide potentiality maps. In this context, land use changes can be linked to multiple factors, including industrial growth, migration, inadequate management practices, and the effects of increasingly intense and frequent meteorological events driven by climate change.

To better understand the context of forest fires, it is essential to consider territorial management, and the policies implemented across different countries. These factors reflect how human interactions with the environment lead to various implications. For instance, exposure to fire-related air pollution can significantly impact public health, affecting large populations [8]. Additionally, anthropogenic activities, such as deforestation, can degrade multiple ecosystem services, including soil formation, food production, erosion control, and heritage values, if not adequately regulated and monitored. Clarke et al. [9] demonstrated that fire activity has exceeded atmospheric water demand thresholds, measured by the maximum daily vapor pressure deficit. Therefore, a preventive approach to fire management, implemented through effective policies, can significantly reduce impacts on both the population and the environment. Given the evolving nature of fire risks, territorial management must be regularly updated to address current needs and contexts.

It is also important to consider historical, political, and economic factors, as well as the development of communities themselves, as they play a key role in shaping spatial patterns and changes. Le Houérou (1993) and Strijker (2005), cited in Skulska et al. [10], highlight some historical aspects, explaining that the rise of industry and the decline in agriculture and livestock activities, leading to rural depopulation, have contributed to forest expansion in these areas. The issue of land abandonment becomes particularly critical when coupled with climatic factors, economic activities, and social or natural phenomena, particularly in the absence of comprehensive forest management strategies for prevention or mitigation. Another example, it is the study published by Economou et al. [11], who conducted multitemporal econometric analyses over a decade following a 2007 fire in the Peloponnese, Greece, to identify and understand the economic impacts of the event on the local population.

Climate change impacts everyone on Earth, and humans are particularly vulnerable to its indirect consequences, such as economic damage, agricultural land loss, and food and water insecurity. These stressors can coalesce into system-wide failures [12]. The specific effects and changes that manifest depend on the unique characteristics of each region and its current land management and use practices. This is why studies on global change along with the relationship between human activities, soil, and land use have become priorities for governments, international institutions, stakeholders, and communities. Studying large forest fires is also essential for developing tools for analysis, planning, assessment, and monitoring. For example, Arango et al. [13] highlight the fundamental role of fire prevention policies, emphasizing the importance of existing road networks, their maintenance, and their role in supporting societal needs, including emergency services. These tools enable us to analyze changes in vegetation and land use resulting from fires, leading to more effective actions and infrastructure planning. Prestemon et al. [14] use statistics to examine the economic effects and benefits of Wildfire Prevention Education (WPE) based on a preventive culture. Such education can help spread knowledge and prevent future fires. Hesseln [15] emphasizes the importance of social sciences in understanding human behavior, communication, and participation in wildfire prevention.

Among the widely used tools for studying big fires, satellite image-based indices, such as the Normalized Difference Vegetation Index (NDVI), are particularly important. Time series data and cartographic research using these indices are valuable tools for visualizing and comparing the spatial impacts of fires on vegetation [16,17]. For evaluating wildfire potential, regional climate models (RCMs) are a new technique that can estimate fire potential over large areas by simulating and projecting precipitation, air temperature, humidity, and wind patterns, which are used to calculate fire indices [18]. Additionally, severity indices such as the Fire Severity Index (FSI) and the Normalized Burn Ratio (NBR) are frequently applied. García-Llamas et al. [19] highlighted the importance of using spatial indices like the NDVI with Landsat 7 ETM images to support better decision making in fire prevention. Other examples involve machine learning (ML), as demonstrated by Jain et al. [20], who showed how this approach can be applied to wildfire response by processing large amounts of physical data. These tools are well-suited for fire detection. Alternatively, Hong et al. [21] conducted a data mining analysis to handle large amounts of data and identify patterns that facilitate the mapping and study of forest fires, as exemplified by a case study in Dayu, China. Another approach, explored by Turco et al. [22], involves investigating the influence of anthropogenic climate change and natural climate variability on burned areas in California, United States, using multitemporal simulation models. Long-term studies are crucial for understanding the evolution of conditions and changes in a study area, particularly in the context of forest fires. For example, Rodrigo-Comino et al. [23] highlight the importance of Circulation Weather Types (CWTs) in correlating and quantifying soil erosion events with surface pressure data at different atmospheric heights. These studies are essential for illuminating the dynamics of land management, shaped by both human activities and fire.

Therefore, conducting and promoting research that tracks changes over several decades is vital. This approach enables improved future land planning and management actions in affected areas. Detailed monthly analyses of events before and after a fire can complement these long-term studies, providing a more comprehensive understanding of the fire's magnitude, progression, and impact. This, in turn, supports informed decision-making, territorial planning, and resource management. However, gathering large volumes of data over extended periods and across broad areas through in situ measurements or experiments can be challenging. This paper aims to analyze the multitemporal conditions of a sixth-generation fire using photointerpretation and the estimation of spatial indices such as NDVI, NBR, and dNBR. We hypothesize that this analysis will help improve our understanding of the changes, importance, relationships, and impact of spatial dynamics before and after a large fire, such as the Guájares fire in 2022.

The rest of the paper is organized as follows. In Section 2, we describe the study area, the data used, the multitemporal analysis of land use changes, and the satellite images (spatial indices and natural color or RGB images). In Section 3, the results of our study indicate the changes in land use from 1956 to 2003, showcased alongside the results obtained for the NDVI, NBR, and dNBR spatial indices. Section 4 presents the discussion of our results, and, finally, Section 5 presents the conclusions we have reached after a multitemporal analysis with the abovementioned tools.

2. Materials and Methods

2.1. Study Area

The rural region of Los Guájares, located in the Southern Granada Province within the Autonomous Community of Andalucía, is bound by the following coordinates: (−3.65 W, 36.84 N), (−3.50 W, 36.84 N), (−3.50 W, 36.91 N), and (−3.65 W, 36.91 N) in EPSG:32630 and Datum WGS84 (Figure 1). It encompasses four municipalities: Albuñuelas (36.928 N, −3.632 W), El Valle (36.929 N, −3.583 W), El Pinar (36.913 N, −3.554 W), and Vélez de Benaudalla (36.832 N, −3.516 W). The forest fire affected 5194 hectares, with a perimeter of 150 km. The highest elevation within the affected area reached 1420 m, while the lowest was 360 m, with slopes exceeding 60% inclination (Figure 2). The main land uses included natural areas and agricultural activities involving herbaceous and woody crops, both irrigated and rainfed. Olive groves and subtropical trees were also present. *Pinus halepensis* forests intermixed with dense shrubs, scattered grasslands, rocky outcrops, and Leptosols. According to the State Meteorological Agency [24], the area has a Mediterranean climate (Csa), characterized by temperate conditions with dry, hot summers, as classified by Köppen and Geiger (1936). On 8 September 2022, a devastating forest fire impacted five municipalities: Los Guájares (2255.92 ha), El Valle (582.03 ha), Albuñuelas (777.29 ha), El Pinar (1336.47 ha), and Vélez de Benaudalla (243.30 ha), as detailed in the Preliminary Report of the Fire in Los Guájares (Granada).

