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Research Article

Forest Fire Risk Zone Mapping of Aalital Rural Municipality, Dadeldhura District, Nepal

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Abstract
Forest fire is one of the leading causes of forest and wildlife loss. The objective of this study was to use satellite imagery and Geographic Information System techniques to assess the forest fire risk zonation map of the Aalital rural municipality. This rural municipality is a part of the Sudurpaschim province, Nepal; is prone to forest fires. Four fire risk zones were established in the study area i.e. very high, high, medium, and low-risk zone. Thematic layers were derived from topographic maps and satellite imageries. For the delineation of fire risk zones, a multi-parametric weighted index model i.e. the FRI (Fire Risk Index) method was adopted. The fire incidence data provided by MODIS were used to validate the resulting forest fire risk zone map. About 25.17% of the total study area lies under the very high-risk zone followed by 46.51% under high risk, 25.68% under medium risk, and 2.62% under the low-risk zone. It can be inferred that the majority of the area is at high risk of forest fire. This map of fire risk zone can help in disaster and forest management as valuable data to prepare effective measures for appropriate fire risk management in the area.

Keywords: geographic information system, fire risk index, remote sensing, satelite imagery, wildfire

1. INTRODUCTION

Forests are one of the most essential components of life on Earth, providing clean air, water, and food while also preventing soil erosion and mitigating climate change. Forests occupy 31% of the world's total land surface area [1]–[3]. Forests, on the other hand, are degrading day by day across the world owing to a variety of factors such as forest fires, urbanization, and population growth, all of which contribute to deforestation [4]. Nepal is a small country, covering only 147,516 square kilometers, yet it boasts a diverse climate, spanning from tropical south to alpine north. Nepal's forest area and other woodlands make up 44.74% percent of the country's total area [5].

A forest fire or wildfire is an uncontrolled fire that burns an area of forest. The nature and origin of the ecosystem, topography, land surface temperature, the weather at the time of the forest fire, and the amount of fuel available on the territory are the influencing factors of forest fires [6]–[8]. Land use and Land Cover (LULC) due to urbanization, modernization, and global population increase have caused land and soil exploitation, deforestation, and desertification leading to the increased number of forest fires worldwide. Fire causes natural disasters such as increased soil erosion, floods, landslides, as well as a loss of water yield and depletion of water quality, the extinction of species, and a decrease in visual amenity [9]. It causes some positive effects, such as aiding in the recycling of bound-up nutrients in the soil, burning old and dead vegetation, and clearing space for newer vegetations to grow [10].

In recent years, there has been a dramatic increase in the number of forest fires in various areas around the world, including the western United States, Australia, western and southern Europe, and various unexpected locations above the Arctic Circle [11]. A global study conducted between 2003 and 2015 to understand the forest area depleted by forest fires revealed that approximately 67 million hectares of forest land area were affected by forest fires on an annual basis [12]. Only in 2015, approximately 98 million hectares of total forest land were affected by fire [5]. As of December 24, 2021, the United States had faced 58,288 wildfires that had burned 7,819,070 acres of forest land since the beginning of 2021 [13]. Similarly, Canada had one of the worst forest fire years in history in 2021. According to a report published by the Canadian Interagency Forest Fire Center [14], there were a total of 6,224 fires that burned an area of 4.18 million hectares

