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MAPATON 2023: implementing a tool for the analysis of forest fire zones in Arequipa

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ABSTRACT

The "Mapaton 2023," a collaborative initiative by the Peruvian Space Agency, Paraguayan Space Agency, and AMERIGEOS, introduces an innovative approach to analyze fire-prone areas in Arequipa, a pivotal endeavor for disaster prevention. Focused on the provinces of Arequipa and Caylloma, recent studies identified over 1,500 affected hectares by forest fires, emphasizing the urgency of employing satellite images and geospatial analysis techniques. Leveraging Landsat 8 satellite imagery, the research calculated indices, including the normalized difference vegetation index (NDVI) for vegetation analysis and the differenced normalized burn ratio (dNBR) for fire severity assessment. Results revealed varying impacts, with some areas exhibiting increased vegetation and others displaying significant damage. The use of ArcGIS online facilitated the presentation of geospatial data, emphasizing the utility of remote sensing in comprehending and addressing forest fires. Drawing insights from analogous studies in Mexico and the Amazon, this research underscores the importance of remote sensing and geospatial analysis in informing preventive measures against wildfires. The findings, crucial for environmental management, are recommended for sharing with relevant authorities, and the continued use of diverse satellite imagery sources is encouraged to enhance accuracy in monitoring and mitigating forest fires.

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1. INTRODUCTION

A forest fire is an unwanted fire that spreads uncontrollably in forest resources, resulting in ecological, economic and social damage [1]. This rapid spread occurs due to a combination of oxygen from the air, vegetation as fuel, and a source of heat, known as the "fire triangle". Flames and smoke manifest forest fires [2], [3].

In Arequipa, many forest fires are caused by irresponsible human activity, such as burning agricultural or forest waste without adequate precautions [3], [4]. Also, some people may intentionally start fires, making the situation worse. The rapid rate of fire spread is closely related to the wind, especially in areas with steep slopes. In these areas, heating the air by the ground creates local updrafts that contribute to an accelerated fire spread; this results in rapid ignition of fuel that has not yet been affected [5].

Forest fires have a devastating impact on the environment. Likewise, the lack of planning and prevention aggravates the problem [6]. The absence of firewalls, the lack of training in prevention techniques and the scarcity of resources to fight fires make it difficult to control them promptly [7]. On the other hand, the intensity of solar radiation is higher when the earth's surface is perpendicular to the sun's rays, known as the optimal view factor. The perpendicular position of the surface varies according to the year's season, the time of day and the latitude [8]. Generally, areas exposed to the sun receive more solar radiation, resulting in lower humidity and sparse vegetation than shaded areas. However, this vegetation in the areas exposed to the sun acts as fuel and will be drier, allowing a more rapid-fire spread [9].

Smoke and airborne particulates produced by wildfires can cause or aggravate respiratory diseases, such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD) [4]. The most vulnerable people, such as children, the elderly, and those with chronic respiratory diseases, are especially susceptible to respiratory complications from smoke exposure. Airborne particles during wildfires can trigger allergic reactions in some people, including allergic rhinitis, conjunctivitis, and rashes [10]. Those with pre-existing respiratory sensitivities or allergies may experience more severe symptoms during these events [11]. Exposure to wildfire smoke can also adversely affect the cardiovascular system [12]. The fine particles in smoke can enter the bloodstream and trigger inflammatory responses, thus increasing the risk of cardiovascular diseases in vulnerable individuals, such as heart attacks and strokes [13]. Local authorities and health agencies must take action to protect vulnerable people during wildfires [14] by providing up-to-date information on air quality, recommending protective measures, such as the use of appropriate masks, and providing access to medical services for those with symptoms or complications related to smoke exposure [4]. In addition, it would be useful to implement a mobile application in which citizens can register and notify about the occurrence of forest fires in real time, as proposed in [15]

The increase in forest plantations and the effects of climate change have caused an increase in forest fires in Chile during the year 2021 [16]. During the last decade, there have been 16 large-scale fires that have affected 440,000 hectares, equivalent to 82% of the area damaged in the last 40 years. In order to classify the affected areas, it is sought to identify the differenced normalized burn ratio (dNBR) peaks; data from the National Forestry Corporation (CONAF) and the Landsat 8 satellite are collected for this purpose. Subsequently, the data is divided into parts to calculate the dNBR and analyze the similarity of the information, allowing the identification of soil cover and pre and post-fire damage. The results indicate that the Maule region presents a 54% damaged area, while in urban areas, a peak of 0.1 is obtained [17]. On the other hand, for forests, data is obtained that significantly coincides with the fires reported by CONAF, with a higher peak of 0.45.

