Climatic Extremes, Vegetation Response, and Fuel Conditions

A five-year analysis of the Palisades and Eaton fire zones in Los Angeles County

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***Abstract*—This study examines how recent climatic variability and vegetation dynamics may have contributed to fuel conditions preceding the 2025 Palisades and Eaton wildfires in Los Angeles County. Using precipitation records from 2020–2025 and Moderate Resolution Imaging Spectroradiometer-derived Normalized Difference Vegetation Index (NDVI) datasets, the study entailed analyzing rainfall anomalies, spatial rainfall distribution, and vegetation changes in and around the two fire perimeters. Results show that 2023 was an exceptionally wet year, with rainfall far exceeding the preceding and following years, particularly in the Altadena region. However, despite this anomalous precipitation, NDVI analyses revealed only limited vegetation recovery in 2023 and 2024, suggesting the landscape did not respond with the expected greening. Instead, vegetation remained in a marginally healthy state, creating persistent dry biomass that likely increased fuel availability. In the Palisades region, vegetation appeared healthier in 2023 but showed signs of drying in 2024, consistent with reduced regional precipitation. These findings highlight that extreme rainfall does not necessarily translate into sustained vegetation recovery and may instead contribute to elevated wildfire risk when followed by rapid drying. Understanding these climatic and ecological interactions is essential for improving proactive wildfire-mitigation strategies in high-risk areas.**

Keywords-Wildfire; ArcGIS; California.

I. Introduction

Wildfires can be incredibly destructive and dangerous. There is no better example than the Eaton and Palisades fires. The level of destruction caused by these fires overshadows that of any wildfires that have happened previously. Thus, it is important to understand the variables at play in how a fire spreads. One of the easiest ways for a fire to spread is through the amount of dead vegetation in each area. Identifying weather patterns that have effects on vegetation levels, such as abnormal rainfall, can be a key indicator to being proactive in reducing the amount of vegetation (dead or alive) in or around areas that have dense population centers and electric-utility equipment to reduce the likelihood of wildfires spreading to or sparking in these areas.

Section 2 reviews the literature, and Section 3 identifies the goals of this research. Section 4 lays out the data selection and acquisition techniques, and Section 5 explains the data cleaning performed. Section 6 describes the computer system used for the analysis and Section 7 describes that analysis. Section 8 concludes.

II. Literature Review

Several research projects explored similar themes, investigating the relationship between precipitation, vegetation dynamics, and wildfire occurrences [1][2][3]. For instance, researchers have examined how antecedent rainfall and excessive vegetation growth correlate with wildfire burned areas across California, analyzing data over extended periods [2]. Other researchers focused on the influence of specific weather phenomena, like atmospheric rivers, on vegetation growth and fuel loading in Southern California ecosystems. The fundamental approaches in these studies often involve analyzing various datasets, such as precipitation data from sources like the Global Precipitation Measurement mission and vegetation indices like the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index derived from satellite imagery like Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat [1][2]. Common methodologies include using Geographic Information Systems (GIS) for spatial analysis, calculating anomalies in rainfall and vegetation, and employing statistical methods like spatial correlations and linear regression models to determine the relationships between these climatic and vegetation variables and wildfire outcomes. These underlying theories and approaches, which link increased rainfall to enhanced vegetation that can later serve as fuel provide a solid foundation for projects analyzing recent rain patterns and vegetation changes to understand their potential impact on wildfire severity. Additionally, the timing and “sharpness” of the rainy season are recognized as critical factors, as shifts in precipitation seasonality can extend the period of high fire risk by increasing the overlap between dry vegetation and fire-promoting winds [3].

III. Problem Identification and Goals

A problem identified in this study is the lack of proactiveness from the City of Los Angeles, local municipal bodies near or around high wildfire-risk areas, and utility companies such as Southern California Edison and Pacific Gas and Electric in reacting to elevated risks of wildfire severity due to fuel loading.

