GI_Forum 2021, Issue 2
Page: 94 - 107
Full Paper
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DOI: 10.1553/giscience2021_02_s94

Examining Wildfire Spread Variables for Assessing Forest Burn Vulnerability

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Abstract

The scale and danger of wildfires are a growing concern in Western Canada. The Northwest Fire Centre is one of six designated wildfire management districts in the Canadian Province of British Columbia. It covers 25 million hectares, or a quarter of the area of the province. The centre sees the greatest area burned from wildfire spread in the province although it experiences the lowest number of active wildfires annually. This study examined two Sentinel-2 images capturing the 'before' and 'after' of a major wildfire that took place in the Lutz Creek area within the Northwest Fire Centre in 2018. Higher-risk wildfire spread areas were identified by combining Normalized Difference Vegetation Index, Normalized Difference Water Index and slope gradient variables. When slope was included, the Moderately High and High burn vulnerability categories increased to ~54% of the area analysed, compared to ~33% when it was not included. Together, all three variables provide the basis for a more accurate assessment of forest burn spread and vulnerability.

Keywords:

wildfire, spread, Northwest Fire Centre, Sentinel-2, British Columbia

1 Introduction

In recent years (2017–2019), British Columbia (BC) reported that the Northwest Fire Centre (NFC) district had one of the lowest numbers of fires; yet, it had the greatest number of hectares burned due to wildfire spread. The NFC (one of six dedicated BC fire districts) is the largest wildfire response centre in the province, covering over 25 million hectares, equivalent to 25% of the province's land area. The Centre stretches from the Pacific coast to just west of the Town of Endako, and south from the Yukon border to Tweedsmuir Provincial Park (Government of British Columbia, 2020a) (Figure 1). The district encompasses part of the northern interior plateau as well as the Coastal Mountain range. The forests consist primarily of pine and spruce trees, with balsam found at higher elevations. Hemlock and red cedar become more prevalent along the coast (Government of British Columbia, 2020b).

Forest fires are one of the primary causes of changes in forest ecosystems throughout Canada (Weber & Flannigan, 1997; Kasischke & Turetsky, 2006; Schroeder et al., 2011; Forsythe & McCartney, 2014). Wildfires are a naturally occurring phenomenon during the summer months in BC. They can reduce insect invasions, control the spread of disease, promote new vegetation growth, and in general help maintain a healthy forest, promoting the diversity of both plant and animal life (Coogan et al. 2019; Government of British Columbia, 2020a; USGS, 2020a). However, above-normal wildfire activity has occurred in BC over the last few decades. A history of effectively suppressing wildfire has led to a significant surplus of fuel (combustible forest materials), resulting in an increased risk of large wildfires, and as a side effect, decreased forest biodiversity (Podur & Wotton, 2010). With Western Canada showing above-average temperatures and less precipitation (according to the Environment and Climate Change Canada (ECCC) climate research program), BC may see above-normal numbers of wildfires during the wildfire season, resulting in potentially significant and devastating wildfires during the 21st century (Kirchmeier-Young et al., 2017; Government of Canada, 2020).

Figure 1: British Columbia's regional Fire Centre districts (Source: Government of British Columbia. 2020b)

In addition to the density and quantity of fuels present, the moisture content (or dryness) of the materials necessary for a wildfire to thrive, spread and accelerate its burn rate is often influenced by slope gradient. Fire moves faster uphill on steeper slopes (the wind promoting uphill spread), and falling debris contributes to downward slope spread (Weise & Biging, 1996; Government of Northwest Territories, 2020).

