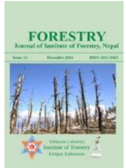
Forestry: Journal of Institute of Forestry, Nepal 21 (2024) 102-115

DOI: https://doi.org/10.3126/forestry.v21i1.79729

Forestry: Journal of Institute of Forestry, Nepal

Journal homepage: www.nepjol.info/index.php/forestry



Analyzing the Relationship between Temperature, Precipitation and Burned Area: A case study from Churia-Siwalik, Nepal

Kiran Poudel[1*] and Rakshya Basnet[1]

[1] *School of Forestry and Natural Resource Management, Institute of Forestry, Tribhuvan University, Kathmandu, Nepal*

KEYWORDS

MODIS
Precipitation
Temperature
Fire
Burnt area
Churia-Siwalik

ABSTRACT

Forest fires are a major hazard, causing significant ecological, economic, and social damage worldwide. In Nepal, particularly in the Churia-Siwalik region, they are a recurring issue, exacerbated by climate change. This study examines the trends and associations between forest fires, climate, and weather patterns in the Churia-Siwalik region over the past two decades. We analyze the trends in burned areas, temperature, and precipitation from 2001 to 2024 using data from MODIS (MCD64A1) on burned areas and climate data on precipitation and temperature from USGS Earth Explorer. The results show a significant increasing trend in burned areas, with an average rise of 51.27 km² per year, reflecting growing wildfire risks. Temperature trends show a significant rise in temperature, and precipitation trends suggest a slight but statistically insignificant decline. The correlation analysis reveals a weak inverse relationship between precipitation and burned areas ($r = -0.048$, $p = 0.82$), while temperature shows a moderately positive correlation with burned areas ($r = 0.42$, $p = 0.039$). These findings underscore the critical role of climate variables in influencing the frequency and severity of wildfires in the Churia-Siwalik region and highlight the need for improved fire management strategies.

INTRODUCTION

Fire is a major hazard for the world's forest. Forests play pivotal role in sustaining a range of ecosystem services, from carbon sequestration and water regulation to habitat provision and biodiversity maintenance (Rai et al., 2024). Every year, millions of hectares of world's forests are destroyed by fires. Forest fires occur annually in all the physiographic regions of Nepal, but fire is more severe in Terai and Churia range (Sharma, 1996), aggravated by land-use change (Kunwar & Khaling, 2006).These fires leads to loss of human and animal life and substantial economic damage by destruction of the wood and non-wood forest products, release of carbon in the atmosphere, high cost of fire suppression, and damage to other environmental, recreational and amenity values (Davidenko & Eritsov, 2003; FAO, 2003, 2005).

*Corresponding author
Email: kiranpoudel015@gmail.com
Received: 30 August 2024 Accepted: 10 April 2025

People and fire have been culturally linked for centuries (FAO, 2003). Forest fire destroys far more trees than all other natural calamities, including parasite attacks, insect infestations, frost and others (Alexandrian et al., 1999). It results in fuel wood shortage, displacement of people and many socio-economic problems worldwide. It not only destroys living forest vegetation, but also consumes the dead vegetation and destroys the litter.

As soon as the soil is exposed by fire it is quickly colonized by invading plants of various kinds. It is one of the prominent causes of forest destruction in Nepal where fire is traditionally linked with rural people's livelihood. A small fire can cause a huge damage. For instance, the 2021 bushfire in Australia and fire in the rainforest in August, 2019, which not only destroyed the forest but also resulted in the extinction of a large number of living beings residing in the forest (Barlow et al., 2020; Xin & Williams, 2019). Every year, forest fires ravage Nepal, destroying vast tracks of land. We have a very limited database on the number of lives lost and forest products, habitat, and animals that have been destroyed as a result as a result of forest fires (Badal & Mandal, 2021).

The growing size and spread of wildfires worldwide have become a significant policy and management concern due to their current and potentially worsening impacts on ecological integrity. Although, majority of fires are caused by anthropogenic ignitions, climate and weather are known to influence the risk of fire spread, regardless of ignition source (Eskandari et al., 2020). There is a stochastic aspect of the forest fire associated with the variability in local weather conditions, e.g., surface moisture, temperature, and wind speed (Bessie & Johnson, 1995). The natural causes of forest fire include rising atmospheric temperatures, low precipitation, accumulation of forest fuel (biomass) and topographic features (Flannigan et al., 2000; Holden et al., 2009). Among the natural drivers, climatic factors are prime drivers of regional fire occurrences (Bowman et al., 2009). Forest fires are most common in Nepal during the dry season, which extends from November to June each year, with highest frequency between March and May (Parajuli et al., 2015).

The Churia-Siwalik region of Nepal encompasses parts of the country's tropical and subtropical bioclimatic zones, forming its largest and longest landscape. This area accounts for 23.04% of Nepal's total forest cover and is home to rich biodiversity. The predominant forest ecosystem in Churia is *Shorea robusta* (39%), followed by tropical mixed broadleaved forests (25%), while *Hymenodictylon excelsum, Senegalia catechu,* and *Albizia* forests are less prominent (Uprety et al., 2023). Furthermore, this region is home to a plethora of wild species of flora and fauna. Some studies (Joshi et al., 2024) have shown that the Churia-Siwalik region stands out as highly susceptible to forest fires. Forest fire occurrences are quite frequent in this region, leading to the deterioration of forest ecosystem and its attributes.

Fire is reported to damage the regeneration of important tree species including Sal (*Shorea robusta*), which is a prominant species of most of the forests of Churia (Uprety et al., 2023). Climate change projections indicate an increasing trend in temperature and variability in rainfall patterns in the Chure region over the coming decades. Average annual temperatures are expected to rise by 1.3°C by 2065 and by 1.8°C by the end of the century under moderate emission scenario. Similarly, precipitation patterns are projected to become more erratic, with an increase in extreme rainfall events and prolonged dry spells, particularly during the pre-monsoon and winter seasons (MoFE, 2021). These changes in climate variability significantly influence the frequency and intensity of forest fires. Rising temperatures and prolonged dry periods are likely to increase the flammability of vegetation, leading to more frequent and severe fires.

