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Brief Report

The Power Grid/Wildfire Nexus: Using GIS and Satellite Remote Sensing to Identify Vulnerabilities

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Abstract: The effects of wildfire on the power grid are a recurring concern for utility companies who need reliable information about where to prioritize infrastructure hardening. Though there are existing data layers that provide measures of burn probability, these models predominately consider long-term climate variables, which are not helpful when analyzing current season trends. Utility companies need data that are temporally and locally relevant. To determine the primary drivers of burn probability relative to power grid vulnerability, this study assessed potential wildfire drivers that are both readily accessible and regularly updated. Two study areas in Idaho, USA with contrasting burn probabilities were compared. Wildfire drivers were obtained and differentiated between the study areas across the 2018–2021 growing seasons. This study determined that mean wind speed, cumulative growing season precipitation, and the mean Normalized Difference Vegetation Index (NDVI) for an area of interest may be reliable indicators of burn probability on a temporally relevant scale. This assessment demonstrates a method and variables that may be utilized by municipal electric utilities, electric cooperatives, and other power utilities to determine where to harden power grid infrastructure within wildfire-prone areas.

Keywords: power grid; wildfire; utilities; GIS; remote sensing

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1. Introduction

In recent years, a number of large wildfires have been ignited by the electrical power grid [1]. Conversely, several unplanned or preemptive power outages have resulted in relation to wildfires or the risk of wildfire [2,3]. The subsequent disruption to customers affected the quality of life, business, and health [4]. Recent assessments suggest climate change and the escalation in wildfire frequency have made fire a significant threat, meriting increased research and preparedness [5]. States, electric utilities, and other agencies are investigating different ways to mitigate such risks [6–8].

As a result of the changing fire regime [5], the potential for wildfires to impact the power grid is likely to increase. The reasons for this are threefold. First, the mean size of wildfires across the western United States has grown from 1665 acres in 1950 to over 6000 acres in 2020 [9]. Second, the number of fires has increased from a low of approximately 350 documented fires in 1950 to well over 1300 fires in 2020, a nearly 400% increase [10]. Thus, the likelihood of a wildfire affecting any part of the power grid has increased due to the size and frequency of fires. In addition, the increased footprint for critical infrastructure supporting America's growing population (the US population in 1950 was 150 million and has more than doubled to 331 million today) further exacerbates this problem. Third, a greater number of Americans are opting to live in areas considered part of the wildland–urban interface (WUI) [11]. While these areas clearly offer attractive quality of life benefits, they also exhibit enhanced risk of wildfire by adding sources of ignition (i.e., humans and electricity infrastructure) to natural areas more prone to fire.

Using existing Burn Probability data, this study sought to identify the variables that best determine the potential for wildfire to occur in areas with critical power grid infrastructure. This paper focuses on landscape vulnerability to wildfire based on identified wildfire drivers. While it is beyond the scope of this study to offer specific recommendations, the desired outcome is that these vulnerable landscapes and the infrastructure found in these areas can be managed and prioritized more effectively with the use of the methodology demonstrated in this paper. Mapping risk can aid on-the-ground workplan development by prioritizing high-fuel-load areas for fuel load reduction prescriptions or fuel breaks to lower risk from high winds by undergrounding utility wires or incorporating enhanced powerline safety measures. In this study, numerous variables were compared (e.g., biomass production, seasonal precipitation, wind speed, and lightning strikes) between two critical infrastructure study areas within the state of Idaho, USA that have contrasting burn probability. The results of this study are presented here to demonstrate a method and to inform energy infrastructure and surrounding land management.

2. Materials and Methods

2.1. Study Area

Two study areas (Figure 1) were chosen based on the Burn Probability (BP) model developed by Scott et al. [12]. The BP model was developed using 2015 LANDFIRE data and fire simulations. The BP model is useful for long-term burn probability, but lacks temporal resolution. It is suitable for current analysis because it is a federally funded reliable working model using generally accepted input data sources and accepted by the U.S. Department of Agriculture.