In a study of peat wildfires in Indonesia using Weighted Linear Combination (WLC) and regression techniques, the Normalized Difference Vegetation Index (NDVI) together with the Normalized Difference Water Index (NDWI) of pre-fire conditions resulted in a greater than 50% contribution to predicting land and forest vulnerability to wildfires. The study also revealed that although surface and air temperatures were able to partially explain forest vulnerability, they were less effective than vegetation and water indices in explaining wildfires in the region (Nurdiana & Risdiyanto, 2015). Similarly, Ferster et al. (2016) concluded that the traditional methods of observing wildfire vegetation loss through indicators such as fuel type, canopy coverage and dry conditions were universally applicable in predicting wildfires. Their recommendation for forest management was to take a holistic approach to wildfire activity to improve prediction models and enhance wildfire control practices.

The National Aeronautics and Space Administration's Moderate Resolution Imaging Spectroradiometer (MODIS), with channels specifically designed for fire detection, is the most commonly used satellite sensor for detecting fires over large regions (Natural Resources Canada, 2021). Wildfires spread either at a slow rate and low intensity, or at a fast rate and high intensity, but lengthening spread days increase the likelihood of considerable areas being burned regardless of a fire's intensity (Podur & Wotton, 2011). With the number of days conducive to the spread of fires increasing, it is important to study past wildfire spread activity to better prepare fire management teams in understanding where and how a wildfire will spread within an ecoregion. Throughout the fire season in BC, lightning strikes are responsible for approximately 60% of wildfires annually; the other 40% occur due to human negligence (Government of British Columbia, 2020a). Reducing the number of human-caused wildfires is achievable through awareness-raising initiatives, and area blockages/closures. However, lightning-caused wildfires are almost unavoidable and increasing (Wierzchowski et al., 2002).

This study, through an analysis of fuel availability and fuel moisture conditions in combination with slope gradient, examines wildfire-conducive factors in the NFC. It aims to examine the conclusions of Nurdiana & Risdiyanto's (2015) study, where NDVI and NDWI provided a strong indication of the vulnerability of forest and land to wildfires; and NDVI and NDWI were shown to be stronger indicators than air and surface temperatures.

2 Data and Methods

The satellite images used in this study were acquired from the United States Geological Service (USGS) Earth Explorer data portal (USGS, 2020b). The cloud-free Sentinel 2A images were acquired on May 16, 2018 (pre-fire) and September 19, 2018 (post-fire). They were the highest-quality images available for this study when prevailing cloud cover and haze/smoke were considered during the 2018 fire season. They were also the closest in terms of date to the lightning-caused Lutz Creek fire that started on August 4, 2018 (Government of British Columbia, 2020a). The boundary file for the NFC was acquired from the Government of British Columbia's Data Catalogue (Government of British Columbia, 2020d).

Using the May imagery, the burnt area from the Lutz Creek fire was examined in terms of NDVI, NDWI and slope gradient characteristics to identify areas that are potentially vulnerable to wildfire spread. Pre-fire conditions were compared to post-wildfire vegetation loss. NDVI rather than the Normalized Burn Ratio (NBR) was utilized to show the burn scar, because while NBR shows fire severity, the aim was to identify surrounding vulnerable areas based on their NDVI values in combination with the other two variables.

The database that was created had all layers resampled to a 20m spatial resolution at 5,362 columns x 3,423 lines; the area measured ~7,341.6504 km^2 (734,165.04 hectares). The geoprocessing of the data was performed in ArcGIS Pro (ESRI, 2020), where the NFC border features were utilized for selection and extraction. For both the NDVI and NDWI images, the calculations were completed using the Spatial Analyst tool 'Raster Calculator'. The following equations were utilized:

$$\text{NDVI [float (Band 8-Band 4) / float (Band 8+Band 4)} \tag{1}$$

$$\text{NDWI [float (Band 11-Band 8) / float (Band 11+Band 8)} \tag{2}$$

The purpose of this process is to show the differences in healthy vegetation and moisture content pre- and post-wildfire. To better observe the pre-fire and post-fire conditions, the NDVI and NDWI results of the post-fire images were subtracted from pre-fire images by using the raster calculator. This revealed the total loss of vegetation, and allowed observation of the moisture conditions in May 2018 and September 2018. Slope gradient was calculated using the 'raster slope' function to predict burn spread vulnerability (ESRI, 2020). The Digital Elevation Model (DEM) data source was the ArcGIS online WorldElevation/Terrain dataset (ArcGIS Online, 2020).

