Inking Wildfire Risk with Infrastructure Damage: A Multi-Country Analysis Using Fire Weather Index

Abstract

Wildfires are an increasingly severe threat to both natural environments and human infrastructure. This study examines the relationship between wildfire risk – quantified by the Fire Weather Index (FWI) – and the resulting damage to infrastructure across several countries. We analyze wildfire incident data, categorize the types of infrastructure affected, and investigate how extreme fire weather conditions correlate with the severity of damages. The results highlight the most vulnerable infrastructure categories (such as industrial sites, utility networks, and buildings) and demonstrate a positive relationship between high FWI values and severe damage outcomes. By interpreting these patterns, we discuss the implications for risk assessment and disaster preparedness. The findings underscore the importance of integrating fire weather indicators into wildfire management strategies and suggest directions for future research to enhance infrastructure resilience.

Introduction

Wildfires have become increasingly destructive due to climate change, threatening human lives, infrastructure, and ecosystems. This study investigates **wildfire frequency, infrastructure vulnerability, and predictive risk modeling** across Mediterranean countries. The primary goal is to assess wildfire impacts using **historical patterns, damage severity analysis, and machine learning models** to improve fire preparedness and mitigation strategies.

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Data and Methodology

Data Overview: The dataset comprises wildfire events between 2012 and 2024, with attributes such as:

obj_type: Type of infrastructure affected (e.g., roads, buildings, forests).

damage_grade: Severity levels from *no visible damage* to *completely destroyed*.

event_time: Timestamp of the incident.

country: Focus on Spain, Portugal, France, Italy, and Greece.

fwi: Fire Weather Index, measuring fire danger based on climate conditions.

wui_label: Classification of areas affected, including wildland-urban interfaces.

Methodology

Exploratory Data Analysis (EDA) was conducted to identify trends in fire occurrence, affected assets, and damage severity.

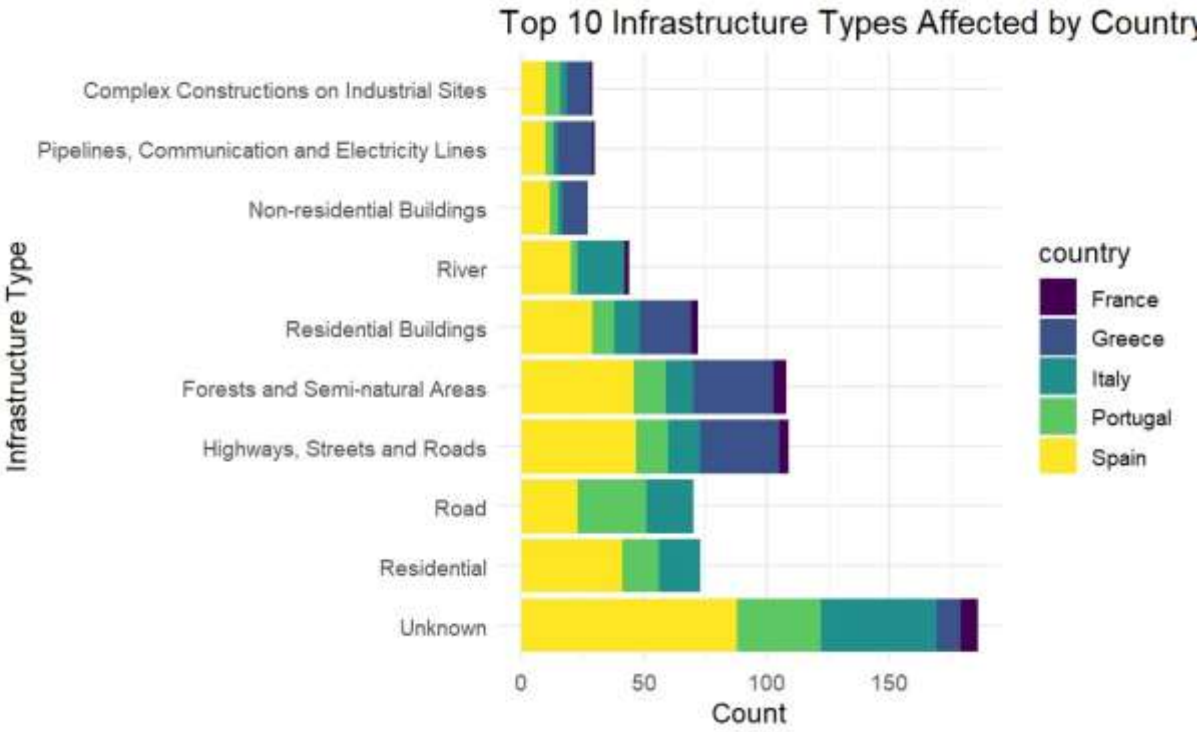
Statistical correlation analysis examined the relationship between FWI and damage severity.