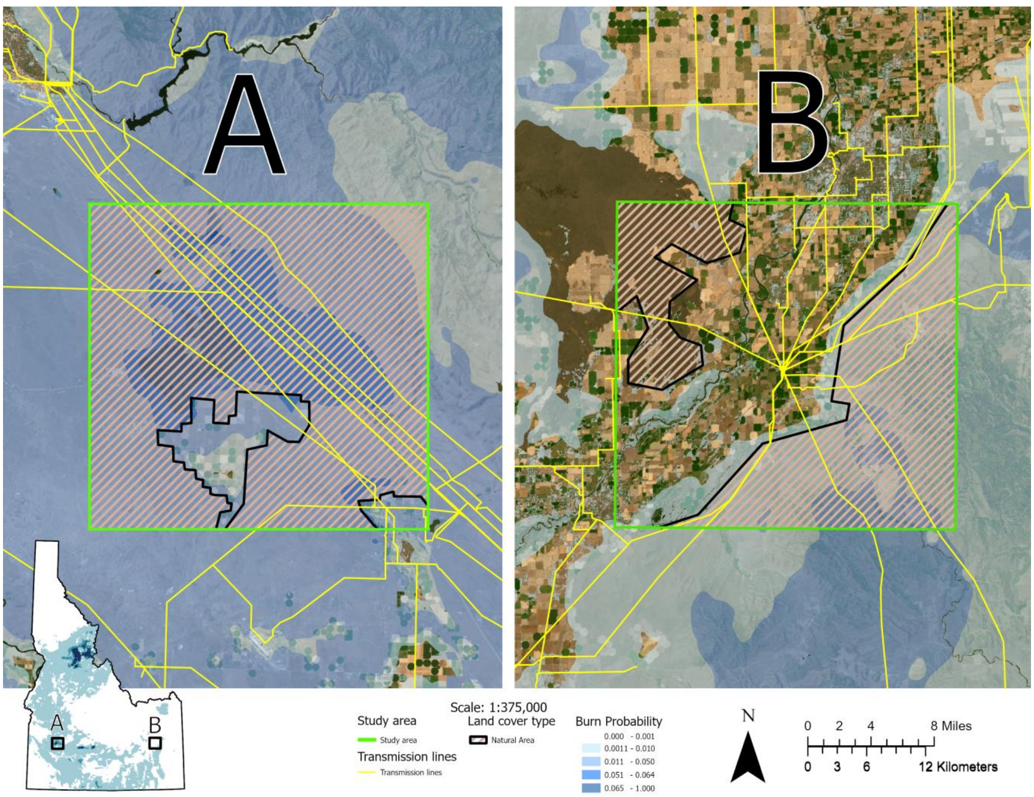

Figure 1. The High Burn Probability (BP) (**A**) and Low BP study area (**B**) analyzed in this project. Burn Probability is represented in the inset map as shades of blue, with high likelihood in darkest blue. Unshaded areas have <1% chance of burning. The diagonal lined areas highlight natural areas, which were the primary focus of this study. Note the large amount of power grid infrastructure indicated by the yellow lines, which are assumed to be of the same significance.

Both study areas had a high density of energy infrastructure, but differed in BP. The High BP study area is located in western Idaho (115.886° W 43.299° N) with a mean annual burn probability of 4.3%, and it is dominated by the invasive annual grass, cheatgrass (*Bromus tectorum*). The Low BP study area is in eastern Idaho (112.118° W 43.312° N) and has a mean annual burn probability of $\leq$1%. While cheatgrass also exists in this area, the vegetation is typified as a sagebrush-steppe ecosystem (*Artemisia tridentata* and native grasses). These areas differ in past fire history as the High BP site has experienced 258 fires while the Low BP site has seen 58 fires since 1950 [10]. The size of each study area was initially identical (1160 km^2). However, since wildfires typically do not occur in irrigated agriculture which dominates the Low BP study area (Figure 1B), those areas were removed from the study sites. This was accomplished using 2019 National Agricultural Imagery Program (NAIP) data to visually identify the built environment [13]. The study area polygons were then edited to contain only natural areas. As a result, the High BP study area covered 1048 km^2, while the Low BP study area covered 578 km^2.

2.2. Spatial Data

There are numerous variables that contribute to burn probability prior to the occurrence of a wildfire. The recency of a previous wildfire is one variable that provides a beginning point from which to consider the development of a subsequent wildfire. Land cover is a critical variable because vegetation biomass becomes fuel as plants die, senesce, or become dormant. In this study, vegetation productivity was estimated using the normalized difference vegetation index (NDVI) derived from NASA MODIS imagery (Table 1). The MODIS composite imagery combines pixels across a 16-day period to create one cloud-free composite with high pixel reliability. Each study month had two composites, which were then averaged to obtain the mean NDVI per month. Because the MODIS program is reaching its end of life, an alternate method of obtaining NDVI is through USGS Earth Explorer, where 30 m resolution multispectral imagery is available from the Landsat sensor.

The natural cycle of biomass production is influenced by precipitation, ambient temperatures, drought conditions, and the interactions between these environmental conditions. Precipitation is considered a primary driver of vegetation productivity across arid and semi-arid environments such as the study sites used in this research [14]. For this reason, monthly precipitation and cumulative precipitation during the growing season (April through September) were examined in the current study. These data were acquired from the Bureau of Reclamation AgriMet network (2022). The Grand View, Idaho station was used for the High BP site; it is located at 42.9125 N, −116.05611 W, elevation 2580 ft. The Shelley, Idaho station used for the Low BP site is located at 43.43452 N, −112.14273 W, elevation 4649 ft. Both stations are located within 50 km of the study area centroid.