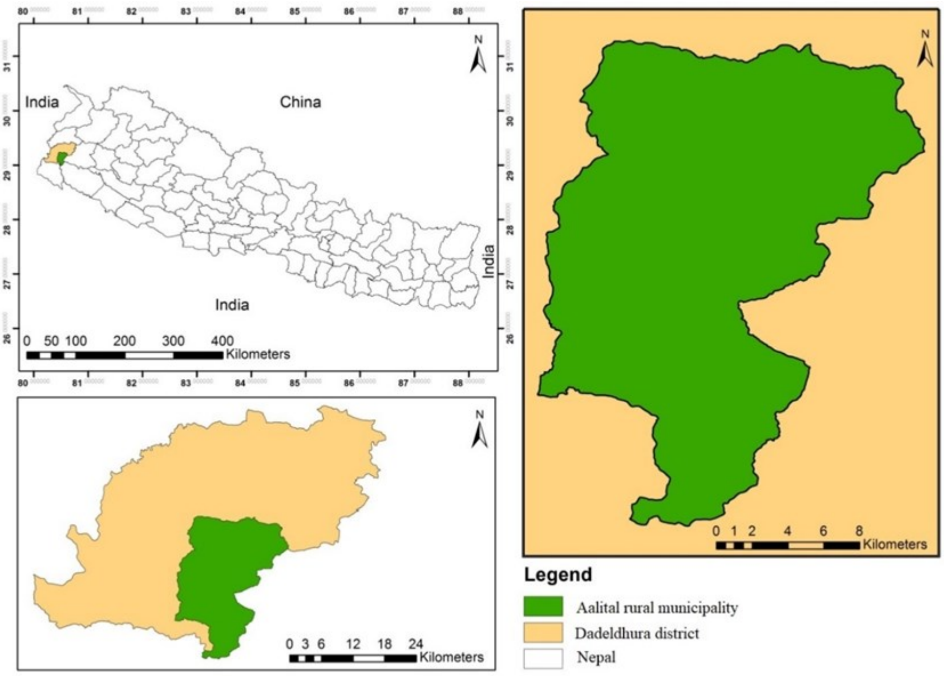

Figure 1. Map of study area showing Aalital rural municipality

throughout the year. When it comes to global forest fire trends, the devastating wildfire in Australia from September 2019 to March 2020 is one of the worst in terms of area burned, human and wildlife casualties, and environmental damage [15].

In a mountainous country like Nepal, people are more likely to use forest fire as a land management tool, clearing forest areas for cultivation and settlement [16]. Nepal recently faced the worst scenario of forest fires throughout the country in the year 2021, with at least 60 wildfire burns in 22 different districts of Nepal, resulting in 5 deaths and the loss, of a large amount of wildlife, cultivated crops, and domestic animals [17]. It appears that there is an irregular pattern in the prevalence of forest fires in Nepal, particularly during the dry seasons from November to June each year [18].

Forest fire assessment is a tedious task due to the lack of availability of the relevant data [19]. Developing nations, such as Nepal, still lack proper access to satellites and GIS-based technology, even though significant progress has been achieved in the development of new methods and instruments for assessing forest fire risk in the global situation. The integrated use of remote sensing (RS) with Geographic Information System (GIS) is quite popular to detect forest fire. Various active forest fires can be monitored using geostationary satellite sensors like Geostationary Operational Environmental Satellite (GOES) or Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board of Meteosat Second Generation satellite (MSG). Different geosynchronous satellites can also be helpful in forest fire monitoring such as Advanced Very High-Resolution Radiometer (AVHRR) onboard National Oceanic and Atmospheric Administration satellites (NOAA), the Along Track Scanning Radiometer onboard ERS-1 (ATSR) and 2 (European Remote Sensing Satellite 1 and 2) and the Moderate Resolution Imaging Spectroradiometer(MODIS) onboard of the Terra and Aqua Satellites [20]. The major issue in the assessment of forest fire is the scale, its size the area it covers, and more practically the inaccessibility it possesses, and all of these makes remote sensing one of the most prominent, practical, and widely applied method [21].

Detection of forest fire in the early stage is very crucial in fighting the fire and saving the forest from getting more destroyed. Only a few developed nations have been able to detect forest fires beforehand or in their early phase. This research aims to assess the forest fire risk zonation map of the Aalital rural municipality of Dadeldhura district, Nepal. This research will aid in the mapping of appropriate forest fire risk zones, as well as in the conservation and promotion of green forest in those areas, by implying appropriate risk management and preservation techniques both before and after any forest fire.

Table 1. Collected datasets in the study area.

Datasets	File type	Data type	Details	Spatial resolution	Sources
Study area boundary	Shp	Polygon	Outline of the study area		Department of Land management and achieve Nepal (http://www.dolrm.gov.np)
Road	Shp	Lines	Highway and associated roads	1:250000	OCHA, Nepal (https://www.unocha.org/)
Settlement	Shp	Points	Clusters of settlements	1:25000	OCHA, Nepal (https://www.unocha.org/)
Land cover 2010	Tiff	Raster	LULC category	30 m	ICIMOD (https://www.icimod.org)
SRTM DEM	Tiff	Raster	Elevation, slope, and aspect	30 m	USGS Earth Explorer (https://earthexplorer.usgs.gov)
Land surface temperature	HDF	Raster	The monthly temperature of night and day time	1 Km	NASA/ MODIS/ MOD11C3 (https://lpdaac.usgs.gov/products/mod11c3v006/)
MODIS Fire data	Shp	Points/ Polygon	Latitude, longitude, confidence, burn date and area,	1 Km	NASA/ MODIS (https://firms.modaps.eosdis.nasa.gov/active_fire/)

2. MATERIALS AND METHODS

2.1 Study area

The study was conducted in Aalital rural municipality (EW: Latitude: 29.1351°N and Longitude: 80.5124°E) of Dadeldhura District, Nepal (Figure 1). The rural municipality occupies an area of 292.87 km^2; politically divided into eight wards. It has a population of 18,531 [22]. Currently, there is no concrete road, 20.8 km of gravel road, and approximately 105 km of earthen road in the rural municipality.