Geospatial technologies, including remote sensing and geographic information systems (GIS), provide innovative and effective methods for detecting and monitoring fires. Remote sensing techniques have also been extensively used in various tasks like land use and land cover detection (Joshi et al., 2021), natural calamities like flood and landslide detection and burnt area mapping at local, regional and global scales (Giglio et al., 2009). The MODIS satellite imagery is commonly applied in forest fires detection and monitoring. MODIS Terra and Aqua have become the primary sensors at regional to global scales for active fire detection and monitoring due to their high temporal resolution and special channels designed for fire monitoring (Zagalikis, 2023).

Nepal is highly under the risk of forest fire and experiences it annually. Researches on forest fire have been gradually increasing but they are still not sufficient. They are limited, with most studies focusing on specific, small areas rather than providing a nationwide perspective. These studies primarily concentrate on fire risk analysis and identifying fire-prone zones. The relationship between forest fires and various responsible causative factors has not been extensively studied (Khanal, 2015; Matin et al., 2017; Mishra et al., 2023) particularly in the context of Nepal's complex topography. Thus, it is indispensable to understand the spatiotemporal patterns and causative factors of forest fires for formulating an efficient fire management plan (Bajracharya, 2002).

There is a need for more comprehensive research that integrates fire behavior, predicts burn areas, and examines the relationship between the fire trends and their causative factors in order to identify gaps and support the development of proactive strategies and improved fire management plans. Therefore, this study aims to identify long-term trends and associations between wildfire and climate and weather in Churia-Siwalik region. It investigates whether temperature, precipitation and burnt area are correlated with historical fire records over more than a century based on MODIS data.

MATERIALS AND METHODS

Study area

The Chure Region (also known as Siwalik), foothills of the Himalayas, spreads across east-west parallel to the high Mountains, covering 12.8 % of Nepal. The Churia (Siwalik) region is one of the major physiographic regions of Nepal. According to forest-cover mapping, the Churia region comprised 72.37% (1,373,743 ha) forest, 1.19% (22,672 ha) OWL and 26.44% (501,848 ha) other Land. The majority of the forest area (76%) was located outside protected areas (PAs) while the remaining forest (24%) was within PAs (18% in core zones-- and 6% in buffer zones) (DFRS/MoFSC, 2015). The mountains of Nepal are the youngest in the world and they provide habitat for various rare and globally threatened species (Subedi et al., 2020).

However, the increasing population pressure has caused the forest cover of the Churia-Siwalik region to deteriorate at an alarming rate as 7.7 million (26% of the national population) people live in 37 districts of Chure region (CBS, 2021). This region suffers from mass erosion, landslides, forest fire and other environmental externalities which make the region vulnerable (Pokhrel, 2012). In the case of forest fires, most of Nepal's burnt area has been found to be in the Chure region where forest fires occur in the pre-monsoon season, making it one of the most vulnerable areas. The climate of the Churia region ranges from subtropical to warm temperate. The average annual minimum temperature in this region ranges from 12°C to 19°C, with an average annual maximum temperature ranging from 22°C to 30°C (Rayamajhi et al., 2019). This physiographic zone is one of the most prone areas for forest fire as the Chure and Siwalik area are under the extreme threat of lightning (Sharma et al., 2020).