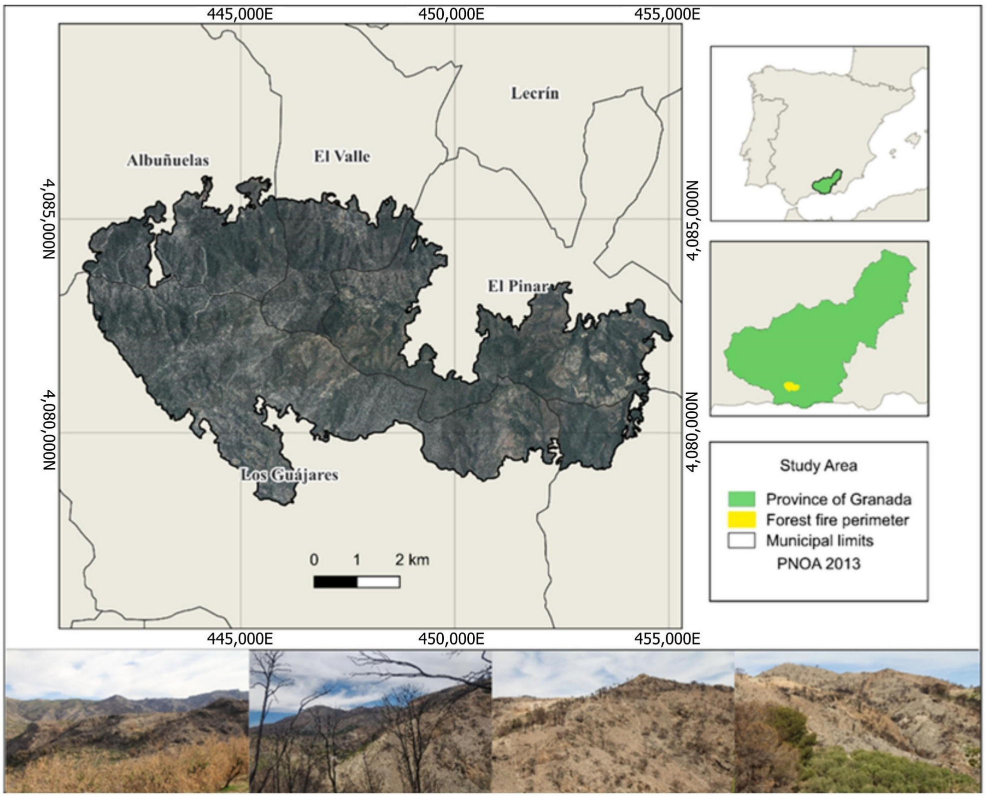

Figure 1. Localization of the study area and photographs during the fieldwork campaign.

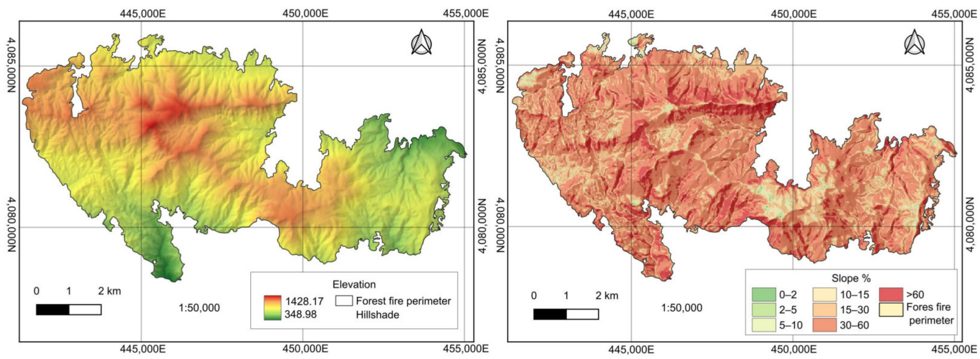

Figure 2. Maps of elevation and inclination of the study area.

2.2. Dataset and Sources

Vector and raster files, along with their associated metadata, were obtained from the National Geographic Information's Download Center [25]. Orthophotos from the National Aerial Orthophoto Plan (PNOA) were downloaded, which had undergone a projection correction process. The selected images correspond to the AMS (B) 1956–1957, Interministerial 1977, National 1984, Olistat 1999, and PNOA Annual 2004. Additionally, land use data were acquired from the Environmental Information Network of Andalucia [26]. This dataset corresponds to the Maps of Land Uses and Vegetation Cover of Andalucia (MUCVA) at a 1:25,000 scale for the years 1956, 1977, 1984, 1999, and 2003. Further details can be found in Table 1 [27–30].

Table 1. Data sources and formats used for this study case.

Data Source	Type
Andalucia Institute of Statistics and Cartography (IECA)	Shapefile and text
National Geographic Information's Download Center	Shapefile, raster, and text
Environmental Information Network of Andalucia (REDIAM)	Shapefile, raster, and text
Land Use Information System of Andalucia (SIOSE)	Text
Spanish Institute of Statistics (INE)	Text
National Orthophoto Plan (PNOA)	Raster
Natural Heritage Information System of Andalucia (SIPNA)	Text
Sentinel 2. Copernicus Browser	Raster

To estimate the various vegetation and forest fire impact indices for the burned area, remote sensing data from Sentinel 2 were downloaded [31]. Sentinel 2 was chosen for its extensive geographic coverage, multiple resolution options (10, 20, or 60 m spatial resolution), availability of platforms, and collaborative websites like the Copernicus Emergency Management Service. The frequency of image uploads to the Copernicus Data Space Ecosystem, with each satellite capturing data every 10 days, provided a temporal resolution of 5 days when combined. This selection was made to enable a multitemporal analysis of monthly satellite images over a year, covering the six months before and after the fire (March 2022 to March 2023), as well as a pre- and post-fire year comparison for the months of August to October. The selected satellite images were from the S2B and S2A missions, considering their multispectral operational instruments and a Level-2A processing level.