Each of the NDVI, NDWI and slope gradient data layers were reclassified into five classes based on observations of each layer's characteristics in the Lutz Creek burn area. Quantiles that divide data layers into equal groups were utilized. All of the layers were then combined using raster join procedures. For the reclassification of the NDWI results, the class ranks were 'inverted' to combine and correctly represent the raster classes. As a result, the combined map shows the highest NDVI results, lowest NDWI results and steepest slope results. The following calculation was performed using the 'Raster Calculator':

$$\text{reclassed NDVI + reclassed NDWI + reclassed Slope} \tag{3}$$

All three input variables were weighted equally. The most common fire susceptibility method used to represent forest burn vulnerability is the natural breaks classification. This method creates classes of similar values and separates them at breakpoints to effectively categorize the data, showing the levels of vulnerability and allowing for easy interpretation (Ghorbanzadeh et al., 2019).

3 Results and Discussion

The change in NDVI between May and September shows the immense burnt area (Figure 2). For this study, the focus was on the large burnt area in the centre of the image (Lutz Creek fire). The burnt area shown further south was a separate wildfire that extended significantly into the neighbouring Prince George Fire Centre. A close look at the burnt area in the NFC reveals a few dense areas with extreme burn scars caused by high-intensity burning.

This study shows that three variables NDVI, NDWI and slope gradient can be utilized to predict locations that are potentially vulnerable to wildfires. In this paper, the definition of 'vulnerability' is "how easily damaged a particular area is to a fire of a given intensity" (CIFFC, 2017).

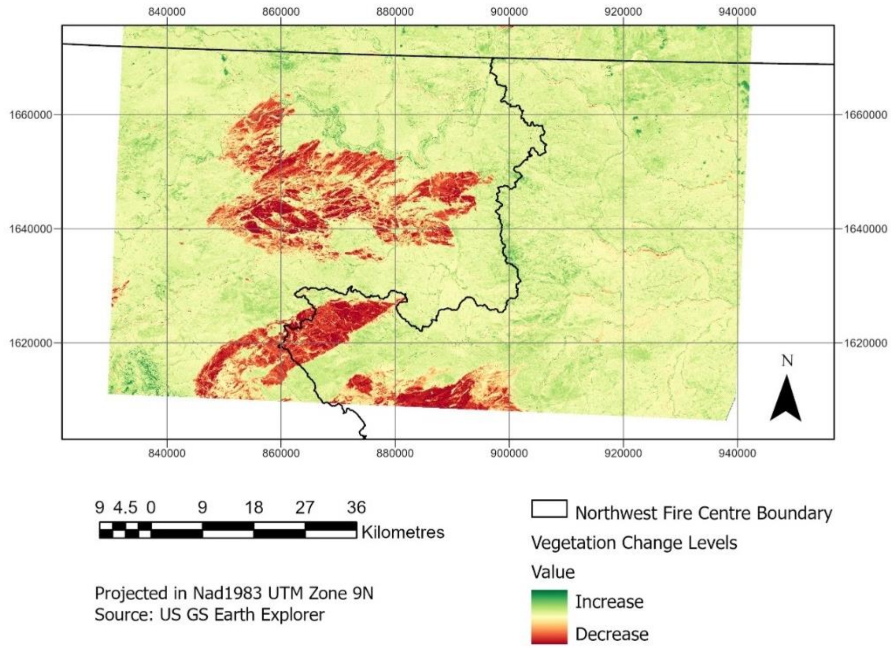

Figure 2: Lutz Creek Wildfire's Burnt Area (2018): The vegetation change difference between May and September

