Final Report

INTRODUCTION

Deforestation in the Amazon rainforest has long been a critical environmental issue, with significant implications for biodiversity, climate change, and global ecosystems. The Amazon, often referred to as the "lungs of the Earth," plays a pivotal role in regulating the global climate. Its deforestation directly contributes to the acceleration of climate change. This project investigates the potential factors —such as El Niño, La Niña, forest fires, etc.—that might be impacting deforestation in the Amazon region. Through an analysis of deforestation trends across nine states in Brazil between 2004 and 2024, we aim to identify correlations between climate events and deforestation patterns. The project also seeks to understand the spatial and temporal variation in deforestation across different regions of the Amazon, shedding light on areas that have seen the greatest environmental impact. By examining the deforested area over time and comparing it to the occurrence of global climate phenomena, this study aims to provide insights into the environmental factors that may drive deforestation.

ASSUMPTIONS & CRITERIA

Assumptions and Scope of the Analysis: In this analysis, it is assumed that El Niño and La Niña events have an observable impact on deforestation in the Brazilian Amazon. Furthermore, it is assumed that no significant policy changes during the 2004-2019 period had a major impact on deforestation patterns. Additionally, the analysis assumes that the effects of climate phenomena and forest fires are uniform across the nine states in the Brazilian Amazon included in the dataset. While the impacts of these events may vary by region in reality, this assumption simplifies the analysis by treating the effects uniformly across all states.

Selection Criteria for Time Period and Geographic Scope

The criteria for selecting the time period and geographic scope for this analysis were based on the availability of data for the period 2004-2024, which provides a comprehensive view of deforestation trends and climate phenomena over a significant period. The nine Brazilian states included—Acre, Amazonas, Amapá, Maranhão, Mato Grosso, Pará, Rondônia, Roraima, and Tocantins—were selected due to their importance in the context of deforestation in the Amazon region.

DATA

Sources:

- **Deforestation Data (def area 2004-2019.csv)**:

  The deforestation data, spanning from 2004 to 2019, was extracted from the INPE (National Institute for Space Research) website. The data is preaggregated, meaning it has already been processed and structured for use. The deforestation monitoring was carried out using the PRODES (Programa de Monitoramento da Floresta Amazônica Brasileira por Satélite) program. PRODES monitors primary forest loss in the Brazilian Amazon using satellite imagery with a spatial resolution of 20 to 30 meters and a 16-day revisit rate. The methodology used by PRODES ensures high precision in detecting forest loss while accounting for cloud cover interference. This dataset provides annual records of deforested areas across nine Brazilian states—Acre, Amazonas, Amapá, Maranhão, Mato Grosso, Pará, Rondônia, Roraima, and Tocantins—measured in square kilometers.

- **Climate Data (el nino la nina 1999-2019.csv)**:

  The climate dataset spans from 1999 to 2019 and includes data on the onset, duration, and severity of El Niño and La Niña, two of the most significant climate phenomena. The data was obtained from Golden Gate Weather Services, which provides detailed records on climate events. Each record includes the start year, end year, and severity level (Weak, Moderate, Strong, Very Strong) of the climate events. This dataset allows for the comparison of the timing and intensity of El Niño and La Niña occurrences in relation to deforestation events.

- **Treecover Loss by Region (treecover_loss_by_region__ha.csv)**:

  The third dataset, sourced from Global Forest Watch, provides detailed records of tree cover loss by region. This dataset offers insights into the extent of deforestation and forest degradation across various regions, including the Amazon, and can be used to correlate changes in tree cover with other environmental or climatic variables. It tracks the change in forest cover over time and can be analyzed to identify trends or areas of particular concern for forest loss.

- **VIIRS Fire Alerts Data (viirs_fire_alerts__count.csv)**:

  The fourth dataset contains fire alert data from the Visible Infrared Imaging Radiometer Suite (VIIRS), which is used to track active fires globally. The dataset provides a count of fire alerts, giving insight into the frequency and intensity of fire events in the Amazon region over a specified period. This data can be cross-referenced with deforestation and climate event data to investigate the relationship between fire occurrence and forest loss.

Characteristics:

Deforestation Dataset:

- Year: The year in which deforestation was recorded.
- Deforested Area (km^2): The total area of the Amazon rainforest that was deforested in all 9 states, measured in square kilometers.
- State: The Brazilian state in which the deforestation occurred.

Climate Dataset:

- Phenomenon: El Ni˜no or La Ni˜na, whichever occurred.

- Start Year: The year when the El Ni˜no or La Ni˜na event began.
- End Year: The year when the event ended.
- Severity: The severity of the climate phenomenon (Weak, Moderate, Strong, Very Strong).

Treecover Loss by Region (treecover_loss_by_region__ha.csv):

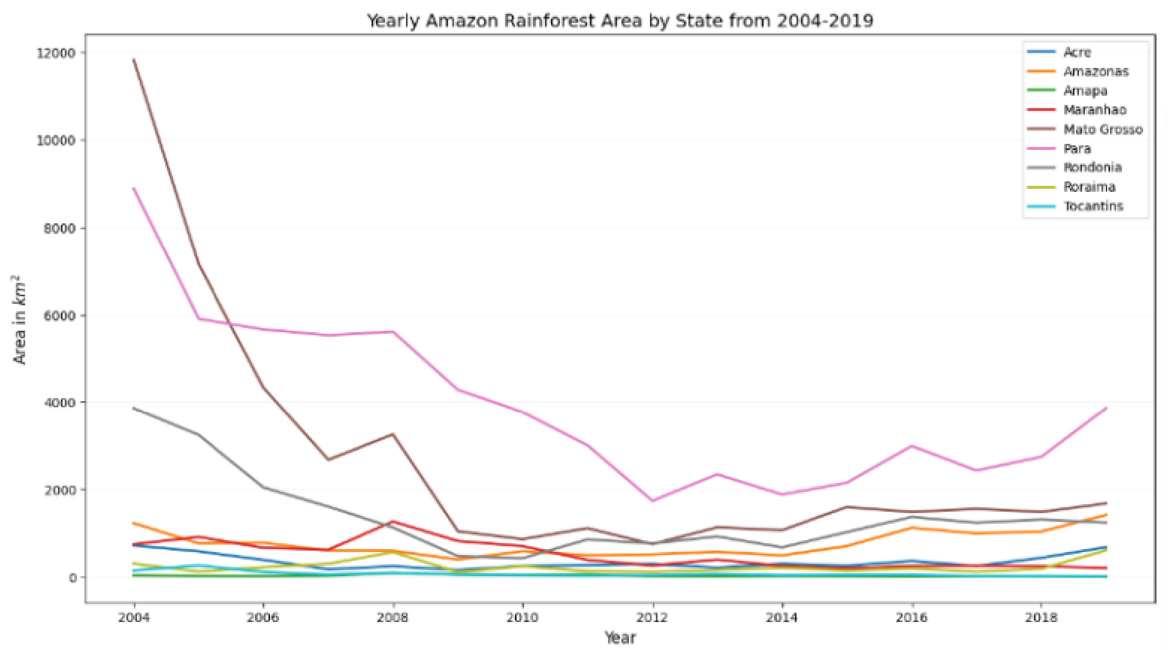
- **iso**: Country code (Brazil for all entries).
- **adm1**: An identifier assigned to each state in Brazil (numeric ID for each state).
- **umd_tree_cover_loss__year**: The year of tree cover loss.
- **umd_tree_cover_loss__ha**: The amount of tree cover loss in hectares for each year and state.
- **gfw_gross_emissions_co2e_all_gases__Mg**: The gross emissions of CO2 equivalent (all gases) in megagrams (Mg), associated with tree cover loss.

VIIRS Fire Alerts (viirs_fire_alerts__count.csv):

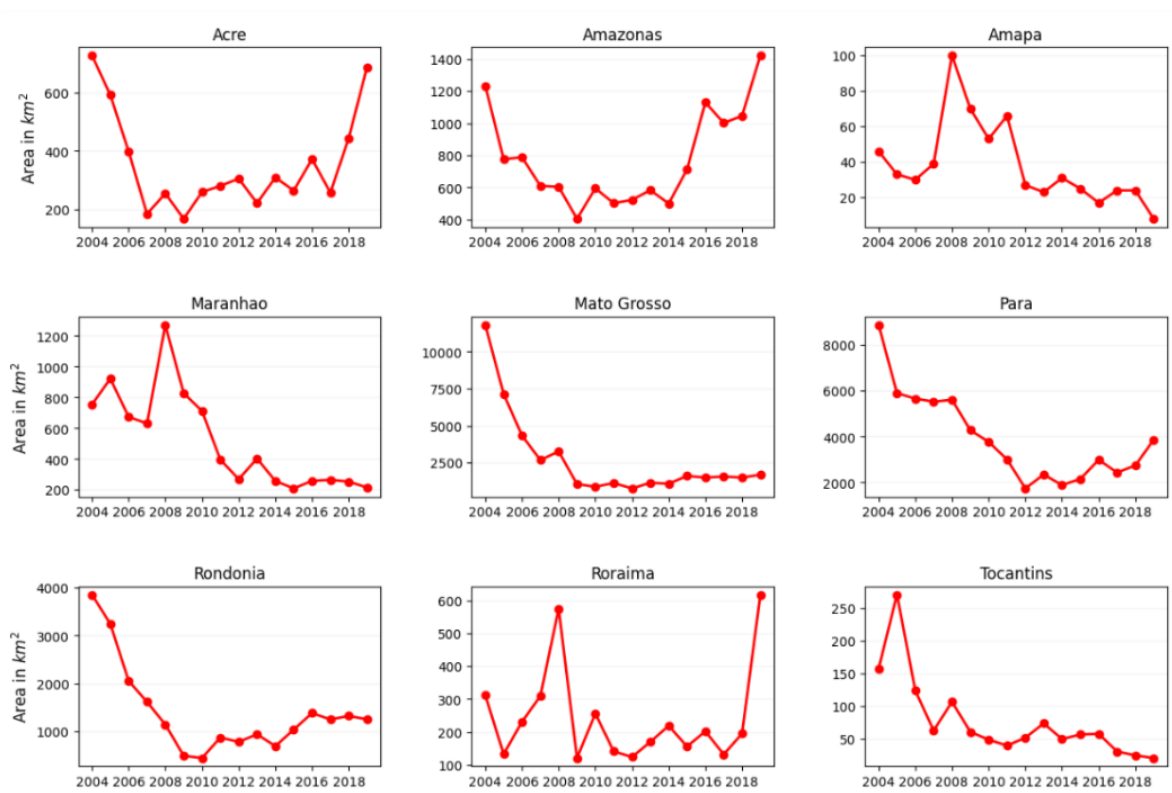
- **iso**: Country code (Brazil for all entries).
- **alert__year**: The year the fire alerts were recorded.
- **adm1**: An identifier assigned to each state in Brazil (numeric ID for each state).
- **alert__count**: The total number of fire alerts detected in that state for the given year.
- **confidence__cat**: The confidence category of the fire alerts (e.g., Low, Moderate, High), indicating the reliability of the fire detection.