In addition to aerial and satellite images, thematic geographic information, such as data from the Spanish Land Use Information System (SIOSE) and the CORINE Land Cover (CLC) project, plays a crucial role in studying and monitoring fires. These data, part of the National Territory Observation Plan (PNOT), were supervised and corrected for proper visualization in the QGIS software, complementing the information from MUCVA. Thematic information has been available since 1990, generated in alternate years to the analyzed fire in Guájares. This allows for greater multitemporal analysis by providing a broader dataset for comparison and reference. A noteworthy example of the importance of multitemporal analysis is the monitoring of the fire in Wakeliangzi, Muli, China, in 2020, by Li et al. [32], where they applied NDVI and NBR indices before and after the fire, using various satellites such as GF-4, Sentinel-2, and Landsat-8.

The preliminary report by the Ministry of Sustainability, Environment, and Blue Economy does not consider isolated or unaffected areas within the fire perimeter. To create a more comprehensive contrast between unaffected and fire-affected areas, we chose to include these areas in our analysis. To achieve this, we utilized data from the "Maps of Vegetal Uses and Land Cover of Andalucia" (MUCVA) at a 1:25,000 scale, covering the years 1956, 1977, 1984, 1999, and 2003. These data were analyzed using the QGIS software version 3.32.2. The "correct geometries" tool in QGIS was used to align edges or vertices of the MUCVA polygons, ensuring a proper analysis. We then used the fire perimeter layer to clip the MUCVA data, creating a subset representing only the area affected by the fire. The attribute tables of the resulting polygons were reviewed. These tables contain various attributes like soil type codes, land use descriptions, perimeter, and area for each polygon. A legend with maximum disaggregation for each year was created based on the Data Model file downloaded from the REDIAM website [33]. This legend allows for the interpretation of up to 112 land cover classes within the MUCVA data.

However, this number can vary from year to year. When the land use and vegetation cover layer is clipped to the fire-affected area, the number of classes is significantly reduced. To simplify the analysis, two new columns were manually added to the attribute table of each map. These columns were created by selecting the land use and vegetation cover code column (displayed as three digits) and using expression selection to group the codes into four major categories based on the Methodology for the Preparation of 1:25,000 Scale Vegetation and Land Use Cartography of Andalucia document. These four major groups correspond to Level 1 (Table 2) and are as follows: (i) agricultural areas; (ii) forest and natural areas; (iii) built surfaces and infrastructures; and (iv) wet zones and water surfaces.

Table 2. Major groups organized considering the different sources of layers.

Code Level 1	Description Level 1
1	Built surfaces and infrastructures
2	Wet zones and water surfaces
3	Agricultural areas
4	Forest and natural areas

2.3. Multitemporal Analysis of Land Use Changes

Once these four groups were created in two new columns, the polygons were converted from multipart to single-part. This involved creating four new columns and calculating the area in hectares and the perimeter using the field calculator. This step facilitated the subsequent statistical analysis. To visualize only the land uses within the four major groups, a dissolve operation was performed based on the column containing the manually grouped Level 1 codes for different years. This operation merged polygons with the same code, resulting in a final layer with multipart polygons representing only four land use classes. To specifically identify areas which underwent changes between one year and another, a union of both years of interest was created before the dissolution step. Subsequently, a new vector layer was generated, considering only those polygons that exhibited a difference between the two years. A new column was added to the attribute table to establish a conditional statement: "If ('U_LEVEL1' is not 'U_LEVEL1_2', 'Yes', 'No')". A comparison was made between the columns containing land use codes for the periods before and after the date of the forest fire. If the values in these columns differed, indicating a change between the two years, the new column would display 'Yes'. Conversely, if the values were the same, it would display 'No', indicating no change in land use between the two selected years. With both layers, one containing only land uses and the other containing polygons which had changes between the two dates, the analysis could proceed.

2.4. Multitemporal Analysis Using Satellite Images

For the multitemporal analysis of satellite images, Python programming in Google Colab was utilized, leveraging the Google Earth Engine (GEE) Application Programming Interface (API). The 'S2_SR_Harmonized' collection was selected, which contains multispectral Sentinel-2 images processed for temporal consistency and atmospheric correction. To minimize cloud cover, images were filtered from the collection, selecting the least cloudy image for each month of analysis. The study area was delineated using a .kml file of the forest fire perimeter. In Google Colab, true color maps (RGB) and Normalized Difference Vegetation Index (NDVI) maps were generated to assess vegetation dynamics and health. According to Verdin et al. [34], NDVI values range from −1 to +1, with positive values indicating vegetation. For the Guájares study, positive NDVI values represent active vegetation. A cutoff point between 0.28 and 0.32 was applied for different months, resulting in two colors of layers: gray for inactive vegetation and green for active vegetation. The NDVI was calculated as follows (Equation (1)):

$$\text{NDVI} = (\text{Band } 8 - \text{Band } 4)/(\text{Band } 8 + \text{Band } 4) \quad (1)$$

Normalized Burn Difference (dNBR) maps were also generated by subtracting the pre-fire NBR from the post-fire NBR. As explained by the UN-SPIDER Knowledge Portal [35], the NBR index, calculated using NIR and SWIR bands, highlights burned areas due to their lower water retention capacity and reduced reflectance. The NBR was calculated as follows (Equation (2)):

$$NBR = (Band\ 8 - Band\ 12)/(Band\ 8 + Band\ 12) \quad (2)$$

Subtracting the pre-fire NBR from the post-fire NBR, as described by Key and Benson [36], allows for the estimation of fire severity. The dNBR was calculated as follows (Equation (3)):

$$dNBR = NBRpre - NBRpost \quad (3)$$

After calculating the indices and defining visualization parameters, the images were downloaded in .tiff format. Finally, the layout and design for each index were created in QGIS.

2.5. RGB Images Before and After the Forest Fire

To analyze the temporal changes in vegetation, satellite images from Sentinel 2 were organized and displayed monthly for the six months before and after the fire. Natural color images were used to facilitate the visual observation of changes in vegetation color due to climatic conditions and recovery processes.

3. Results

3.1. Land Use Changes in Long-Term Periods (1956–2003)

From 1956 to 2003, the study area was predominantly composed of forests and natural landscapes, followed by agricultural lands, with minimal portions occupied by built-up areas, infrastructure, wetlands, and water surfaces. Notably, forested areas experienced their most significant percentage increase from 1956 to 1977, followed by a smaller, steady increase through to 2003. In contrast, agricultural lands declined during the same period.