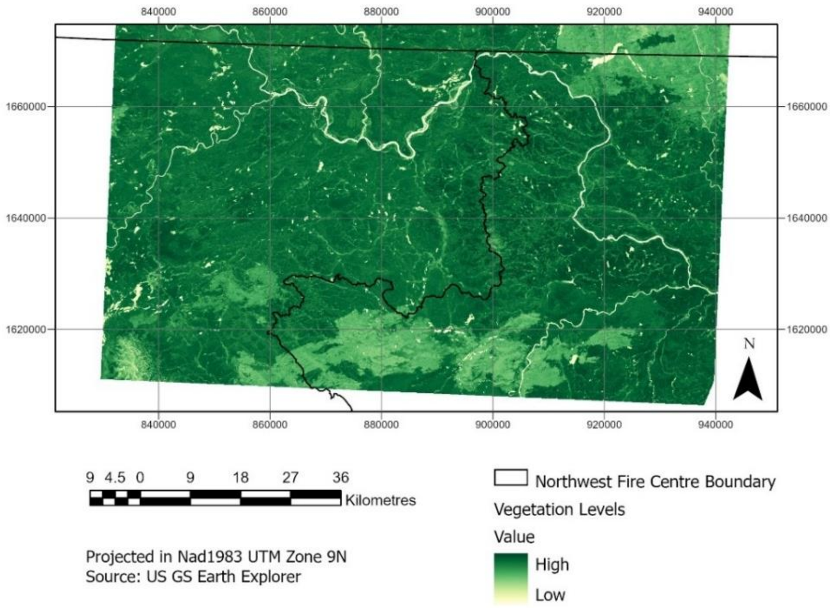

Figure 3: May NDVI Calculation Results pre-fire

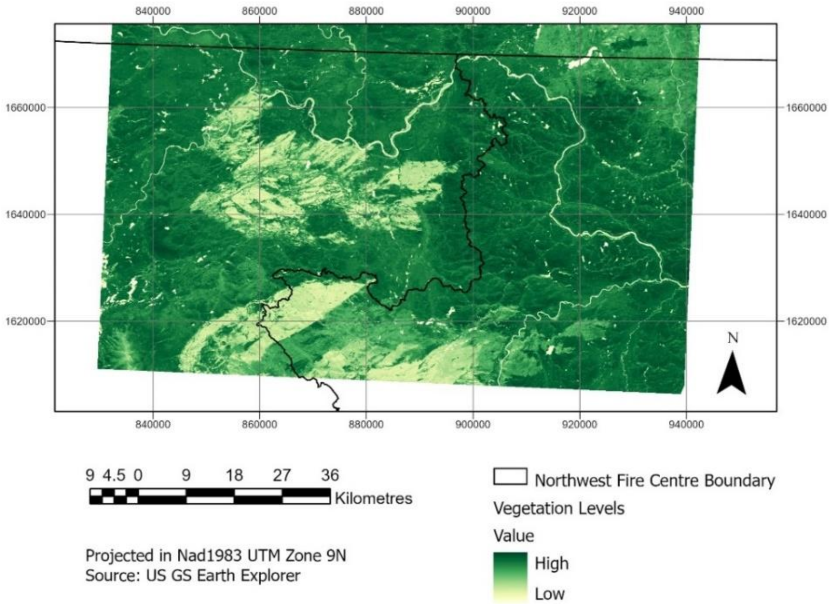

Figure 4: September NDVI Calculation Results post-fire

The NDWI for May and September (Figures 5 and 6), reveals a value range of between -1 and +1. Low NDWI results (below 0) show there are low to very low moisture levels. In Figure 6, the results show even lower NDWI levels, meaning drier conditions are present when compared to Figure 5. Meteorological conditions may play a role here (hot, dry conditions), and it is possible that large wildfires could create their own (drier) weather conditions. Meteorological data were not part of the analyses, as there are no weather stations located in close proximity to Lutz Creek.