VISUALISATIONS

1. Upon reviewing the deforestation data, it was observed that **2004** marked a particularly severe year for deforestation across the Amazon states. Following this peak, the deforested area showed a downward trend until **2012**. However, after **2012**, deforestation began to rise again, particularly in certain states. This suggests that, while there may have been short-term improvements, long-term deforestation trends have fluctuated over the years. In particular, **Mato Grosso** experienced the most significant decline in rainforest area from **2004** onwards, showing a dramatic reduction in deforestation over time. **Pará** and **Rondônia** also saw substantial declines in deforestation, ranking third in terms of the total area affected. On the other hand, **Tocantins** and **Amapá** showed relatively insignificant changes in deforestation. This may be due to the fact that these states had lower initial forest cover, and thus the relative impact of deforestation was less pronounced compared to other states. Once deforestation occurred, the remaining forest area in these regions was smaller, leading to less noticeable changes in the overall deforestation figures.

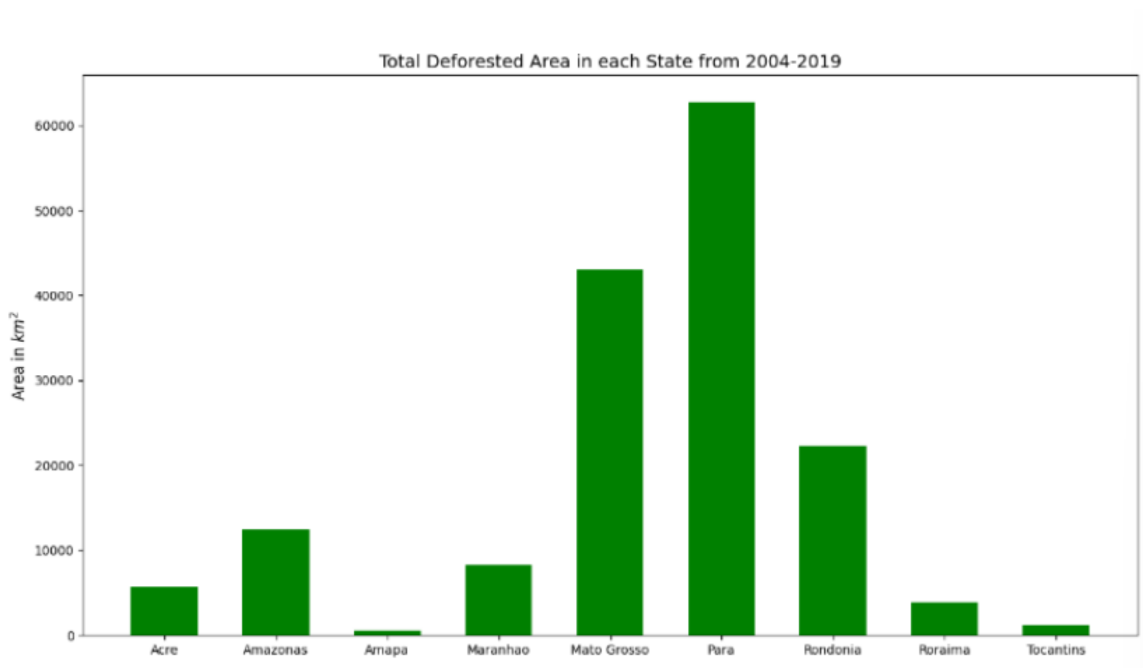


2. **State-wise analysis of deforestation:** To gain a clearer understanding of these trends, the deforested area for each state was plotted separately. This allowed for a visual comparison of the deforestation patterns across different regions, providing valuable insights into which states were most affected over time. From **2004 to 2012**, while many states experienced a decline in deforestation, it is evident that not all regions followed this downward trend. Specifically, **Amapá**, **Maranhão**, and **Roraima** saw an increase in deforestation during this period, suggesting that various factors such as local land-use practices, economic pressures, or policy enforcement could have influenced these regional variations. The rising deforestation in these states indicates a potential divergence from the broader trend of deforestation reduction observed in other areas of the Amazon during the same timeframe.



3. **Total Deforested Area in each State:** When examining the total deforested area on a state-by-state basis from 2004 to 2019, **Pará** stands out as the state

with the highest deforestation over the period. This indicates that Pará has been under significant environmental pressures, leading to substantial forest loss. The high deforestation rates in Pará could be attributed to various factors, such as agricultural expansion, illegal logging, and land-use changes, all of which have contributed to the degradation of the Amazon rainforest in this state. In contrast, **Amapá** exhibited the least deforestation, suggesting that its forest cover has been less impacted compared to other states. This could be due to a combination of factors, including lower rates of deforestation activities, stronger enforcement of conservation policies, or even the inherent challenges of accessing and developing the region's forests. As part of our investigation, we will delve deeper into the role of fires in deforestation, particularly in Pará. The aim is to determine whether the state's high deforestation rates can be partially attributed to the large number of fires that may have accelerated the loss of tree cover. By analyzing fire events in relation to deforestation patterns, we can assess whether fires have been a significant contributing factor to the observed deforestation trends in Pará and other states.

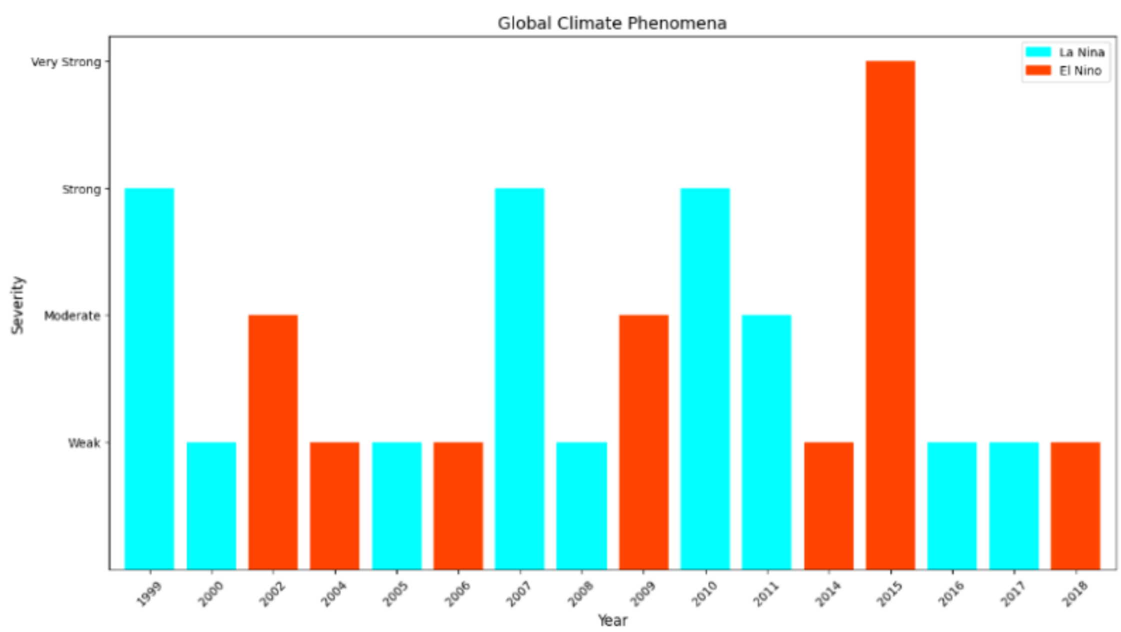


1. **El Niño and La Niña Impact on Deforestation in the Amazon:** El Niño and La Niña are two opposing climate phenomena that significantly influence weather patterns, particularly in the Amazon rainforest.