The research developed in [18] presents the detection of forest fires in the Yunnan region, China, an area with a high amount of forest land prone to fire. For which the Himawari-8 satellite was used, which has an advanced observation system, data was collected every 10 minutes with a high temporal resolution. A machine learning method called gradient boost decision tree (GBDT) was used, and multi-temporal information was combined to create a fire spot recognition algorithm based on this geostationary satellite. In order to verify the algorithm's accuracy, its results were compared to three other existing algorithms using data from forest fires in Yunnan. The multi-temporal GBDT (MT-GBDT) algorithm showed the best detection accuracy, making it practical for rapid detection and helping to prevent fire propagation due to the high data rate from the satellite. Therefore, it is recommended to use the combination of the MT-GBDT algorithm with the Himawari-8 satellite for effective preliminary detection of fires.

Arequipa is a region prone to forest fires due to its dry climate and flammable vegetation [3]; it faces the challenge of managing and minimizing the impact of these fires. The need for efficient and coordinated management to prevent, control and mitigate forest fires is crucial. The use of satellite information and dashboards is a potentially useful tool. For this reason, collecting and analyzing real-time data on fires' location, magnitude, and progression are essential to make informed decisions and adjust response strategies [19]. Near real-time (NRT) forest monitoring systems based on aerial and satellite data are advanced tools for managing and protecting forest resources. Conservation international conducted studies in [20] where users reported that these systems significantly improved forest conservation and management capacity, allowing for better response to fires and illegal deforestation. The dissemination of NRT information has been used by governments, non-governmental organizations (NGOs), industry and community groups, increasing transparency and improving governance in the protection of forest resources [20].

The lack of a centralized system for monitoring and reporting can make decision-making difficult. Likewise, dashboards are visual tools that allow the presentation of data in a clear and accessible way. For this reason, a dashboard can integrate data from fire detection sensors, weather conditions, and topography to provide real-time information about the location and spread of fires. On the other hand, using dashboards to manage forest fires in Arequipa can help address the identified problems by facilitating data-based decision-making, inter-institutional coordination and real-time monitoring [20]. The practical implementation of these tools will require an investment in technology, training and collaboration between different actors to guarantee a more efficient and successful response to forest fires [21].

The continuation of this manuscript is as follows: section 2 presents a review of the literature related to the research. Section 3 shows the different forest fire events to be analyzed in the investigation. In section 4, the authors describe the analysis carried out with the satellite images of the identified areas. Section 5 presents the results obtained in the investigation and shows the analysis of those results. Finally, in section 6, the authors describe the conclusions reached in the investigation.

2. LITERATURE REVIEW

It is necessary to know the reality of the investigations regarding forest fires and the existing mitigation or detection methods. For example, Mexico [20] is considered an important place for the conservation of forest ecosystems, and unfortunately, it also has a history of fires in this sector. According to the National Forestry Commission (CONAFOR), between 2015 and 2019, 442,000 hectares were registered. That is why it seeks to explain how geography has helped to understand the territorial dynamics of fires; it also seeks to contribute and generate greater interest in these issues. For this reason, it was proposed to carry out an information search regarding forest fires in Mexico in international journals such as Scopus, and then the information was evaluated to classify them according to their affinity or theme. Finally, the information was synthesized and analyzed to reach general conclusions. Following this methodology, 41 articles on forest fires in Mexico were identified, of which 41.5% were published from 2018 to 2021, 7.3% were published before 2004, the equivalent of 3 articles, 82.9% of works were developed by academics from Mexican Institutions. In this sense, the primary investigations given in the geospatial analysis are focused on the areas affected by forest fires, map development and risk models. These studies focused on affected areas, maps and risk models, underscoring the need to expand research to address this phenomenon more comprehensively. However, increasing the study of forest fires is recommended because it has great potential to contribute to this phenomenon.

Given the constant forest fires in Mexico, in [16] proposed to analyze the impact on the health of these fires through the quantification of particulate matter (PM) 2.5 particles and carbon dioxide (CO_2) emissions. As a methodology, satellite images from Google Earth and Vsmoke were used with an algorithm written in Fortran 77. As the main result, they calculated the dispersion of PM 2.5 pollutants with a fire simulation of 48 hectares and a dispersion of 240 hectares. They emitted more than 3.5 tons of carbon monoxide per hour in the first 24 hours. After crossing their simulation with the images and data from Google Earth, it is concluded that although there was a large-scale forest fire, the nearby populations were not affected, and they also recommended and proposed escape routes for the populations in the event of a nearby forest fire in their communities.