In 1956, forest and natural areas made up 81.9% of the total area, while agricultural lands accounted for 17.8%. By 2003, these proportions shifted to 84.3% for forest and natural areas and 15.4% for agricultural lands. Forested areas consistently covered over 4500 hectares starting from 1956, while agricultural lands remained below 1000 hectares. This area reflects the entirety of land impacted by the forest fire (Figures 3 and 4).

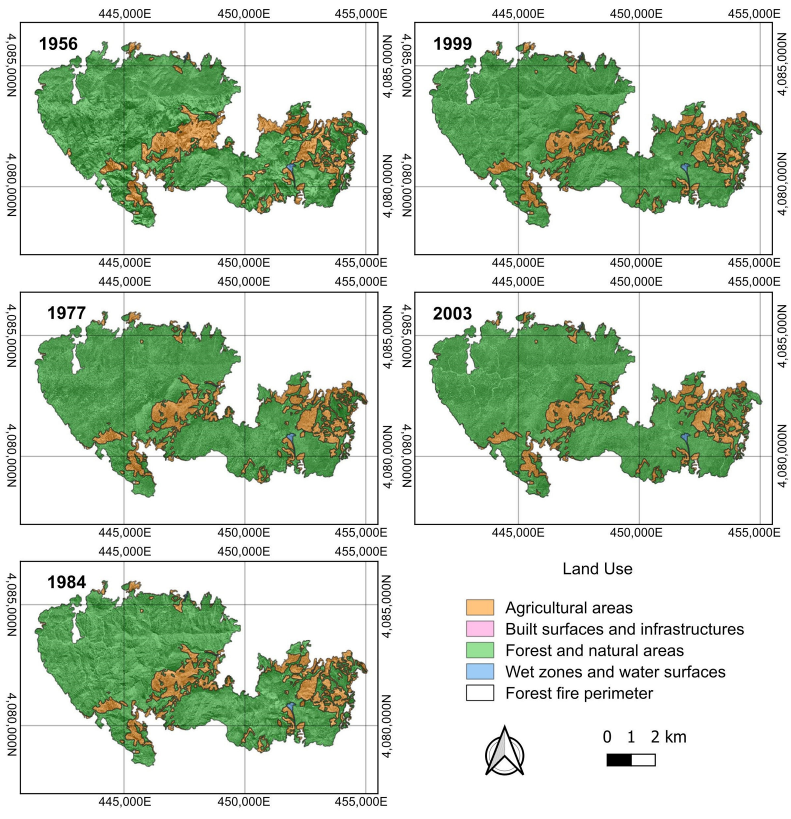

Figure 3. Land use maps showing the changes among selected dates.

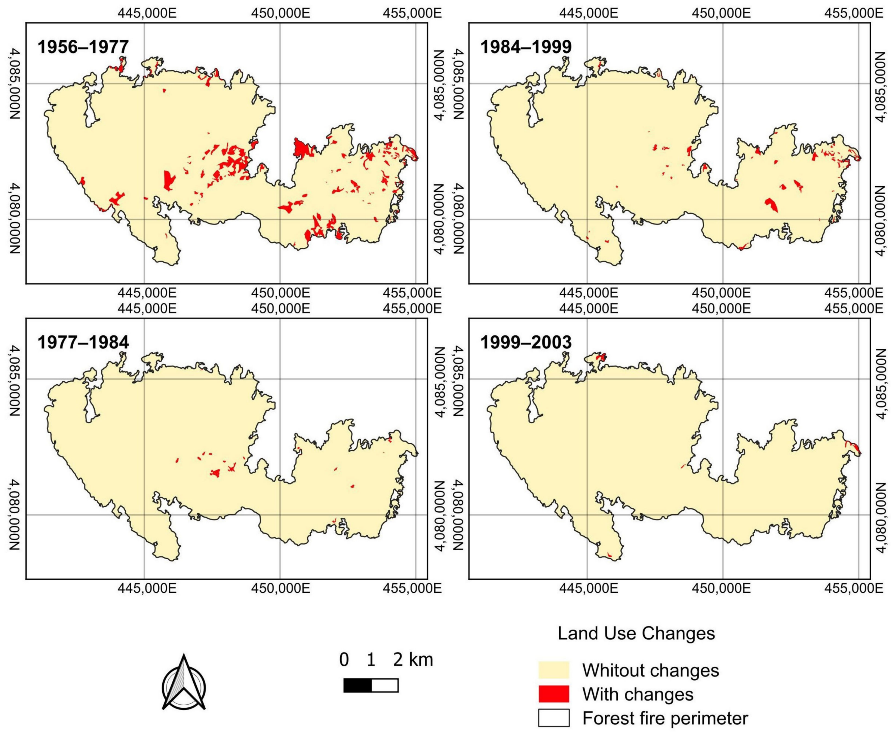

Figure 4. Maps considering land use changes between specific intervals of years.

3.2. Analysis of Satellite Images Before and After the Forest Fire

After capturing natural color images over the course of a full year, the impact of weather conditions on vegetation between March and August 2022 became evident. During this period, a reduction in the intensity of green tones was noticeable in both forested and agricultural areas, likely due to seasonal crop changes and lower moisture levels, as August and September typically experience higher temperatures (Figure 5). Following the fire, from October 2022 to March 2023, subtle shifts toward brown tones could be observed, likely resulting from erosion processes and the initial stages of vegetation recovery (Figure 6).

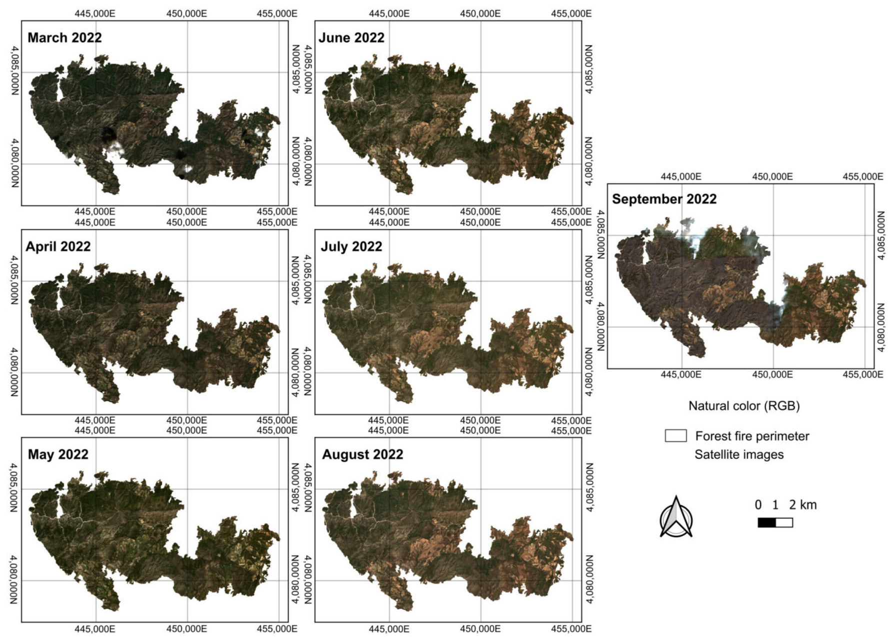

Figure 5. Satellite images with natural color from March 2022 to September 2022.