- **El Niño** is associated with warmer-than-average sea surface temperatures in the central and eastern Pacific Ocean, which disrupts atmospheric patterns. In South America, El Niño brings dry conditions, which increase the likelihood of forest fires in the Amazon. These conditions make it easier for fires, both natural and human-induced, to spread and become uncontrollable. The dry spell during El Niño years worsens deforestation, as fires can destroy large areas of forest. In regions where fire management is insufficient, the spread of uncontrolled fires exacerbates environmental damage.
- **La Niña**, on the other hand, is characterized by cooler-than-usual sea surface temperatures in the central and eastern Pacific, leading to wetter conditions in the Amazon. The increased rainfall associated with La Niña reduces the

frequency and intensity of forest fires, as higher moisture levels make it less likely for fires to start or spread. These wet conditions are generally beneficial for the Amazon, as they help to reduce fire-related damage and support the preservation of the rainforest.

In this analysis, we will examine the years and severity of El Niño and La Niña events to explore whether there is any correlation between these climate phenomena and deforestation rates in the Brazilian Amazon. The chart below shows the occurrence and intensity of these events across the years, which can help us understand how they relate to the deforestation patterns observed during those periods.

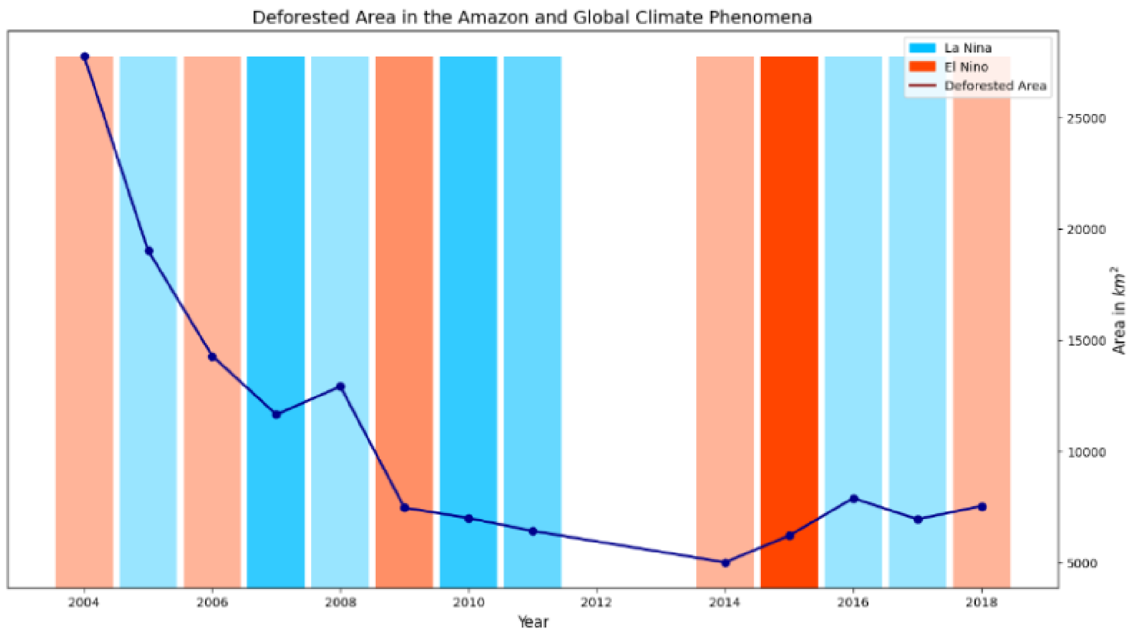


When overlaying the deforestation trend line with the severity of El Niño and La Niña events, using the transparency of the bars to indicate the intensity of each climate phenomenon, we aimed to assess whether there was any observable correlation between these events and deforestation rates. The hypothesis was that El Niño, with its dry conditions, would lead to an increase in deforestation due to more frequent and intense fires, while La Niña, with its wetter conditions, would help reduce deforestation by limiting fire risks.

However, after analyzing the data, it becomes evident that there is no clear correlation between the severity of these climate events and fluctuations in deforestation. The deforestation rate does not consistently increase or decrease in direct response to either El Niño or La Niña events. The transparency of the bars, which represent the intensity of each event, does not show a strong link to changes in deforestation patterns.

This lack of correlation suggests that while El Niño and La Niña may influence some environmental factors, deforestation in the Amazon rainforest is likely driven by a broader set of variables. These include land-use policies, illegal logging, agricultural expansion, and socio-economic factors, which appear to play a more dominant role in shaping deforestation trends than climate phenomena alone.

Thus, the data indicates that the relationship between climate events and deforestation is not as straightforward as anticipated, and other factors may need to be considered to fully understand the causes of forest loss in the region.



INDICES CHOSEN AND WHY?

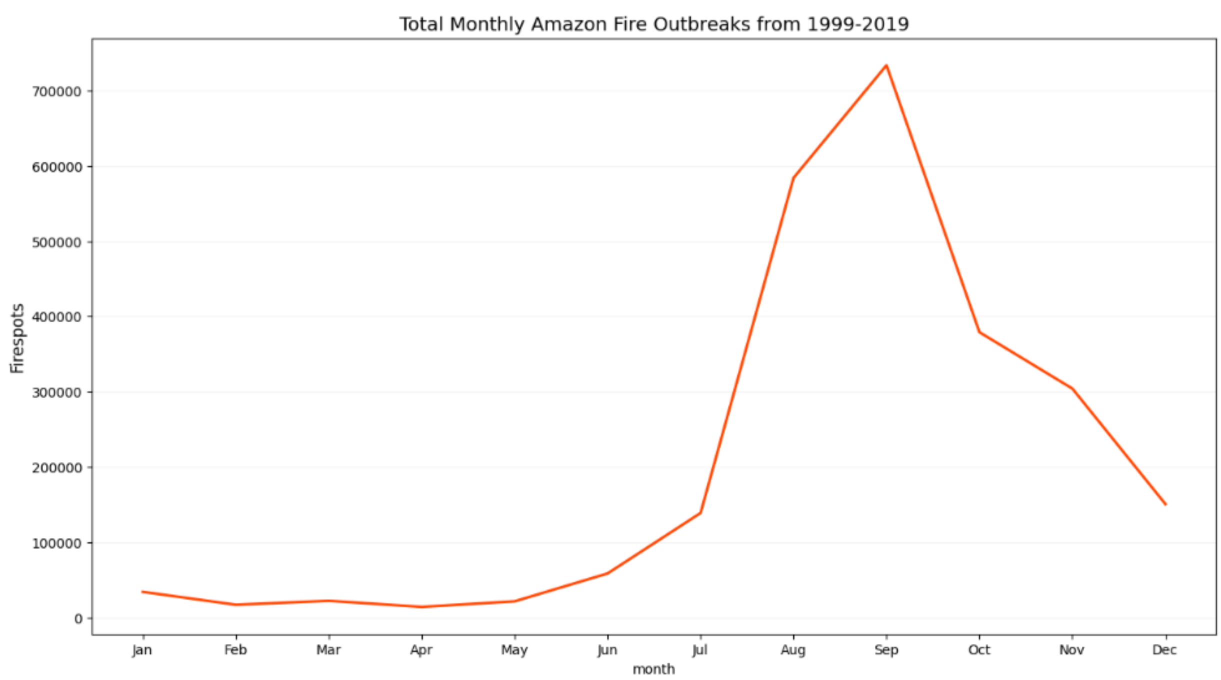
PARA-For this study, several indices were chosen to evaluate the effectiveness of fire detection and burn severity mapping in the selected regions. The selected indices, which include pre- and post-fire versions, provide a comprehensive understanding of the changes in vegetation and surface properties before and after the fire event. The following indices were chosen for analysis:

1. False Color Composite (FCC): is a combination of multiple bands, often involving NIR, red, and SWIR bands, to enhance the visibility of fire-impacted areas. By comparing pre- and post-fire FCCs, changes in vegetation health, structure, and burn severity can be easily visualized.
2. Normalized Difference Vegetation Index (NDVI): is widely used to assess vegetation health by comparing the difference between NIR and red bands. It uses red and near-infrared bands to measure vegetation density and health which helps us in understanding how the fire affected vegetation cover. A significant drop in NDVI values post-fire indicates a loss of vegetation and damage to the landscape.
3. Burn Area Index (BAI): is used to detect fire-impacted areas based on spectral reflectance differences in the red and SWIR bands. It is particularly useful in identifying the extent of burned areas and is sensitive to both vegetation and soil changes following a fire.