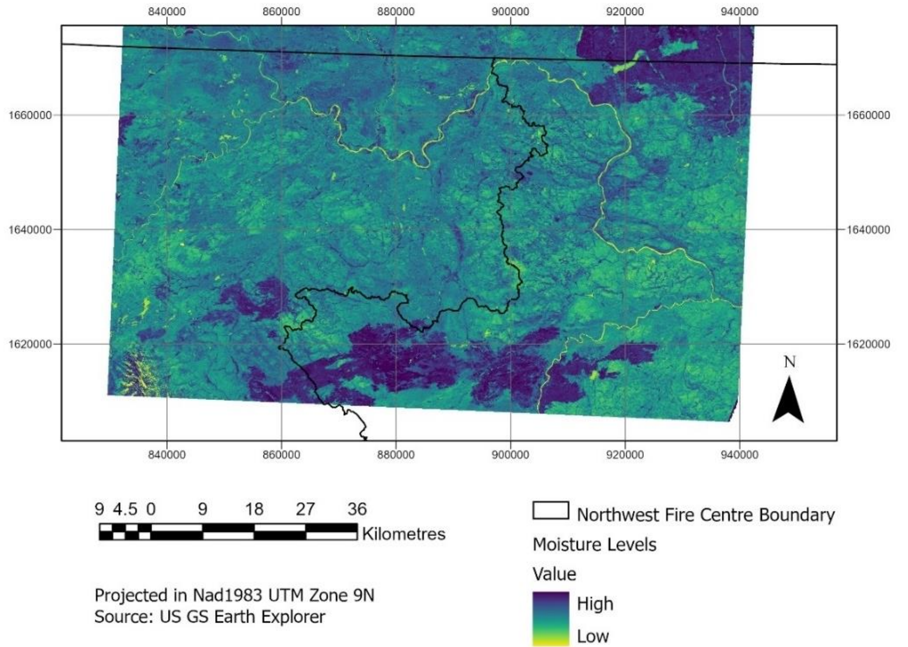

Figure 5: May NDWI Calculation Results pre-fire

A closer look at the changes from May to September (Figures 2 and 7) as well as the results in Table 1 reveals that in May the mean NDVI was 0.418, and the mean NDWI was -0.114. This shows that the vegetation is healthy but has a slightly low water content. For September, the mean NDVI was 0.460 and the mean NDWI was -0.230, showing that the vegetation was slightly healthier than in May, but that the region could have experienced low moisture levels in the interim period. The increase of 0.042 in mean NDVI between May and September can be attributed to the normal increases in vegetation growth during the summer months and warm temperatures, which promote healthier growth. Additionally, increased temperatures and lower precipitation during the summer months (as generally experienced in BC) may have resulted in drier vegetation conditions. Overall, the mean NDVI and mean NDWI from May and September show that there was increased fuel availability. Combined with generally lower moisture levels during the summer months, this provided ideal conditions for the wildfire that took place.