2.1.1 Climate of the study area

The rural municipality lies in the western part of the Chure range with an arid steppe cold climate having an average land surface temperature of 4.1° C to 17.1°C and rainfall of 1500 to 2000 mm [23]. It lies in the humid subtropical range and consists of a dense *Shorea robusta* Sal forest associated with *Terminalia tomentosa* (Saj), *Syzygium cumini* (Jamun), *Bombax ceiba* (Simal), etc. The study area faces huge fire risks caused by natural or human activity throughout the year.

2.2 Data collection

In this study, variables directly related to the incidence of fire occurrence have been considered as the independent variables and it includes Land used land cover (LULC), land surface temperature, topographic factors (slope, altitude, and aspect), distance from the road, and proximity to the settlement area [24]. Similarly, the incidence of fire occurrence was considered as dependent variables as it is not directly related to fire occurrence. The independent and dependent datasets were collected through different data sources as listed in Table 1.

2.2.1 Land use land cover (LULC)

LULC is considered to be the most important factor for the spreading of fire. A huge amount of degraded land, greater slope, human activities like grazing make the area highly susceptible to forest fire [25]–[27]. Thus, LULC analysis was carried out by categorizing it into nine different land use classes through the provided data of ICIMOD having a spatial resolution of 30m.

2.2.2 Land surface temperature (LST)

The LST of any area determines the vegetation type of the area and is directly related to the moisture content as well as relative humidity. The dryness of a region makes the site more prone to fire. The dry subtropical climatic condition makes the study area more vulnerable to forest fires. The LST algorithm produces day and night LST values at 1 km spatial resolutions in swath format using brightness temperatures from MODIS bands 31 and 32. It produces LST HDF files from MODIS Level-1B 1-km data. NASA/MODIS monthly mean land surface temperature data from 2001 to 2020 was used in this analysis. Monthly temperatures for each year (2001-2020) were averaged to create an effective simulation for the fire risk area, and then a layer was created.

Table 2. Weight, value, and rating allocate to various variables.

Variables	Weight (%)	Class	Value Assigned	Rating
		Water	0	No risk
		Human buildup	1	Very low
		Bare land	1	Very Low
		Agricultural land	2	Low
Land cover	40	Grass and Shrubland	2	Low
		Sparse vegetation	3	Medium
		Hardwood	4	High
		Mixed vegetation	5	Very high
		Coniferous forest	5	Very high
		< 10	1	Very Low
		10 -15	2	Low
Land surface temperature	20	15 - 20	3	Medium
		20 - 25	4	High
		25 - 30	5	Very high
		<10	1	Very low
		10 - 15	2	Low
		15 - 20	2	Low
Slope (%)	10	20 - 25, 25 - 30, 30 – 35	3	Medium
		35- 40	4	High
		40 - 45	4	High
		>45	5	Very high
		0- 500	5	Very high
Distance from the road (m)	5	500 - 1000	4	High
		1000 - 1500	3	Medium
		>1500	2	Low
		0- 1000	5	Very high
Proximity to settlement (m)	5	1000 - 1500	4	High
		1500 - 2000	3	Medium
		>2000	2	Low
		North	1	Very low
		Northeast	2	Low
		East	3	Medium
		Southeast	4	High
Aspect	5	South	5	Very high
		Southwest	5	Very high
		West	3	Medium
		Northwest	2	Low
		North	1	Very low
		0-500	5	Very high
		500-1000	4	High
Elevation(m)	5	1000-1500	4	High
		1500-2000	3	Medium
		2000-2500	2	Low
		>2500	1	Very low

Source: Gheshlaghi et al. [24], Jaiswal et al. [31], Alkhatib, A. A. [32]

2.2.3 Topography

There is an effect of terrain attributes on the forest survival following wildfire [28]. Hence, slope, aspect, and elevation were retrieved using SRTM DEM (30 m) under topographic variation, as shown in Table 1. The Digital Elevation Model (DEM), which was computed by the Shuttle Radar Topography Mission (SRTM) and extracted from the US Geological Survey's EROS Data Center, was used in this work to extract elevation, slope, and aspect data.