Likewise, the investigation [22] refers to forest fires as one of the main disasters for forests, causing damage to the ecological and social economy. In the first two days of June 2018, a forest fire broke out in the Daxing'anling Khanma National Nature Reserve in Inner Mongolia and the Aba River logging operation. Timely and accurate removing burned forest areas after a fire is essential to reduce catastrophic losses, maintain ecological balance, and safeguard forest resources. In remote sensing imagery, the normalized burn ratio (NBR) is often used to identify burned areas. The wide field viewer (WFV) sensor image from the Gaofen-1 satellite is the data source used in this paper, adopting the normalized difference vegetation index (NDVI) image and the threshold generated by the Otsu method since it does not depend on the infrared band, concluding that the advantage of this method is that it does not depend on the short-wave infrared band and is entirely automatic. In addition, it can be extracted with greater precision and efficiency than 94% of forest fires.

On the other hand, in Bolivia [23] during the middle and end of 2019, forest fires affected flora, fauna, and local contamination. They propose to know the areas burned by forest fires using satellite images. To do this, they used the images of the Atlas-V vehicle that carried the landsat data continuity mission (LDCM) satellite and calculated the reasons for burning the vegetation index, contrasting before and after the disaster. As a main result, they found through the processing of mosaic images of the vegetation index, the soil adjusted vegetation index (SAVI), where the burned areas are visualized in their respective mosaics and that the departments of Beni and Chiquitania were the most affected with 1,183,134 hectares and 3,825,359 hectares respectively. They conclude that the Amazon was the most affected, highlighting the use of satellite images and remote sensing to support the prevention of forest fires worldwide.

Forest fires are usually catastrophic and increase the higher the ambient temperatures, as is the case today. Among them, terrestrial carbon-rich ecosystems are usually affected more by peat fires, which negatively impact the land and the climate. Therefore, in [9] the possibility of using telemetry to map peat fire areas in Moscow, Russia, from the year 2010 is tested. Landsat 5-TM data were used to map peat fires by comparing pre-images and post-fire, for which the NDVI, normalized difference moisture index (NDMI), NBR, NBR2, medium infrared burn index (MIRBI) and burned area index (BAI) were calculated. Among these indices, the most suitable for identifying burned areas were NDMI and NBR, obtaining 93 and 92% accuracy, respectively.

In this way, the investigation [24] states that there has been a notable increase in the activity of fires in the Peruvian Andes in the last decades. However, drought-related climatic factors, which could indirectly contribute to severe forest fires, still need to be thoroughly investigated. Since fire prevention tools are limited, it is necessary to develop strategies to discourage burning and thus reduce impacts in regions where forest fires are often the result of human activity. This study aims to explore the conditions conducive to forest fires in the Peruvian Andes. Daily precipitation and temperature data from the Pisco gridded data set were used from 2002 to 2016. In addition, moderate resolution imaging spectroradiometer (MODIS) satellite images (product MOD09A1) were collected to characterize Andean vegetation using spectral indices. Analysis of the data revealed that climatic parameters, such as accumulated precipitation, frequency of dry days, and frequency of hot days, are statistically associated with conditions that could contribute to increased wildfire occurrence. Our findings suggest that the decrease in vegetation water content, estimated by the Global Vegetation Moisture Index (GVMI) during the dry period and the beginning of the wet period, can be used to identify potential conditions for the occurrence of wildfires. Based on this study, it is recommended that forest managers consider the implementation of prevention strategies that include continuous monitoring of climatic parameters and vegetation.

Forest fires are a growing concern worldwide, as several investigations mention that global warming will affect the number and size of these fires in certain areas. Zubieta *et al.* [25], explain the effects of forest fires on vegetation through satellite images in California, USA, and a functional analysis of data. To locate the areas with the occurrence of forest fires, the monitoring trends in burn severity (MTBS) multi-agency program was used, and to study the recovery of green areas, the NDVI from various Landsat satellites was used, adding them to the areas of interest through the Google Earth Engine (GEE) platform. Negative NDVI values were obtained; between the years 2009 and 2016, the values went from -0.0856 to -0.0418, seeing a progressive increase in recovery of 0.0438 NDVI points in 7 years, which indicates that the recovery time of NDVI to values positive after a forest fire takes more than seven years.