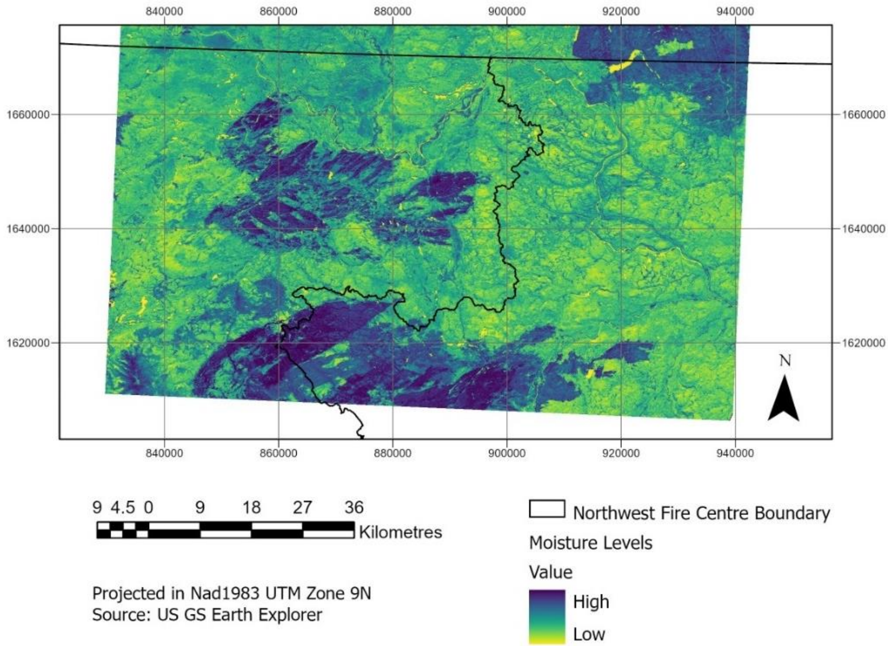

Figure 6: September NDWI Calculation Results post-fire

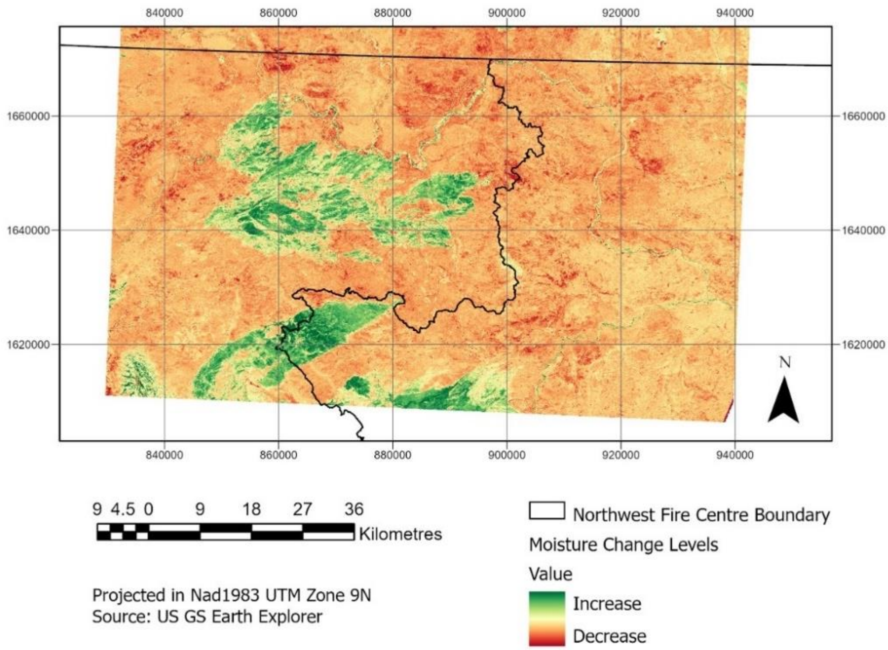

Figure 7: May-September NDWI Difference Results

Table 1: Mean Differences between May and September

Image	NDVI mean	NDWI mean
May	0.418	-0.114
September	0.460	-0.230
Change Difference	0.042	-0.116

The reclassified raster layers for NDVI and NDWI (Figure 8) reveal that there are quite a few clusters of high vulnerability where fire may thrive and spread. Most of the map shows moderately high vulnerability and provides a general picture of the locations where wildfire may spread.