2.2.3.1 Slope

Slope influences the fire spread in two different ways: i) Preheating (radiation and convection) and ii) Draft. Low dense air warmed by the surface on slopes creates a channel for lighter air to move up the hill, resulting in a draft. Cooler air rises from below, displacing the warmer, less dense air. As a result, during the day, local breezes tend to detonate slopes. Wildfires usually burn upslope due to the local up-slope winds. As a result, the steeper the slope, the faster and more furiously the fire will burn.

2.2.3.2 Elevation

The altitude of the area differs from 1292 to 2198 m mean sea level. Higher elevations are associated with greater rain availability. Therefore, the fires are likely to be less awful at higher elevations [29]. However, the elevation range (900m) does not entail a significant rainfall difference between the highest and the lowest areas of the study site.

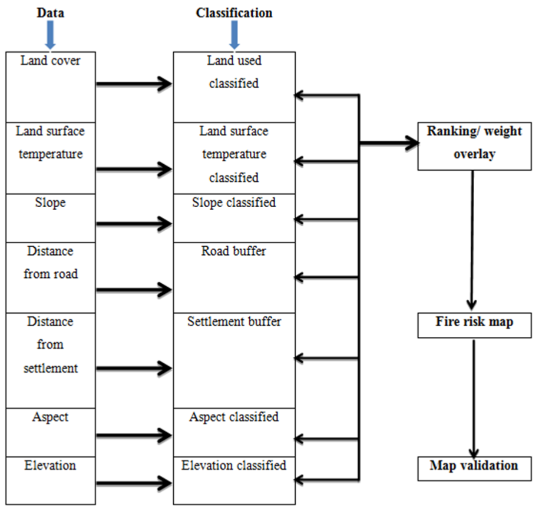

Figure 2. Flow chart of data analysis.

2.2.3.3 Aspect

Aspect is the direction in which the slope is facing. It regulates the amount of heat emitted from the sun that is received. In comparison to slopes facing northerly, slopes facing south to southwest may get the greatest sun radiation, resulting in a warmer environment. The warmer slope results in lower relative humidity, higher land surface temperatures, and faster moisture loss. As a result, fuel will be showier and drier, catching fire more immediately and burning more readily. On south-facing hills, the fire's duration will also be prolonged.

2.2.4 Distance from the road

Movement and activities of humans, animals, and vehicular on roads cause enough opportunities for human-made and accidental forest fires. Thus, any forest patches situated near roads patches are more fire-prone. The forests of the study area are joined with two vehicular and several other pedestrian roads induced the intentional and accidental forest fire cause. The sale of resin and some other NTFP is a primary income source for the population in this study area. During tapping and collection, people throw carelessly cigarettes butts, and matches, which cause fires in the forest area. The road network was digitized using topographic maps of spatial resolution 1:250,000 scale acquired from the OCHA, Nepal, and contains all highways and adjacent roads (Not including earthen road). These data are stored in a vector format in a GIS database (Shp files).

2.2.5 Proximity to settlement

Forested areas located near human settlements and habitats are more vulnerable to fire due to the cultural and habitation practices of the people. Despite few settlements within the study area forest, it still creates hazardous forest fires. The dataset settlements were digitized using topographic maps of spatial resolution 1:250,000 scale acquired from the OCHA, Nepal, and contains all clusters of settlements. These data are stored in a vector format in a GIS database (Shp files).

2.2.6 Dependent variables

Forest fire events and their flicker area or size are the only outcomes of the driven force when all

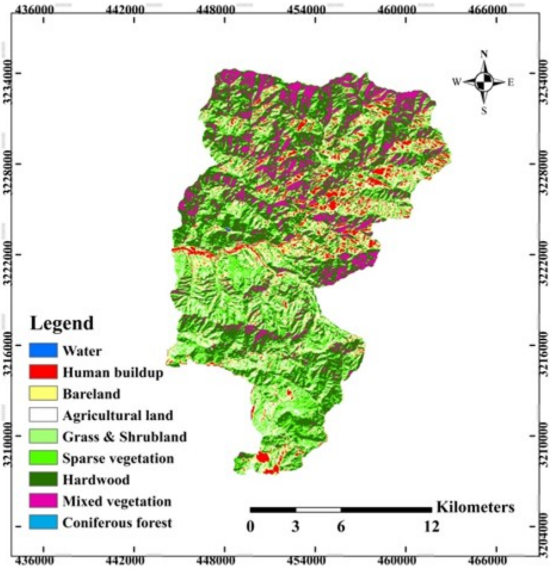

Figure 3. LULC map.