Alarcon-Aguirre *et al.* [26] in 2022 identified the problem of fire in vegetation and Amazonian landscapes; they also analyzed that fires produce 30% of deforested areas. Therefore, it was determined that the knowledge and application of remote sensing are essential to detecting fires and the severity that they cause. The purpose of the research was the presentation of algorithms that would allow the mapping of the severity level of burns through the changes in backscatter data provided by the Sentinel-1 satellite. The mapping area was in the southeast of the Peruvian Amazon. On the other hand, they used absolute and relative prediction tools and the radar forest degradation index (RDFI) through polarization patterns of burned areas and vegetation. As part of the results, the intensity of the burns was estimated at approximately 40% at the high level, 43% at the moderate level and 17% at the low level. Likewise, 384 locations that represent the areas affected by fires, samples of absolute and relative predictors, were determined to identify the severity of burns. In conclusion, the research specifies that the cross-polarization of Sentinel-1 stands out for having adequate accuracy in detecting and counting burns.

3. WILDFIRE EVENT

Table 1 shows a list of the forest fires registered in the Arequipa region where each fire's presented dates, places, latitude, and longitude were considered. The data presented is a compilation from 2018 to 2022 in the region of interest. Table 1 shows that the year that records the highest number of occurrences of forest fires in the Arequipa region is 2021, with five reports registered.

Table 1. Forest fires in the arequipa region

Date	Forest fires in the Arequipa region		
	Place	Latitude	Longitude
10/6/2016	Distrito de Lluta	-16.0158	-72.0164
20/8/2016	Distrito Jacobo Hunter	-16.440940	-71.559701
28/8/2017	Reserva nacional de Salinas y Agua Blanca	-16.1021	-71.219
2/9/2018	Polobaya	-16.564565	-71.377487
21/9/2018	Distrito Pocsi	-16.503906	-71.361049
22/8/2019	Volcán Chachani	-16.345385	-71.540115
30/8/2019	Provincia de castilla	-15.464556	-72.295986
31/10/2019	Valle del Colca, provincia de Caylloma	-15.556535	-71.879805
29/11/2019	Distrito Yura	-16.305135	-71.630242
16/8/2020	Volcan Misti	-16.298174	-71.405226
24/9/2020	Huaynacotas	-14.845942	-72.774658
7/7/2021	Caylloma	-15.192577	-71.773743
22/7/2021	Distrito de Chiguata	-16.408855	-71.538817
11/9/2021	Chiguata	-16.405948	-71.376457
27/9/2021	Faldas del volcan misti	-16.298174	-71.405226
9/10/2021	Provincia de Caylloma, distrito de Cabanaconde	-15.625413	-71.977991
15/4/2022	Alto Selva Alegre	-16.360924	-71.498640
27/8/2022	Alto Selva Alegre	-16.379816	-71.520042
10/10/2022	Poscsi y Polobaya (hacienda La Trampa y el ojo Orihuela)	-16.504565	-71.359892
04/12/2022	Distrito de Coporaque	-14.790747	-71.541506

For this reason, on August 7, 2018, a fire was registered on the slopes of the Misti volcano, which initially affected some nine hectares of natural pastures. Likewise, it is presumed that the fire started from a poorly put out bonfire that had been made by people who were ascending the Misti volcano; the Regional Emergency Operations Center (COER) recommended that the population avoid using fire to clean the crop fields since the wind could turn it into a fire destroying agricultural land, domestic fauna and wildlife [27].

On the other hand, on July 7, 2021, a forest fire was registered in Caylloma; in the last week of that date, six forest fires were registered, 4 of them were in Arequipa, where one of these fires affected 226.72 hectares of natural pastures that include 15.86 hectares of queñua forest. It is considered that most of the fires are caused by the human being who makes bonfires, and burning garbage. For this reason, the head of the National Forest Service for Wildlife (SERFOR) announced that forestry brigades were formed together with the army in order to identify the culprits and be able to prosecute them for causing damage to nature [28]. This way, on December 4, 2022, at 6:30 p.m. in Sinaya hill, Coporaque district, Caylloma province, where no damage to the life and health of people was reported, the emergency being attended by the personnel of the District Municipality of Coporaque and residents of the community [27], [28].

4. SATELLITE-BASE ANALYSIS OF FOREST FIRES

4.1. Study area

As shown in Figure 1, the study area is located in the province of Arequipa, Peru. This area belongs to the low mountain zone, with a temperate and dry climate in southern Peru, with an annual mean temperature between 7.0 °C and 22.2 °C [29]. The region is mountainous. In addition, the high population density index of 13.9 inhabitants per square kilometre [30] favours the application of the prototype due to the number of pets in this region [31].