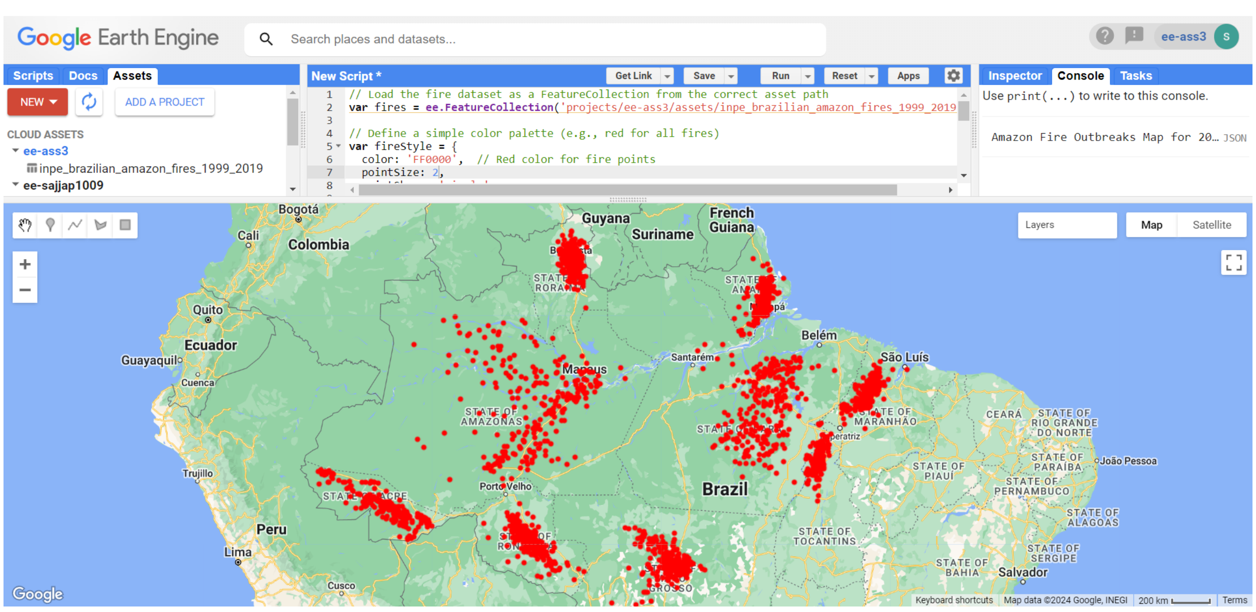
By analyzing both pre- and post-fire data, we can gain a comprehensive understanding of how each region responds to fire events and how effectively each index detects fire-affected areas.

CHOICE OF PLATFORM, SATELLITE, DURATION FOR RASTER ANALYSIS

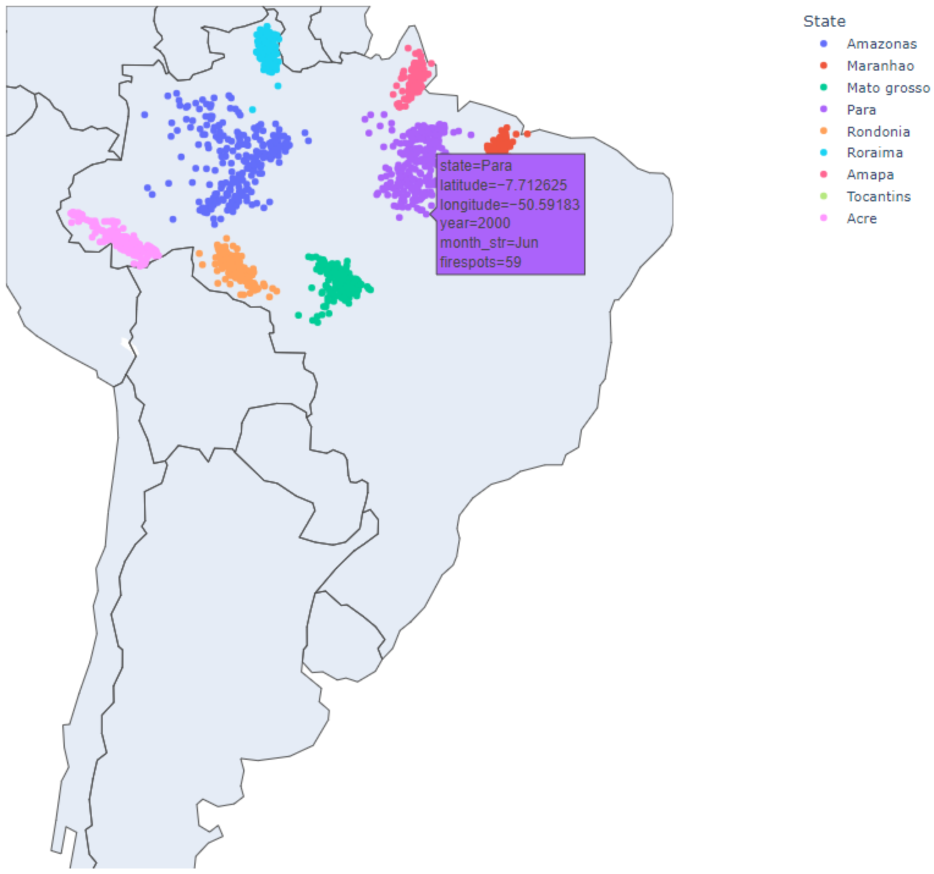
For this analysis, **Landsat 8** satellite imagery was utilized to examine changes in vegetation and fire impact over the region of interest. The platform used for processing and visualization was **Google Earth Engine (GEE)**, enabling efficient handling of large datasets and applying custom cloud-masking algorithms. The pre-fire analysis was conducted using images from January to June, corresponding to the wet season in Brazil, which typically experiences minimal fire activity and lush vegetation cover. In contrast, the post-fire analysis focused on the period from July to November, aligning with the dry season and peak forest fire occurrences in the region, providing a clear temporal distinction for evaluating the effects of fire events.



First we have plotted all the firespots across the 9 states using google earth engine and python as well.



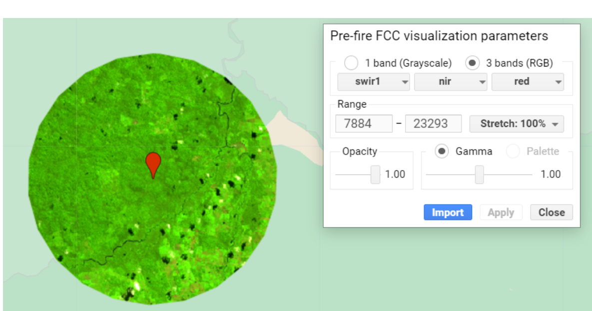
I have made a similar dynamic visualisation in python where on hovering over every firespot, i get its coordinates, state, year, month.



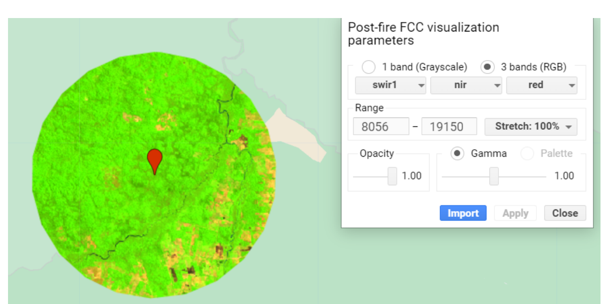
ROI 1- Para, Brazil

False Colour Composite (FCC)

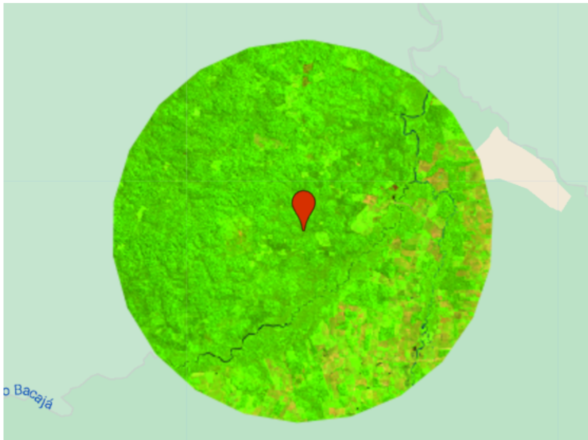
- In the Pre-Fire FCC, the dominant green color around the point of interest indicates healthy vegetation.
- While in the post fire FCC, we can clearly see a colour shift towards a yellowish tone which suggests loss of vegetation after forest fire.
- Throughout the last 10 years we can see that in the pre fire FCC, the overall vegetation has comparatively decreased (left column) and looking at post fire FCC, we can observe that the vegetation loss due to forest fire has increased (right column)