Landscapes can exhibit very high wildfire potential, but still not experience a wildfire in a given year, or even across numerous years. This is because the landscape has not experienced an ignition event. In the U.S., two-thirds of the area burned by wildfires due to lightning-caused fires [15]. This study used lightning frequency data acquired from the NOAA National Lightning Detection Network (NLDN).

Wind speed is considered a contributor to wildfire ignition and spread [16]. Hourly wind data from 2018–2021 were obtained from Idaho Power, which maintains ten stations across Idaho. These data were converted from miles per hour into kilometers per hour. This study utilized data from two stations, one within each study area. The availability of these data established the temporal limits for this study as these data were the most constrained (four years of records compared to decades of other data).

ArcGIS Pro was used to assemble and prepare these data for spatial and statistical analysis. The zonal statistics such as table tool were used to extract raster pixel values for NDVI and land cover within each study area. These data were summarized by mean, median, and standard deviation. Precipitation and wind speed were derived from recording station data. These data were extracted for each study area by first selecting the appropriate station and then selecting the temporal records of interest. Data were summarized by month using mean, median, and standard deviation. The NLDN lightning strike data were first employed as a sub-set for each study area using the clip tool. A count of lightning strikes by year and month was determined using the summarize tool.

Table 1. Summary of potential driver variables used in this study. Note that variables are taken at different resolutions.

Variable	Units	Spatial Resolution	Frequency	Data Source
Vegetation productivity (NDVI)	Index	250-m	16 days	NASA MODIS https://ladsweb.modaps.eosdis.nasa.gov/search/order/1/MOD13Q1--61 (accessed on 1 April 2023.)
Precipitation	Centimeters (cm)	Station	Hourly	BoR AgriMet https://www.usbr.gov/pn/agrimet/wxdata.html (accessed on 1 April 2023.)
Lightning	Count/frequency	0.1-degree grid cell	Daily	NOAA NLDN https://www.nssl.noaa.gov/education/svrwx101/lightning/detection/, https://www1.ncdc.noaa.gov/pub/data/swdi/database-csv/v2/ (accessed on 1 April 2023.)
Wind Speed	Kilometers per hour (km/h)	Station	Hourly	Idaho Power Idaho Power data is specific to this study; alternative data source: https://www.weather.gov/, https://www.idahopower.com/ (accessed on 1 April 2023.)
Previous wildfires	Presence/absence	N/A	Daily	ISU GIS TReC Historic Fires Database https://giscenter.isu.edu/Research/Techpg/HFD/index.htm (accessed on 1 April 2023.)
Land cover	Categorical	30-m	Biannual	LANDFIRE https://www.landfire.gov/data_overviews.php (accessed on 1 April 2023.)
Burn Probability	Annual likelihood	30-m	Updated 2015	Wildfire Risk to Communities spatial datasets https://www.fs.usda.gov/rds/archive/Catalog/RDS-2020-0016 (accessed on 1 April 2023.)
Transmission lines	Presence/absence	N/A	Updated 2022	National Homeland Security Infrastructure Dataset https://hifld-geoplatform.opendata.arcgis.com/ (accessed on 1 April 2023.)

This process was followed for both study areas and resulted in a database table describing seven potential driver variables: NDVI mean, NDVI median, monthly precipitation, cumulative growing season precipitation, wind speed mean, wind speed median, and lightning strike frequency. This table was exported to an Excel spreadsheet and prepared for statistical analysis.

2.3. Statistical Analysis

Drivers listed in Table 1 were compiled by year (2018–2021) and month (June–September). These values were then log transformed to normalize the data distribution and support a more rigorous statistical analysis given the small sample size (n = 16 per driver per site). Analysis of Variance (ANOVA) was performed; p-values less than 0.01 were considered statistically significant.

Both the original data and log transformed data were exported into JMP statistical software. Using ANOVA, variables were identified that could be used to differentiate burn probability between the study areas.

3. Results and Discussion

The Burn Probability model used in this study [12] showed a clear distinction between the two study sites. The high BP area has an average annual BP of 4.3% compared to the low BP area (<1%). These probabilities were validated using the Historic Fires Database (HFD) which confirms the relative wildfire risk of each study site, as 258 wildfires have been documented within the high BP site compared to only 58 wildfires in the low BP site since 1950. Thus, the study areas exhibit not only differing levels of burn probability, but also differing frequency of actual wildfire occurrence. It is under this general basis that the research was conducted.

Total Monthly Precipitation and Lightning Frequency had *p*-values greater than the threshold of 0.01 (Table 2), meaning there was no statistical difference for these variables between study areas. Therefore, they are not considered reliable indicators of power grid vulnerability to wildfire.