Figure 1. Map of Arequipa highlighting the provinces with the highest incidence of fires

4.2. Dataset

Landsat 8, or LDCM, is in the sun-synchronous orbit, considered an LEO orbit; this satellite was created by the company "Orbital Sciences Corporation" in the town of Gilbert, Arizona [32], [33]; it is possible to have high-resolution images by the built-in sensors and relatively low altitude (generating multiple orbits around the earth). The satellite works in an orbit of 705 km above the equator. It has a temporal resolution of 16 days and two fundamental instruments when capturing data and images of the terrestrial area: an operational land imager (OLI) and a thermal infrared sensor (TIRS). More details are shown in Table 2.

4.3. Treatment of satellite images

As shown in Figure 2, for the processing of satellite images, it is essential to carry out a preprocessing phase to correct various interferences [23]. This stage is vital to ensure accurate and valid information is obtained from satellite images [32], considering that the study area is close to the equator, it is to be expected that there will be a lot of clouds, so a filter should be applied for this issue [34]. Likewise, it is of the utmost importance to carry out an additional processing step to calculate crucial indicators of the intensity and severity of forest fires [1], especially when it requires studying changes over time, it is necessary to apply change detection methods, such as transformation-based, classification-based, and advanced models [35]. In this study, a subcategory of the transformation-based change detection was used: the Index-based approach.

Table 2. Spectral bands Landsat 8

Sensor	Spectral band	Area of use	Wavelength	Resolution
OLI	Band 1	Coastal spray	0.433-0.453 µm	30 m
OLI	Band 2	Blue	0.450-0.515 µm	30 m
OLI	Band 3	Green	0.525-0.600 µm	30 m
OLI	Band 4	Red	0.630-0.680 µm	30 m
OLI	Band 5	Near infrared	0.845-0.885 µm	30 m
OLI	Band 6	Short wavelength infrared (SWIR 1)	1.560-1.660 µm	30 m
OLI	Band 7	SWIR 2	2.100-2.300 µm	30 m
OLI	Band 8	Panchromatic	0.500-0.680 µm	15 m
OLI	Band 9	Cirrus	1.360-1.390 µm	30 m
OLI	Band 10	Long wavelength infrared	10.30-11.30 µm	100 m
OLI	Band 11	Long wavelength infrared	11.50-12.50 µm	100 m

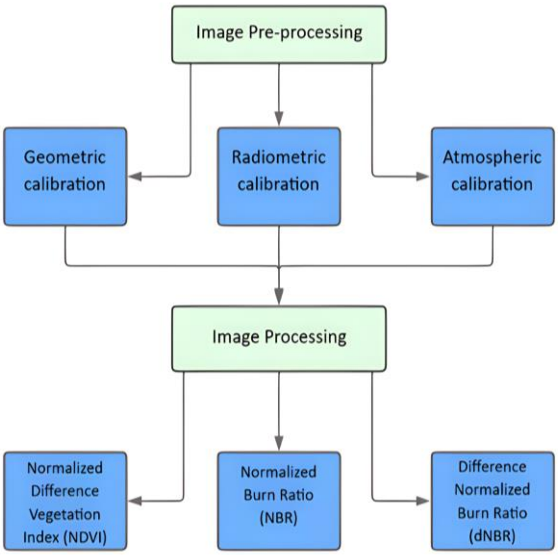

Figure 2. Block diagram for image processing

The NDVI is a widely used index to estimate the vegetation and its health in a specific area. NDVI can help identify areas that have experienced significant loss of vegetation due to deforestation [36]. By monitoring and mapping changes in NDVI over time, the community can detect the loss of forests and green areas, which can trigger actions to halt deforestation and promote sustainable land use practices [37]. It is calculated using a satellite image or remote sensor's near-infrared (NIR) and red (RED) light reflectance. The formula for NDVI is shown in (1).

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

where:
NIR = near infrared reflectance
RED = reflectance in the red band

The NBR is an index used to assess the impact of a fire in an area, especially in forest areas. Likewise, the NBR can be used to identify areas that are more susceptible to forest fires. By analysing the vegetation and its health in different regions, areas with the highest fire risk can be identified, making it possible to focus prevention efforts on priority areas [38]. It is based on the difference between the satellite image's NIR and mid-infrared (SWIR) reflectance. The formula to find the NBR is shown in (2).