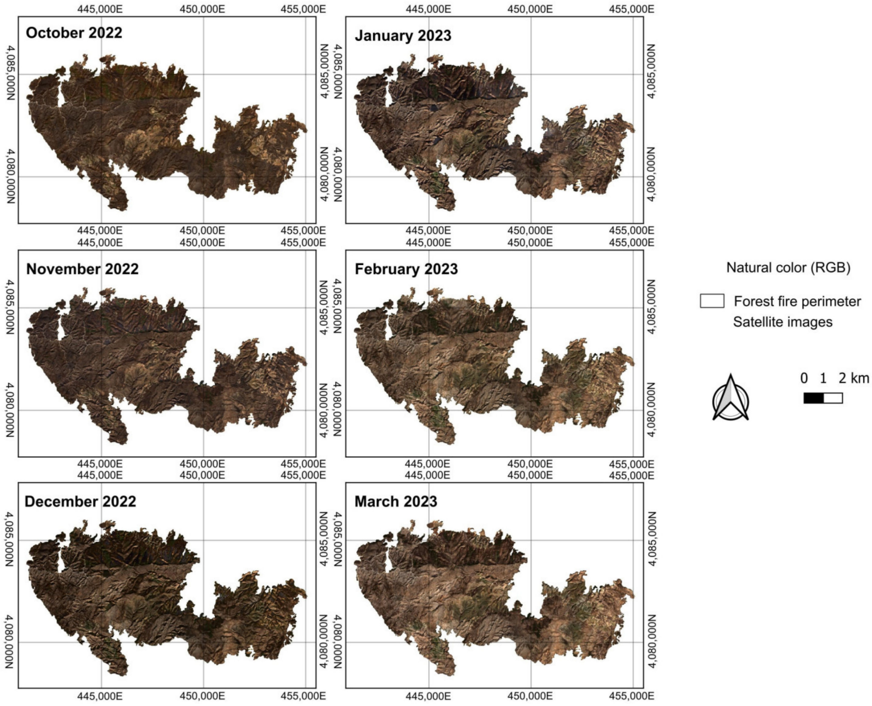

Figure 6. Satellite images with natural color from October 2022 to March 2023.

As shown in Figure 7, in 2021, the vegetation and agricultural areas of the study site could be distinguishable by subtle color variations that reflected different land uses. However, in 2023, when comparing the same months (August to October) after the forest fire, the fire's impact on the soil became evident. Differences in tone on various slopes highlight the effects, with some areas appearing darker than others due to slope characteristics and possible erosion processes.

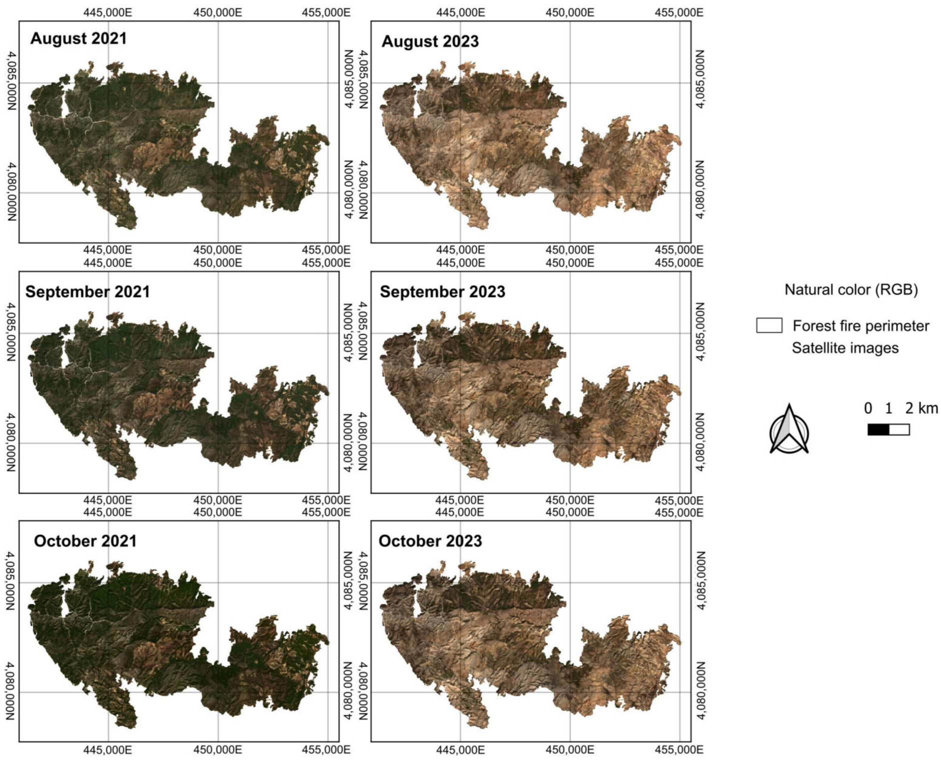

Figure 7. Satellite images with natural color from August to October in 2021 and 2023.

3.3. Normalize Difference Vegetation Index (NDVI)

Using the Normalized Difference Vegetation Index (NDVI), maps were generated to display active and inactive vegetation. The NDVI was calibrated through visual analysis, allowing for the clear demarcation of firebreaks, road networks, and other features. Between March and September 2022, a decline in active vegetation was evident due to climatic conditions, such as very dry, hot summers (Figure 8). During and after the fire, active vegetation decreased sharply, leaving isolated "islands" of vegetation, primarily in agricultural areas. These areas, though impacted, still showed signs of active vegetation, with a gradual recovery post fire as crop cycles influenced the vegetation levels throughout the year. By February and March 2023, vegetation had increased in the central and eastern parts of the study area. This resurgence was likely due to rainfall in December 2022, which stimulated new vegetation growth in agricultural zones (Figure 9).

