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Master thesis

ASSESSING THE WILDFIRE OF CHITWAN NATIONAL PARK, NEPAL

Vurderer skogbrannen i Chitwan nasjonal park, Nepal

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Abstract

Although fire has long been an Essent foremost of the forest ecosystem and has a significant impact on the flora and fauna, it is also widely believed to be one of the main causes of biodiversity loss and environmental deterioration. Furthermore, little study has been conducted on the timing and location of wildfires in Nepal. Because of this, Chitwan National Park is highly susceptible to wildfires (DFRS, 2015). For wildfire monitoring, detection, and management, geographic information systems (GIS) and remote sensing (RS) are frequently used. Quick and affordable solutions are produced through RS and GIS. United States Geological Survey Earth Explorer website was used to retrieve the Landsat image and digital elevation module. The ICIMOD website was used to acquire information on the study area's land use, land cover, road network, and population. A difference-normalized burn ratio (dNBR) was calculated using geographic information software to assess the severity of the burns and A multi-criteria weighted-overlay analysis was performed to determine the wildfire risk zone. Throughout the research period, 3617 fire events were reported in CNP, with 3135 of them taking place in the core region and 482 in the buffer zone. The variance in the mean value of fire frequency was examined using one-way ANOVA, and it was found that the number of wildfire occurrences during the summer months was substantially high (p-value less than 0.05 at the 5% level of significance). Since 2021 saw the most fire events in CNP from 2001 and 2021 (384 fire incidents), the severity of the year's burns was calculated. A total of 76558.68 hectares of forest were burned in CNP in 2021, per the burn severity study. The research indicates that there is a high risk of wildfire for 6391.6 hectares in CNP, a moderate risk for 154054.4 hectares, and a low risk for 7754.02 hectares. Most events took place in the core area, which was the consequence of deliberate fire used to manage grasslands and slow down succession. However, prevention is advised since it might impair the species that depend on a specific grassland ecosystem.

Keywords: Burn-severity, Chitwan, GIS, Nepal, Remote sensing, Wildfire

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Abbreviations

CNP: Chitwan National Park

DEM: Digital Elevation Module

DFRS: Department of Forest Research and Survey

dNBR: Differenced Normalized Burn Ratio

DNPWC: Department of National Parks and Wildlife Conservation

DOS: Dark Object Subtraction

F: Flat

GIS: Geographical Information System

GON: Government of Nepal

GPS: Global Positioning System

Ha: Hectare

HKH: Hindukush Himalaya

ICIMOD: International Centre for Integrated Mountain Development

LST: Land surface temperature

LULC: Land Use and Land Cover

MODIS: Moderate Resolution Imaging Spectro-radiometer

NASA: National Aeronautics and Space Administration

NDVI: Normalized Difference Vegetation Index

NE: Northeast

NOAA: National Oceanic and Atmospheric Administration

NW: Northwest

OLI: Operational Land Imager

S: South

SE: Southeast

SRTM: Shuttle Radar Topography Mission

SW: Southwest

TIRS: Thermal Infrared Sensor

USGS: United States Geological Survey

VIIRS: Visible Infrared Imaging Radiometer Suite

W: West

Assessing the wildfire of Chitwan National Park, Nepal

1. Introduction

1.1 Background

A wildfire is any fire on forestland that is not used to maintain or manage the forest according to an approved plan (Parashar & Biswas, 2003).Wildfire has significantly formed many ecosystems ((Franklin, Regan, & Syphard, 2021)). Even though fire is critical to the development and distribution of today's ecosystems, human activities and climate change have changed global fire regimes, exposing many ecosystems to risk (Pausas & Keeley, 2009).Wildfire is a significant contributor to forest loss and degradation, biodiversity, and ecosystem functioning, as well as causing irrevocable harm to human health, lives, and property(Zhang & Biswas, 2017). Wildfires are one of the most severe environmental issues confronting the globe today, and they are becoming increasingly dangerous to forest ecosystems (Moreira et al., 2011). Wildfires threaten human life and result in significant losses of lives and property (Wibbenmeyer & McDarris, 2021). Forest fires are reported to have become more frequent in recent years, both globally and in Nepal (Yadav et al., 2020) The frequency of intense wildfire occurrences with disastrous effects has been rising, despite the fact that the yearly worldwide area burnt has been declining for some time. Recurring fire activities affect over a third of the world's surface, with an average of 4.5 million Km2 of land burning annually (Robinne et al., 2018).

In Australia, the 2019–2020 bushfire season was one of the most destructive in history, with estimates of the total area burned ranging from 24.3 to 33.8 million hectares. (Deb et al., 2020).According to a report, the 2019–20 bushfires may have altered between 15% and 23% (28–43 thousand hectares) of the temperate rainforest in south-eastern Australia, needing century-long recovery, assuming recovery is at all conceivable under south-eastern Australia's drying environment (Collins et al., 2021). The years 2019 and 2020 witnessed the worst wildfires in the Amazon region in a decade, and during the summer 2019 dry season, concern was raised globally due to a sharp increase in forest fires in the region, with Brazil being the most severely impacted nation (Ruiz-Saenz et al., 2019). According to (Silveira, Silva-Junior, Anderson, & Aragão, 2022), Bolivia and Brazil share the Amazon region that is most affected by wildfires, with the former contributing on average >70% of active fires and more than half of the burned area each year, while the latter has contributed with about 15% of active fires and one-third of the burned area.

Globally, the frequency of forest fires is rising, with Asia accounting for most of the major incidences (Giglio, Van der Werf, Randerson, Collatz, & Kasibhatla, 2006). In South Asia, the tropical moist deciduous forest and tropical dry deciduous forest had the highest number of fire occurrences. Bangladesh has the most emerging hotspot forest area (34.2%) among the seven South Asian nations, followed by India (32.2%) and Nepal (29.5%) (Pachauri & Meyer, 2014). People in the Hindukush Himalaya (HKH) region suffer economic losses because of forest fires caused by both natural and artificial causes, raising carbon dioxide emissions and contributing to climate change (Chowdhury & Hassan, 2015). Higher than 600,000 active fires with a confidence level of 50% or more were reported in the HKH region by MODIS sensors over a ten-year period (January 2010 to May 2021).

Every year in Nepal, forest fires pose a danger to destroying tropical, subtropical, and temperate forests in the Terai, Siwalik, and mid-hills region, especially those with significant populations of *Shorea robusta* and *Pinus roxburghii*. Grazers, poachers, and collectors of non-timber forest products are responsible for 58 per cent of all forest fire incidents, while negligence accounts for 22% and accidents for 20% of all incidents (Kunwar & Khaling, 2006). Other than anthropogenic intervention, erratic weather patterns and a protracted winter drought are other factors that contribute to forest fires in Nepal, which have underlined the need for an effective system for assessing, warning about, and monitoring forest fire risks (Matin et al., 2017)The hot and dry weather and the proximity of the forests to human settlements, highways, and agricultural land cause massive devastation in the tropical and sub-tropical forests of Terai and Siwalik hills every year (Kunwar & Khaling, 2006). Nepal's wildfires are also due to a changing climatic pattern and a long winter drought. The protracted drought in 2009 increased the number of fire incidents substantially, resulting in deaths and massive devastation of human dwellings and woods (Qadir, Talukdar, Uddin, Ahmad, & Goparaju, 2021). The incidence of wildfires is not constant throughout the year because the availability of fuel on the forest floor and the appropriate conditions for fires are most ideal in the dry season (November to June) (Parajuli et al., 2020). The year 2021 has turned into one of the worst for forest fires. The whole range of hills in Nepal that extended through Northeast India and up to Myanmar was affected by uncontrolled forest fires, as were the states of Himachal and Uttarakhand in western Himalayan India (Bhattarai et al., 2022). With the number of wildfires in the year being 15 times more than that of 2020, forest fires in Nepal in 2021 might be regarded as the worst in a decade (H. P. Pandey, Pokhrel, Thapa, Paudel, & Maraseni, 2022).

1.2 Fire as good and evil

Fire has long been a vital component of the forest ecosystem and has been crucial in influencing the flora and animals. Individual members of a species may benefit or suffer from a fire, but the impact of a single fire is not as substantial for the ecology as a shift in the fire regime (Hamilton, 2007).

Evolutionary adaptations have prevented many landscapes from being devastated by fire alone. However, by modifying the timing of the fire, its strength, the fuels it consumes, or the biological capability for utilizing the burn's aftereffects, fire and hoof, fire and axe, fire and plough, and fire and sword all increase the effects (Afreen, Sharma, Chaturvedi, Gopalakrishnan, & Ravindranath, 2011). The spatial and temporal variability in a fire's intensity can substantially influence the structure and species composition of communities following a fire (Russell-Smith, Ryan, & Cheal, 2002).

Few fire-tolerant species that can replace naturally occurring species in unaltered environments are strongly encouraged by fires (Verma, Singh, Mani, & Jayakumar, 2017). The frequency and severity of fires determine how they affect forest communities (He et al., 2019). Forest fires often start as ground fires that spread because of fuel from the buildup of dry litter, dry grasses, or herbaceous groundcover during the dry season from February to June (Ganteaume et al., 2013)

In fire-prone ecosystems, managing fire regimes is a critical problem for biodiversity preservation (Bowman et al., 2009). Different fire regimes may affect the structure, composition, and variety of a particular forest's vegetation (Pausas & Keeley, 2014). Forest species richness may be positively, negatively, or not related to fire frequency (Tessler, Wittenberg, & Greenbaum, 2016).

1.3 RATIONALE OF THE STUDY

Wildfire risk mapping considering multiple spatial properties is very critical for the prevention of fire, mitigation of its negative impacts, and land management (Avitabile et al., 2013). Understanding the fire risk zonation prediction and its documentation will provide trustworthy guidance to concerned authorities for implementing an effective plan to minimize disaster to some extent (Singh, Maharjan, & Thapa, 2020).