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This research aimed to highlight the effects that abnormal amounts of rain have on vegetation levels in the Los Angeles area. Some metrics aiming to aid in identifying these changes are precipitation patterns in the Los Angeles area, such as how much overall rainfall has occurred in the area of interest over the last five years, identifying any outliers, creating a map that highlights areas of concentrated rainfall, and comparing the difference in these areas. Also, this study entailed looking into NDVI data and identifying what changes in vegetations levels have occurred over the last several years. The goal of this research was intended to understand how weather patterns can be a predicting factor in how severe a wildfire can be to allow the target audience to create or better enact policies in developing wildfire-prevention measures.

IV. Data Selection and Acquisition

For this project, three datasets were needed: the fire-perimeter data from Cal Fire, the precipitation data from the National Weather Service, and the vegetation data from NASA.

A. Fire-Perimeter Data

For fire perimeter data, Cal Fire's public archive shape files were used to focus the analysis in the perimeter of Palisades and Eaton fires [4].

- Data Type: Vector Shapefile
- Data Provider: Cal Fire

B. Precipitation Data

Precipitation data were obtained for the Los Angeles region directly from available national weather-service stations. These data were formatted in a comma-separated file (CSV).

- Data Type: txt Data
- Data Provider: National Weather Service

C. Normalized Difference Vegetation Index (NDVI) Data

NDVI data came from the MOD13Q1 MODIS, downloadable through the Application for Extracting and Exploring Analysis Ready Samples (AppEEARS) platform [5]. These files covered the time span from January 2020 up until January 2025.

- Data Type: Raster Data
- Data Provider: NASA EARTHDATA

The required data were downloaded from the sources as either shapefiles or as a text file in the form of a CSV.

V. Data Cleaning

These data required some preprocessing before the analysis. The precipitation data needed cleaning, and the NDVI data were not in a state usable by ArcGIS Pro.

A. Precipitation Cleaning

When working with precipitation data, several unneeded columns needed to be deleted. The precipitation dataset also only had the data points as daily values from January 2020 to January 2025. To create a more meaningful analysis, the daily datapoints had to be aggregated into mean monthly values using a python script that went through the CSV and averaged every value in every month of every year. The CSV also reformatted the date column into a format that ArcGIS Pro could ingest without any misinterpretations. Once this dataset was uploaded into ArcGIS Pro, one main concern that arose was that no weather stations were within a meaningful distance to the palisades fire perimeter or in the perimeter itself, resulting only in speculation for that area.

B. NDVI Data Processing

After collecting NDVI data, preprocessing took place to make these data usable in ArcGIS Pro. The data set was downloaded as a Geo tagged image file format file through the AppEEARS platform. This folder included multiple bands, like quality control, and metadata layers. The process entailed isolating the NDVI bands and removing the others. Then, a mosaic by region and year was created to enable the time series for the NDVI analysis. A Python script was used to extract and format the dates from the file names. Then, an acquisition date field was created, which allowed cleaning of the date field that ArcGIS could not recognize until it was configured with a Python script, leading to the creation of a time slider.

C. Limitations

A few data and methodological limitations should be noted. Precipitation measurements were limited by the absence of weather stations within or immediately adjacent to the Palisades fire perimeter, requiring rainfall patterns to be inferred from nearby stations and regional raster surfaces. This constraint reduces the spatial precision of precipitation estimates for that area. In addition, NDVI processing required mosaicking and temporal standardization across multiple MODIS tiles, which may introduce minor smoothing in the time series. While these limitations do not alter the overall trends observed in the analysis, they highlight the need for denser environmental monitoring networks and more granular vegetation datasets to improve future wildfire-risk assessments.

D. System Information

ArcGIS Pro was used on Windows machines because ArcGIS Pro is only available on Windows. Other programs used for this project included PyCharm to clean the precipitation data and a Python IDE, used to extract and standardize the acquisition dates from the NDVI file names for use in a time series in ArcGIS. Although not used extensively, Tableau was used to create a line chart visualization.