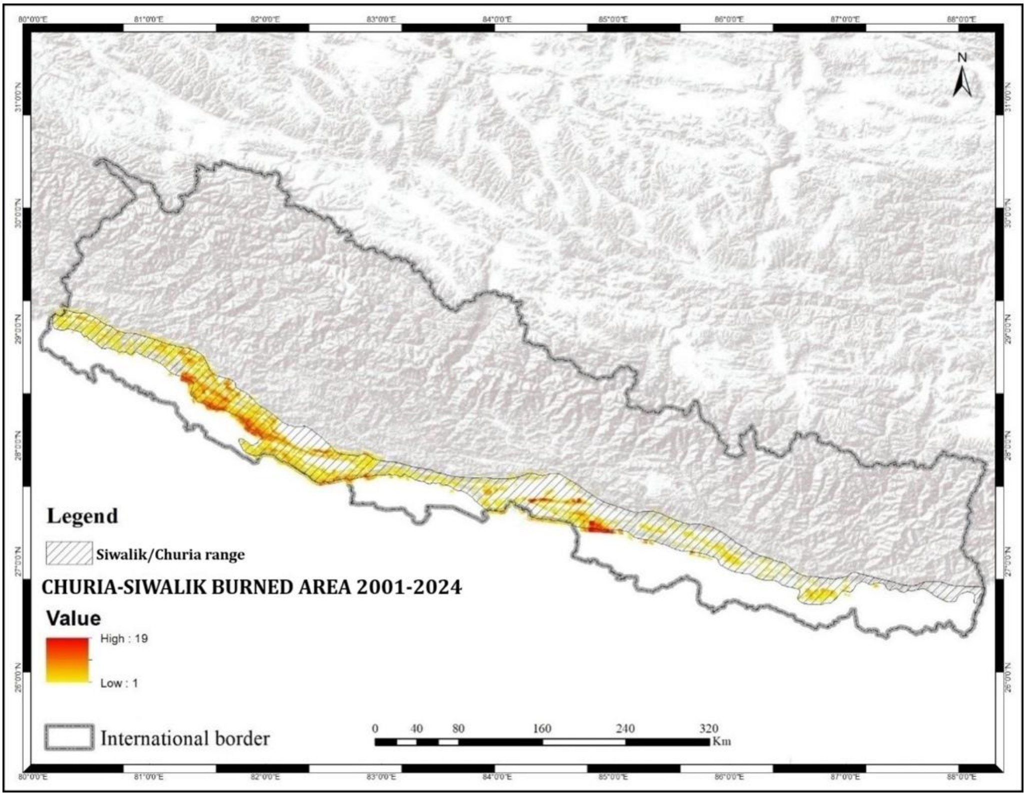


Figure 1: Study area showing the burned area from 2001-2024

Data collection

This study used data from the Moderate Resolution Imaging Spectroradiometer (MODIS) "MCD64A1" of burnt regions. The data acquired from the MODIS radiometer have been identified as a viable and reliable resource for monitoring forest fires and prediction of forest fire risk mapping (Mohajane et al., 2021; Zhao et al., 2021). Since, climate is generally understood as a key parameter in initiating and driving fire events, the burnt-area from MODIS were compared with the climate data (Khanal, 2015). The Terra and Aqua combined MCD64A1 Version 6 Burned Area data product which is a monthly, worldwide gridded 500m product including burned-area and quality information per pixel, was downloaded from the Google Earth Engine. The MCD64A1 burnt-area mapping technique combines 500 m MODIS Surface Reflectance images with 1 km MODIS active fire observations to create a map of the burned area. The vegetation index (VI) is calculated using a measure of temporal texture and MODIS shortwave infrared atmospherically adjusted surface reflectance bands 5 and 7. Within each MODIS tile, the algorithm determines the date of fire for the 500 m grid cells (Earth Engine, 2020).

The climate data of the study areas were retrieved using the Earth Map platform. The data were extracted, analyzed and graphed. The 'Precipitation' product is derived from processing Climate Hazards Group Infrared Precipitation with Station data (CHIRPS v2) grids at a 5-day temporal resolution to generate a total annual precipitation analysis for the period from 2001 to the present. The 'Maximum Temperature' product is derived from processing the European Centre for Medium-Range Weather Forecasts

(ECMWF) ERA5 atmospheric reanalysis of the global climate product (Earth Map, 2023).

Data analysis

Data analysis was done using R-software (R Core Team, 2023). The data were examined to identify trends and patterns in burned areas along with the temperature and precipitation across the study area. We performed the Mann-Kendall test equation (1) to see if there was a trend since it is a non-parametric statistical trend test that does not need data to be normally distributed. The null hypothesis was specified in this test, stating that there is no trend, and the alternative hypothesis, stating that there is a trend (Chinchorkar et al., 2015).

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \quad \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

$$sign(x_j - x_i) = \begin{cases} 1 \; if \; (x_j - x_i) > 0 \\ 0 \; if \; (x_j - x_i) = 0 \\ -1 \; if \; (x_j - x_i) < 0 \end{cases}$$

Where $x_1, x_2, \dots x_n$ represent n data points, x_j represents the data point at time j, and S is the Mann–Kendall test.

Equation (2), Theil–Sen method (TSA) was used to quantify yearly trend and trend during the time (trend) in R studio (Dhakal et al., 2016).

$$b = Median\left(\frac{x_j - x_l}{j - l}\right) \quad \forall l < j \quad \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where b is the estimation of the slope of the trend and x_l is the l^{TH} observation.

Normal distribution of the data set was examined using Kolmogorov Smirnov and Shapiro Wilk test. Since burned area during the burning seasons did not comply with normal distribution, logarithmic transformations were used to make the distribution normal (Urrutia-Jalabert et al., 2018).

Correlation studies were conducted between burnt area in the Churia-Siwalik areas, series of precipitation, and maximum temperatures. After the conversion, the three variables pass the normal distribution test; hence Pearson correlation test was carried out (Koutsias et al., 2013; Rasul et al., 2021).

$$R = \frac{\sum(x - \overline{x})(y - \overline{y})}{\sqrt{\sum(x - \overline{x})^2 \sum(y - \overline{y})^2}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Where x represents variables and y represents yearly burned areas. The R value ranges between +1 (strong positive relationship) and -1 (strong negative relationship). Zero degree means non-relationship between variables.

RESULTS

Trends of burned area in Churia-Siwalik region

Between 2001 and 2024, a total of 20,468 wildfires were recorded in the Churia-Siwalik region, affecting a cumulative area of 26,947.01 km². The highest number of fire incidents were experienced in 2016 followed by 2019 and 2024. The year 2016 experienced the highest burned area of 3,908.87 km², while the lowest burned areas were observed in 2015 (105.62 km²) and 2002 (119.07 km²) (Figure 2). Over the 23-year period, the annual burned area exhibited a statistically significant increasing trend, with an estimated rise of 51.27 km² per year (p = 0.04). This trend reflects an overall increase of approximately 1,179 km² in burned lands from 2001 to 2024. In the Churia-Siwalik region, from 2021 to 2024, Bardiya district witnessed the largest total burned area, followed closely by Banke, Parsa, and Dang districts. In contrast, the Eastern districts, including Jhapa and Ilam, reported significantly lower burned areas during the same period (Table 1).

Table 1: District wise burnt area in the Chure region from 2000-2024

S. N.	District	Total Burned Area from 2000-2024
1	Bardia	620171
2	Banke	542491
3	Parsa	427864
4	Dang	426243
5	Surkhet	391950
6	Kanchanpur	246654
7	Kailali	235279
8	Salyan	224861
9	Chitwan	180768
10	Kapilvastu	165616
11	Dadeldhura	90009
12	Bara	87537
13	Nawalparasi	80256
14	Argakhachi	76536
15	Doti	73510
16	Pyuthan	67237
17	Udayapur	63327
18	Makwanpur	61826
19	Sindhuli	48874
20	Rautahat	47536
21	Mahottari	42963
22	Sarlahi	28635
23	Saptari	24434
24	Rupandehi	23690
25	Dhanusha	19550
26	Sunsari	12327
27	Dhankuta	7179
28	Bhojpur	7022
29	Palpa	5222
30	Kavrepalanchowk	5073
31	Siraha	2752
32	Tanahu	2421
33	Lalitpur	1544
34	Morang	874
35	Ilam	731
36	Jhapa	269