With a paucity of data on forest cover loss and a system that can create data on forest cover loss, Nepal lacks a defined policy for dealing with forest fires, as well as a means to monitor how wild animals are dying and losing habitat as a result of fires (Badal & Mandal, 2021). The first step in creating an efficient wildfire management system for the nation is assessing wildfires' spatial and temporal distribution. The delineation of the fire-prone zone by wildfire risk hazard mapping can help authorities use efficient wildfire prevention and suppression techniques across the nation (Singh et al., 2020). Remote Sensing and GIS are the most efficient, affordable, and trustworthy methods for managing wildfire risk (Sahana & Ganaie, 2017).

Previous research suggests that the anticipated fire potential zones can correlate with past fire incidences. Therefore, a fire risk map can be helpful in planning future land use (Chaudhary, Chhetri, Joshi, Shrestha, & Kayastha, 2016). Limited research has, however, been done on the location and timing of wildfires in Nepal. Accordingly, Chitwan National Pa**rk** is a drier area (Khanal, Poudel, Mathema, Pokharel, & Kharal, 2016), making it particularly vulnerable to wildfires. Therefore, this study aimed to evaluate the zone of wildfire danger in Chitwan National Park by using remote sensing and GIS.

1.4 Objectives

The general objective of the study is to assess the wildfire in Chitwan National Park.

Specific objectives:

1) To assess the seasonal pattern of wildfire in the Chitwan National Park (CNP).
2) To determine the wildfire risk zone of the study area.

2. Literature Review:

2.1 Wildfire as a good and bad phenomenon

Unplanned fires, such as those started by lightning, intrusive human activity, and errant controlled fire activities, are referred to as wildfires (Hoover & Hanson, 2021). Wildfires are natural phenomena that are vital components of many ecosystems, playing crucial parts in ecosystem dynamics and the survival of fire-adapted species (Pausas & Keeley, 2009). Fires generate new habitats with more resources and fewer competitors, and many plants have developed a range of adaptations for survival in the face of periodic fires to take advantage of such fire-generated habitats (Keeley & Brennan, 2012). At the ecological level, fires increase the number of ecological niches that are viable by forming snags, deadwood patches, and gaps; as a result, flames hasten the evolutionary process (Pausas & Keeley, 2019).

The evolution and construction of ecosystems depend on fire, yet fire may also be harmful since it can alter vegetation cover, density, structure, composition, variety, and productivity (Juárez-Orozco, Siebe, & Fernández y Fernández, 2017). Additionally, it may alter the amount of nutrients like C, P, Ca, Mg, Na, K, ON, NO3, and NH4 in the soil, which would modify the soil's chemical makeup (Knicker, 2007). Being a catastrophic agent, fire may quickly destroy enormous amounts of biomass, resulting in negative consequences such as post-fire soil erosion, water runoff, and air pollution (Johnstone & Chapin, 2006). With the introduction of significant amounts of greenhouse gases, forest fires play a significant role in the loss of biodiversity and the habitats of many endangered species in the area (Volkova, Roxburgh, Surawski, Meyer, & Weston, 2019). forest fire kills far more trees than any other natural disaster, including parasite assaults, insect infestations, cold, etc. (Alexandrian & Esnault, 1999). It also destroys dead vegetation, eliminates trash, and kills off active forest flora. Fires are a significant factor in the alteration of forests, and when fire frequency increases, there is a more significant chance of permanent forest loss, making forests highly fragile ecosystems (Driscoll et al., 2021).

Depending on their extent and character, forest fires are classified as surface, ground, underground, and crown fires. Surface fires, which burn undergrowth and dead material along the forest floor, are the most prevalent type of forest fire in South Asia. Forest fires in South Asia are largely caused by humans, who are preparing land for shifting agriculture, deforestation, controlled burning to stimulate fresh flushes of grasses, collecting minor forest produce, and burning firewood. In northeast India and Bangladesh, shifting agriculture is the leading source of fire (Reddy et al., 2020) In Nepal, around 27.8 per cent of forest fires result in biomass loss and damage (Bhujel, Maskey-Byanju, & Gautam, 2017). Around 3,75,000 acres of forest, which is extremely high took place between 2000 and 2014 (Khanal, 2015). Similarly, in 2016, devastating forest fire result in huge economic loos in Nepal, which cost USD 1,07,798 in forest resources (Bhujel, Sapkota, & Khadka, 2022).

2.2 Causes of Wildfire

Fires historically happen sporadically throughout time or space. The main contributors to this spatiotemporal variability include fuels, geography, weather/climate patterns, and ignitions. The biosphere's numerous components, including wildfire regimes, are anticipated to be significantly impacted by long-term climate variations, including global climate change (Swetnam, 1993). Future climate changes might lead to a long-term net increase in fire activity because of warmer weather conditions that would increase the frequency of days with extremely high and intense fire weather (Pitman, Narisma, & McAneney, 2007). Aside from that, seasonal changes in the fire incidence pattern are governed by seasonal fluctuations in the surface energy budget, which are influenced by insolation and precipitation, and which, in turn, reflect seasonal variations in soil moisture. Fire has a strong seasonal cycle in the western United States since the summer maximum dominates the general pattern of fire initiation during the year in lightning-started fires. Seasonal cycles of the meteorological conditions responsible for fuel ignition and flammability end with forests fire result in destruction of nature (Whitlock & Bartlein, 2003). Fire activity frequently increases if fine fuel cover is sufficiently continuous under dry or protracted drought conditions (Scasta, Weir, & Stambaugh, 2016). Conversely, these protracted droughts can lower biomass output over time, leading to more exposed soil and drought-tolerant forbs. Both anthropogenic and natural factors trigger wildfires. Increased heatwave frequency, accompanying droughts, and rising global temperatures enhance the risk of wildfire by fostering hot, dry conditions that are ideal for a fire. Reductions in fire weather are conceivable in some places due to changes in rainfall and seasonality, which complicate trends in fire weather (Barbero, Abatzoglou, Pimont, Ruffault, & Curt, 2020).

There are very few fires that originate naturally in Nepal, and 40% of wildfires in the mid-hills are started intentionally while 60% are caused by accidents (Kunwar & Khaling, 2006).

Among all recognized sources of forest fires, cattle grazing in search of fresh grass and smokers account for around 45 per cent of all fires.

2.3 Remote Sensing for Wildfire:

Nowadays, remote sensing (RS) and geographic information systems (GIS) are widely employed for wildfire monitoring, detection, and management. RS and GIS yield quick and cost-effective solutions. In combination with multitemporal RS data, GIS has become a potent tool for investigating and tracking the effects of several environmental elements in recent years (Sunar & Özkan, 2001). Utilizing RS approaches, it is possible to monitor vegetation, analyze burnt areas, identify vegetation that is susceptible to fire, and detect the thermal signal of ongoing fires (Khatakho et al., 2021).

Due to their extensive coverage and inexpensive cost, RS data sets are useful for the evaluation of burned areas as well as the identification and monitoring of fires in close to real-time. Sentinel-2 and Landsat-8, which provide high-resolution images and additional spectral data, have further increased the possibility of identifying ongoing fires and creating new burnt-area mapping indices (Rahimi, Azeez, & Ahmed, 2020).

The excellent temporal resolution of MODIS's fire monitoring products has led to widespread adoption. The NASA Terra and Aqua satellites' MODIS sensors are frequently utilized for active forest-fire detection and monitoring across the world, providing location data on the fires burning there (Thapa, 2021).

2.4 Wildfire in Nepal:

Over the last few decades, rising global temperatures and more prolonged droughts have created favorable conditions for wildfires (Jolly et al., 2015). From 2001 to 2019, there was a uniform rise in forest loss due to fire over the tropics, subtropical and temperate Australia, and boreal Eurasia **(Jolly et al., 2015)**. South Asia is regarded as one of the world's hotspots for wildfires since more than half of its forested lands have been lost by fire in the previous 15 years, from 2003 to 2017(Reddy et al., 2019).

Evidence shows that Nepal's wildfire frequency is rising as well, threatening the native vegetation of the nation. Between January 1 and April 7, 2021, the National Oceanic and Atmospheric Administration - National Aeronautics and Space Administration (**NOAA**-NASA) Suomi NPP satellite's Visible Infrared Imaging Radiometer Suite (VIIRS) observed about 41,000 hotspots in Nepal (Devkota, 2021).

Large-scale deforestation is wreaking havoc on tropical, subtropical, and temperate forests dominated by Sal tree (*Shorea robusta*) and Pine (*Pinus sp.)* in the Terai, Siwalik, and mid-hills. The primary cause of many forest fire events in these zones is the combination of hot, dry weather and populated areas (North et al., 2022). Wildfires are more prone to break out in the dry season, which lasts from November to June every year, and have witnessed an increase in breakouts in Nepal (Qadir et al., 2021)). Seasonality, which refers to when fires occur throughout the year, is a critical element of the fire regime and influences how fire affects ecosystem structure and function by influencing phenological patterns and species composition (Huesca et al., 2009). Therefore, identifying the seasonal variations of wildfires would assist managers in timing their fire prevention efforts.

Wildfires in CNP caused a 1.33 per cent decline in forest cover between February and April 2013(Bahadur KC, Heyojoo, Karna, Sharma, & Panthi, 2017). They asserted that locals purposefully set most fire incidents to gather Saccharum spp., while other reasons included human negligence and accidents. Identification of hazards and implementation of preventative actions to lessen their frequency and severity are both parts of the risk assessment process. To effectively control forest fires, it is essential to have a solid grasp of their risks. The three essential elements for managing forest fires are detecting hotspots, assessing risk likelihood, and risk-reduction actions (Paudel, Adhikari, & Bhusal, 2019). Risk mapping, identification and monitoring, damage assessment, and post-recovery planning are the data required for management. A better understanding of the consequences of forest fires and their management is required considering the current trend of rising wildfire intensity.