Table 2. Seven potential wildfire drivers were compared between study areas to determine which variable(s) indicate differences in Burn Probability (BP) using a confidence interval of 0.01 (indicated by ***). Variables recommended for management application are in bold.

Variable	*p*-Value
Wind Mean (km/h)	<0.001 ***
Wind Median (km/h)	0.007 ***
Total Monthly Precipitation (cm)	0.293
Cumulative Growing Season Precipitation (cm)	<0.001 ***
NDVI Mean	<0.001 ***
NDVI Median	<0.001 ***
Lightning Frequency	0.054

The remaining five drivers all showed a statistical difference between the High BP and Low BP study areas, meaning each of these can be used to identify vulnerability of the power grid to wildfire. While the *p*-values for both the mean and median of wind and NDVI were statistically significant, the mean value is suggested as a more practical indicator variable simply because it is more commonly utilized and understood. Thus, the most easily accessible and reliable variables to identify power grid vulnerability to wildfire are wind mean (higher wind speed results in higher vulnerability), cumulative growing season precipitation (lower cumulative precipitation results in higher vulnerability), and NDVI mean (lower mean NDVI results in increased vulnerability) (Figure 2).

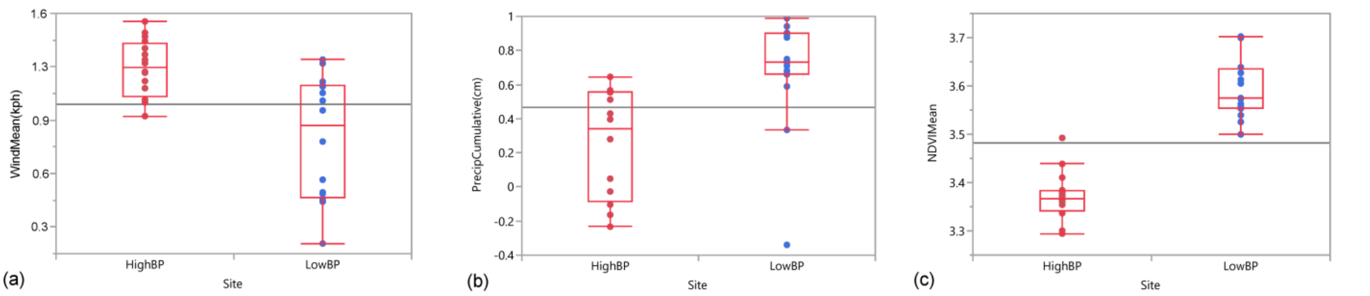

Figure 2. Distribution of data values for each recommended variable by study area. (**a**) Wind Mean, (**b**) Cumulative Growing Season Precipitation, and (**c**) NDVI Mean.

It is important to understand these indicator variables correctly, as they are relative drivers and do not suggest absolute thresholds. For instance, across a utility's management area, sites with higher mean wind speed result in higher vulnerability relative to other sites with lower mean wind speed. Furthermore, sites with extremely low NDVI (approaching zero or below zero) are likely devoid of vegetation (fuel) and exhibit concomitantly low vulnerability to wildfire.

4. Conclusions

The results from this study concur with the overall burn probability model developed by Scott et al. [12]. For management purposes, the BP model provides a valid initial approach to evaluating power grid vulnerability to wildfire. However, the BP model is not temporally dynamic. Thus, during a given fire year, using mean wind speed, cumulative growing season precipitation, and/or NDVI mean will allow utility managers to assess fire susceptibility under current conditions. The goal of this study is not to establish through statistical analysis the cause-and-effect relationships, but rather to demonstrate through this assessment the vulnerabilities in two areas with previously established differences in risk and to identify probable correlations between burn probabilities.

Future work could include investigating the interesting and somewhat counter-intuitive relationship between NDVI and wildfire vulnerability that was exhibited in this study. That is, lower NDVI mean values suggest heightened vulnerability. While this relationship correctly described the differences observed between the two study areas used in this research, it is likely that a broader study would reveal a parabolic curve that more fully describes the relationship between NDVI and wildfire vulnerability. For example, while the high BP study area exhibited lower NDVI relative to the low BP study area, assuming low NDVI values indicate high burn probability is incorrect. Taken to the extremes, this assumption suggests areas entirely devoid of vegetation (with an NDVI value of -1.0) would be most susceptible to a wildfire. At the opposite end of this spectrum are areas sustaining very high NDVI values. Such areas are typically characterized by large volumes of biomass that are actively growing and contain high water content. Such areas have a low burn probability. Between these extremes, we see heightened burn probability, and hence an overall parabolic or U-shaped curve. Additional research is merited to explain this trend in greater depth.

Supplementary Materials: The following supporting information can be downloaded at: https://giscenter.isu.edu/research/Techpg/PGWF/index.htm (accessed on 2 April 2023), Abstract and Poster, Literature Review, related Vegetation Index technical report, and other related reports.

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