VI. Analysis

The study focused on precipitation changes throughout the last five years (2020–2025), comparing 2023 precipitation to previous and subsequent time periods, to identify differences through heat maps. From there, 2023 and 2024 were explored as key years to determine whether the heavy rainfall in 2023 led to vegetation growth that later dried out. NDVI rasters were used to track vegetation levels across Altadena and Palisades, along with spatial raster

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calculations to see what changed and what did not. This macro-to-micro approach helped in understanding whether environmental shifts might have contributed to fire vulnerability leading into 2025.

A. Precipitation Variation 2020–2025

As stated earlier, to gain a deeper insight into how precipitation has changed over the years, data were aggregated from daily values to monthly averages. Figures 1 and 2 line charts showcase differences over time, revealing stark findings.

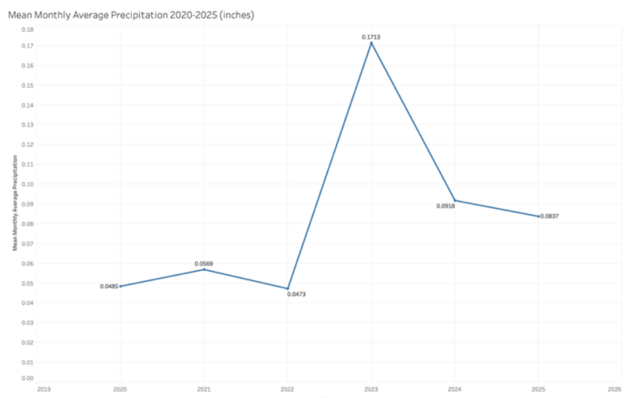

Figure 1. Average precipitation in LA County, 2020–2025

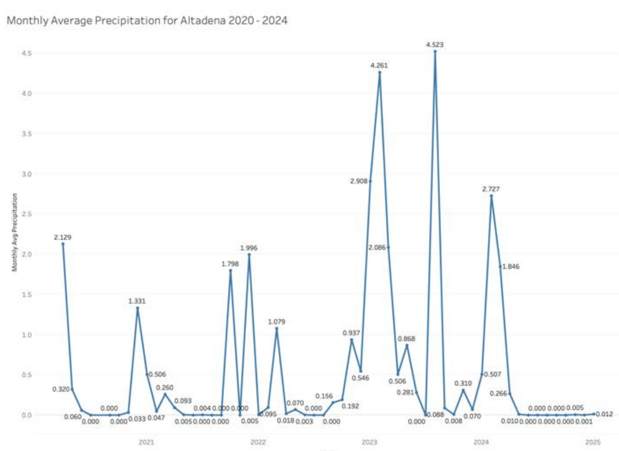

Figure 2. Altadena's rainfall, 2020–2025

Huge disparities emerged in rainfall differences in 2023 when compared to previous and subsequent years. The data revealed a 53.6% reduction in Los Angeles areas from 2023 to 2024 and an even more staggering 66% reduction in rainfall in Altadena from 2023 to 2024.

B. Precipitation Heat Map Analysis

Figure 3 shows little difference in precipitation between the years 2020–2022 when compared to 2023, outside of the two hot spots. Orange indicates similar amounts of precipitation all around. Although Altadena saw substantially more rain in Year 1 than in Year 3, Figures 4 and 5 show that, when inverted to show the difference in 2024 from 2023, Altadena is much drier, appearing almost white in the figure, the lowest possible range in the color scheme, further showing the disparity in precipitation.

These maps were created using the Kernel Density analysis tool to create initial heat maps of the specific time frames used (2020–2022, 2023, 2024) in ArcGIS Pro. Then, the Raster Calculator was used to calculate the differences between heat maps to create a new one based on that calculation, resulting in Figures 3 through 5.