3. Materials and Methods

3.1 Study Area

Chitwan National Park (CNP), with an area of 952.68 square kilometers and a buffer zone of 729.37 square kilometres, is located in southern Central Nepal, comprising the areas of Chitwan, Nawalparasi, Parsa, and Makawanpur districts. CNP is located between N 27°20' 19" and N 27°43' 16" longitude and E 83° 44' 50" and 84° 45'03" latitude. This park encompasses the significant areas of Chure Hills, Rapti, Narayani, and the Riu River. The CNP has 84.65 per cent forested land, 4.75 per cent grassland, 0.55 percent shrubland, and 10.35 per cent other land. There are forests of riverine, tropical, and subtropical nature, with approximately 70% of the Sal (*Shorea robusta)* forests (Lehmkuhl, 1994). According to the CNP management plan (2015a), Sal grows in pure stands on well-drained soils, such as the lowlands near Kasara in the park's center. Harro (Terminalia belerica), Satisal (Dalbergia latifolia), Botdhayero (Anogeissus latifolia), Panchphal (Dillenia indica), and Dabdabe (Garuga pinnata) cohabit with Sal on the southern face and northern slopes of the Churia Hills. The average minimum temperature in CNP is 8 degrees Celsius, and the average maximum temperature is 35 degrees Celsius. The average annual rainfall in the park is 2600 mm, with around 80 per cent of the rainfall falling within four months of the rainy season (Baidya, Bhuju, & Kandel, 2009).

From 2001 to 2013, there was an upsurge in the number of forest fire occurrences recorded in Chitwan National Park (Ruda, Kolejka, & Silwal, 2020). The tropical deciduous forest in CNP makes it more likely for forest fires to occur, but there is currently no effective strategy for managing fires there. However, actions like building fire lines and clearing them before the fire season are in practice (H. P. Pandey et al., 2022).

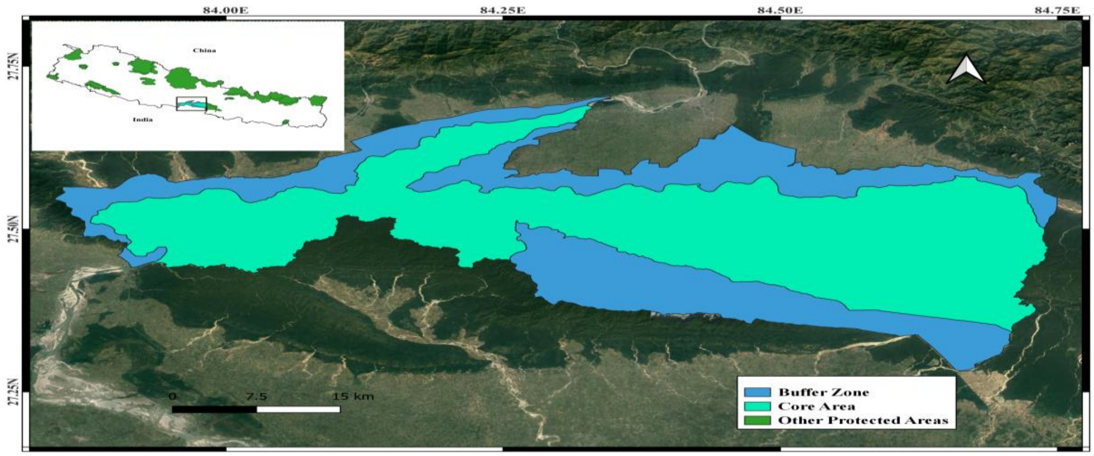

Figure 1: Chitwan National Park

Being a hotspot for biodiversity, CNP is a popular tourist destination and supports several wild species of flora and fauna. While some ecological processes may require fire, uncontrolled fire is harmful. Therefore, it is important to evaluate the CNP in terms of fire risk and management.

3.2 Methodology

3.2.1 Data Collection

i) MODIS Data:

In this study, archival data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on active fire incidence were employed. The location of MODIS fire occurrences was collected from the active fire data website (https://firms.modaps.eosdis.nasa.gov/active fire/) for the years 2000 to 2021 to the extent of the national boundaries, i.e., Nepal. FIRMS delivers near real-time and conventional fire products from MODIS' Terra and Aqua platforms from November 2000 to the present (Yao, Green, Michael, Davies, & Román, 2021).

ii) Landsat Data:

Level-1 Landsat 8 OLI/TIRS Collection 2 Level 1product Images for the pre- and post-fire seasons were obtained from the United States Geological Survey (USGS) Earth Explorer (http://earthexplorer.usgs.gov/). The Landsat 8 satellite's Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) have been collecting photographs of the Earth since February 2013. Landsat 8-9 image data files contain 11 spectral bands with spatial resolutions of 30 meters for bands 1-7, 9-11, and 15 meters for band 8 (Adab, Kanniah, & Solaimani, 2013). Since a single scene of Landsat imagery was unable to capture the entire extent of CNP, four images- two for pre fire and two for post fire were obtained to accomplish objectives.

iii) Digital Elevation Module (DEM):

The aspects, slope, and elevation of the CNP were extracted using the Digital Elevation Module (DEM) output from the Shuttle Radar Topography Mission (SRTM). Since 2014, SRTM elevation data have been accessible at 30m resolution and are designed for use in scientific applications utilizing a Geographic Information System (GIS) or other specialized software applications (Ping, 2003).

3.2.2 Data Analysis:

i) Seasonal Variability:

To extract the location of fire occurrences for the region of interest, Chitwan National Park in Nepal, the data received from MODIS were imported into Arc map software version 10.4.1. This was done using the geoprocessing tool Clip in Arc map. The Chitwan National Park's core region and buffer zone were further used to filter out the fire incidences. The geographical data was chosen based on the four seasons in order to evaluate the seasonal trend (winter, summer, monsoon, and autumn).

The seasons of summer (March to May), monsoon (June to August), autumn (September to November), and winter (December to February) were used to describe the times of year when forest fires occur. The Shapiro-Wilk test was used to determine if the frequency of fires was normal throughout the year. ANOVA analysis was used to evaluate how the mean value of fire frequency varied across the seasons after ensuring that it was normal.

ii) Burn Severity:

The two scenes of downloaded Landsat image were merge and part for the merged Landsat image was clipped to the extent of CNP. Then for the atmospheric correction the Dark Object Subtraction (DOS) was applied. The DOS approach is an image-based atmospheric correction method. The assumption of DOS correction is that there is an object in total shadow and that the sensor received radiance at the satellite is the result of atmospheric scattering. (Pax-Lenney, Woodcock, Macomber, Gopal, & Song, 2001). After that water masking of image was done as it may impact the burned area delineation product. The Normalized Burn Ratio (NBR), which measures burn intensity, was used to detect burnt regions. It is computed as a ratio between the Near Infrared (NIR) and Shortwave Infrared (SWIR)readings (Key & Benson, 2005).

$$NBR = \frac{NIR - SWIR}{NIR + SWR} \qquad (1)$$

Burn Severity of CNP was calculated by subtracting NBR of post fire from NBR of pre fire which is Differenced Normalized Burn Ratio (dNBR) (Eidenshink et al., 2007)

$$DNBR = NBR\ Pre\ Fire - NBR\ Post\ Fire \qquad (2)$$

Burn severity spectral index dataset was divided into five categories based on USGS burn severity categories to create burn severity maps for each research region (Fig. 3).Unburned (U), low severity (LS), moderate-low severity (MLS), moderate-high severity (MHS), and high severity (HS) are all possibilities (HS) (Cocke, Fulé, & Crouse, 2005).

Accuracy Assessment of Burn Severity:

The dNBR picture generated after the analysis was separated into unburned pixels with values less than 0.1 and burnt pixels with values greater than 0.1 to construct a binary classified (burned versus unburned) burn severity map (Escuin, Navarro, & Fernández, 2008). To verify the accuracy of the maps made using the dNBR index, active fire sites from MODIS were overlaid on binary classified severity maps and cross verified with the classification of the map collected. The MODIS dataset has a coarse geographic resolution. Given these limits, only firing locations with a confidence level greater than 90% were evaluated for accuracy (Soverel, Perrakis, & Coops, 2010).

iii) Fire Risk Zonation

Since many factors might affect the likelihood of a fire, we evaluated a total of 7 environmental variables to evaluate the research area's fire risk. Independent factors that are directly related to fire occurrences have been used to determine the forest fire danger zone. As independent variables to the forest fire risk zonation, aspect, slope, elevation, land use and land cover (LULC), land surface temperature, road, and settlement were employed (Figure 3) (Thakur & Singh, 2014).

Based on a thorough literature search, the contributions of each component to fire risk were evaluated, and each variable's specifics are shown in Table 1.

Topography:

The topography of the area may have a great influence on the vegetation and as result in the occurrence of fire **(Iniguez, Swetnam, & Yool, 2008)**. Aspect, slope, and elevation components are topographic features that play a significant role in fire risk zone analysis and were used for risk zonation (Dong, Li-min, Guo-fan, Lei, & Hui, 2005). SRTM- DEM was used for the determination of the aspect, slope, and elevation of the CNP.

Slope

The slope is a very crucial topographic feature that has a significant impact on fire, particularly when propagating (Jaiswal, Mukherjee, Raju, & Saxena, 2002). Fire generally transfers quickly in the up-slope and low in the downslope (Weise & Biging, 1997). DEM was used for the generation of slope map and was categorized as 0-10 degrees, 10-20 degrees,20-30 degrees, and above 30-degree with those categories defining low, low, moderate, and high with overall weight given 10 as mentioned in the table.

Aspect

Aspect has an important influence on wildfire occurrence; various studies imply that south and southwest aspects favor wildfire occurrence because they receive strong sun radiation, which creates low humidity and high fuel and soil temperatures (Hayes, 1941). Aspects of CNP were categorized as Flat, North (N), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W), and Northwest (NW) with those categories defining Low, Low, Low, Moderate, High, High and High-risk zone respectively with overall weight given 5.

Elevation

Several studies indicate that lower elevations have a higher risk of wildfire, and vice versa. Several wildfire risk models have taken elevation into account (González & Pukkala, 2007). The CNP elevation map was constructed using a DEM and categorized as 0 - 200m, 200m - 400m, 400m - 600m, and > 600m, with those categories defining High, Moderate, Moderate, and Low danger zones with overall weight given 5 as mentioned in table.