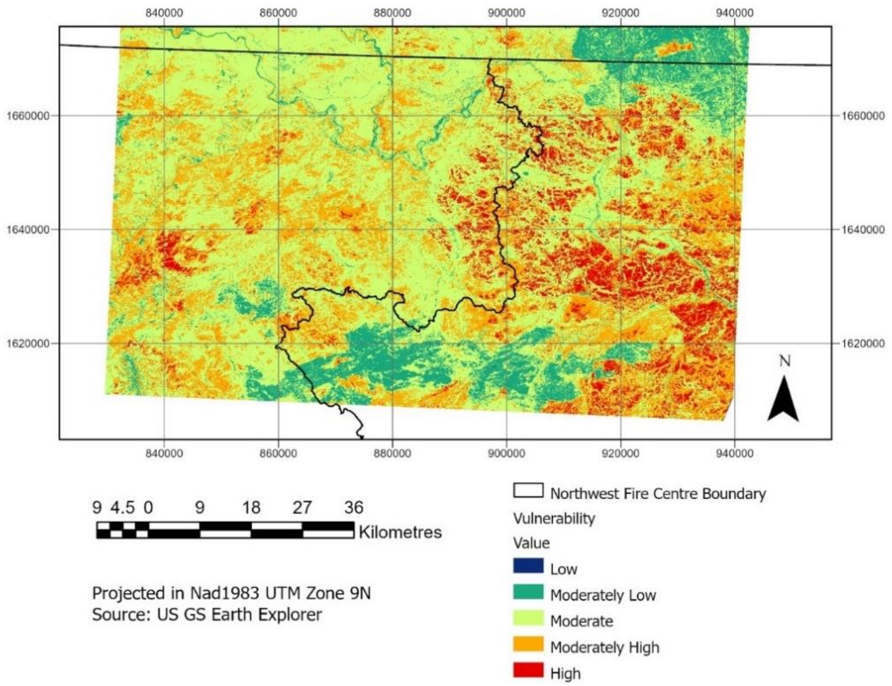

Figure 8: Land Vulnerability based on high NDVI and low NDWI results.

The reclassified raster results of NDVI, NDWI and slope gradient combined (Figure 9) reveal that more of the study area was identified as being vulnerable; locations of Moderately High to High vulnerability were found in the general area where the wildfire took place. The shape of the area where the fire burned can be observed. The results demonstrate that the area to the east, over the NFC district boundary, could be the next area to be affected by high fuel/burn spread.

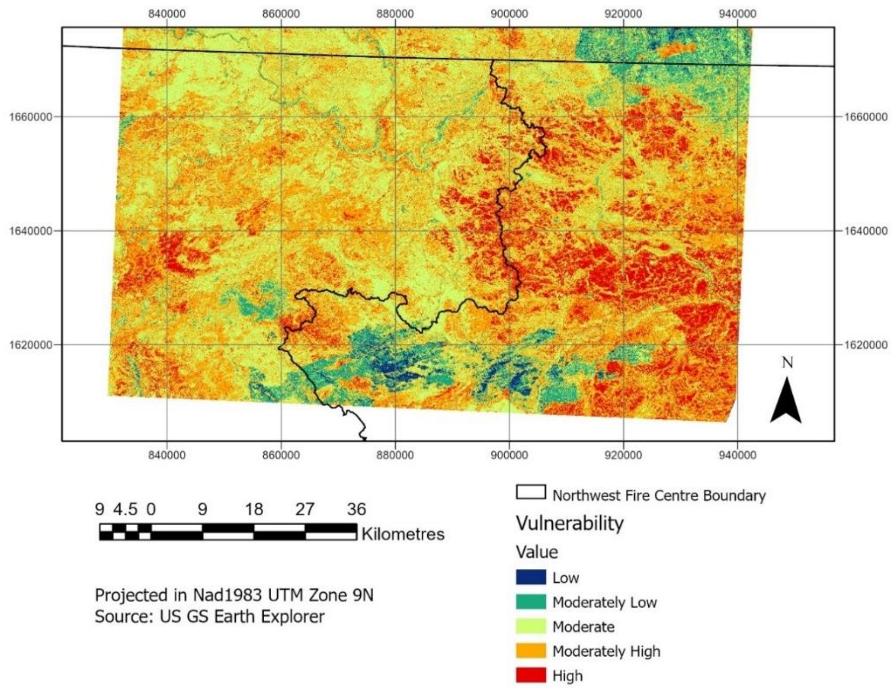

Figure 9: Land Vulnerability based on high NDVI, low NDWI and Slope Gradient results.