Pre Fire FCC 2014

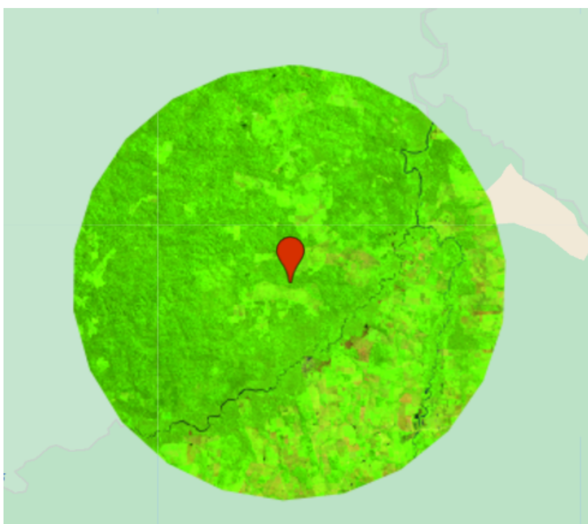


Post Fire FCC 2014

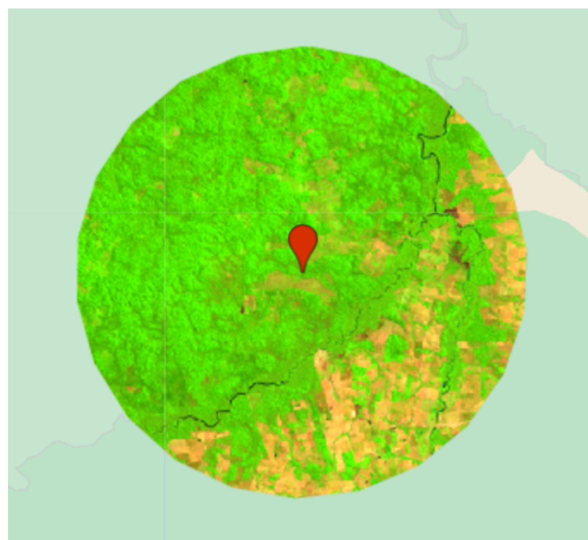


Pre fire FCC 2019

Post fire FCC 2019



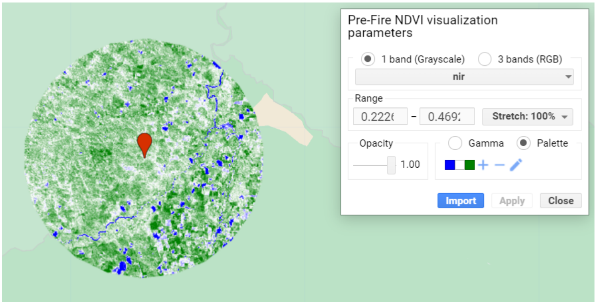
Pre Fire FCC 2024



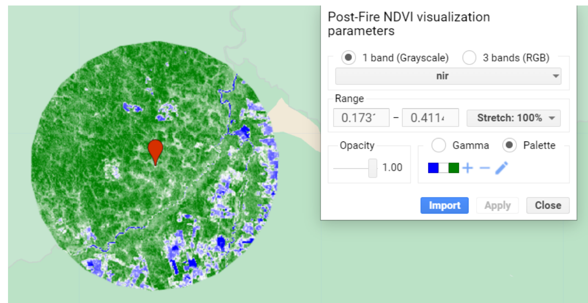
Post Fire FCC 2024

Normalised Difference Vegetation Index (ndvi)

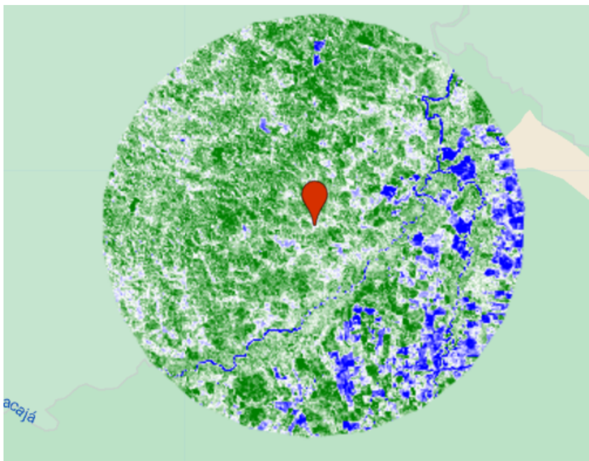
- In the below figures, highest NDVI values are represented as Green and lowest NDVI values are represented as Blue. White represents moderate NDVI. So, in terms of increasing NDVI - the colour representation is Blue <White <Green.
- For all 3 years, we can see that in pre fire snippet, the vegetation is moderate. We can also clearly see that in post fire NDVI snippet, the amount of area in blue is more (intense too) which implies that there has been a loss in the vegetation due to fire. We also observe a darker shade of green as compared to pre fire in all three years which might be because of regeneration due to high rainfall in the amazon.
- Hence this supports are assumption that forest fires are responsible for degradation of rainforests in brazil.



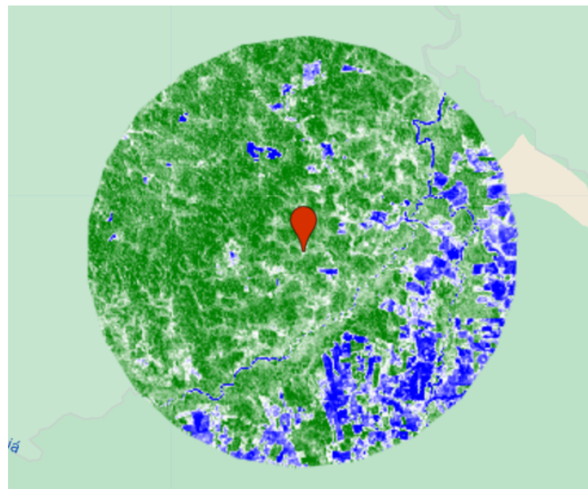
Pre fire NDVI 2014



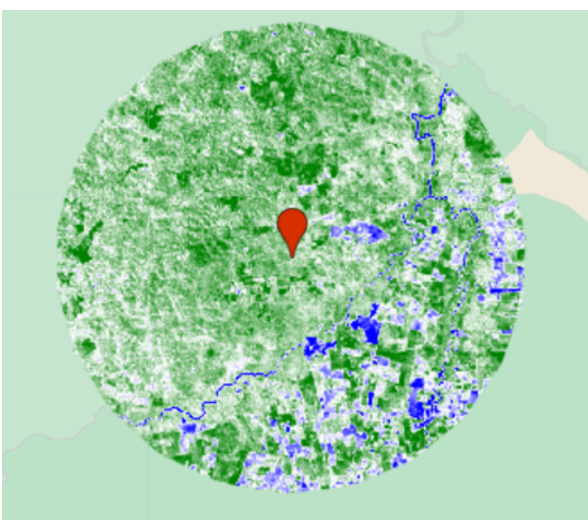
Post fire NDVI 2014



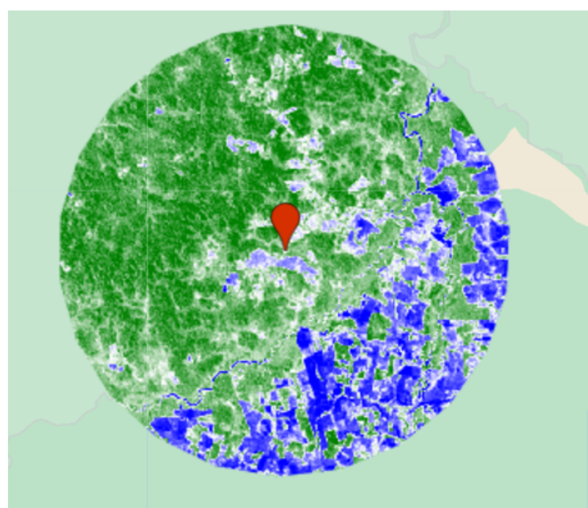
Pre fire NDVI 2019



Post fire NDVI 2019



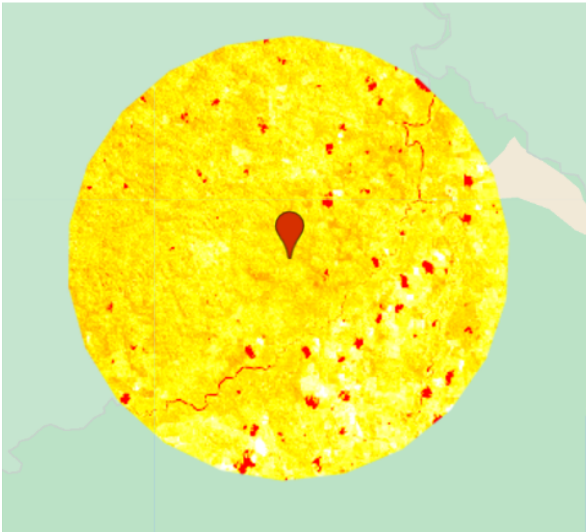
Pre fire NDVI 2024



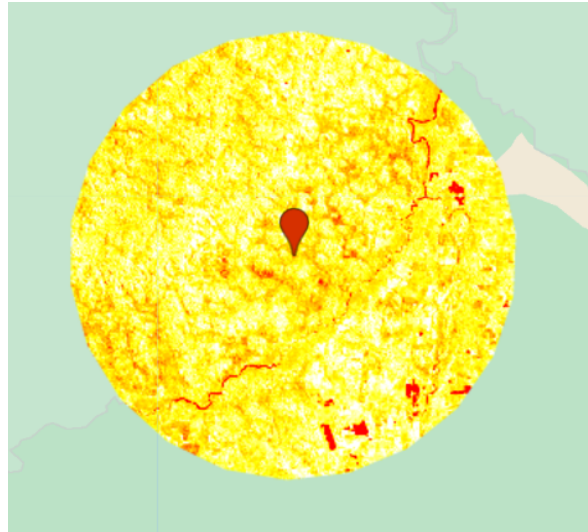
Post fire NDVI 2024

Burn Area Index (BAI)

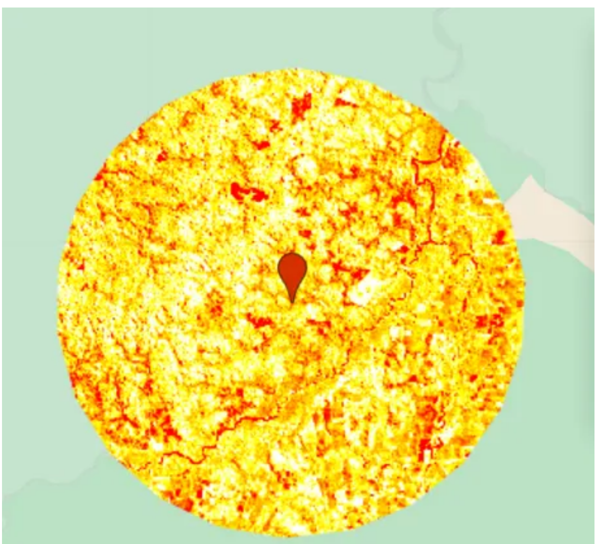
- In our analysis, White <Yellow <Orange <Red represents the increasing order of BAI values. It can detect burned regions well and track early regrowth, which is valuable in a high-rainfall region like the amazons.
- For the year 2014, we see that the post fire BAI snippet shows lighter shades of yellow which might suggest regrowth due to the high rainfall in the amazons.
- For the years, 2019 and 2024, we can clearly observe moderate to high intensity burns due to forest fires (dark orange-red tones) in the post fire snippets.