Land Use Land Cover:

Land cover is seen as a key component in fire spread and has been given a high weightage in affecting wildfires (Vetrita & Cochrane, 2019). The spatial distribution of various fuels is critical for assessing fire risk zones across different land cover types because fuels play a significant role in fire initiation and combustion (Vadrevu, Eaturu, & Badarinath, 2010). The spatial layer of the LULC map was obtained from the International Centre for Integrated Mountain Development (ICIMOD) website (http://rds.icimod.org/), which offers land cover maps with a spatial resolution of 30 m. From the downloaded LULC layer, CNP was clipped. LULC was categorized as Broadleaved Forest, built up, Shrub Land, River, Bare Land, and Agricultural Land as High, Low, Moderate, No Risk, Low and Moderate respectively with overall weight given 60 as mentioned in table.

Land Surface Temperature:

Land surface temperature (LST) is defined as the temperature felt when the land surface is touched with the hands or the skin temperature of the ground (Rajeshwari & Mani, 2014). LST map was created using the thermal band of Landsat 8 satellite data obtained for the summer season of 2021 from the Earth Explorer website (https://earthexplorer.usgs.gov/). The moisture content and humidity of fuel on the forest floor are closely related to temperature (Heyward, 1938). Many studies have suggested that the LST increases after the incidence of wildfire (Maffei, Alfieri, & Menenti, 2018), therefore taking consideration of LST while determining is important (Singh et al., 2020). LST was categorized as 0 - 20˚C, 20-25˚C, 25-30˚C and above 30˚C as Low, Moderate, High, High categories with overall weight given 60 as mentioned in table.

Calculating LST from remotely sensed images is needed since it is an important factor controlling most physical, chemical, and biological processes of the Earth (Qin & Karnieli, 1999).

LST retrieval includes the followings steps

Conversion of a digital number to radiance

Landsat 8 OLI and TIRS thermal bands (Bands 10 and 11) data were converted to Top of the Atmosphere (TOA) spectral radiance using the metadata file's radiance rescaling parameters. As a result, the digital number for Landsat 8 thermal band images is calculated to create radiance using the equation below.

$$L_\lambda = MLQcal \; + \; AL - o_i$$

Where: L_λ=TOA spectral radiance (Watts/ (m2 × srad × µm)),

ML=Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number),

AL=Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number), $Qcal$ =Quantized and calibrated standard product pixel values (DN) and o_i is the correction for Band 10 (Chatterjee, Singh, Thapa, Sharma, & Kumar, 2017).

Conversion of radiance to At-Satellite temperature

The thermal constants given in the metadata file were used to convert Landsat 8 OLI and TIRS thermal band data from spectral radiance (produced in step a) to top of atmospheric brightness temperature:

$$T = \frac{K_2}{\ln(\frac{K_1}{L_\lambda} + 1)}$$

T=Top of atmosphere brightness temperature (K),

L_λ=TOA spectral radiance (Watts/ (m2 × srad × µm)),

K_1=Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number),

K_2=Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number). (Chander & Markham, 2003).

Conversion of Kelvin to Celsius

At-Satellite temperature obtained from step b) is then converted into Celsius

°C=T-273.15

where T = the temperature at the satellite estimated using OLI/TIRS sensors (Nordstrom, 1993).

Normalized Difference Vegetation Index (NDVI)

Normalized difference vegetation index was used to calculate land surface emissivity.

$$\text{For Landsat 8 OLI/TIRS NDVI} = \frac{\text{Band 5}-\text{Band 4}}{\text{Band 5}+\text{Band 4}}$$

Where, Band 5 is Near Infrared, while Band 4 is Red (Huang, Tang, Hupy, Wang, & Shao, 2021).

Obtaining of the land surface emissivity

The land surface emissivity is calculated after the NDVI. After calculating the NDVI, the land surface emissivity is computed. The following formula was used to compute the land surface emissivity of the two sensor images.

$$e = 0.004\,PV + 0.986$$

Where e=Land surface emissivity,

PV =Proportion of vegetation,

$$PV = \left(\frac{NDVI - NDVImin}{NDVImax - NDVImin}\right)^2$$

Where *NDVI min*=minimum value of *NDVI*,

NDVI max=maximum value of NDVI (Valor & Caselles, 1996).

Land Surface Temperature (LST)

Then LST was calculated from the following equation:

$$LST = \frac{BT}{\left\{\left(1 + \frac{w \times BT}{p}\right) \times \ln(e)\right\}}$$

Where *BT*=at satellite temperature,

w=wavelength of emitted radiance

$$p = \frac{h \times c}{s}$$

h=plank's constant (6.626 × 10-34 JS), *s*=Boltzmann constant (1.38 × 10-23 J/K), *c*=velocity of light (2.998 × 10-8 m/s and *p*=14380 (Oguz, 2013).

Distance from road and settlement:

Areas near roads and settlements have high anthropogenic disturbances and are very important factors for the identification of fire risk zonation (Singh et al., 2020). The ICIMOD website (http://rds.icimod.org/) was used to obtain the spatial layer of the road map and the region within the CNP was rasterized by buffering the road network layer. The distance from the road was classified as High danger, Moderate risk, Low risk, and No risk zones at 100, 200, 300, 400, and >400m with overall weight given 5. Similarly, the spatial layer of settlement location was also acquired from the ICIMOD website for current (http://rds.icimod.org/) and the area of interest was rasterized by buffering the settlement points layer. The distance from the road was categorized as 0-1000 m, 1000-2000 m,2000m-3000m, 3000-4000 m, and >4000 m as High risk, Moderate risk, Low risk, and No risk zone with overall weight given 5 as mentioned in table (Singh et al., 2020).

Weight factors for different groups for risk model:

Multi-criteria weighted-overlay analysis was applied for the fire risk zonation of CNP. LULC was weighted highest as it plays a major role in fire stimulation with fuel flammability. LST was considered the second most important variable as higher temperature leads to a higher risk to fire. Slope, distance to settlement, and road distance were considered the third most important variables. As seen in the table, each variable including multiple classes was labeled differently based on their impacts on wildfire. The considered factors were weighted in the percentage of their influences.

Table 1: Details on fire risk parameters

S N	**Parameters**	**Weight**	**Class**	**Fire sensitivity**
1	LULC		Broadleaved forest	High
			Built up	Low
		60	Shrub Land	Moderate
			River	No Risk
			Bare land	Low
			Agricultural Land	Moderate
2	Slope(degree)		0-10	High
		10	10-20	High

			20-30	Moderate
			>30	Low
3	Aspect	5	Flat	Low
			N	Low
			NE	Low
			E	Moderate
			SE	High
			S	High
			SW	High
			W	Moderate
			NW	Low
4	Distance from road(m)	5	100	High
			200	High
			300	Moderate
			400	Moderate
			>400	Low
5	Distance from settlement(m)	5	0-1000	High
			1000-2000	High
			2000-3000	Moderate
			3000-4000	Low
			>4000	No Risk
6	Elevation(m)	5	200	High
			400	Moderate
			600	Moderate
			800	Low
7	Land surface temperature (°C)	10	0-20	Low
			20-25	Moderate
			25-30	High
			>30	High

(*Sources: Department of forest and natural resources, Chitwan)*

4. Results and Discussion

4.1 Result

4.1.1 Seasonal Variability

For the duration of the research (November 2000 to December 2021), 3617 fire incidents were recorded in CNP, with 3135 of them occurring in the core region and 482 in the buffer zone. The status of fire incidents density for core area and buffer zone is presented in table 1. It is clearly stated that from result, core area bears more fire occurrence than buffer zone in summer season which is fire season in case of Nepal (Parajuli et al., 2020). Additionally winter season also bears the high density of fire for the study area. Furthermore, the spatial-temporal maps of fire incidents were obtained for study (Figure 2)

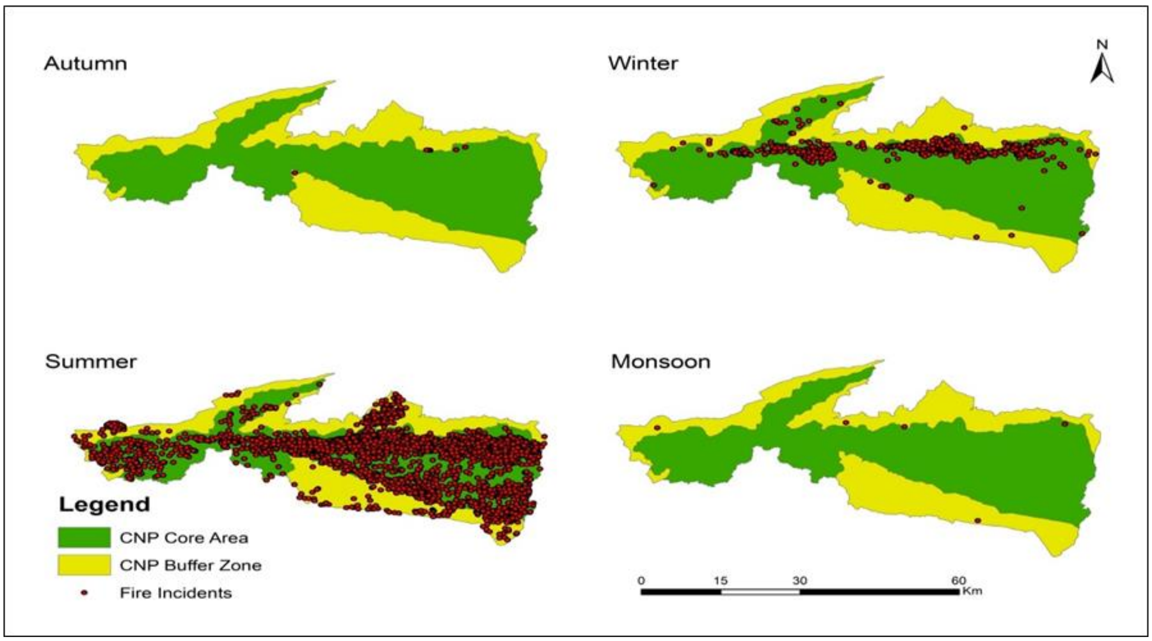

Figure 2: Spatial-temporal fire incidents distribution pattern in different seasons

(*Data Sources: https://firms.modaps.eosdis.nasa.gov/)*

Table 2: Fire incidents density for core area and buffer zone of CNP in different seasons from 2001-2021.