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \quad (2)$$

where:
NIR = near infrared reflectance
SWIR = short wave infrared reflectance

The dNBR is a modified version of the NBR that compares two moments in time, usually before and after a wildfire. The dNBR is a valuable tool for the community in preventing forest fires since it provides relevant information for decision-making and implementing effective strategies to protect the environment and the lives of people and fauna [38], [39]. To assess the change in the impact of fire in an area, the formula for dNBR is shown in (3):

$$dNBR = NBR_{post-fire} - NBR_{pre-fire} \quad (3)$$

where:
$NBR_{post-fire}$ = NBR value after a fire event
$NBR_{pre-fire}$ = NBR value before a fire event

In addition, according to the table evaluated, it is observed that there are severity levels when calculating a differential between NBR post-fire and NBR pre-fire where bare soil yields different quantifiable values than recently burned areas [1], [40]. A previous and a subsequent NBR is attributed to obtain the difference between one event and another; according to the intensity of ash and affected soil, it marks a severity index according to Table 3.

Table 3. Fire severity compared with sNBR values

Severity level	dNBR range	dNBR not scaled
Enhanced regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
Enhanced regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
Unburned	-100 to +99	-0.100 to +0.99
Low severity	+100 to +269	+0.100 to +269
Moderate - low severity	+270 to +439	+0.270 to +0.439
Moderate - high severity	+440 to +659	+0.440 to +0.659
High severity	+600 to 1300	+0.660 to +1.300

5. RESULTS AND DISCUSSION

The preprocessing of images was carried out on the GEE platform before downloading them. The type of preprocessing applied to the images depends on the intended use of the images after processing e.g., in [41], a preprocessing model with masks was developed for identifying buildings. In this case, the preprocessing phase focused on applying masks for clouds and the atmosphere.

Image processing was carried out for six cases of forest fires, which consisted of finding the NDVI and dNBR. The cases of interest are located in the provinces of Caylloma and Arequipa; in this sense, three maps were obtained with the NDVI indices for both provinces Figures 3 and 4. The index has a variation of values from -1 to 1, where values from -1 to 0 represent areas without vegetation, those closest to -1 represent bodies of water, while from 0 to 1 are areas with vegetation, while closer to 1, the vegetation is denser.

The pixels go from blue to green, with blue corresponding to -1, white to 0, and green to 1. On the maps, tones from white to green predominate, blue has little presence due to the low presence of bodies of water. In the regions of interest (ROI), the intense green colour shows areas such as forests and cultivated areas, while the lighter tones represent bare terrain, white and similar colours generally correspond to cities.

On the other hand, maps with dNBR indices for the ROI were made for both provinces Figures 5 and 6. In this index, values from -1 to 1 are handled, with negative values being for areas with increased vegetation, or that do not present burns, and positive values corresponding to areas where fires have started, and depending on the severity of the burn, values will be in the range of 0 to 1.

The colours from green to red are used in the maps; the green colour corresponds to the range from -1 to 0, and for values close to 0, the yellow colour is used, while the red colour is used to represent values between 0 and 1. In the maps presented, areas with green tones can be observed, which are generally areas with vegetation that has been growing. Likewise, areas with red tones can be observed that indicate some affectation to the vegetation that was present, which does not imply that it has disappeared, but it does mean that the decrease in vegetation has been considerable, which may be closely related to the occurrence of a forest fire.