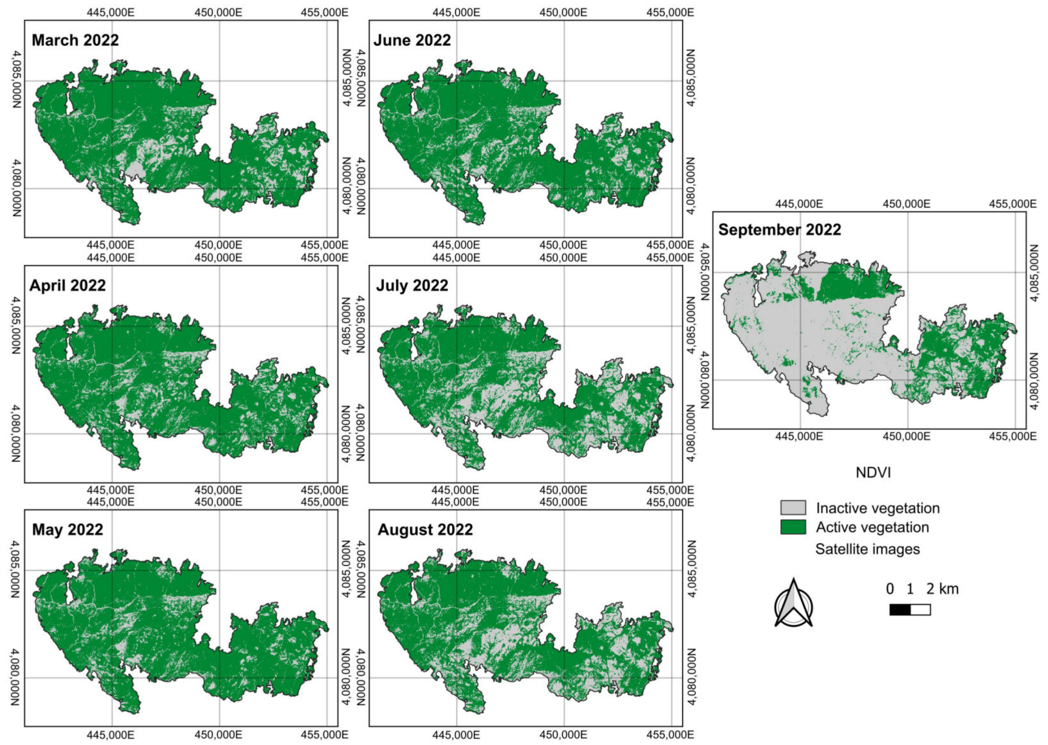

Figure 8. Normalize Difference Vegetation Index (NDVI) from March 2022 to September 2022.

In August, September, and October of 2021 (Figure 10), vegetation changes were primarily concentrated in agricultural areas. However, in the same months of 2023, these changes were more prominent in the northern part of the study area. The images also reveal that the northern area has a higher vegetation density, with some smaller areas showing signs of recovery as well. This observation is significant because the high vegetation density in the northern area, combined with factors such as slope, wind patterns, and precipitation, provides insights into how fire behavior and vegetation recovery occur following a large-scale fire event.

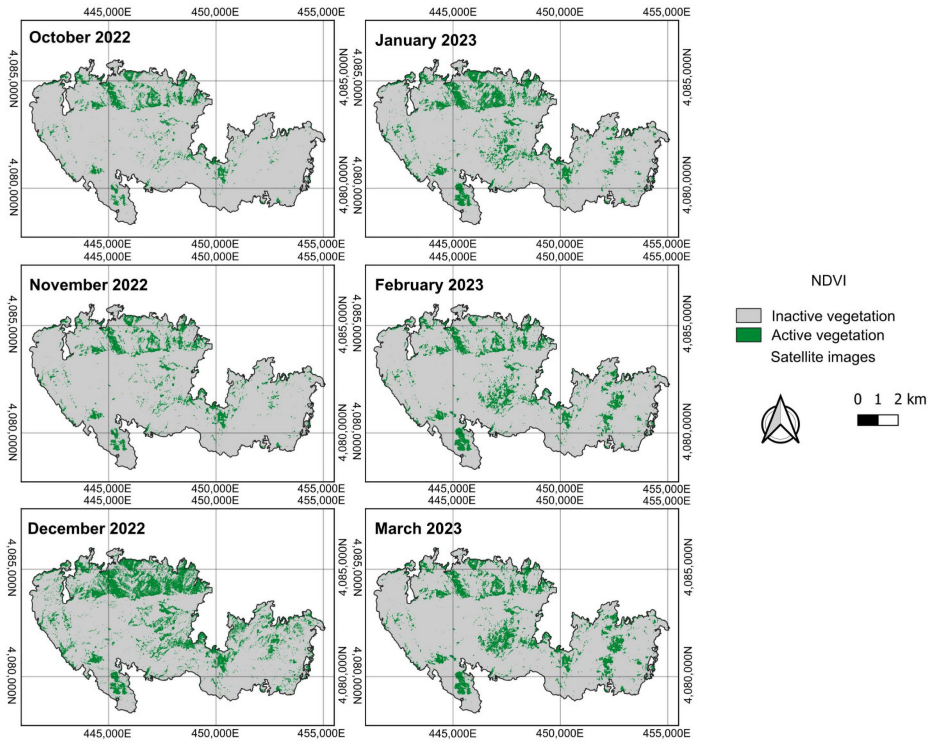

Figure 9. Normalize Difference Vegetation Index (NDVI) from October 2022 to March 2023.