	Fire Incidents		Fire Density	
Season	Core Area	Buffer Area	Core Area	Buffer Area
Autumn	2	5	0.009	0.007

Monsoon	1	4	0.004	0.005
Summer	2550	434	11.418	0.595
Winter	582	39	2.606	0.053

(Source: office of buffer zone, pragatinagar, Chitwan)

4.1.2 Fire Trends in different years of Chitwan National Park

The frequency patterns of fire occurrences are shown on a line graph for the period from 2001 to 2021 in Chitwan National Park. The year with the most occurrences, 2021, had 384 fire incidents, followed by 2016 with 319 fire incidents, while the year with the fewest events, 2002, had 30 fire incidents.

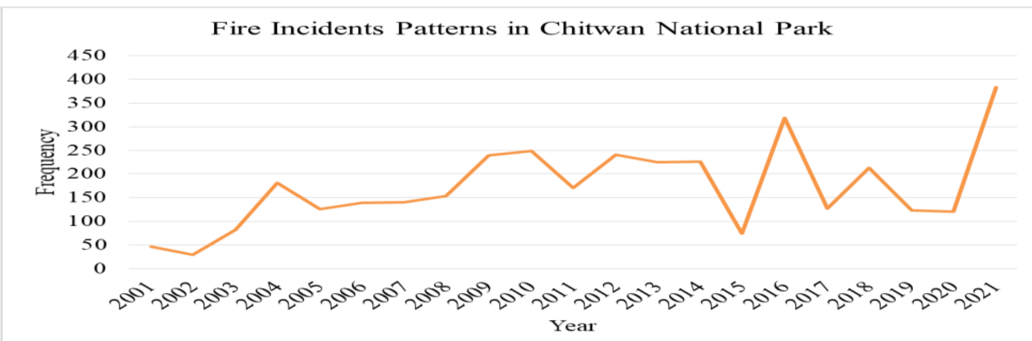

Figure 3: Fire Incidents Frequency from 2001-2021 in Chitwan National Park

(Data sources: https://rds.icimod.org)

4.1.3 Trends of Fire Incidents in different Management Regime of Chitwan National Park

The bar graph (Figure 4) shows that number of fire incidents were high in Core area as compared to buffer zone of Chitwan National Park year wise. The greatest number of fire incidents were occurred in 2021 (332 fire incidents) in core area and buffer zone area while less fire incidents in 2002(22 fire incidents) in core area (52 fire incidents) and least incidents of fire in buffer zone in year 2001 (2 fire incidents).

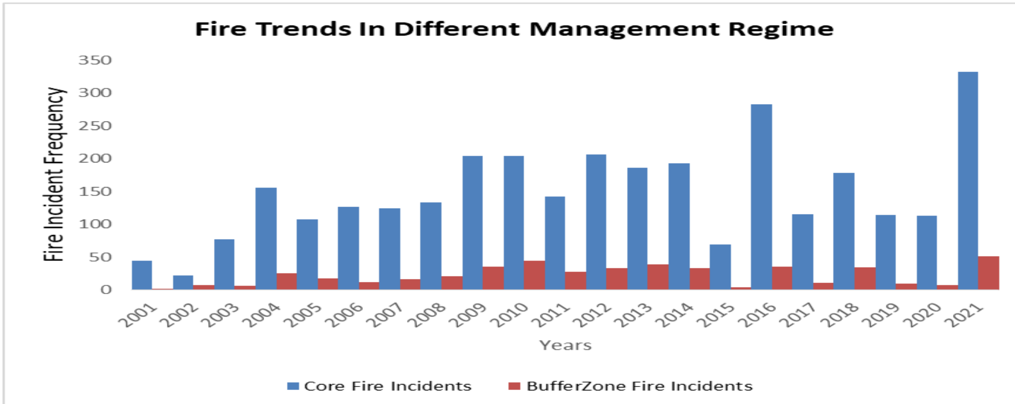

Figure 4: Fire trends in Different Management Regime in different years from 2001 to2021

(Data source: division forest office , Chitwan)

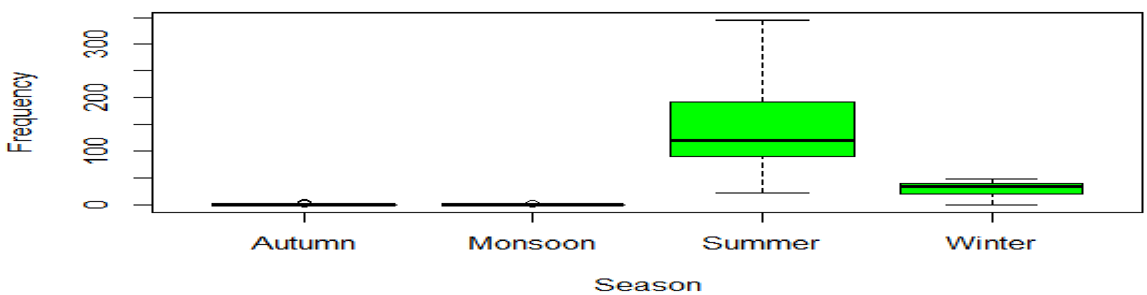

Figure 5: Boxplot showing fire frequency in different seasons from years 2001 to 2021

The Shapiro-Wilk test was used to determine if the distribution of yearly fire incident data is normal or not, and the data was found to be normal (p-value > 0.05). The T-test was then used to determine the significance of difference in fire frequency between the two management regimes of Chitwan National Park, namely the Core Area and the Buffer Zone. The results demonstrate that the core region has a higher mean fire frequency than the buffer zone (t = -7.6516, df = 40, p-value = 2.359e-09). The Shapiro-Wilk test, which was used to determine the normality of the frequency distribution in different seasons, revealed that the distribution of fire events in different seasons was not normally distributed (p-value less than 0.05). The data was then translated to log form after certain outliers were eliminated. The normality test was then repeated. This resulted in a p value greater than 0.05, indicating that the data is normal.

From above boxplot, it can be visualized that each of the classes have different data distribution with summer season having higher median value than that of other seasons. Autumn and monsoon season have almost same data distribution of fire frequency. One way ANOVA was conducted to determine variation in mean value of fire frequency which shows significance with p-value less than 0.05 at 5% level of significance. Then, Tukey HSD was conducted to test to determine the pairs with significant difference among 4 pairs. The result implies that there is significant difference in mean value among 3 pairs of fire frequency in different seasons i.e., Summer-Autumn, Summer-Monsoon and Summer-Winter.

4.1.4 Burn Severity:

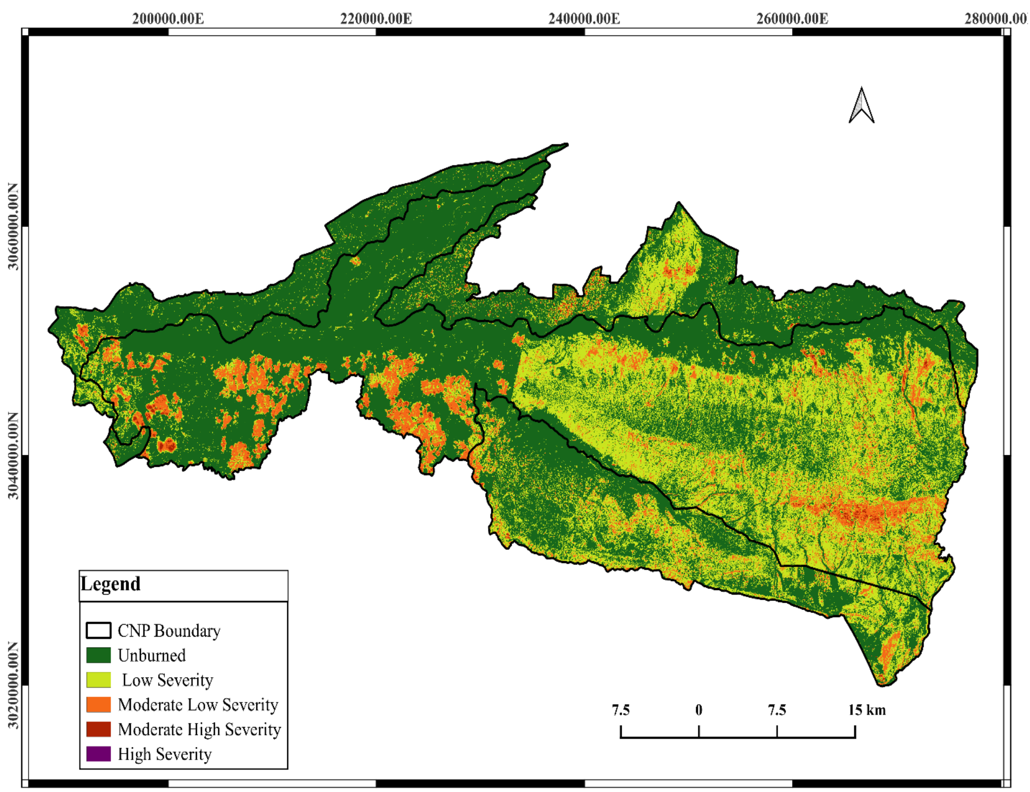

Figure 6: Burn Severity Map of Chitwan National Park

(Data sources: Department of forest and wildlife resources, Nepal)

Since from November 2001 to 2021 the most incidence of fire in CNP occurred in year 2021(384 fire incidents), the burn severity of the year 2021 was determined. According to the burn severity analysis, a total of 76558.68 hectares of forest were burned of CNP in 2021, with 4.23 hectares burned in high severity, 1031.31 hectares burned in moderate high severity, 16,456.32 hectares burned in moderate low severity, 59,066.82 hectares burned in low severity, and 91,641.32 hectares remaining unburned (Table 3).