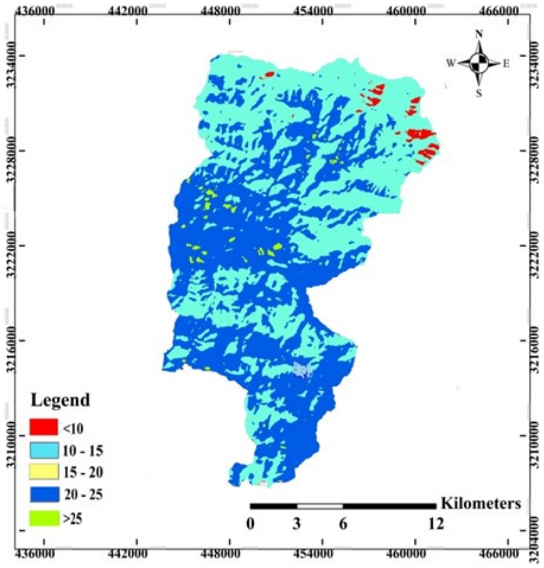

Figure 4. Land surface temperature map

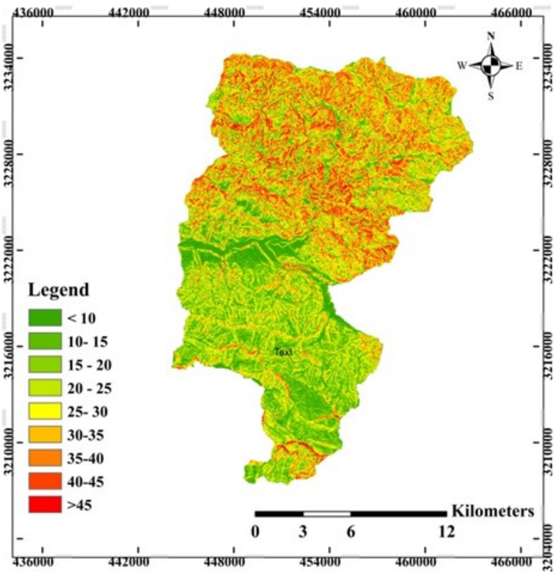

Figure 5. Slope map.

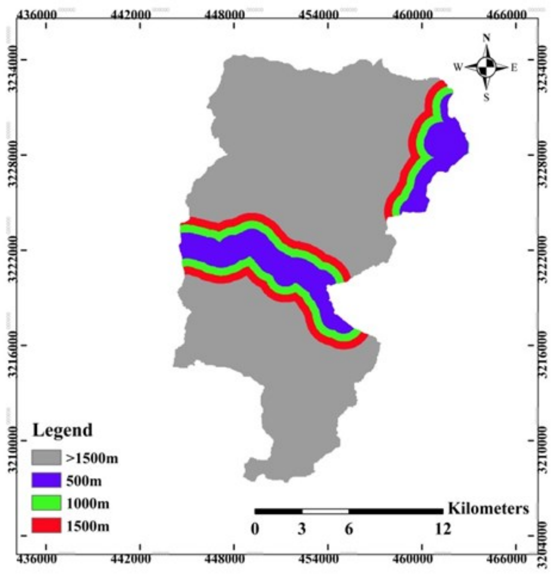

Figure 6. Distance from road map.

independent variables listed above have a favorable atmosphere for the flame. As a result, study area-dependent variables such as size and burning incidences have been considered. FIRMS (Fire Information for Resource Management System) use a 1km resolution MODIS instrument onboard NASA's Terra and Aqua satellites to provide active fire information for burn area identification. The detection confidence ranges from 0 to 100 %, with more than 30 % indicating finer and more accurate detection [30]. As a result, this study relied on data with a confidence level of better than 30%. Between 2016 AD and Mid 2021, a total of 130 forest fire counts (85% of all counts) were recorded in the rural municipality's forested territory.