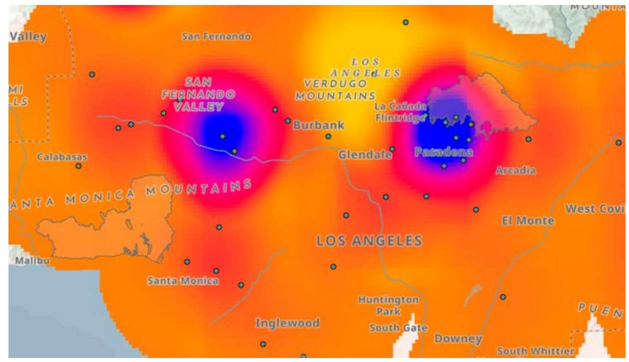

Figure 3. Difference in precipitation between 2023 and 2020–2022

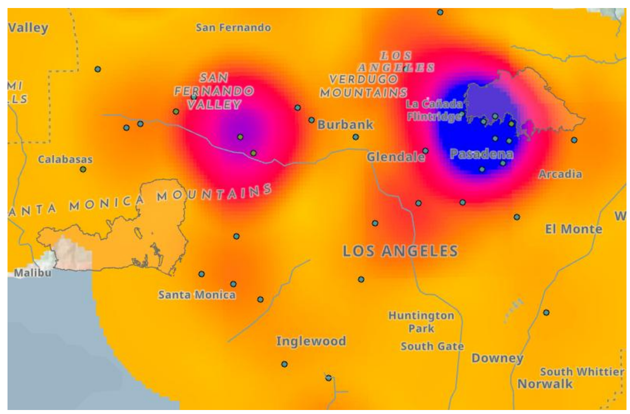

Figure 4. Difference in precipitation between 2023 and 2024

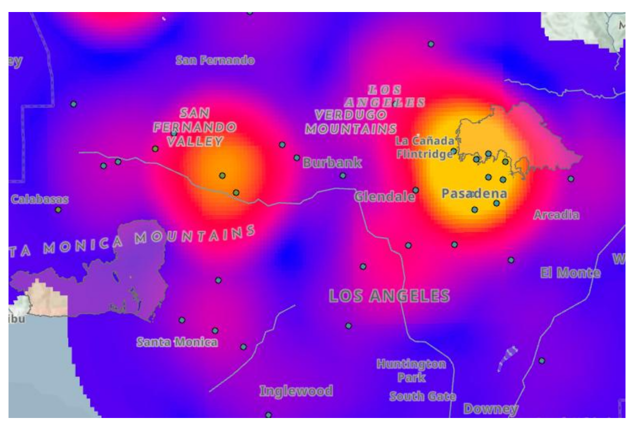

Figure 5. Difference in precipitation between 2024 and 2023

C. Altadena NDVI Analysis

For Altadena, with the most rainfall of any year in the five-year period, strong vegetation growth was anticipated. The assumption was that more rain should mean greener vegetation, especially around the fire perimeter. That is not what emerged.

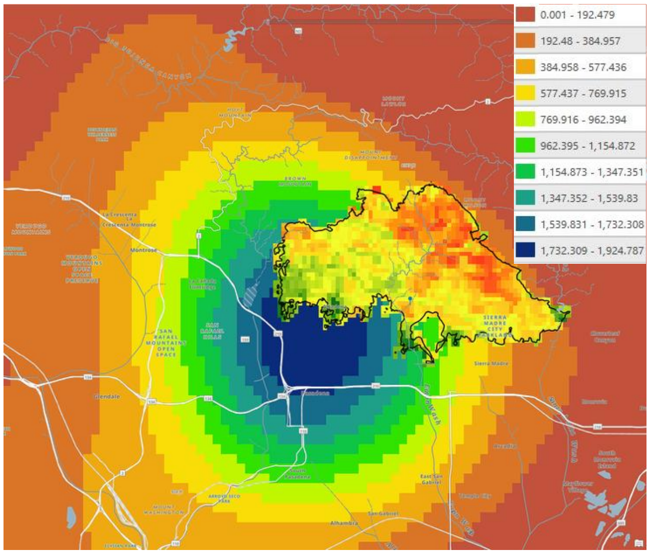

Figure 6. Altadena NDVI raster (2023)

A raster calculation on the 2023 NDVI compared with the precipitation legend, shown in Figure 6 revealed that most of the Altadena fire zone sits inside the dark blue and green zones, representing heavy rainfall. Only the southern edge touches areas with lower rain, shown in yellow or orange. A great deal of healthy vegetation was anticipated. Instead, the NDVI showed the area to be dry. The large mix of yellow and light green indicates the vegetation did not respond as anticipated. Questions arose about whether the vegetation would take longer to appear than initially believed.