Table 3: Burn Severity of Chitwan National Park

Fire Severity	Area in Hectare
Unburned	91,641.32
Low Severity	59,066.82
Moderate Low Severity	16,456.32
Moderate High Severity	1031.31
High Severity	4.23

(Source: Department of forest, sauraha)

4.1.4.1 Accuracy of Burn Severity:

A total of 384 fire incidents were detected in year 2021out of them a total of 14 active fire points were detected by MODIS with a confidence level of 90 or higher. After the over laying the active fire points in the binary classified image a total of 14 active fire points of which 11 active fire points were located in the burnt region of the categorized image and 3 points were in the unburned area (Soverel et al., 2010). The overall accuracy was computed as follows:

$$\text{Over all Accuracy} = \frac{\text{Correctly Classified points}}{\text{Total Points}}$$

The overall accuracy of binary classified burn severity was determined as 78.57 percent.

4.1.5 Fire Risk Zonation

4.1.5.1 Land Use Land Cover:

The LULC map indicated that 68.66% (115481 hectares) of the total CNP including the buffer zone of the study area was broad-leaved forest, 24.87% (41832 hectares) was agricultural land, 3.74% (6290 hectares) was bare area, 2.61% (4386 hectares) was river, 0.11% (178 hectares) of the forest was shrub land, and 0.02% (178 hectares) was built up area. Broadleaved forest had the greatest incidence of wildfire with 2893 fire occurrences during the study period, followed by Agricultural Land with 568 incidences and Bare Land, Riverine area, and built-up with 103,46,7 and 0 incidences, respectively (Table 4).

Table 4: Area and No. of Fire incidents LULC

LULC	Fire events	Area (Hectares)
Shrubland	7	178
Broadleaved closed Forest	2893	115481
Agricultural Land	568	41832
Bare Land	103	6290
Riverine area	46	4386
Built-up	0	33

4.1.5.2 Slope:

The slope map prepared to form the DEM indicated that out of the total area of CNP including buffer zone86.60% (145661hectares) is under 0-10 degrees of slope, 11.77% (19797 hectares) of the area is under 10–20-degree slope, 1.57% (2641 hectare) of the area is under 20-30 degree of slope and 0.06% (101 hectares) is above 30-degree slope. Lower slope classes, 0-10 degree, and 10-20 degree had the most fire occurrences, 3379 and 206, respectively, whereas upper slope classes, 20-30 degree and above 30 degrees, had the fewest, 30 and 2 respectively (Table 5).

Table 5: Area and No. of Fire incidents in each slope class

Slope	Area (Hectare)	No. of Fire Incidents
0-10	145661	3379
10-20	19797	206
20-30	2641	30
>30	101	2

4.1.5.3 Aspect:

The aspect map which was generated from the DEM indicated that out of the total area of CNP including buffer zone13.69% (23027 hectares) of the area was under S aspects, 12.84% (21597 hectares) of the area was under NW aspect, 12.71% (21378 hectares) of the area was under SW aspect, 11.56% (19444 hectares) of the area was under west aspect, 10.84% (18233 hectares) of the area under NE aspect, 10.53% (17711 hectares) of the area under SE, 9.31% (15660 hectares) of the area under N aspect, 9.00% (15138 hectares) of the area under E aspect, 8.08% (13590 hectares) of the area under west aspect and 1.44% (2422 hectare) of the area under Flat. The southern aspects, i.e., S, SE, and SW, had the highest fire occurrences, 482, 476, and 381 correspondingly (Figure 5).

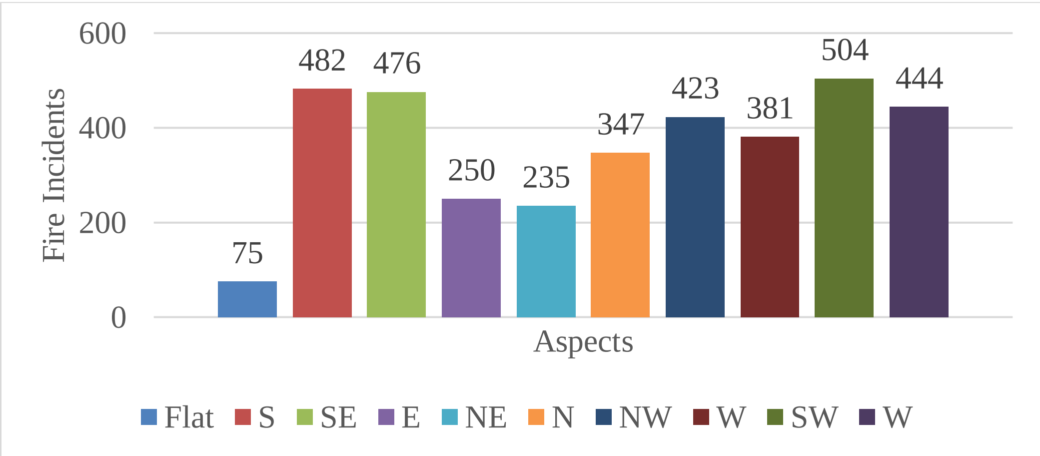

Figure 7: No. of Fire incidents with respect to different aspect classes

4.1.5.4 Elevation

Table 6: Area of each elevation class

Elevation	Area
97-200	64404
200-400	69887
400-600	28426
>600	5483

Similarly, the Elevation map prepared from the DEM indicated that out of the total area of CNP including the buffer zone 41.55%   (698.87 hectares) of the area was found to be under 200-400 m elevation, 38.29% (644.04 hectares) of the area was found to be under 92-200 m elevation, 16.90% (284.26hectare) of the area was found under 400-600m and 3.26% (54.83 hectares) of the area was found to be above 600 m (Table 6). Lower elevation had the most fires, with elevation classes 92-200m and 200-400m having 1301 and 1859 wildfire occurrences, respectively, while higher elevation had the fewest, with 400-600 m and above 600 having 441, and 46 wildfire incidents, respectively (Figure 8).

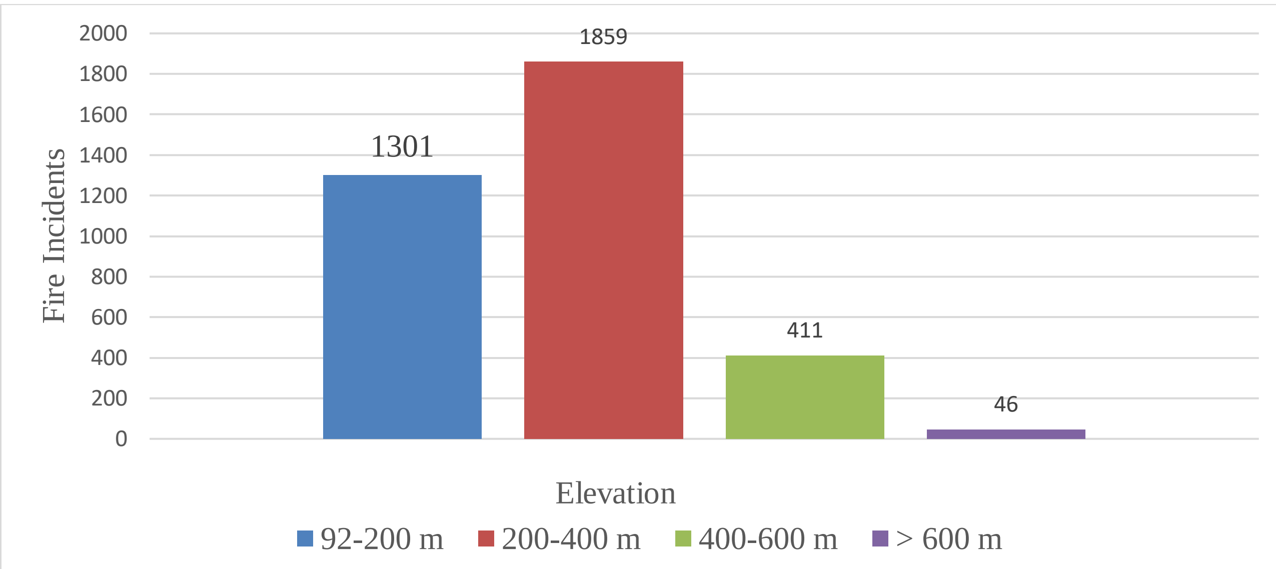

Figure 8: Fire incidents for each elevation class

4.1.5.5 Land Surface Temperature

LST map prepared from the Landsat 8 image which was divided into four categories as 20˚C,20-25˚C,25-30˚C and above 30 ˚C and for these classes area was found as4.41% (74.18 hectares) 89.38% (1503.38hectare), 5.93% (99.74hectare) and 0.28% (4.7hectare) of the total CNP including buffer zone. LST Classes 0-25˚C, 20-25 ˚C,25-30˚C and above 30 ˚C had 97, 3467, 51 and 2 wildfire counts respectively (Table 7).