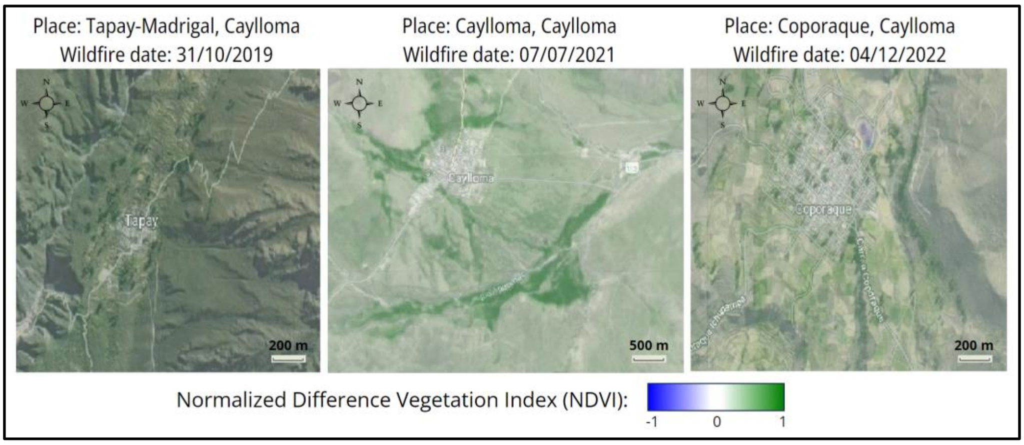

Figure 3. NDVI for the province of Caylloma

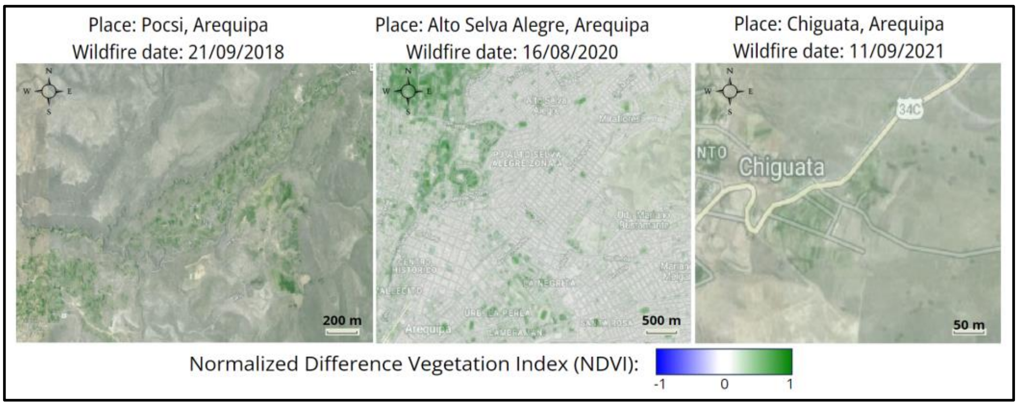

Figure 4. NDVI for the province of Arequipa

On the other hand, ArcGIS Online was used to create dashboards, ArcGIS is a comprehensive geographic information system (GIS) platform developed by Esri, a global leader in geospatial technology. This platform offers us various tools to analyse and visualise geographic data, helping organisations and professionals make decisions with precise information based on location and spatial context. ArcGIS allows us to create from interactive maps to very sophisticated geospatial analysis, used in various industries to address challenges related to land management, resources and geographic information.

ArcGIS dashboard is a powerful tool for presenting geographic information and related data in graphical forms such as dashboards, tables, or maps. The geospatial situation is presented personalised to allow an immediate and understandable view. The dashboard allows users to interact, analyse data, perform analytics, and gain actionable insights. ArcGIS dashboards apply to various applications and industries, including emergency management, urban planning, natural resource monitoring, and geographic data analysis. They offer a practical means of conveying geospatial information and making informed decisions through data analysis and visualisation. In the end, ArcGIS dashboards allow companies to optimise the use of geographic data and improve decision-making. One also has StoryMaps, a tool to create visual presentations that combine maps, images, and text to tell stories involving geographic data. It is an effective way to communicate geospatial information and analysis in an engaging and easy-to-understand way. It can be used in education, public communication, reporting, and other contexts where one wants to present geographic information powerfully.

In Figure 7, StoryMaps were displayed that narrated the process of obtaining dNBR and NDVI, in addition to describing the various trainings provided by the organization of the Mapatón 2023 contest. In addition, Dashboards were developed to quickly and understandably obtain information on the number of people in the Arequipa region, the number of schools by region, the fire stations and military bases, the essential hydrographic basins of the region, and anemometer maps, all of them based on the geopolitical divisions of Arequipa, to relate them to the panel control of the primary fires that occurred in the area.