2.3 Data analysis

Remote sensing and GIS were used to analyze the data. The factors for the forest that was in descriptive form were analyzed and converted into a rating system and risk index of the forest fire. These factors were analyzed and categorized in the following sequence of importance: land cover, land surface temperature, slope, road network, proximity to settlement, elevation, and aspect. After deciding the effect of an individual's forest fire risk factor, the various category classes of individuals' factors were given appropriate ratings. Weight was specified based on literature to avoid error and achieve a practical conclusion to the model [31]–[33]. A higher rating indicates that the factor has a greater impact on the fire risk in a given area (Table 2). The factors were then combined to calculate the

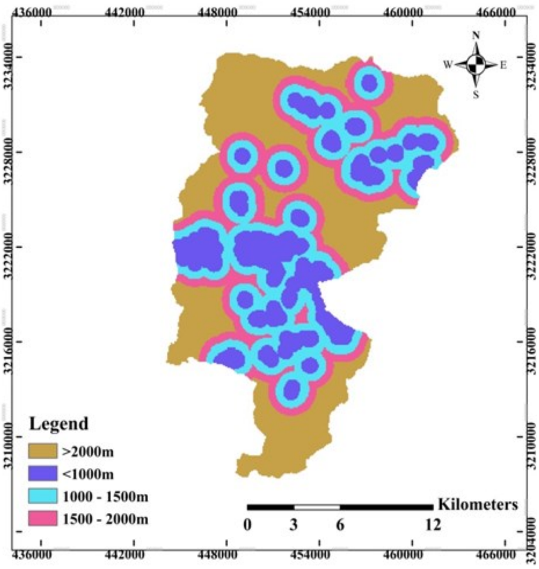

Figure 7. Proximity to settlement map.

forest fire risk index (FRI) using the forest fire risk index (FRI) model. The overall flow chart of the data analysis is shown in Figure 2.

$$FRI = 40\%\ LC + 20\%\ LST + 10\%\ DR + 10\%\ S + 10\%\ PS + 5\%\ E + 5\%\ A \quad \textbf{(1)}$$

Here, LC= land cover, LST = land surface temperature, DR = distance from the road, S= slope, PS = proximity to settlement, E = elevation and A = aspect.

2.4 Validation for fire risk zonation

In any natural hazards assessment, model validation is essential. It is the process of comparing model predictions to a real-world dataset to determine their accuracy or predictive ability [33]. Thus, we used MODIS hot spot data to corroborate our forest fire risk area conclusions in this study. The number of hot areas in each risk class was tallied to evaluate each index. It would be reasonable to locate the majority of hot spots in the very high-risk zone and the fewest in the low-risk zone.

3. RESULTS AND DISCUSSIONS

3.1 Thematic maps

Table 1 was used to create all the theme maps, including LULC map (Figure 3), Land surface map (Figure 4), Slope map (Figure 5), Distance from road map (Figure 6), Proximity to settlement map (Figure 7) and Elevation map (Figure 9).

3.2 Land cover

The study area contained hardwood forest of about 1/3rd (33.29 %) of the whole study area, triggers the risk of forest fire as hardwood is categorized as high risk. It was followed by sparse vegetation (15.08 %), grass and shrubland (14.12%), mixed vegetation forest (11.46%), agricultural land (10.39%), bare land (7.76%), built-up area (5.84%), water (1.02%) and coniferous forest (1.001%) (Figure 3).

3.3 Land surface temperature (LST)

The LST category of 20-25°C showing high risk for forest fire has covered approximately half of the whole area (49.69%), followed by 10-15°C (45.41%), 0-10 °C (2.1%), 15-20°C (1.48%) and more than 25°C (1.32%) (Figure 4).

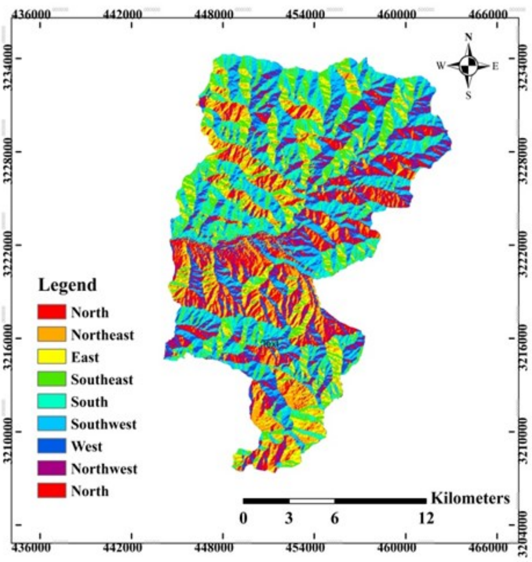

Figure 8. Aspect map.