Table 7: No. of fire incidents for each LST class

LST (˚C)	No. Fire Incidents
0-20	97

20-25	3467
25-30	51
>30	2

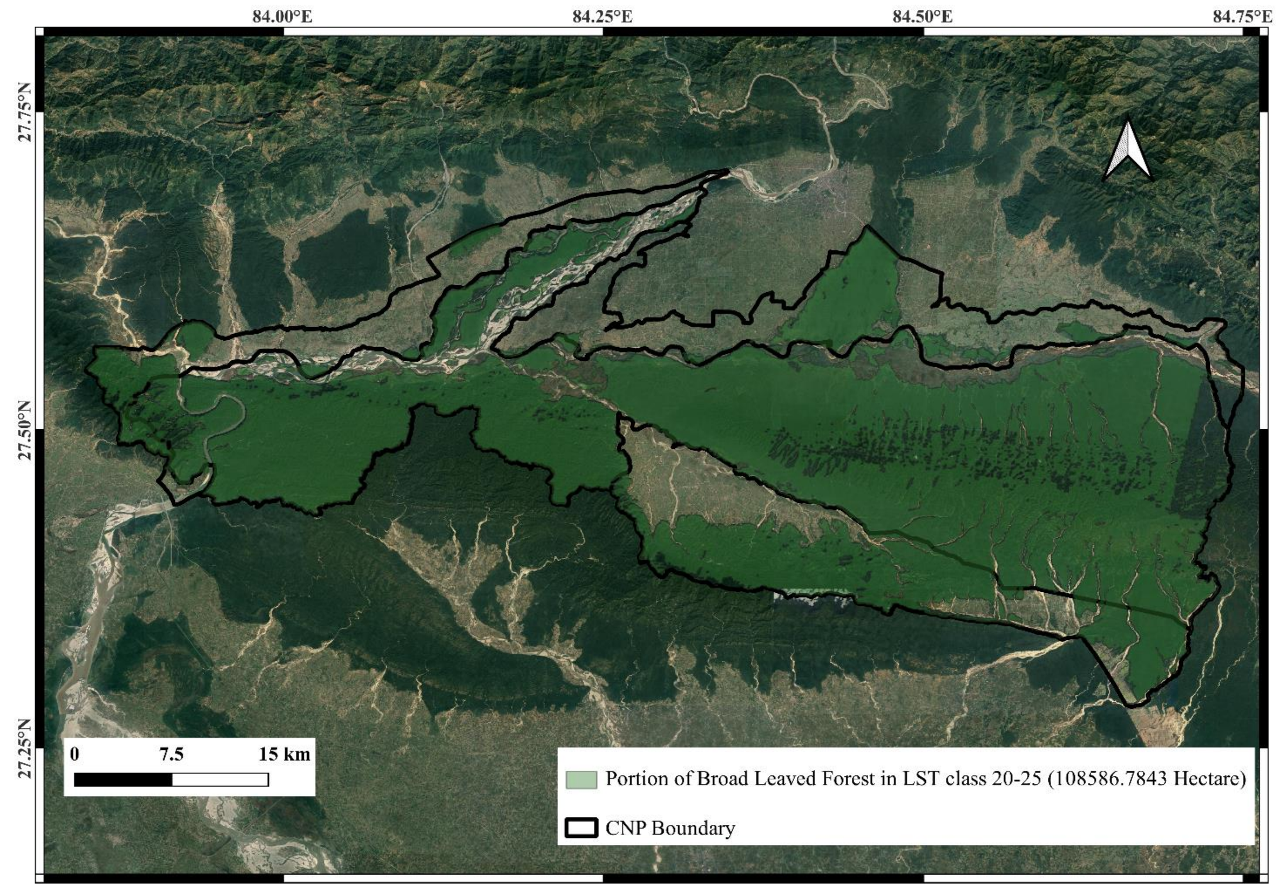

Figure 9: Portion of Broad-leaved Forest within LST class 20-25˚C

(*Data sources: https://rds.icimod.org)*

4.1.5.6 Distance to Road:

From the proximity map of the road, it was found that the area within 0-100m,100-200m, 200-300 m, 300-400m, and above 400m distance from the road in CNP was 4.31% (7249 hectares), 2.44%

(4104 hectares) 3.29% (5534 hectares) 2.60% (4373 hectares) and 87.36% (146940 hectares) of the total CNP including buffer zone. The fire incidents density per 100 hectares of area for distance to road class 0-100 m, 100-200 m, 200-300 m, 200-300 m, 200-400 m, and above 400 m are 2.096, 1.73, 2.26, 2.19 and 2.16 respectively (Table 8).

Table 8: Area, No. of Fire incidents and incidents of fire incidents per 100 hectares with respect to distance to road.

Distance to the road (m)	No. of Fire incidents	Area (Hectare)	Incidents of fire incidents/100 hectare
0-100	152	7249	2.096
100-200	71	4104	1.73
200-300	125	5534	2.26
200-400	96	4373	2.19
above 400	3173	146940	2.16

4.1.5.7 Distance to Settlement:

From the proximity map of settlement, it was found that area 0-1000 m, 1000 – 2000 m, 2000 – 3000m, 3000-4000m, above 4000m from the settlement was 3.02%(5079.64 hectare),8.12% (13657.84 hectare) , 11.05%(18586.1 hectare) 11.50%(19343 hectare) and 66.31% (111533.42hectare) of the total CNP including buffer zone. The fire incidents density per 100 hectares of area for distance from class 0-1000 m, 1000-2000 m, 2000-3000 m, 2000-3000 m, and above 4000 m are 0.52, 0.55, 0.98, 1.85, and 2.68 respectively (Table9).

Table 9: Area, No. of fire incidents and incidents per 100 hectares with respect to distance from settlement

Distance from Settlement	Area (Hectare)	No. of fire incidents	Incidents/100 hectare
0-1000 m	5079.64	26	0.52
1000-2000 m	13657.84	75	0.55
2000-3000 m	18586.1	181	0.98
3000-4000 m	19343	357	1.85

above 4000	111533.42	2978	2.68

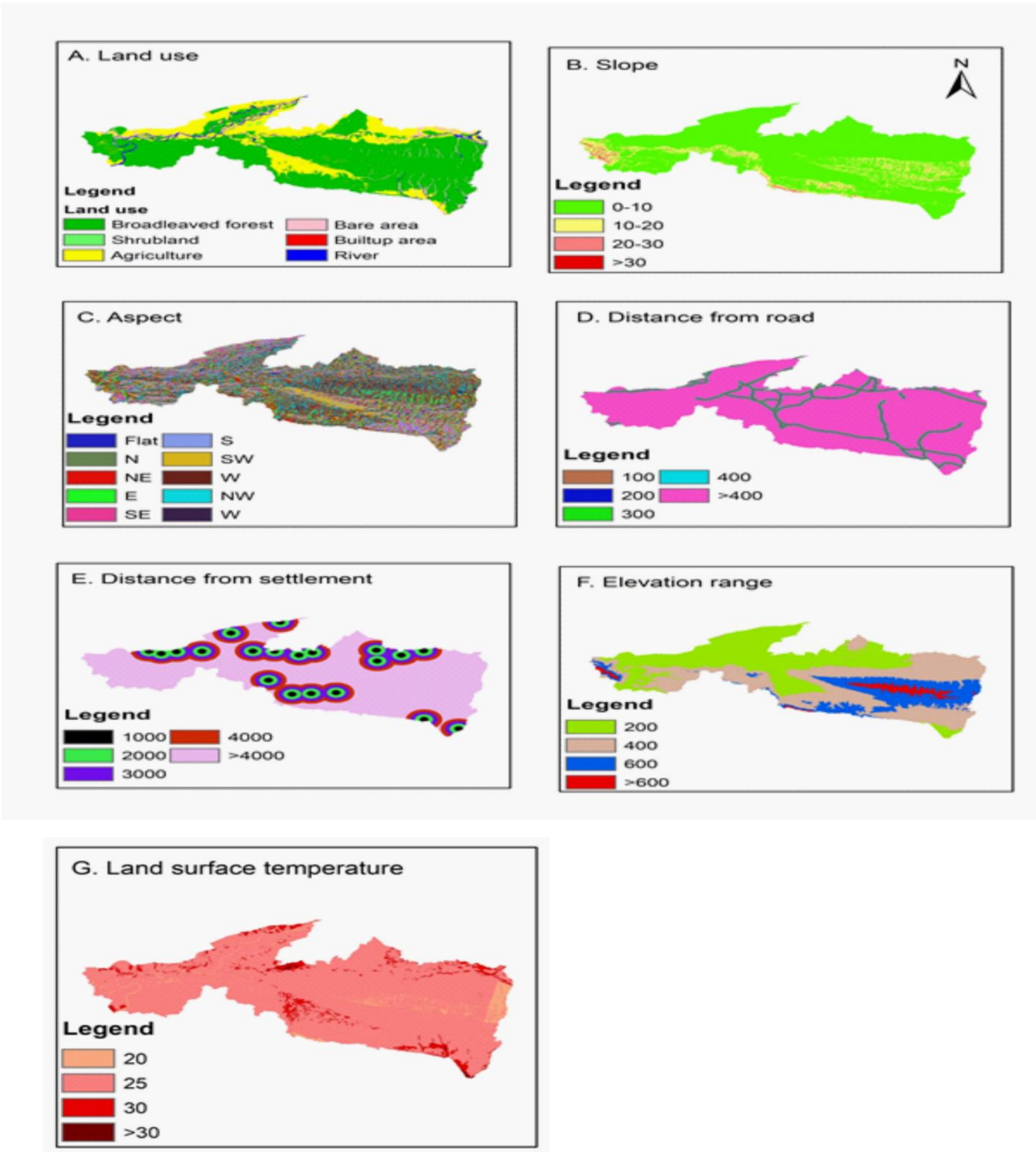

Figure 10: Variables (a) LULC (b) Slope (c) Aspect (d) Distance from road (e)Distance from settlement (f) Elevation. and (g) LST

4.1.5.8 Fire Risk Zonation:

According to the weights given to each attribute and their impact on forest fire, the CNP is divided into high, medium, and low-risk zones using GIS methodologies. The area is shown in the Table 10, and the figure 9 shows the wildfire risk zones. According to the findings, there is a high risk of wildfire for 6391.6 hectares in CNP, a moderate risk for 154054.4 hectares, and a low risk for 7754.02 hectares.