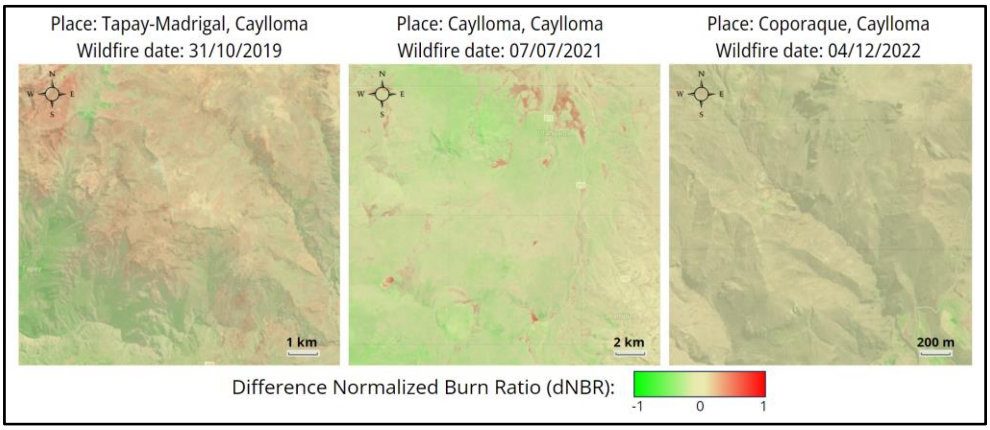

Figure 5. DNBR for the province of Caylloma

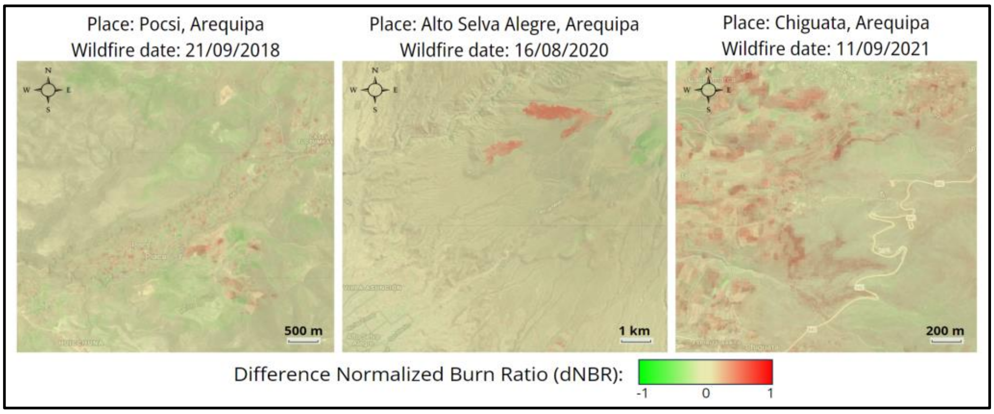

Figure 6. DNBR for the province of Arequipa

Figure 7. Developed dashboards

The provinces of Caylloma and Arequipa have been affected by recurring forest fires; the study of these through remote sensing and image processing has led to the generation of maps where burned areas can be evidenced. The application of the NBR index made it possible to find values of burned areas for dates before and after the date on which the fire occurred Table 1 for six districts belonging to the provinces mentioned above; with these values, the dNBR index of in such a way that it is possible not only to locate but also to highlight the severity of the burn in those selected areas. On the other hand, the calculation of the NDVI index was carried out to make a comparison with the areas most affected by burns, as well as visualising the impact on the local vegetation. The comparison of the maps with NDVI and dNBR indices shows that in those areas where the most severe burns were recorded, they affected the vegetation in such a way that its recovery, evaluated during the year of occurrence of the fire, is not entirely complete, thus proving the detrimental impact of the forest fires.

The study of the NDVI index is also relevant to knowing the vegetation conditions and the photosynthetic activity that act as factors that can affect the behaviour of the expansion of fires since a low or moderate quality of vegetation causes the areas with said characteristics are more prone to the occurrence and expansion of forest fires [37]. Likewise, the loss of large areas of vegetation, driven in part by the limited action and prevention plans for this type of situation, should be considered a call for the corresponding authorities to intervene appropriately in the management of forest fires, for which the communication of the findings made through interactive and systematised platforms such as dashboards made from our results is valuable.

It is not enough to identify burnt areas and the preparation of maps in forest fire risk management; it is essential to present the data clearly and to integrate the visualisation of factors that favour the spread of fires; the recognition of these factors is essential for the preparation of risk management plans [17]. In case a large volume of images needs to be studied, it may be advisable to explore other image processing methods, such as principal component analysis (PCA) [42]. It is expected in future work that the images obtained can reach the authorities and take preventive measures due to the high incidence of fires in these regions, in addition to improving the calculation of the indexes with satellite images from different sources and thus verifying the calculation of molecules particles from these fires with more resolution. Likewise, as recommended in the results of lost vegetation areas should be compared with the forest cover information provided by official entities.

6. CONCLUSION

In conclusion, the NDVI vegetation index was calculated using the previous methods in 6 cases with times prior to the fire reports to obtain the results in images of the burn indices on these regions. Finally, NDVI was calculated after the date of the fire; in the reports, it was verified that there were considerable fires in 6 regions of the two provinces of Arequipa and Caylloma. Characteristics allowed an excellent availability of data in the ROI. In the study of forest fires, the use of more than one index must be taken into account so that there can be a contrast between the results obtained by each index, which allows a better understanding of the phenomenon and reduces interpretation errors. It is important to note that remote sensing is very helpful for analysing forest fires since accidents can be related to specific conditions in the studied areas, allowing the government to establish corrective and preventive measures in the event of these fires. Types of events, since quick action helps reduce human, economic, environmental, and resource losses.

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