Pre fire BAI 2014

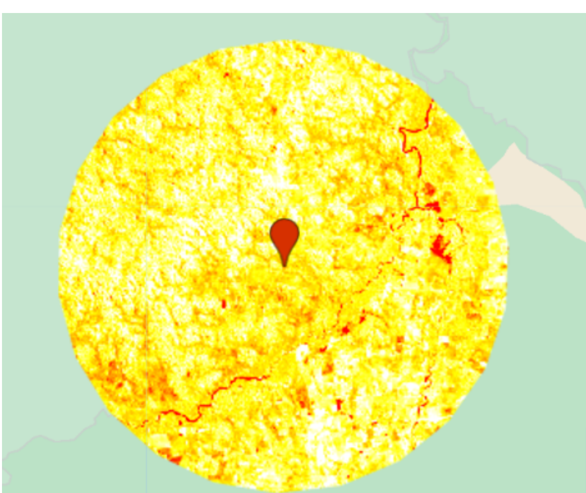


Post fire BAI 2014

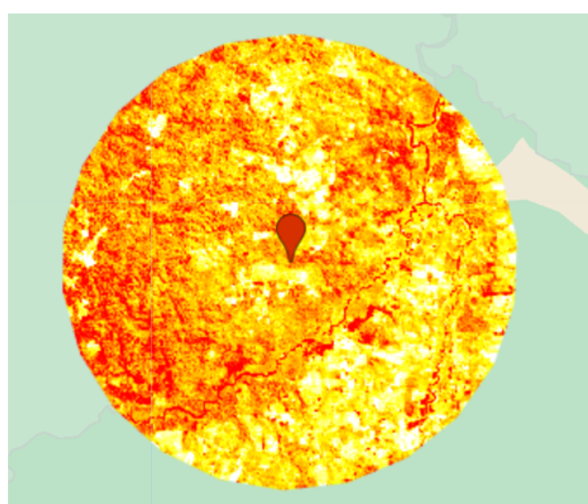


Pre fire BAI 2019

Post fire BAI 2019



Pre fire BAI 2024



Post fire BAI 2024

Overall, the data highlights that throughout the years, the state of **Para** has experienced multiple forest fires, significantly impacting vegetation. Using the VIIRS (Visible Infrared Imaging Radiometer Suite) dataset, we analyzed fire alerts categorized into three types:

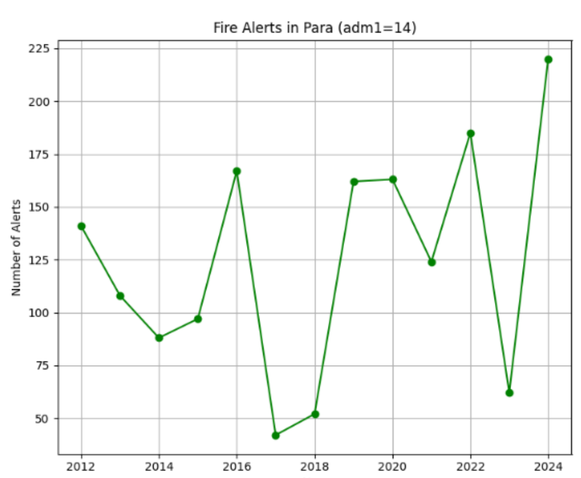
1. **Low-Confidence Fire Alerts**: These represent potential fire detections with lower confidence, often associated with weaker signals or phenomena that

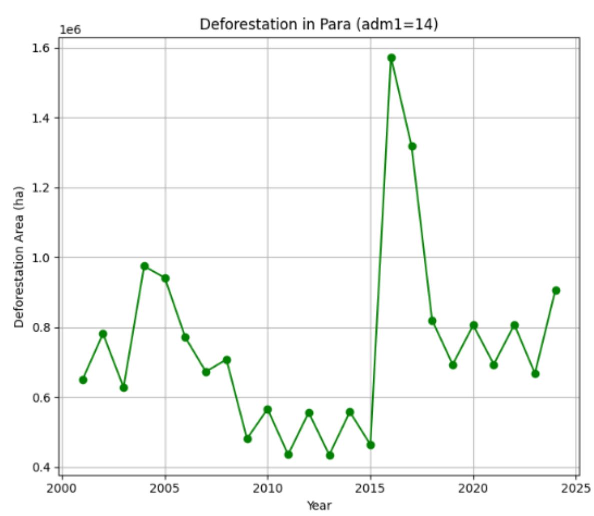
could mimic fire activity, such as sunlight reflections or warm land surfaces. They are less reliable and typically require further validation.

2. **Moderate-Confidence Fire Alerts**: These indicate fire detections with moderate reliability, balancing between weak and strong fire signals. They are useful for broader fire monitoring and are generally dependable indicators of fire presence.
3. **High-Confidence Fire Alerts**: These represent highly reliable fire detections, with strong and consistent fire signals. They are typically prioritized for immediate response and used in critical scenarios such as disaster management.

Using data from **Global Forest Watch**, we obtained the number of **high-confidence VIIRS fire alerts** sent out for every state in Brazil from 1999 to the present. This dataset supports our analysis in GEE, which focuses on the number of high-confidence fire alerts in **Para** compared to the year they were reported. Additionally, we analyzed a second plot from Global Forest Watch showing the extent of deforestation in Brazil from 1999 to 2024.

Our third plot overlays the fire alert data with deforestation trends, clearly illustrating that **forest fires and deforestation in the Amazon are directly proportional**. The intertwined relationship shows that as the number of fires increases, so does the extent of forest degradation, underlining the compounding threats to the Amazon rainforest ecosystem.





ROI 2- Amapa, Brazil

Issue of Cloud cover in Amapa

- The state of Amapa is highly clouded throughout the year especially during the wet season unlike the state of Para which isn't clouded throughout the year.
- **Using `CLOUD_COVER` Metadata**:
    - **Why it failed**: Sorting by `CLOUD_COVER` does not guarantee cloud-free images, as low `CLOUD_COVER` values might still include localized clouds over

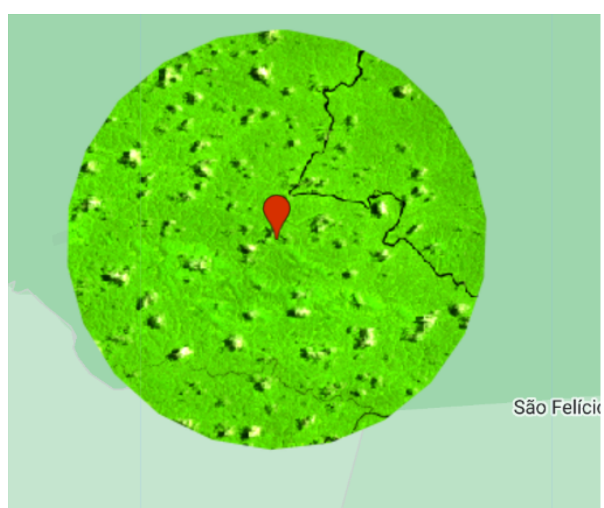
the region of interest (ROI). Additionally, Landsat metadata only provides scene-level cloud percentages, not pixel-level masking.

- **Cloud Masking Using `QA_PIXEL` Band**:
    - **Why it failed:** Some pixels flagged as "clear" may still contain haze or thin clouds, affecting the visualization.
- **Cloud-Free Image Selection**:
    - **Why it failed**: After applying the cloud mask, no completely cloud-free images were available for the specified date ranges, particularly in high-cloud-cover seasons or regions.
    - The reliance on `Collection.first()` after filtering could have inadvertently returned images with residual clouds if no valid alternatives existed.
- Hence we had to proceed with the images with the cloud for the state of Amapa.

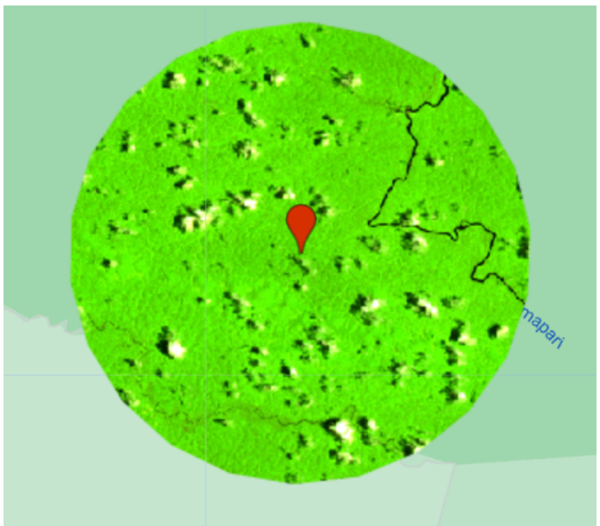
False colour composite (FCC):

- Looking at all 3 years, we see that there is very minor change in FCC which implies that there has been a very less impact on the vegetation in post fire. This suggests that the fire could have been minor or there was a fast regrowth (we will confirm this with BAI)..
- Another important point to note is that the intensity of the green colour might differ in the images of pre and post fire due to the reflectance on a specific day. We can see that mostly when it is clouded, the shade is darker due to reflectance while it differs on a sunny day.