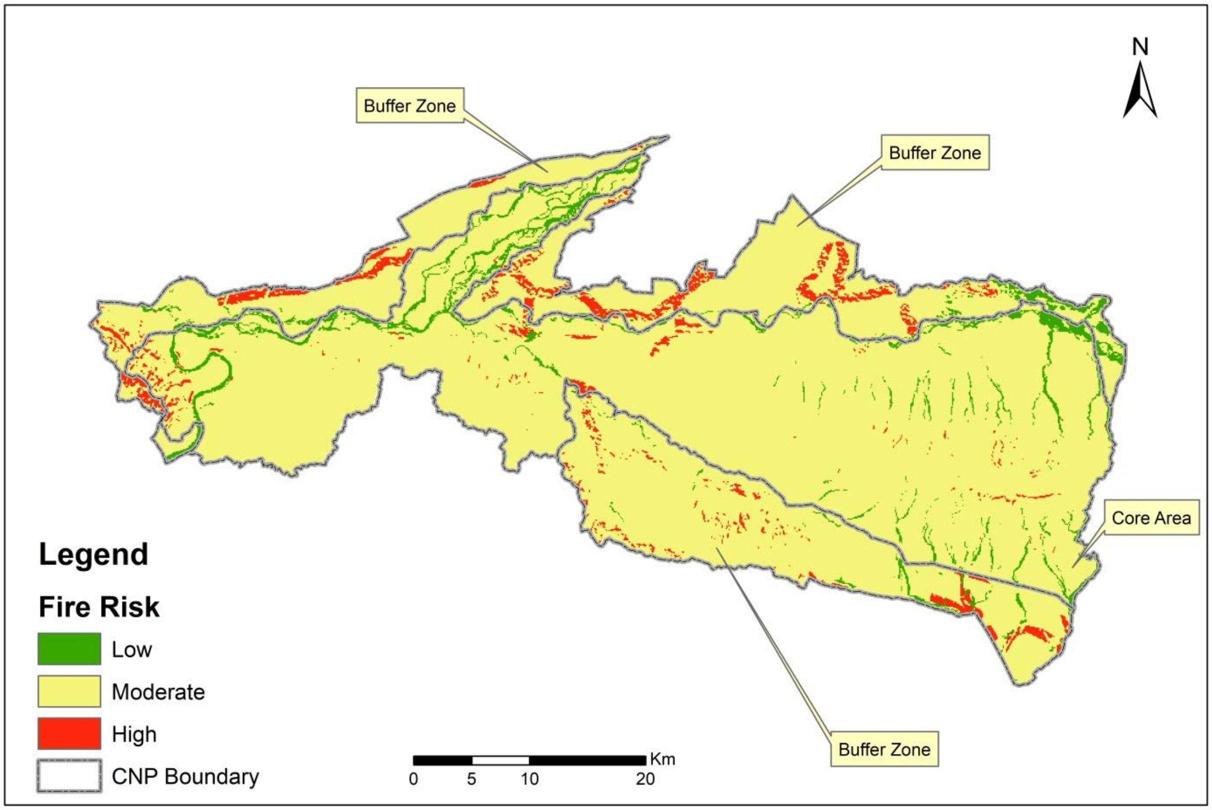

Figure 11: Fire Risk Zonation Map of CNP

Table 10: The risk zone statistic

S. N	Risk level	Area
1	High	6391.6
3	Moderate	154054.4
2	Low	7754.02

4.1.5.8.1 Validation

The fire risk zonation map validation revealed that there were 2.35 fire incidents per 100 hectares in the high-risk zone, 2.1 fire incidents per 100 hectares in the intermediate risk zone, and 1.53 fire incidents per 100 hectares in the low-risk zone (Table 11). This demonstrates that the danger region in CNP was accurately reflected on the fire risk zonation map.

Table 11: Fire Risk Zonation Validation Table

Fire Risk	Fire Incidents	Area (hectare)	Density (No. per 100 hectare)
High	150	15000	2.35
Moderate	3235	323500	2.1
Low	119	11900	1.53

4.2 Discussion

4.2.1 Seasonal Variability

This study provides the fire events frequencies and risk assessment of the Chitwan National Park from years 2001 to 2021. The analysis suggests that the maximum fire incidents took place during summer season followed by the winter season .The number of forest fires in our research area fluctuated throughout all years because forest fires get affected by the temperatures (Reddy et al., 2019). Forest fires were usually observed high during the dry, hot, pre-monsoon season i.e., summer season. In various regions of Nepal, similar results were noted (Matin et al., 2017). The trees became flammable due to the high ambient temperature and dry litter on the ground during the dry pre-monsoon or summer season (Bhujel et al., 2022).

Fires were mostly reported in March, April, May, and June because the fuel moisture content is lower during these months, making the material more flammable (Kraaij, Baard, Cowling, van Wilgen, & Das, 2012). There were less fires during the rainy and wet summer months (June to January) due to the heavy rain and sufficient moisture content in an area. The fire incidence rate was high in March, April, and May as they indicated summer season in Nepal. This is due to the fact that most tree species shade their leaves during the dry season (March to May). Dry leaves, twigs, and litter that accumulated on the forest floor, along with undergrowth species, grasses, weeds, and alien species, served as fuel for forest outbreaks.

The annual fire occurrence pattern showed significant variation. In 2015 and 2020, there were only 74 and 121 hotspots identified, which might have led to an accumulation of fuels in the region. As a result, there were the most fire incidents happened after successive years of 2015 and 2020, 319 incidents in 2016 and 384 in 2021 respectively. We also find out that the core area of Chitwan National Park had affected by fire than as compared to buffer areas. A focus on megafauna in protected areas encourages the use of fire to sustain deteriorated stages of the forest vegetation that could support herbivore groups. The fire incidents in the core area were high because of the strict law made by the parks. People have access to collect fodder, fuelwood and forage from the buffer zone area which eventually make less accumulation of materials as compared to core area due to restriction made by the Parks.

4.2.2Fire Risk Zonation

CNP has 7754 hectares of low fire risk, 154,071 hectares of moderate fire risk, and 6375 hectares of high fire risk. The CNP experienced the most wildfire events in the broad-leaved vegetation during the research period. Out of 3617 occurrences, there were 2893 fires overall. Among the LULC class for this study, CNP has the maximum amount of broad-leaved forest at 115481 hectares. According to previous studies, broad-leaved forests have a significant number of wildfire events (Wang, Wu, Kunze, Long, & Perlik, 2019). The elevation class between 200 and 400 m has the most fire events of any elevation class, with 1859, as seen in the figure, whereas lower elevation classes of 200 m had 1301 fire occurrences.

According to DNPWC (2018), the CNP includes around 70% Sal-dominated broad-leaved forest, which mostly develops on low plains and provides fuel for burning at lower elevations.

The lower slope classes had more fire incidents, which indicates that the slope has a significant effect on the incidence of wildfires. 3379 fire occurrences occurred in the slope class 0–10, compared to 206 in the slope class 10–20. (Table 5). This could be because the bulk of the study area is flat, has a low slope, and is covered in broad-leaved forests that are dominated by Sal trees; as a result, the majority of fire occurrences happened in this slope that 73.6% of the enhanced fire threat in his study area was on slopes less than 25% (Qadir et al., 2021).

Due to the significant anthropogenic disturbance and the numerous studies that show that areas close to human settlements are more susceptible to wildfires than those far from human settlements, residents and visitors may mistakenly or intentionally start fires in these locations (Bhusal & Mandal, 2019). Contrary to what the aforementioned studies indicate, in CNP, the frequency of fires and the density of fire incidents are lower for wildfire events that are close to populated areas than for those that are farther away. The cause of this could be because areas closer to settlement are buffer zones where the gathering of forest products, such as fuelwood and leaf litter, is allowed for subsistence needs, whereas the core area of CNP is rigorously restricted, which may lead to fuel collecting on the forest floor (Cochrane & Laurance, 2002). People typically go a great distance from their settlement to start a fire, which might account for the increase in fore incidents farther from population areas, according (Tiwari, Shoab, & Dixit, 2021).

The network of roads may be able to restrict the fire by functioning as a fire control line, even though it is believed that regions adjacent to roadways have a higher risk of wildfire. The road network may aid in the spread of flames due to the high concentration of anthropogenic activity in the vicinity, but it may also make it easier to reach the fire zone and serve as a fire break (K. Pandey & Ghosh, 2018). The number of fires per 100 hectares varies rather little as one moves away from the road network (Table 8).LST increases the danger of wildfires, and research demonstrates that higher LST classes have more fire occurrences (Maffei et al., 2018). Given that LST in forested regions is lower than in non-forested areas (Wan Mohd Jaafar et al., 2020), and the fact that 108586.8 hectares (94.03%) of the broad-leaved forest fell within this LST class (Figure 7), the LST class 20–25 had the highest frequency of wildfire occurrences (3467) in our study.

5. Conclusion and Recommendation

5.1 Conclusion

Analysis of the MODIS hotspots from the time period 2001 to 2021 indicates that the Chitwan Core area is highly sensitive to forest fire in comparison to Buffer zone area. Out of the total incidents i.e.,3617, 3135 fire incidents occur in Core area of Chit wan National Park from year 2001 to 2021. The fires occurred mostly during summer season as compared to other seasons.

According to this study, 6391.6 hectares of CNP are at high danger of wildfire, 154054.4 hectares are at moderate risk of f wildfire, and 7754.02 hectares are at low risk. Elevation, slope, aspects, LULC, LST, distance from road, and distance from habitation area all have an impact on wildfire danger in the CNP.

5.2 Recommendation:

CNP is the oldest national park in Nepal, and it is a biodiversity hotspot that sustains a lot of wildlife inside its territory. However, there is always the risk of fire in CNP as half of the Chitwan district of Nepal is CNP the district also suffers more forest fire than other surrounding districts The study recommends the following for the study area:

i) The majority of incidents happened in the core area, which is the result of intentional fire for the purpose of managing grasslands and setting back succession, however prevention should be done since it may harm the biodiversity that depends on particular grassland ecosystem.

ii) About 70% of CNP is composed of Sal-dominated broad-leaved forests, which are very vulnerable to wildfires. To reduce fire and associated damages, a proper fire control approach should be used, such as clearing the forest floor before the summer fire season and constructing fire lines.

iii) National Park Administration should remain alert and prepared for combating wildfires, especially during the summer season.

iv) Construction of fire towers and alarm systems where fire risk is high.

v) More scientific studies related to fire should be encouraged and promoted to produce synergic effect in prevention and control of hazardous fire.

6. Acknowledgment:

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