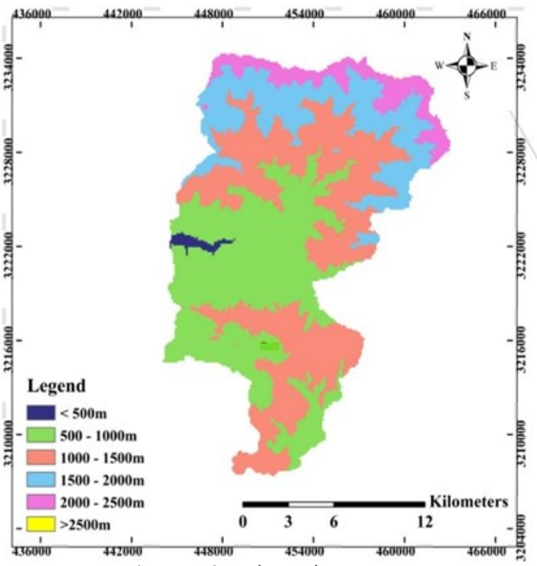

Figure 9. Elevation map.

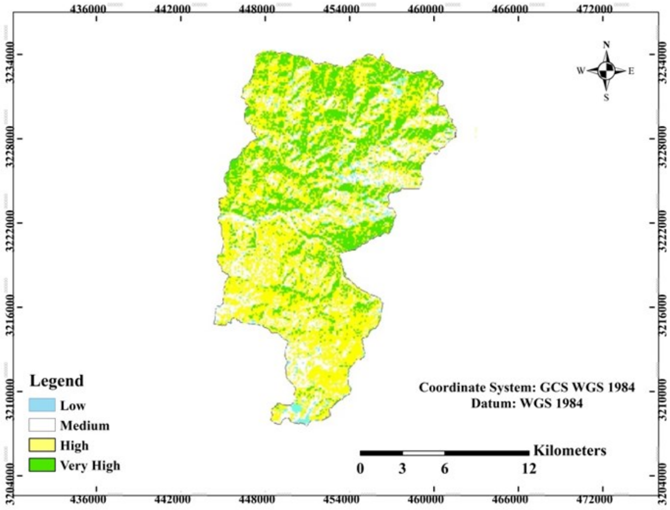

Figure 10. Forest fire risk zonation map.

3.4 Slope

Here, the majority of the area belongs to the area having less than 35° slope and indicates a mostly low and medium risk of a forest fire. The slope category of 15-20° has covered the highest area (15.34%), followed by 20-25° class (15.14%), 25-30° class (14.67%), 30-35° class (13.78%), 10-15° class (12.82%), 35-40° class (11.29%), < 10°class (8.05%), 40-45° class (6.81%) and more than 45° class (2.06%) (Figure 5).

3.5 Distance from the road

Only gravel roads were taken into account. About 10.91% of the area was classified as very high-risk (< 500 meters from a road), 6.174 % of the total area was classified as high-risk (500–1000 m), 6.212% of the total area was classified as medium-risk (1000– 1500 m), and 76.69 % of the total area was classified as low-risk (Figure 6).

3.6 Distance from the settlement

About 20.59% of the area felled under the higher risk category (<1000m), 23.31% felled under the medium-risk category (1000-1500m), 18.27% felled under the low-risk category (1500-2000m) and 37.82% area felled in no risk category (>2000m) (Figure 7).

3.7 Aspect

The rural municipality covers almost all aspects with approximately equal area. Southwest (17.48%) aspect and southeast (14.54%) aspects consist more geographical coverage area followed by south (12.91%), north (12.178%), northwest (11.38%), northeast (11.17%), west (10.90%), and east (9.40%) (Figure 8). In total, over 45% of areas in the south, southwest, and southeast were highly vulnerable to wildfire.

3.8 Elevation

The area covered by the 1000-1500m elevation class was the largest of the six elevation classes i.e., 37.12% followed by followed by 500-1000m (36.69%), 1500-2000m (18.04%), 2000-2500m (7.31%), and >2500m (0.004%) (Figure 9).

3.9 Forest fire risk zonation

About 25.17% of the total area of the rural municipality felled under a very high-risk zone followed by 46.51% under high risk, 25.68% under medium risk, and 2.62% under low-risk zone (Figure 10). The northern part of the study area consists high density of hardwood and mixed vegetation (Figure 3), high slope (Figure 5), south and southwest aspect (Figure 8) in comparison with southern part, which increase overall risk of a forest fire.

3.10 Validation for fire risk zonation

Out of the total 45 forest fire occurrence points according to MODIS fire data, 27 points lay in the very high-risk zone, 14 lay in a high-risk zone, 4 points lie in medium risk zone and no point lies in a low-risk zone. The results in Figure 11 reveal that the majority of the MODIS-derived hot spots are located in the very high-risk zone.