The NDVI and NDWI statistics for Figure 8 (that identify the five vulnerability categories) were extracted (Table 2). When the third variable, slope gradient, was added to the analysis (Table 3), the importance of including it becomes apparent.

Table 2: Burn Vulnerability Areas based on NDVI and NDWI

Category	Hectares	Square km	Percent
High	54,284.72	542.8472	7.3940
Moderately High	191,810.28	1,918.1028	26.1263
Moderate	410,662.24	4,106.6224	55.9360
Moderately Low	77,233.08	772.3308	10.5199
Low	164.04	1.6404	0.0223
No Data	10.68	0.1068	0.0015

Output classes that identify raster calculation results with values greater than seven (7) represent moderately vulnerable to highly vulnerable areas. Of note is that areas found to be of Moderately High to High vulnerability risk increased when the slope gradient variable was included (approximately 54% of the study area compared to approximately 33%). When slope was included, the Moderate vulnerability category decreased from approximately 56% to 37%, with most of the area being transferred to higher categories of fire-burn susceptibility.

Moderately Low and Low categories varied somewhat but accounted for just 10.5% (Figure 8 and Table 2) and 7.5% (Figure 9 and Table 3) of the study area.

Table 3: Burn Vulnerability Areas based on NDVI, NDWI, and Slope Gradient

Category	Hectares	Square km	Percent
High	95,916.48	959.1648	13.0647
Moderately High	307,317.52	3,073.1752	41.8595
Moderate	275,121.36	2,751.2136	37.4740
Moderately Low	55,780.88	557.8088	7.5979
Low	17.20	0.1720	0.0023
No Data	11.60	0.1160	0.0016

The main goal of this study was to determine whether Nurdiana & Risdiyanto's (2015) study showing NDVI and NDWI to be strong indicators of forest vulnerability to wildfires had relevance for the forests of British Columbia. The results illustrate that these factors can indeed be utilized to examine potential fuel loads for forest fires. When slope gradient was included as an additional variable, the calculations for wildfire vulnerability were improved. The combined variables of NDVI, NDWI and slope gradient could assist fire prevention efforts by helping to predict how a wildfire might spread. This particular combination of variables can also help identify how vulnerable land is to wildfire.

4 Conclusion

Using a major wildfire, in Lutz Creek (BC), from the Northwest Fire Centre district, this study assessed a combination of three variables – fuel availability (NDVI), fuel moisture (NDWI), and slope gradient - to ascertain whether they can be used to predict the vulnerability of land to wildfire spread. The NDVI variable was calculated to represent fuel availability as well as to observe wildfire spread/burned area. NDWI was utilized to observe general moisture levels in the study area. Slope gradient was calculated to determine where in the ecoregion wildfire spread is more likely. These three variables provide useful information for predicting land vulnerability to wildfire spread.

The results show that slope was a very important indicator for determining how a wildfire could spread. When slope gradient was included, larger areas were identified as being of Moderately High or High vulnerability. Although slope gradient by itself does not predict vulnerable areas for wildfire spread, when the three variables are combined, they present a good estimate of where/how a wildfire may spread.

This knowledge could potentially be applied to help fire management teams better predict, prepare for and monitor wildfire activity. Additionally, since wildfires are best left to run their course, fire management teams can predict the impact a wildfire may have, and decide at what point it will become appropriate to take mitigating action.

Finally, during particularly dry seasons, this prediction method could identify areas of land that are extremely vulnerable to wildfire spread; regions could thus take precautions, limiting human access to the areas identified. This would help prevent accidental fires caused by human negligence, which account for 40% of all BC wildfires (Government of British Columbia, 2020a). Since the data from studies similar to this one will in all probability show dispersed areas vulnerable to wildfire spread, Fire Centres would be unable to protect all identified vulnerable areas. Nonetheless, applying this approach could reduce the risk of very dangerous and large fires of human origin occurring in highly vulnerable areas.

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