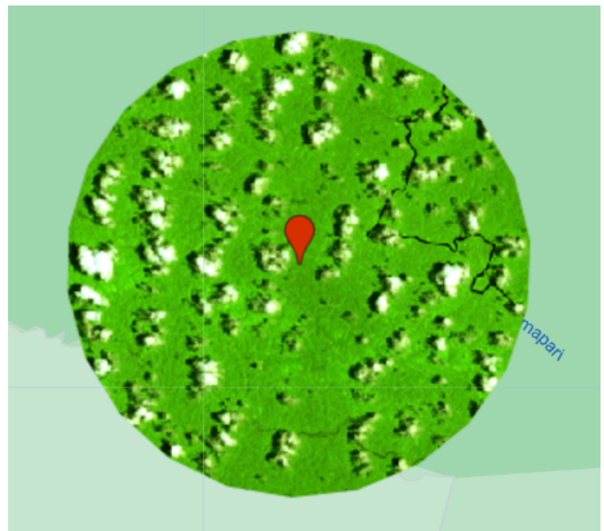
Pre fire FCC 2014



Post fire FCC 2014

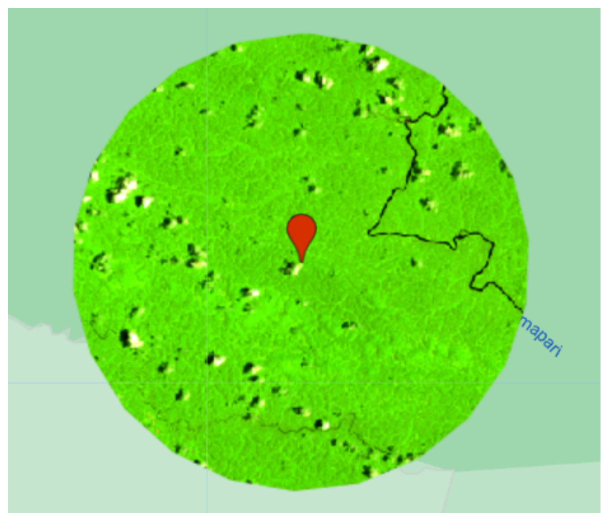


Pre fire FCC 2019



Post fire FCC 2019

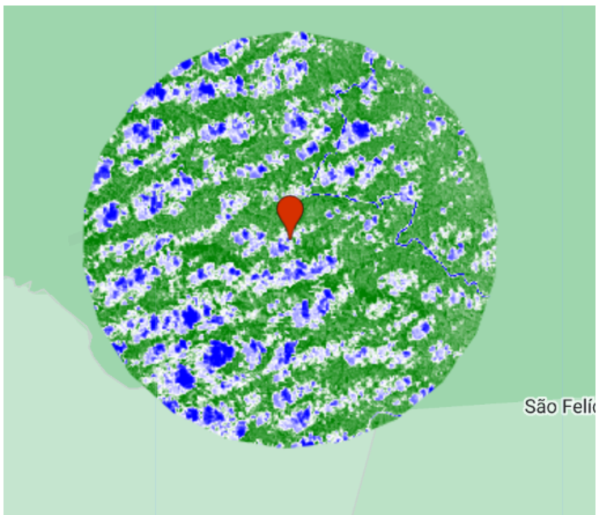
Pre fire FCC 2024



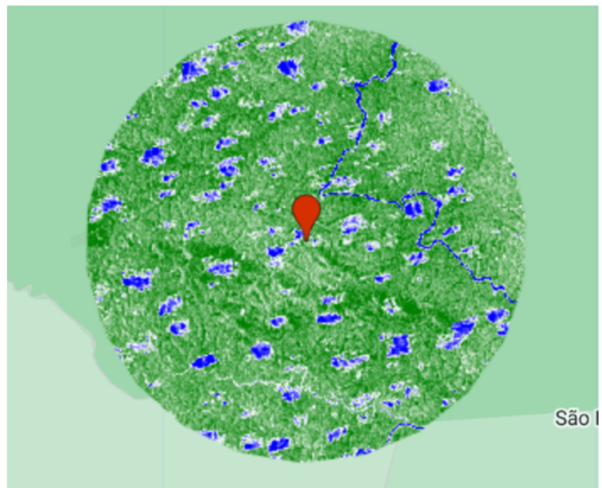
Post fire FCC 2024

Normalized Difference Vegetation Index (NDVI):

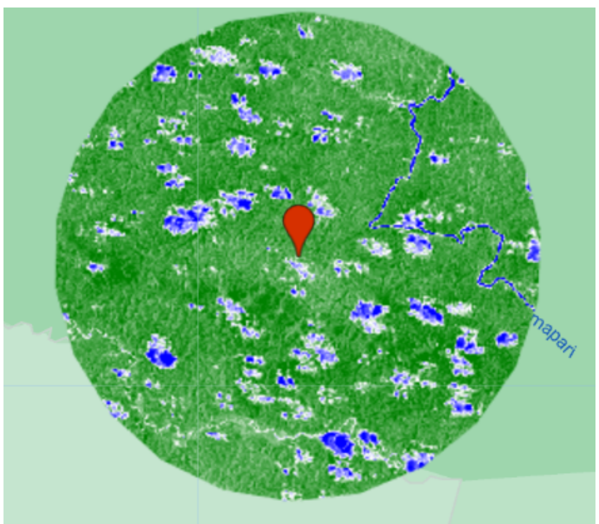
- In the Pre-Fire NDVI image (2014/24) , the area around the point of interest appears white, indicating relatively low vegetation density or health prior to the fire. This could suggest that the vegetation in this area was already compromised, possibly due to environmental conditions or ongoing fire impacts. The result is not 100% accurate due to the cloud cover.
- In the Post-Fire NDVI image (2014/24) , the area around the point of interest turns green, indicating a noticeable increase in vegetation health or density. This change suggests a significant regrowth or recovery of vegetation post-fire, likely influenced by favorable climatic conditions in Amazon, such as high rainfall.
- While in 2019 we see that there is a loss of vegetation in the post fire image (blue spots).