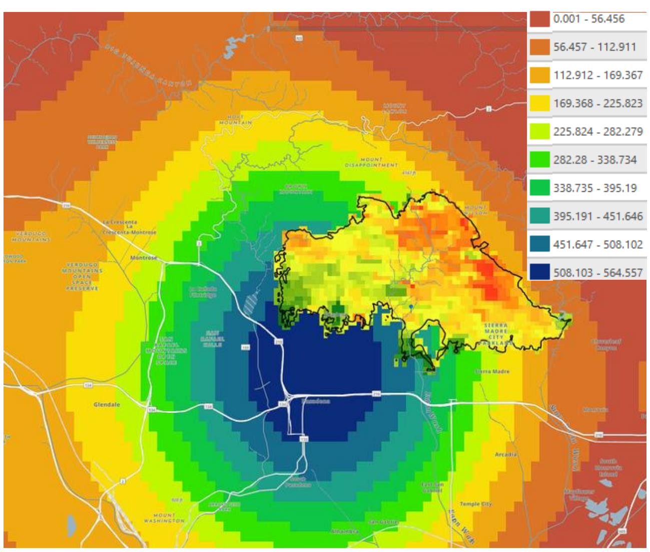

Figure 7. Altadena NDVI raster (2024)

After seeing results from 2023, a new hypothesis was that vegetation needed more time to bounce back. Data show that 2024 brought a great deal of rain. Using the same NDVI raster calculations, this time for the full year of 2024, the focus again was on the fire perimeter. Some very subtle changes emerged, especially in the northern part of the perimeter, as shown in Figure 7 where colors shift slightly from red-orange to more of a yellow tint; however, the vegetation still seemed sparse. Two years of heavy rainfall yielded little rebound in greenness. The vegetation remained in a borderline zone, neither dead nor thriving. The lingering dryness meant great amounts of biomass had sufficient structure to burn.

D. *Palisades NDVI Analysis*

With no direct precipitation data for this region, the study relied on visual patterns and assumptions from the surrounding area.

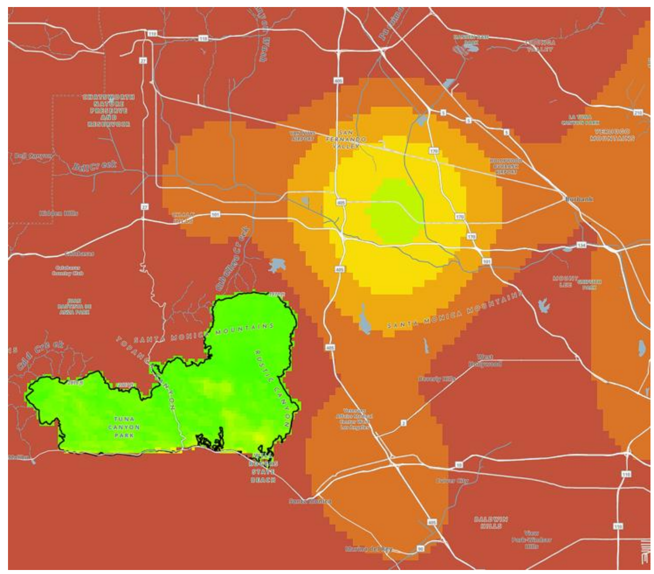

Figure 8. Palisades NDVI raster (2023)

The precipitation raster shown in Figure 8 reveals that although the Palisades itself doesn't light up on the map, rainfall was taking place in the area, especially to the northeast and toward parts of Los Angeles. Vegetation inside the Palisades fire perimeter shows quite green with small patches of yellow. Overall, it appears lush and full.

The Palisades probably got good precipitation. Perhaps not as much as Altadena, but enough to support healthy vegetation. This region seemed to hold up well in 2023. Surrounding areas were getting rain, and the vegetation data backed that up. The Palisades looked strong.