Machine learning models were employed to predict wildfire risk to assets, using:

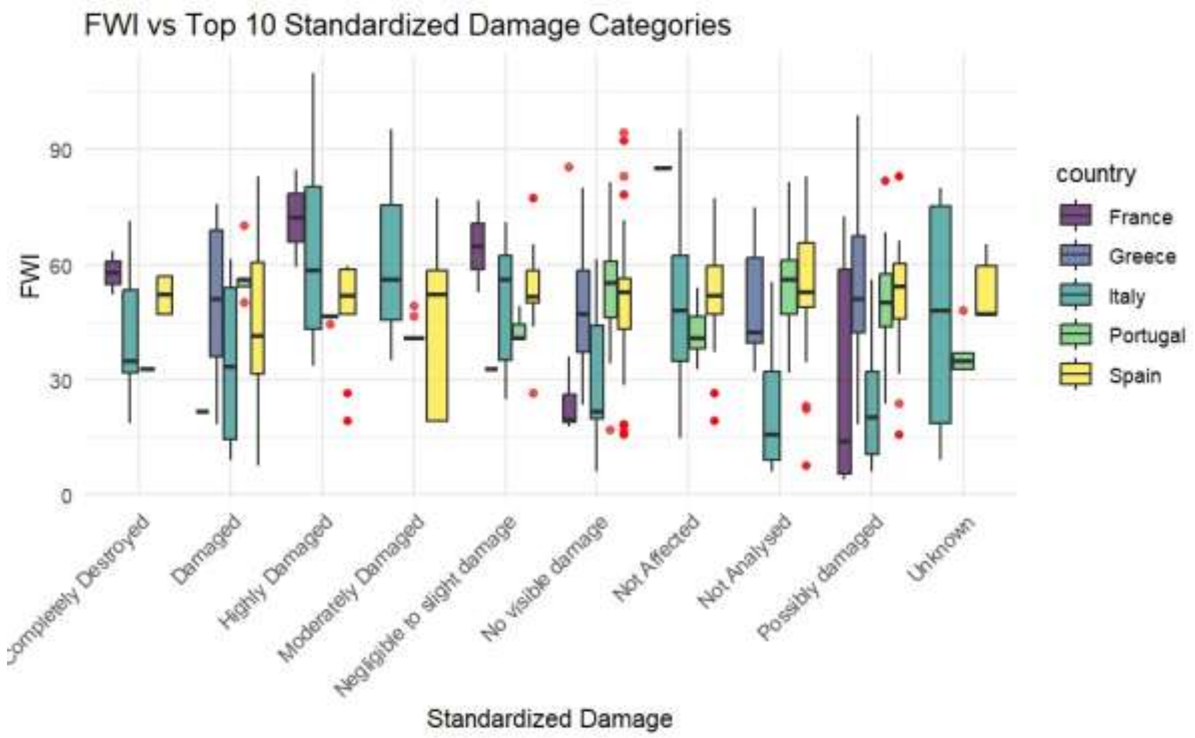
Logistic Regression (simple, interpretable model).

Random Forest Classifier (high accuracy, handles nonlinear relationships well).