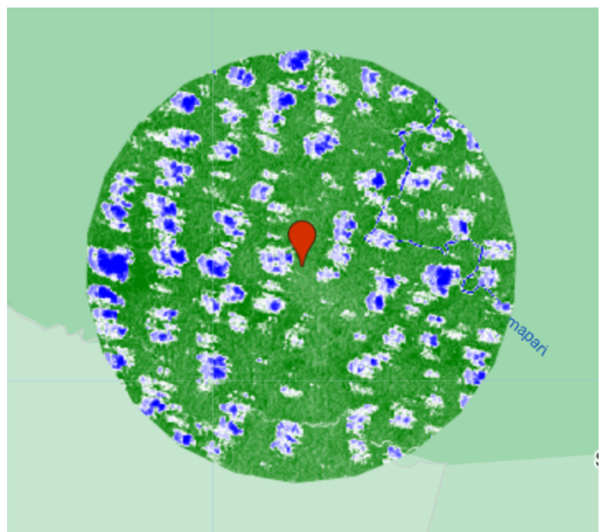
Pre fire NDVI 2014



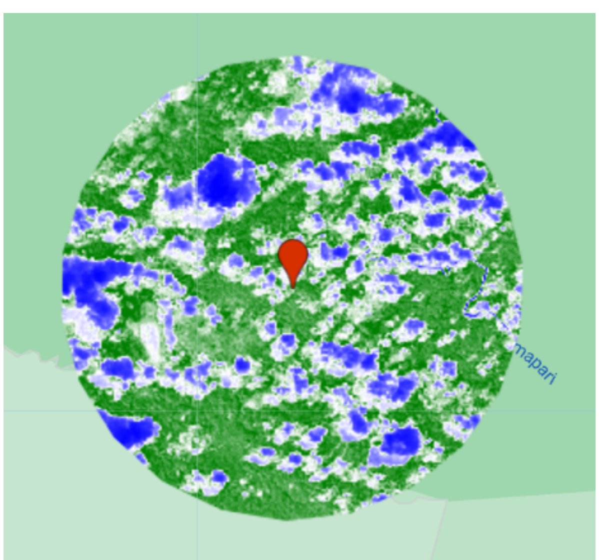
Post fire NDVI 2014



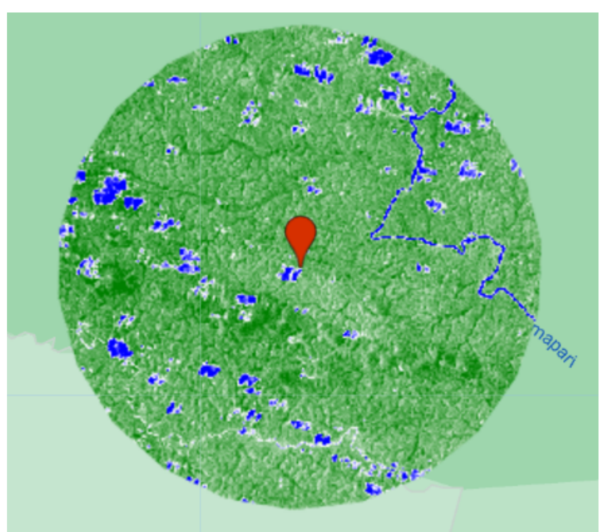
Pre fire NDVI 2019



Post fire NDVI 2019



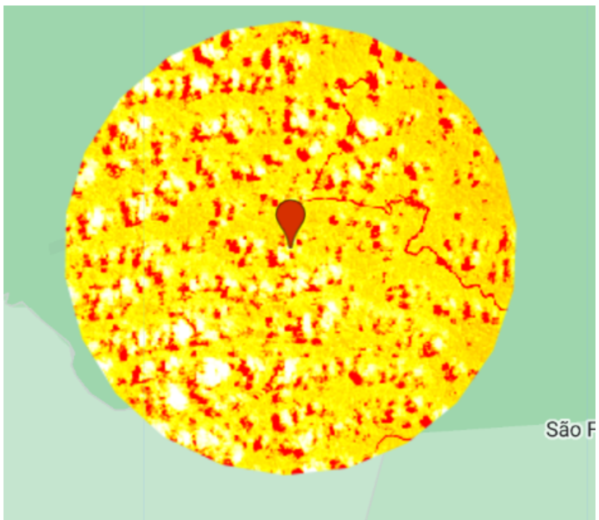
Pre fire NDVI 2024



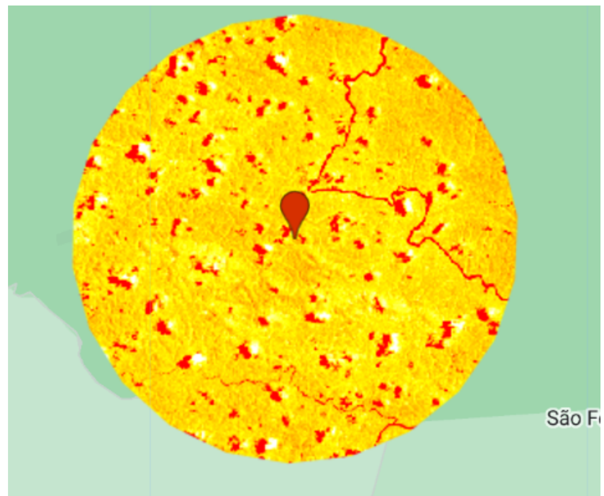
Post fire NDVI 2024

Burned Area Index (BAI)

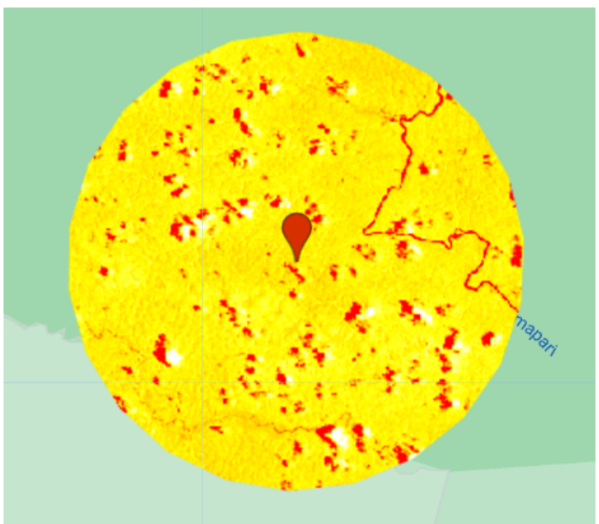
- If we have a look at all the pre and post fire BAI snippets, its clear that there were few fires and that too of low severity which aligns with our FCC results.
- The yellow in post fire BAI shows the signs of regrowth.



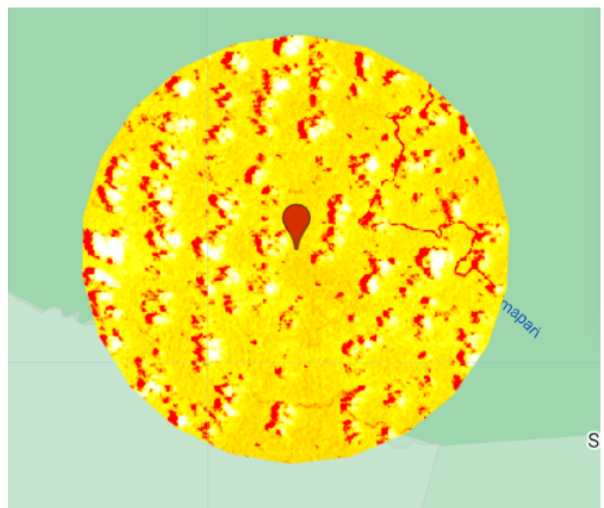
Pre fire BAI 2014



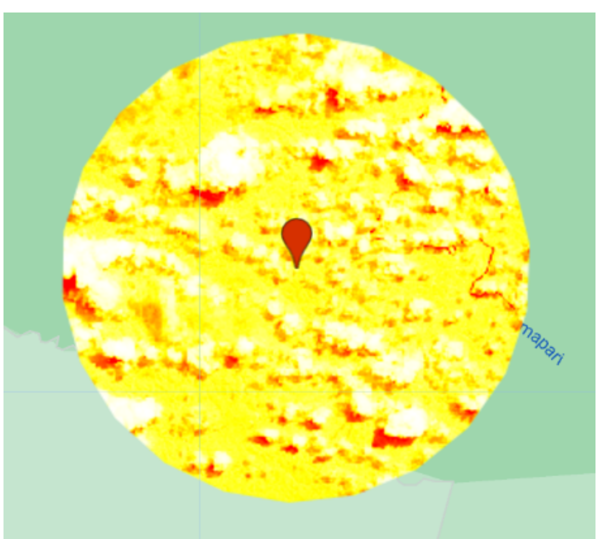
Post fire BAI 2014



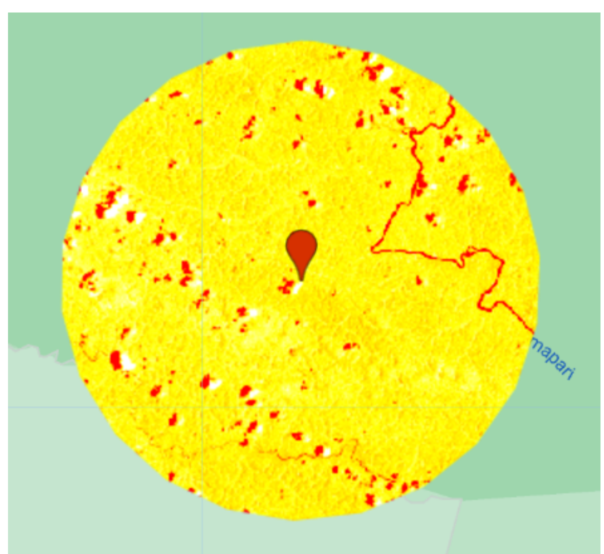
Pre fire BAI 2019



Post fire BAI 2019

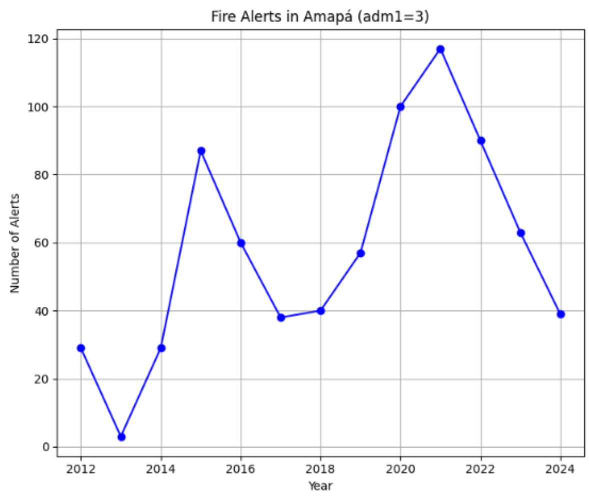


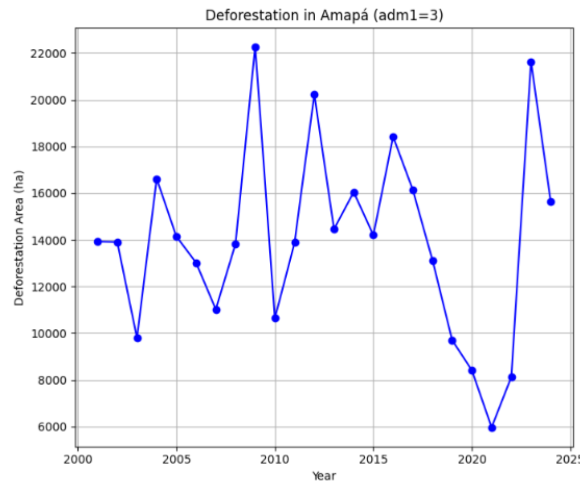
Pre fire BAI 2024



Post fire BAI 2024

We can conclude that forest fires in Amapá have been significantly fewer compared to Pará, with minimal destruction observed. The wet climate of Amapá has also facilitated rapid regrowth, as evident from the patterns observed in the BAI analysis. Just like para, i have another plot that supports my analysis on GEE:





In 2014, 2019, and 2024, Amapá experienced significantly fewer fire alerts compared to Pará, where an average of 160 alerts were recorded each month. This highlights the contrasting fire activity between the two regions.

CONCLUSION

We have analyzed the state with the highest deforestation, **Para**, and the state with the least deforestation, **Amapa**, to understand the overall trends between forest fires and deforested areas. To gain a broader perspective, we plotted a scatter plot for all nine states in the Amazon region, showing the relationship between the number of forest fires and the deforested area.

The analysis revealed a high correlation, with an **R^2 value of 0.9**, indicating a strong linear relationship between the two variables. This high value suggests that **forest fires significantly contribute to deforestation**, reinforcing the intertwined nature of these environmental threats. It underscores the need for targeted strategies to mitigate fire occurrences to reduce their devastating impact on the Amazon rainforest.