Figure 9 for 2024 starts to show a shift. Comparing the precipitation raster to 2023, the area had less rainfall. Most of the surrounding region appears as orange or light orange which indicates lower precipitation levels.

Inside the fire perimeter shown in Figure 9 is a good amount of green vegetation but it is starting to fade. Some bright green zones from 2023 are leaning more toward yellow, providing a noticeable change. The vegetation began to dry out enough to start making the region more vulnerable. Rather than a sudden collapse in vegetation health, the area experienced a gradual decline. Thus, although the landscape appeared healthy, it had a great deal of dry fuel, especially in Palisades where rainfall could not be measured directly.

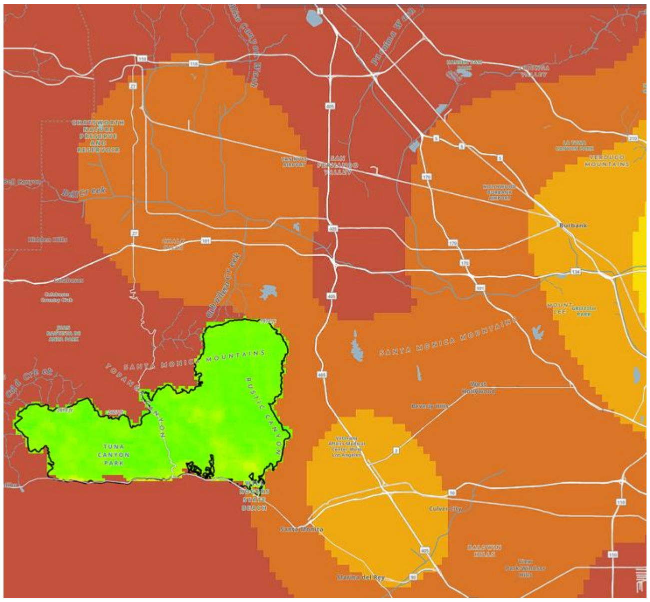

Figure 9. Palisades NDVI raster (2024)

VII. CONCLUSIONS AND FUTURE WORK

This analysis shows that extreme rainfall events do not automatically translate into meaningful or sustained vegetation recovery, and that this disconnection can create hazardous fuel conditions leading into a wildfire season. Although 2023 was an exceptionally wet year across Los Angeles County, and especially in Altadena, the NDVI data revealed only limited vegetation improvement in 2023 and 2024. Even after two consecutive years of above-average precipitation, vegetation inside the Eaton fire perimeter remained in a marginal state rather than rebounding to healthier levels. This finding suggests that the ecosystem may have been unable to fully capitalize on the rainfall due to factors such as soil-moisture retention, vegetation type, or preexisting stress conditions. The result was a landscape with persistent dry biomass that served as readily available fuel by 2025.

In the Palisades region, vegetation appeared healthier in 2023 but showed a gradual decline in 2024, consistent with reduced rainfall in the surrounding area. Vegetation may have been drying out under the surface. Although the changes were subtle, they point to a slow drying trend that can increase fire susceptibility even when the landscape appears relatively green at first glance. The absence of nearby weather stations limits the precision of precipitation estimates for this region, but the vegetation patterns still indicate a meaningful shift toward drier conditions. Rain does not automatically mean recovery. The land may not respond in expected ways to heavy rainfall in anticipated ways and may provide even greater risk for fires.

Overall, findings highlight a critical insight for wildfire mitigation: rainfall anomalies alone are not reliable indicators of reduced fire risk. What matters is how vegetation responds over time, and whether periods of heavy rain are followed by sustained drying that leaves behind accumulated, partially recovered, or weakened biomass. These dynamics underscore the need for proactive vegetation management, improved monitoring of post-rainfall vegetation health, and more nuanced risk assessments that consider climatic extremes and ecological response. Understanding these interactions is essential for developing policies and interventions that can better anticipate and reduce wildfire severity in high-risk regions.

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