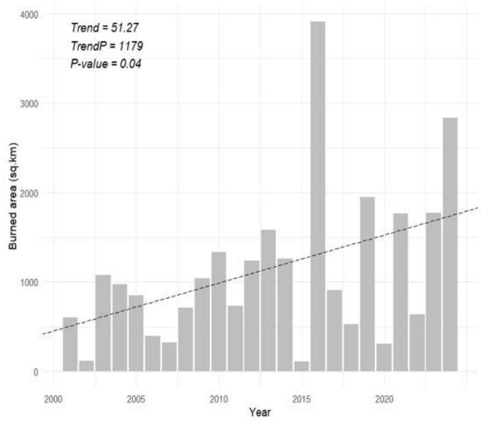


Figure 2: The trend of burned areas (km²) in Churia-Siwalik region from 2001-2024 ***(Dashed line represents the increasing trend)***

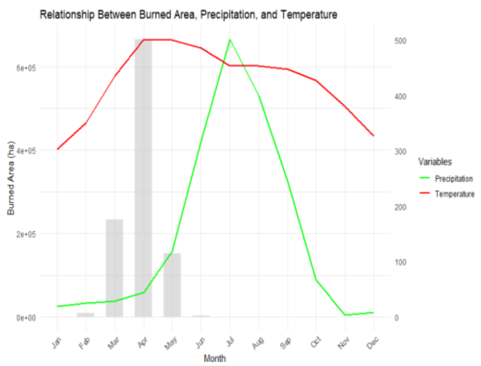


Figure 3: Monthly trend of burned area in Churia-Siwalik region from 2001-2024

The graph above depicts the month-wise trends of temperature, precipitation and burned area during the period of 2001 to 2024. A clear pattern emerges from the data, offering valuable insights into the seasonal dynamics of climate and fire incidents. We can observe that the precipitation levels were maximum in July (i.e., >= 500 mm) but lowest in December, suggesting a marked contrast between wet and dry seasons. In addition to that, the temperature was at its peak during April with a gradual decline in the later months. Similar trend is revealed by the graph that April has the highest burned area followed by March and May. This directly indicates that huge scale of fire incidents was recorded mostly in the pre-monsoon season. The combination of higher temperatures, lower precipitation, and dry vegetation most likely creates favorable conditions for fire outbreaks during this period.

Trend of precipitation and temperature

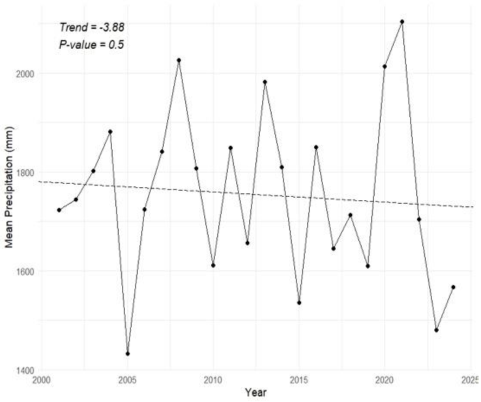


Figure 4a: Trend of precipitation from 2001-2024

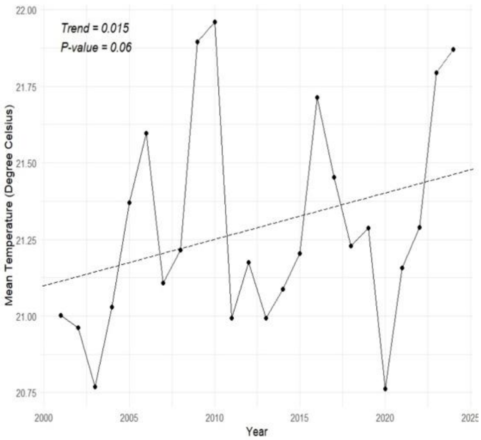


Figure 4b: Trend of temperature from 2001-2024

Figure 4a and Figure 4b shows a negative trend in precipitation but insignificant (p>0.1) result and positive trend in temperature with significant (p<0.05) result. Temperature shows an annual rise of 0.015°C whereas the precipitation displays the declination of -3.88 mm over the study period.

Correlation between burned area and climatic variables

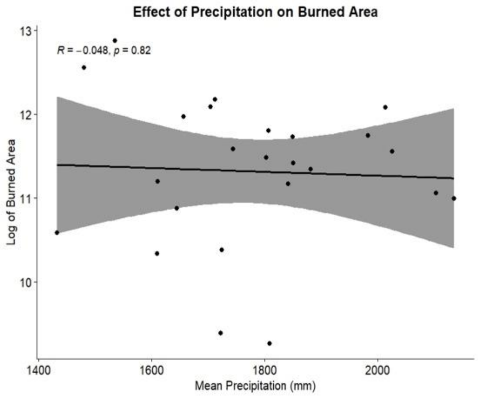


Figure 5a: Correlation between monthly burned areas (originally measured in hectares) and precipitation

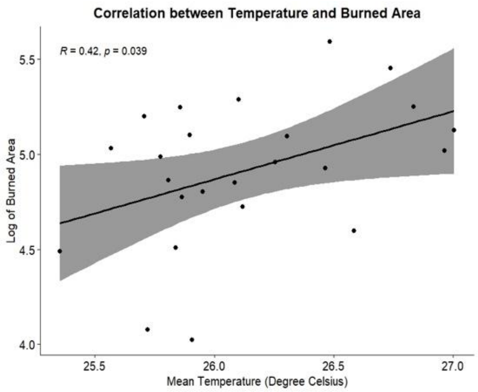


Figure 5b: Correlation between monthly burned areas (originally measured in hectares) and temperature

The Pearson correlation analysis conducted in Figure 5a and Figure 5b reveals an extremely weak negative correlation (r = -0.048, p = 0.82) between precipitation and burned area in the Churia-Siwalik region. Additionally, the relationship between burned area and maximum temperature shows a moderate positive correlation (R = 0.42, p = 0.039), implying that higher temperatures are associated with increased burned areas. These results highlight the significant influence of temperature on wildfire occurrence in the region.