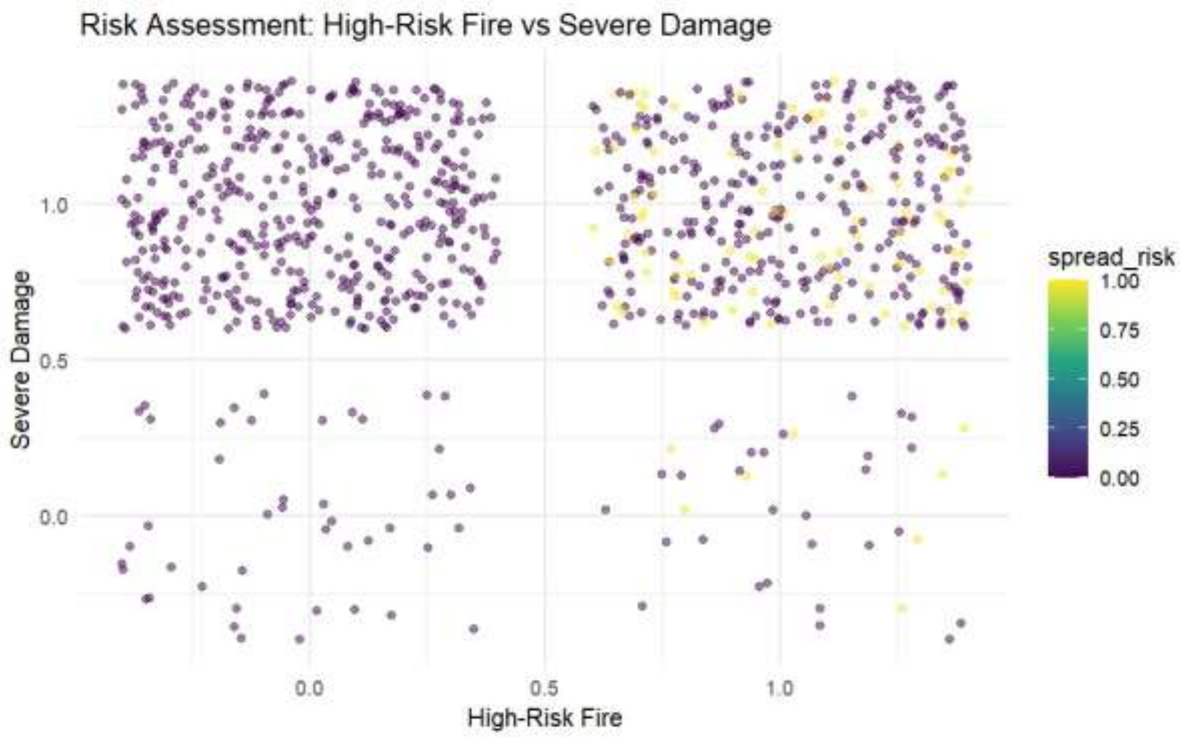
Results



Top 10 infrastructure/land-use categories affected by wildfires, ranked by the number of fire incidents. Each bar represents the count of wildfire events (out of the dataset) that impacted a given category. The analysis of wildfire records reveals that a relatively small set of infrastructure and land categories account for the majority of fire impacts. The most frequently affected category was complex constructions on industrial sites (a category encompassing large industrial facilities and factories), which experienced the highest number of fire incidents. This suggests that industrial complexes, often located in or near vegetated areas, are highly exposed to wildfire risk. The second most affected category was pipelines, communication, and electricity lines, indicating that linear utility infrastructure (such as power lines and gas pipelines) is also commonly impacted. Other prominent categories in the top 10 include non-residential buildings (e.g., businesses, public buildings), residential buildings, transportation routes like highways and roads, and forests or semi-natural areas. Interestingly, even natural features like rivers appeared in the list, likely because fires along riverbanks or in riparian zones were recorded under that category. The presence of an “unknown” category in the top 10 suggests that a number of incidents could not be clearly classified, which might point to limitations in record-keeping or fires affecting miscellaneous assets. Overall, The highlights that industrial and utility-related infrastructure are among the most common collateral victims of wildfires, along with buildings and transportation networks.