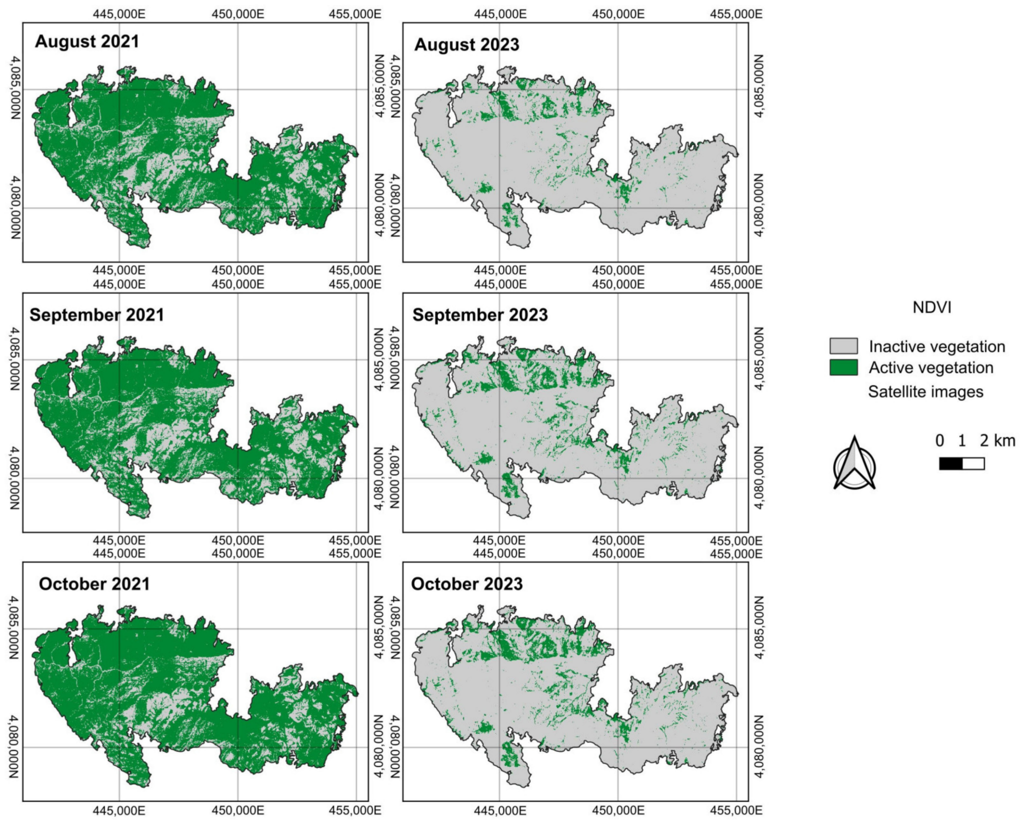

Figure 10. Normalized Difference Vegetation Index (NDVI) from August to October in 2021 and 2023.

3.4. Normalized Burn Ratio (NBR) and Difference Normalized Burn Ratio (dNBR)

The Normalized Burn Ratio (NBR) highlights areas with high values, indicating healthy vegetation, while low values represent regions affected by fire or areas of bare soil left with reduced vegetation post fire. In Figure 11, panel 11a (August 2022) shows vegetation in relatively healthy condition, although some areas show the effects of high summer temperatures. In contrast, panel 11b (October 2022) displays extensive bare soil and vegetation damage resulting from the fire. Notably, October was the month immediately following the fire, and the presence of "islands" of healthy vegetation in certain areas suggests that these zones were minimally affected by the event.

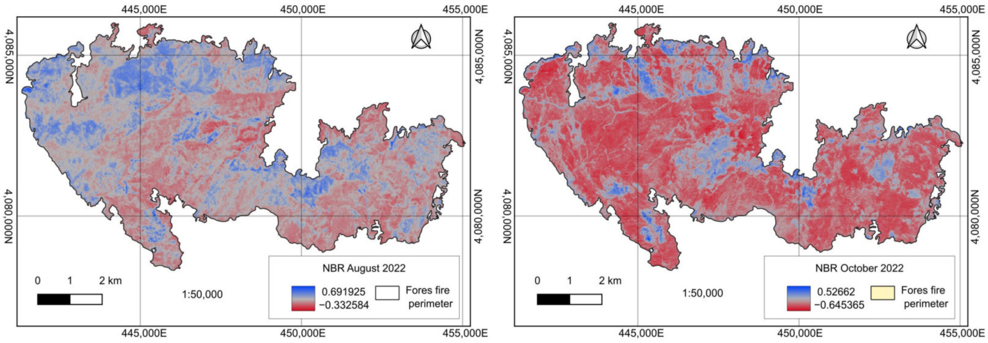

Figure 11. Normalized Burn Ratio (NBR) from August and October 2022.

A comparison of August and October 2022—a month before and after the fire—was conducted to analyze burn severity (Figure 12). The results indicate that "moderate–low" and "moderate–high" burn severity levels were predominant, likely due to the brief interval between image analyses. This also highlights the vegetation's response to the fire. Agricultural areas showed a relatively lower impact, which could be attributed to differences in size, distribution, and boundaries between crops and natural vegetation.

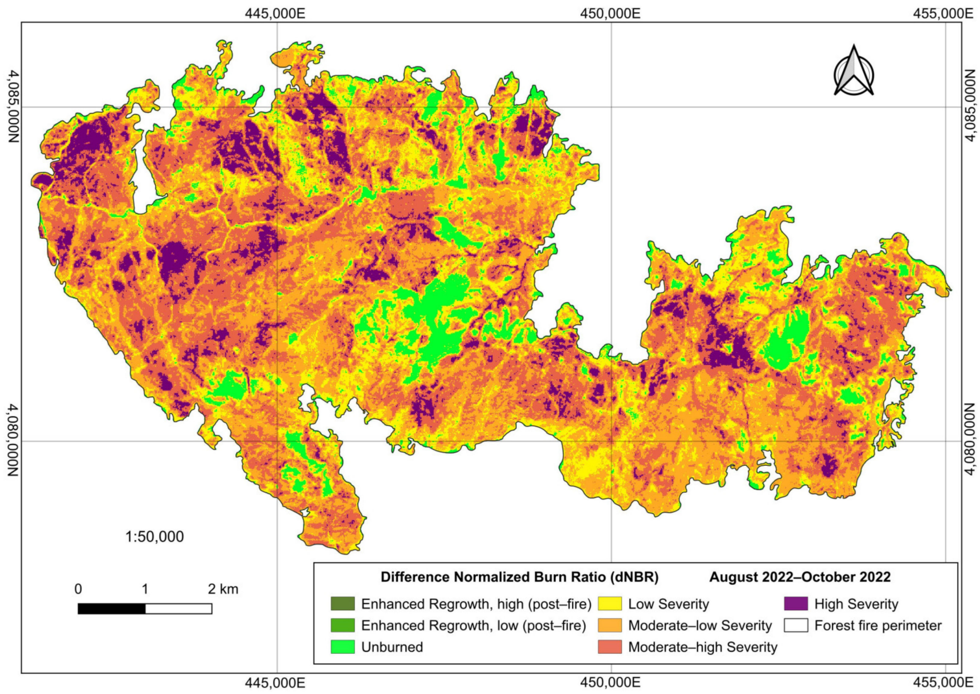

Figure 12. Difference Normalized Burn Ratio (dNBR) from August and October 2022.