DISCUSSION

For the Churia-Siwalik region, the Mann-Kendall test (MK) and Theil-sen test provide valuable information regarding the trend of yearly burnt area, precipitation and temperature. The slope of the trend line of burned area is not extremely steep, but it is positive, suggesting a 1,179 km² increase in burned area over the years. If the current trend continues, wildfire will worsen the region's situation, as fire has an impact on the environment's biotic and abiotic elements by destroying wildlife habitat, increasing soil erosion, insect infestation, overgrazing, stressed vegetation, microclimate change, and a variety of other effects, all of which contribute to a loss of species diversity (Boerner, 2000; Jhariya & Raj, 2014; Mekonen, 2020).

The temperature and precipitation trends during the study period also suggest significant shifts that may be contributing to the rise in fire incidents. The result of our study shows that temperature has risen by 0.015°C annually ($p < 0.05$), while precipitation has decreased by 3.88 mm per year ($p > 0.1$). Although the precipitation decline was statistically insignificant, the upward trend in temperature is noteworthy and aligns with global and regional patterns of warming (Ghimire, 2019; Paudel & Kafle, 2012; Shrestha et al., 1999). This rise in temperature is likely exacerbated by deforestation (0.18 percent each year), which reduces transpiration, leading to decreased rainfall and higher temperatures in the region (Neupane & Dhakal, 2017; Rai et al., 2017). The combination of higher temperatures and reduced precipitation creates favorable conditions, like dry grasses and shrubs for fire outbreaks, especially during the pre-monsoon season.

The correlation analysis between burned area, precipitation, and temperature further emphasizes the role of climatic factors in wildfire dynamics. While the relationship between precipitation and burned area showed a very weak correlation ($r = -0.048$, $p = 0.82$), temperature exhibited a moderate positive correlation with burned area ($r = 0.42$, $p = 0.039$). These findings suggest that while precipitation may not have a strong influence on fire occurrence, higher temperatures are more likely to contribute to larger fire events in the region. This is consistent with previous studies that highlighted the importance of temperature in driving fire activity, as drier conditions and increased evapotranspiration from rising temperatures lead to more flammable vegetation (Ahmad et al., 2017; Carvalho et al., 2008; Koutsias et al., 2013). Furthermore, Joshi et. al (2024) suggest that an increase in precipitation is associated with a decrease in the forest fire incidents, which corresponds to our research's conclusion.

An analysis of the data from that period revealed that in 2015, there was high precipitation (51.64 mm) during the spring season while that of 2016 had relatively low precipitation (15.79 mm). This suggests that the fire count and burned areas were higher than usual in the year with a precipitation deficit, as noted by Hamal et al. (2022). Pokharel et al. (2023) also suggested that extreme drought conditions and a deficit in precipitation were likely responsible for triggering the record-breaking wildfire season of 2021. The previous research of Bhatta et al. (2022) mentions that the extended lack of rainfall combined with intense heat creates perfect conditions for fires to spread quickly which coincides with our result.

Our study reveals an increasing seasonal trend in burned area. Furthermore, our study observed that 2015 had the lowest burned area while 2016 had the highest. Similar result was obtained by Parajuli et al. (2020), Badal & Mandal (2021), Bhujel et al. (2022) and Joshi et al. (2024). The study report on climate and climatic variation over Nepal

(Government of Nepal, 2015) and Bhujel et al. (2017) also highlighted rising trends in mean temperatures during the periods 1971-2012 and 2000-2015 across the country. Both results validate with the findings of this research.

This indicates that the increase in burned area in the Chure region might be the result of the prolonged drought, possibly leading to a decrease in fuel moisture content. Further, increased temperature leads to high evapotranspiration and decreased humidity, increasing drier organic matter in the area's soil (Chen et al., 2014; Hidayati et al., 2020; Matin et al., 2017). Drier fuels are not only more susceptible to ignition, but they may also support more vigorous fire spread and, on the oxther hand, drier organic matter causes deeper, more difficult-to-extinguish fires and leads to a larger burnt area (Badal & Mandal, 2021; Bhujel et al., 2017; Flannigan et al., 2016). In wooded ecosystems, dry conditions shortly before or during the fire year or season are linked to an increase in burnt area (Carvalho et al., 2008).

This assessment highlights that the pre-monsoon season, particularly from March to April, being the most vulnerable month is a critical period for fire incidents, with the largest scale of fires occurring in these months. Similar results have been supported on the prior studies (Bhujel et al., 2017; Khanal, 2015; Matin et al., 2017).The month of April not only exhibited the highest temperatures but also experienced the largest burned area, followed by March and May. This suggests a strong correlation between elevated temperatures and the extent of fire activity during the pre-monsoon months. Later, when the monsoon season begins and temperature starts to decline in mid-June, the country's forest fire problem diminishes. Air temperature has a direct influence on fire behavior because of the heat requirements for ignition and continuing the combustion process (Živanović et al., 2015). Precipitation (rain or snow) has a direct and immediate effect on fuel moisture and relative humidity. Precipitation will quickly dampen the surface of fuels to the point that fires cannot ignite and no wildfires will occur, i.e. precipitation plays a role in controlling wildfire (Hamal et al., 2022; Wang et al., 2021). Hence, the pattern of rainfall and temperature is a big factor in determining the fire season (the period when wildfires occur).

Following the fire, new fire-prone conditions may develop in these ecosystems, increasing fire frequency, decreasing rotation, and making it harder for trees to reach maturity, resulting in a progressive loss in seed bank and making ecosystem recovery difficult (Robinne, 2021). Hence, it is important to address the ecological, economic, and social repercussions of the region's increasing fire occurrences.

CONCLUSION

This study offers a broad overview of the spatiotemporal patterns of fire activity in Chure-Siwalik region over the years (2001-2024). It made an effort to correlate the observed trends in burnt areas with climate data. It depicts that there is an increase in burned area and temperature in the study area. The burnt areas were found to be negatively correlated with precipitation ($r = -0.048$, $p = 0.82$) and positively correlated with temperature ($r = 0.42$, $p = 0.039$). These relationships can be beneficial in predicting future fire seasons so that timely planning and resource allocation can be done to mitigate the unforeseen fire damages. Likewise, it is equally advantageous for necessitating adaptive strategies in fire management and conservation efforts to cope with the long-term effect of climate changes. Maintaining and conserving these various forest types is essential from a conservation standpoint because they include a high biodiversity of not just plant species, but also serve as a preferred home for a variety of wild animals.