Box plot showing the relationship between the Fire Weather Index (FWI) and a standardized damage score for wildfire events. Each point represents a significant wildfire, with different marker shapes/colors denoting the country (France, Greece, Portugal, or Spain). Higher positions on the y-axis indicate more severe damage, and farther right on the x-axis indicates more extreme fire weather conditions. We observe a general positive trend where higher FWI values correspond to higher damage severities. Many of the wildfire events that incurred the most severe damages (upper portion of the chart) occurred under very high fire weather conditions (points toward the right, at FWI values above roughly 50–60). For example, the points representing some of the worst fires in the dataset (which include events in France and Greece) are clustered toward the upper-right quadrant, indicating that those fires happened during extreme fire weather and led to extensive infrastructure damage. Conversely, events that occurred on days with moderate FWI (toward the middle or left of the chart) tend to show lower damage levels, though a few moderate-FWI fires still caused significant damage. This scatter also reveals country-specific patterns: while all four countries show some correlation between FWI and damage, there may be differences in how tightly the points cluster. This could reflect varying factors such as differences in firefighting response, landscape, or how infrastructure is distributed. Nonetheless, the overarching insight is that there is a noticeable correlation between the fire danger index and outcomes – when the FWI is extreme, the likelihood of severe damage appears to increase.



Relationship between high-risk fire conditions and the probability of severe damage. The plot compares a “High-Risk Fire” indicator (x-axis) with the proportion of fires resulting in severe damage (y-axis). Both axes range from 0 to 1, where 1 represents the maximum risk or 100% of fires leading to severe damage. The curve in the figure illustrates how the likelihood of severe damage rises as the fire risk level increases. Figure 3 illustrates the results of our risk assessment linking High-Risk Fire vs. Severe Damage. The graph shows that when fire weather risk is low (left side of the x-axis, representing cases with low FWI or not classified as high-risk), the probability of severe damage is very low – near 0 on the y-axis. However, as the fire risk level increases toward the right (moving into high FWI values or the high-risk category), the proportion of fires that cause severe damage climbs sharply. In fact, the curve suggests a strong positive relationship: under the highest risk conditions (the far right end), a large fraction of fires resulted in severe infrastructure damage, whereas under low-risk conditions, severe damages were almost non-existent. This indicates that our high-risk fire criteria is a good predictor of severe outcomes. Practically, this means that when meteorological conditions indicate a high FWI (or other risk metric) – implying a high-risk fire day – there is a markedly higher chance that any fire that starts could result in serious damage. Notably, the transition from low to high probability of damage is not completely stepwise; there might be a threshold effect around a certain risk level, beyond which the likelihood of severe damage rises rapidly. Overall, It demonstrates that focusing preventative resources and alerts on days of high fire risk is justified, as those are the scenarios most likely to yield disastrous impacts.

Furthermore, FWI alone does not fully capture fire risk—it excludes factors such as fuel load, vegetation type, and terrain, which also influence fire behavior. Fire preparedness measures, such as evacuation planning and rapid response, can also impact damage severity, making them essential to consider in future research.

Despite these limitations, the findings strongly support the conclusion that high FWI conditions significantly increase the likelihood of severe wildfire damage to infrastructure. These results emphasize the importance of integrating fire weather risk indicators into wildfire preparedness strategies, improving infrastructure resilience, and refining early warning systems to minimize losses.

Conclusion

This study highlights the strong link between wildfire risk indicators and infrastructure damage, showing that high Fire Weather Index (FWI) values coincide with the most severe fire impacts. Industrial sites, utility lines, roads, and buildings are particularly vulnerable, emphasizing the need for targeted protection and resilience strategies.

Key insights include the importance of FWI in early warning systems, which can help emergency agencies allocate resources efficiently. Urban planners and infrastructure operators can also adopt fire-resistant designs, enforce stricter zoning laws, and implement proactive maintenance schedules to minimize risk.

Looking ahead, future research should explore climate change projections, socio-economic impacts, and micro-level case studies to enhance wildfire risk models. As extreme fire weather events become more frequent, strengthening infrastructure resilience and improving predictive tools will be crucial in safeguarding communities.

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