3.11 Discussion

Approximately 45% of the study area falls under the south, southeast, and southwest aspects, implying that these aspects pose a higher risk of fire incidence. More than half of the area is covered by a 20-40 degree slope, which is a highly flammable forest fire. Because of nearby roads (500m) in the study area, approximately 10.91% of the area falls within the fire risk zone. Locations nearby road coverage are more prone to fire incidence than locations further away from the interference of humans, such as good transporting, leakage from tankers, smoking, oil, and so on, that might induced and result in fire [34]. Similarly, a natural environment near a human settlement is extremely sensitive to fire as a result of human-caused activities that can result in an unintentional fire. In the research area, there are more communities near and within the forest, accounting for approximately 20.59% of the total area, increasing the risk of wildfire. Due to a multitude of variables such as Sal forest [35], height gradient, sloppy terrain, and so on, this rural municipality is located in the Siwalik region, which is the most prone to fire risk among all other regions [36]. Land use/land cover types, proximity to roads/settlement, aspect, elevation, and slope are the most important parameters for wildfires [37]. In general, the south side gains more sunlight, which dries out the soil and speeds up the ignition process [32].

About 0.22 million ha of forest land were burned by fire, in 2016, accounting for 3.4% of Nepal's total forest area and destroying 2500 ft^3 of valuable timber and about 12500 ft^3 fuelwood, resulting in a loss of approximately US$ 107,798 [18]. Forest fires caused the most burnt area annually in Nepal between 2000 and 2013, with 30,220 hotspots in 2005, 2009, and 2012. From 2000 to 2016, about 35,374 wildfire incidents were found in Nepal, with burnt areas of 17, 23, and 920 ha [18]. This finding is in line with that of Chaudhary et al. [35], who found that the western part of Nepal is at more risk of fire due to low rainfall. Forest fires are becoming more common in Nepal, posing a serious threat to human life and the natural environment [17]. According to Matin [37], 89% of wildfires in Nepal occur in the period of pre-monsoon season (March-May). From March to June each year, more than 40,000 ha of Nepalese forests are burned down, as a result, enormous degradation and destruction of biodiversity and forest occurs [38].

Wildfire is regarded as one of the most destructive drives, wreaking havoc on resources in a short period [39]. For wildfire prevention and control management of risk zones, including variables that cause fire, appropriate logistics, infrastructures, financial resources, and extensive understanding of the wildfire are required [36]. In western countries such as Australia, the United States, and Canada, forest fire risk maps are used to plan suitable efforts to minimize or prevent wildfires; however, in Nepal, such practices are lacking [40]–[42]. Preparing and publishing forest fire risk zonation maps will help Nepal's disaster preparedness efforts greatly in this area [42]. Hence, this study is an effort to identify wildfire high-risk zones in the municipality of Aalital, which will aid the local and federal governments in developing appropriate or suitable wildfire prevention and control mechanisms.

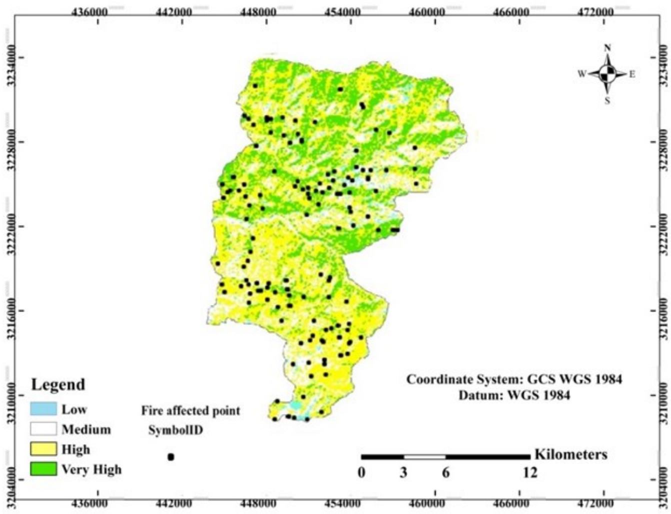

Figure 11. Forest fire risk zonation map with fire-affected point.

4. CONCLUSIONS

The study infers that the majority of the study area falls under the high-risk zone of a forest fire. The number of forest fires is comparatively high in the northern region in comparison to the southern part. This study highlights the immediate necessity of preventing the incidence of forest fires in the very high and high-risk zone of the Aalital rural municipality. In general, creating a forest fire risk zonation map is the first step in developing a forest fire management and prevention strategy. As a result of the study's findings, authorities will be able to develop effective forest fire risk management initiatives in the area.

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