These findings will be valuable for wildlife ecologists, wildfire managers, and policymakers in wildlife management. The

Chure, a young mountain range with a fragile soil structure, can benefit from our study's results. By designating this region as a biodiversity hotspot, establishing crucial wildlife movement corridors, and implementing forest landscape restoration programs, climate-resilient conservation practices, and sustainable land use strategies, we can support fire-affected areas through active community and stakeholder involvement.

Similarly, the extent of the burnt area followed a comparable trend, with April experiencing the largest proportion of land affected by fire. These findings highlight April as a critical month for fire management and preparedness, suggesting that interventions during this period could be particularly crucial in mitigating the severity of wildfires.

The conservation practices can be implemented through the integration of remote sensing and GIS in the preparation of fire risk modeling and identification of fire sensitive regions which can be helpful in developing advanced early fire detection system that can lead to effective fire management. Additionally, the incorporation of advanced machine learning techniques or remote sensing data with on-ground data could allow for a deeper understanding of the complex interactions between climatic conditions, land cover, and fire behavior, further improving the reliability of the results.

REFERENCES

Ahmad, F., Goparaju, L., Qayum, A., & Quli, S. M. S. (2017). Forest fire trend analysis and effect of environmental parameters: A study in Jharkhand State of India using Geospatial Technology. *World Scientific News*, 90(November), 31–50. http://www.worldscientificnews.com/wp-content/uploads/2017/08/WSN-90-2017-31-50.pdf

Alexandrian, D., Esnault, F., & Calabri, G. (1999). Forest fires in the Mediterranean area. *Unasylva*, 50(197), 35–41. http://www.fao.org/3/x1880e/x1880e07.htm

Badal, D., & Mandal, R. A. (2021). Spatial Assesment of Forest Fire Distribution, Occurrence and Dynamics in Province-2, Nepal. *Biomedical Journal of Science & Technical Research*, 27441–27459. https://doi.org/10.26717/BJSTR.2021.35.005666

Bajracharya, K. M. (2002). Forest fire situation in Nepal. International Forest Fire News, 26, 84–86.

Barlow, J., Berenguer, E., Carmenta, R., & França, F. (2020). Clarifying Amazonia's burning crisis. *Global Change Biology*, 26(2), 319–321. https://doi.org/10.1111/GCB.14872

Bessie, W. C., & Johnson, E. A. (1995). Relative importance of fuels and weather on fire behavior in subalpine forests. *Ecology*, 76(3), 747–762. https://doi.org/10.2307/1939341

Bhatta, M., Joshi, R., & Sapkota, R. P. (2022). Assessment of forest fire and its impact on plant biodiversity of the buffer zone, Langtang National Park, Nepal. *Indonesian Journal of Social and Environmental Issues (IJSEI)*, 3(3), 241–251. https://doi.org/10.47540/ijsei.v3i3.679

Bhujel, K. B., Maskey-Byanju, R., & Gautam, A. P. (2017). Wildfire Dynamics in Nepal from 2000-2016. *Nepal Journal of Environmental Science*, 5, 1–8. https://doi.org/10.3126/njes.v5i0.22709

Bhujel, S., Shah, P. R., & Rimal, B. (2022). Analysis of forest fire dynamics in Nepal: A temporal and spatial assessment (2001–2020). *Journal of Forest and Livelihood*, 20(1), 24-37. https://doi.org/10.3126/jfl.v20i1.56575.

Boerner, R. E. (2000). Effects of fire on the ecology of the forest floor and soil of central Hardwood forests. *Workshop on Fire, People and the Central Hardwoods Landscape*, 57–63.

Bowman, D. M. J. S., Balch, J. K., Artaxo, P., Bond, W. J., Carlson, J. M., Cochrane, M.

A., ... & Pyne, S. J. (2009). Fire in the Earth system. *Science*, 324(5926), 481–484. https://doi.org/10.1126/science.1163886

Carvalho, A., Flannigan, M. D., Logan, K., Miranda, A. I., & Borrego, C. (2008). Fire activity in Portugal and its relationship to weather and the Canadian Fire Weather Index System. *International Journal of Wildland Fire*, 17(3), 328–338. https://doi.org/10.1071/WF07014

Central Bureau of Statistics. (2021). National Population and Housing Census 2021. https://censusnepal.cbs.gov.np/

Chen, F., Niu, S., Tong, X., Zhao, J., Sun, Y., & He, T. (2014). The impact of precipitation regimes on forest fires in Yunnan Province, Southwest China. *Scientific World Journal*, 2014. https://doi.org/10.1155/2014/326782

Chinchorkar, S. S., Sayyad, F. G., Vaidya, V. B., & Pandye, V. (2015). Trend detection in annual maximum temperature and precipitation using the Mann Kendall test – A case study to assess climate change on Anand of central Gujarat. *Mausam*, 66(1).

Davidenko, & Eritsov. (2003). Russian Federation Fire 2002 Special Part I The Wildland Fire Season 2002 in the Russian Federation An Assessment by the Global Fire Monitoring Center (GFMC). *Soil Science*, 28(28), 2–14.

DFRS/MoFSC. (2015). *STATE of NEPAL' S FORESTS* (Issue December).

Dhakal, S., Sedhain, G. K., & Dhakal, S. C. (2016). Climate change impact and adaptation practices in agriculture: A case study of Rautahat District, Nepal. *Climate*, 4(4), 1–22. https://doi.org/10.3390/cli4040063

Earth Engine. (2020). *MCD64A1.006 MODIS Burned Area Monthly Global 500m*. Earth Engine Data Catalog. https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MCD64A1

Earth Map. (2023). *Earth Map*. Open Street Map.