4. Discussion

4.1. General Considerations

The condition of vegetation and soil—shaped by climatic factors, topography, human activities, and environmental conditions—serves as a vital reference when studying wildfires using remote sensing and geographic information systems (GISs) in a multitemporal analysis. Zagalikis [37] highlights the broad application of geospatial technologies due to their accessibility, accuracy, and scalability, underscoring the value of remote sensing (RS) and GIS in forest management and planning. Thematic data, coupled with modern geospatial technologies, demonstrate the critical role of integrating human and environmental dynamics across space and time, particularly in the context of large-scale fires. We agree with Puerta-Piñero et al. [38], who emphasize the importance of land use and multitemporal analysis in understanding post-fire vegetation recovery. In the Los Guájares wildfire region in Granada, Spain, significant land use changes were noted between 1956 and 1977, notably a reduction in agricultural areas and an increase in road networks—a transformation attributed to the roughly 20-year period between the observations.

It is worth remarking that a practical example of GIS in emergency response could also be conducted, like in the paper published by Lestari et al. [39] on the Indonesian island of Pali, where small three-wheeled mobile fire units (MFUs) were deployed. This GIS-driven approach, tailored to the island's unique road and territorial characteristics, enhanced emergency response and population support capabilities.

Although these changes may not be immediately visible at the current map scale, like in our article, they are present, including the emergence of firebreaks in the northwest of the study area. Firebreaks are designed to remove vegetation (fuel) to inhibit the spread of fires by reducing organic matter that could otherwise accelerate fire movement. Wang et al. [40] discuss various methods for controlling fire spread, including fuelbreaks and the creation of green fire barriers, underscoring the importance of fuel management in fire prevention and control, which could also be included in the future. Despite the apparent stability in land use classification into four primary categories—forestry, agriculture, wetlands and water bodies, and built areas—a closer examination of vegetation cover types and graphs reveals subtle shifts. This wildfire had a significant impact, especially on forested areas, followed by agricultural land. Our conclusions coincide with those of Ascoli et al. [41], who emphasize the need for multitemporal studies of land use change in Italy to understand fuel accumulation, which can heighten fire risks and recurrence, thus informing more effective land management practices. Therefore, land use maps were analyzed up to 2003 to assess changes and impacts over the past two decades, considering the need for a follow-up study.

Regarding the NDVI, a marked reduction in vegetation was observed, with small, isolated areas remaining, which, according to preliminary reports and cartography, are considered unburned zones despite their location within the fire-affected area. In analyzing active and inactive vegetation across different dates, it is essential to highlight the role of factors like temperature, humidity, rainfall, and soil types in monitoring post-fire vegetation recovery. We agree with Pérez-Cabello et al. [42], who emphasize the importance of tracking vegetation recovery after a fire to ensure updated, accurate information, supported by satellite and remote sensing technologies. In terms of fire severity, patterns indicate a higher burn severity in analyses conducted shortly after the fire. For instance, as Cansler et al. [43], we also demonstrate the value of pre- and post-fire comparisons in a multitemporal study of fires. In this case, the authors compared different areas in Washington State, USA, spanning 35 years.

4.2. Potential Areas for Improvement

Acknowledging mental health concerns among both firefighters and the general population is commendable and underscores the need for a holistic approach to fire management and recovery. This aspect would add a crucial dimension to the study, broadening its impact and relevance. The call for more systematic multitemporal studies is well-founded. Such research can provide invaluable insights into long-term spatiotemporal changes, aiding in the identification of potential risks and vulnerabilities. By examining vegetation dynamics and susceptibility factors, the study could contribute to more effective fire prevention and mitigation strategies. The emphasis on community participation and planning would also be essential. As Kete [44] points out, involving local communities and fostering effective communication among stakeholders are crucial for successful fire management and prevention policies. By incorporating these elements, our study, in the future, can offer practical recommendations for policymakers and practitioners.

Another point would be to consider incorporating other quantitative analysis techniques to strengthen the empirical foundation of this study. This could involve statistical modeling or spatial analysis to identify significant trends and patterns. This would also allow for a deeper exploration into specific case studies within the selected study area, Los Gúajare, which could provide more nuanced insights into the impacts of forest fires on affected communities. Moreover, another possible research line would be the design of practical implications of the findings for policymakers and practitioners. This could involve developing specific recommendations to improve fire management and recovery efforts.

Wildfires pose risks that extend beyond physical damage, impacting the health and well-being of the population and affecting the mental health of response teams, as highlighted by To et al. [45]. Additionally, understanding the characteristics of emerging fire patterns and implementing educational initiatives, along with widespread dissemination, are crucial. Moving beyond monthly monitoring intervals, continuous surveillance and, ideally, multitemporal analyses spanning over a decade are essential. Rigorous field studies are necessary to validate GIS-derived information, ensuring accuracy and revealing potential variations [46].

Finally, employing tailored methodologies for land use or index calculations (e.g., NBR, dNBR, NDVI, SAVI) is crucial to meet the specific needs of the study area. This approach would enable comparisons between data from comprehensive studies encompassing the entire perimeter and data excluding "unburned" zones. Such comparisons could be used in the future with techniques related to field sampling or in situ experiments to train models through, for example, machine learning, helping identify nuances and contribute to the establishment of pauses and improving the precision of multitemporal remote sensing studies.

5. Conclusions

Our study provides a foundational exploration of a forest fire's impacts in Los Guájares, emphasizing the value of multitemporal analysis and the integration of social factors. By examining evolving spatial patterns and relationships over time, this research contributes to a deeper understanding of fire-related issues. The integration of GIS and remote sensing proved invaluable in analyzing the spatial dynamics of land use changes. The analysis of thematic data, corroborated by orthophotographs, revealed that forest and natural areas were the predominant land uses, while agricultural areas decreased between 1956 and 2003. By employing satellite imagery and spatial indices like NDVI and NBR, we were able to assess post-fire recovery, identifying correlations between vegetation recovery and factors such as slope steepness and soil conditions. These findings align with the moderate-to-high severity levels associated with the September 2022 Guajares fire.

We consider that incorporating short-term replications of this study could help clarify current conditions and assess the implications of new fire patterns on vegetation recovery and spatial dynamics. In the medium term, multitemporal studies can inform the development of enhanced fire prevention measures and more rigorous research. Long-term studies can significantly impact development strategies, particularly in the areas of prevention and immediate response. By increasing awareness of wildfire risks, individuals can take proactive steps to prevent or mitigate damage. Future, more detailed studies are crucial for understanding the impact of fires on burned areas, induced changes, and the effects on local populations, including economic implications. By effectively utilizing the tools employed in this study, we can implement appropriate prevention measures, develop better strategies, and contribute to the well-being of both people and the planet by gaining a deeper understanding of spatial dynamics.

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