Eskandari, S., Miesel, J. R., & Pourghasemi, H. R. (2020). The temporal and spatial relationships between climatic parameters and fire occurrence in northeastern Iran. *Ecological Indicators*, 118. https://doi.org/10.1016/j.ecolind.2020.106720

FAO. (2003). *State of the world's forets*. 5, 126.

FAO. (2005). Situation and developments in the forest sector. In *State of the word's forests* (pp. 1–66). http://www.fao.org/3/a-y5574e.pdf

Flannigan, M. D., Stocks, B. J., & Wotton, B. M. (2000). Climate change and forest fires. *Science of the Total Environment*, 262(3), 221–229. https://doi.org/10.1016/S0048-9697(00)00524-6

Flannigan, M. D., Wotton, B. M., Marshall, G. A., de Groot, W. J., Johnston, J., Jurko, N., & Cantin, A. S. (2016). Fuel moisture sensitivity to temperature and precipitation: climate change implications. *Climatic Change*, 134(1–2), 59–71. https://doi.org/10.1007/s10584-015-1521-0

Ghimire, P. (2019). A Review of Studies on Climate Change in Nepal. *The Geographic Base*, 6, 11–20. https://doi.org/10.3126/tgb.v6i0.26163

Giglio, L., Loboda, T., Roy, D. P., Quayle, B., & Justice, C. O. (2009). An active-fire based burned area mapping algorithm for the MODIS sensor. *Remote Sensing of Environment*, 113(2), 408–420. https://doi.org/10.1016/j.rse.2008.10.006

Government of Nepal, Department of Hydrology and Meteorology. (2015). Study of Climate and Climatic Variation over Nepal. https://old.dhm.gov.np/uploads/climatic/1407411953Climate%20and%20Climatic%20variability.pdf

Hamal, K., Ghimire, S. K., Khadka, A., Dawadi, B., & Sharma, S. (2022). Interannual variability of spring fire in southern Nepal. *Atmospheric Science*

Letters, *December* 2021, 1–13. https://doi.org/10.1002/asl.1096

Hidayati, I. C., Nalaratih, N., Shabrina, A., Wahyuni, I. N., & Latifah, A. L. (2020). Correlation of climate variability and burned area in borneo using clustering methods. *Forest and Society*, 4(2), 280–293. https://doi.org/10.24259/fs.v4i2.9687

Holden, Z. A., Morgan, P., & Swetnam, T. W. (2009). Fire severity in the western United States: A spatial and temporal analysis. *Fire Ecology*, 5(1), 1–17. https://doi.org/10.4996/fireecology.0501001

Jhariya, M. K., & Raj, A. (2014). Effects of wildfires on flora, fauna and physico-chemical properties of soil-An overview. *Journal of Applied and Natural Science*, 6(2), 887–897. https://doi.org/10.31018/jans.v6i2.550

Joshi, S. R., Khaling, S., & Kunwar, R. M. (2021). Land use and land cover change detection and prediction in the Kathmandu district of Nepal using remote sensing and GIS. *Sustainability*, 12(9), 3925. https://doi.org/10.3390/su12093925

Joshi, K. P., Adhikari, G., Bhattarai, D., Adhikari, A., & Lamichanne, S. (2024). Forest fire vulnerability in Nepal's Chure region: Investigating the influencing factors using generalized linear model. *Heliyon*, 10(7), e28525. https://doi.org/10.1016/j.heliyon.2024.e28525

Khanal, S. (2015). Wildfire trends in Nepal based on MODIS burnt-area data. *Banko Janakari*, 25(1), 76–79. https://doi.org/10.3126/banko.v25i1.13477

Koutsias, N., Xanthopoulos, G., Founda, D., Xystrakis, F., Nioti, F., Pleniou, M., Mallinis, G., & Arianoutsou, M. (2013). On the relationships between forest fires and weather conditions in Greece from long-term national observations (1894-2010). *International Journal of Wildland Fire*, 22(4), 493–507. https://doi.org/10.1071/WF12003

Kunwar, R. M., & Khaling, S. (2006). Land use and land cover change detection and prediction in the Kathmandu district of Nepal using remote sensing and GIS. Sustainability, 12(9), 3925. https://doi.org/10.3390/su12093925

Matin, M. A., Chitale, V. S., Murthy, M. S. R., Uddin, K., Bajracharya, B., & Pradhan, S. (2017). Understanding forest fire patterns and risk in Nepal using remote sensing, geographic information system and historical fire data. *International Journal of Wildland Fire*, 26(4), 276–286. https://doi.org/10.1071/WF16056

Mekonen, S. (2020). Coexistence between human and wildlife: The nature, causes and mitigations of human wildlife conflict around Bale Mountains National Park, Southeast Ethiopia. *BMC Ecology*, 20(1), 1–9. https://doi.org/10.1186/s12898-020-00319-1

Mishra, B., Panthi, S., Poudel, S., & Ghimire, B. R. (2023). Forest fire pattern and vulnerability mapping using deep learning in Nepal. *Fire Ecology*, 19(3), 3. https://doi.org/10.1186/s42408-022-00162-3

MoFE. (2021). Nepal's Third National Communication to The United Nations Framework Convention on Climate Change (UNFCCC). In *Government of Nepal Ministry of Forests and Environment*.

Mohajane, M., Mkhwanazi, M., & Mkhize, M. (2021). Forest fire risk mapping using remote sensing and GIS: A case study of the Kruger National Park, South Africa. *Journal of Environmental Management*, 278, 111469. https://doi.org/10.1016/j.jenvman.2020.111469

Neupane, M., & Dhakal, S. (2017). Climatic variability and land use change in Kamala Watershed, Sindhuli District, Nepal.

Climate, 5(1), 11. https://doi.org/10.3390/cli5010011

Parajuli, A., Chand, D. B., Rayamajhi, B., Khanal, R., & Baral, S. (2015). Spatial and temporal distribution of forest fires in Nepal. *XIV World Forestry Congress*, Durban, South Africa.

Parajuli, P., Joshi, S., & Bhandari, S. (2020). Temporal and spatial distribution of forest fires and their environmental and socio-economic implications in Nepal. *Environmental Monitoring and Assessment*, 192(7), 436. https://doi.org/10.1007/s10661-020-08459-5.

Paudel, P., & Kafle, G. (2012). Assessment and prioritization of community soil and water conservation measures for adaptation to climatic stresses in Makawanpur district of Nepal. In *Journal of Wetlands Ecology Wetland Friends of Nepal*, 2012(6). WFN. http://www.nepjol.info/index.php/jowe

Pokhrel, K. P. (2012). Conservation of Chure Forest in Nepal: Issues, Challenges and Options. *Economic Journal of Nepal*, 35(4), 262–278. https://www.nepjol.info/index.php/EJON/article/view/13067

Pokharel, B., Sharma, S., Stuivenvolt-Allen, J., LaPlante, M., Gillies, R., Khanal, S., Wehner, M., Rhoades, A., Hamal, K., Hatchett, B., Liu, W., Mukherjee, S., & Aryal, D. (2023). Amplified drought trends in Nepal increase the potential for Himalayan wildfires. Climatic Change. https://doi.org/10.1007/s10584-023-03495-3

Rai, Nitant & ma, Qin & Poudel, Krishna & Himes, Austin & Meng, Qingmin. (2024). Evaluating the Uncertainties in Forest Canopy Height Measurements Using ICESat-2 Data. *Journal of Remote Sensing*, 4. 10.34133/remotesensing.0160.

Rai, R., Nepal, M., Karky, B., Tamalsina, N., Khadayat, M., & Bhattarai, N. (2017). *Costs and Benefits of Reducing Deforestation and Forest Degradation in Nepal*. www.sandeeonline.org

Rasul, A., Ibrahim, G. R. F., Hameed, H. M., & Tansey, K. (2021). A trend of increasing burned areas in Iraq from 2001 to 2019. *Environment, Development and Sustainability*, 23(4), 5739–5755. https://doi.org/10.1007/s10668-020-00842-7

Rayamajhi, S., Pokharel, R. K., Tiwari, K. R., Heyojoo, B. P., Chhetri, B. B. K., & Kandel, P. N. (2019). An Assessment of the President Chure-Tarai Madhesh Conservation Development Program. *Forestry: Journal of Institute of Forestry, Nepal*, 16, 101–110. https://doi.org/10.3126/forestry.v16i0.28362

Robinne, F.-N. (2021). Impacts of disasters on forests, in particular forest fires. *UNFFS Background Paper*.

Sharma, S. (1996). Forest fire hazard distribution mapping in Nepal using satellite imageries: A research report. *Kathmandu, Nepal: Forest Fire Research Section, Department of Forest Research and Survey, Ministry of Forests and Soil Conservation.*

Sharma, S., KC, H. B., Neupane, B., & Dhakal, S. (2020). Life on Chure and Siwalik Under the Extreme Threat of Lightning. *Amrit Research Journal*, 1(1), 86–94. https://doi.org/10.3126/arj.v1i1.32459

Shrestha, A. B., Wake, C. P., Mayewski, P. A., & Dibb, J. E. (1999). Maximum temperature trends in the Himalaya and its vicinity: An analysis based on temperature records from Nepal for the period 1971-94. *Journal of Climate*, 12(9), 2775–2786. https://doi.org/10.1175/1520-0442(1999)012<2775:MTTITH>2.0.CO;2

Subedi, N., B, S., Manish Raj Pandey, P., Rabin Kadariya, P., Thapa, S. K., Gurung, D. A., Prasai, A., Lamichhane, S., Regmi, R., Dhungana, M., Regmi, P. R., Paudel, R. P., Kumpakha, B., Shrestha, B., Gautam, B., Baral, R., Paudel, U., Yadav, S., Pariyar, S., & Babu Ram Lamichhane, P. (2020). *Faunal Diversity in Chure Region of Nepal*. President Chure Terai-Madhesh Conservation Development Board and National Trust for Nature Conservation, Kathmandu, Nepal.

Uprety, Y., Tiwari, A., Karki, S., Chaudhary, A., Yadav, R. K. P., Giri, S., Shrestha, S., Paudyal, K., & Dhakal, M. (2023). Characterization of Forest Ecosystems in the Chure (Siwalik Hills) Landscape of Nepal Himalaya and Their Conservation Need. *Forests*, 14(1), 1–18. https://doi.org/10.3390/f14010100

Urrutia-Jalabert, R., González, M. E., González-Reyes, Á., Lara, A., & Garreaud, R. (2018). Climate variability and forest fires in central and south-central Chile. *Ecosphere*, 9(4). https://doi.org/10.1002/ecs2.2171

Wang, S., Li, H., & Niu, S. (2021). Empirical research on climate warming risks for forest fires: A case study of grade i forest fire danger zone, Sichuan province, China. *Sustainability (Switzerland)*, 13(14). https://doi.org/10.3390/su13147773

Xin, Y., & Williams, R. A. (2019). Effects of burn season on large seedlings of oak and other hardwood regeneration three years after shelterwood harvest. *Forestry Studies*, 71(1), 1–16. https://doi.org/10.2478/FSMU-2019-0009

Zagalikis, G. (2023). Remote sensing and GIS applications in wildfires. In *Climate Change and Fires* (Working Title). IntechOpen. https://doi.org/10.5772/intechopen.111616

Zhao, P., Zhang, F., Lin, H., & Xu, S. (2021). GIS-Based Forest Fire Risk Model: A Case Study in Laoshan National Forest Park, Nanjing. *Remote Sensing*, 13(18), 3704. https://doi.org/10.3390/rs13183704

Živanović, S., Gocić, M., Ivanović, R., & Martić-Bursać, N. (2015). The effect of air temperature on forest fire risk in the municipality of Negotin. *Glasnik Srpskog Geografskog Drustva*, 95(4), 67–76. https://doi.org/10.2298/GSGD1504067Z