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Spatial and Temporal Distribution of Forest Fires in Mahdesh Province

Sanjay Kumar Chaudhary[1] | Shiv Kumar Manjan[1] | Shailendra Kumar Yadav[2]
Ashok Parajuli[1] | Jyoti Manjan[1]

[1]Tribhuvan University, Institute of Forestry
Hetauda Campus, Hetauda

[2]Division Forest Office Kathmandu
Ministry of Forests and Environment, Govt. of Nepal.

Corresponding Author
Shiv Kumar Manjan
Email: shiv.manjan@hc.tu.edu.np

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Abstract

Forest fires are the main causes of forest degradation worldwide, and Madhesh Province in Nepal is highly vulnerable despite its limited forest cover. This study analyzes the spatial and temporal distribution of forest fires in Madhesh Province and identifies fire risk zones using Remote Sensing (RS) and Geographic Information System (GIS) techniques. Key influencing factors are land cover, slope, aspect, elevation, land surface temperature, proximity to settlements, and to roads were integrated using a Fire Risk Index method. The final risk map classified the area into five categories are very low, low, moderate, high, and very high. Validation was conducted using VIIRS S-NPP fire incidence data from March 2012 to April 2022. A total of 28,619 fire incidents and fire density 0.14 were recorded, with the highest number in 2021 (4,173). Approximately 93% of fires occurred during the hot and dry season (March to mid-June), with March alone accounting for 52%. Parsa District experienced the highest number of incidents. Notably, 67.5% of fires occurred within high and very high-risk zones, which covers 51.75% of the study area, confirming the model's reliability. The development of a forest fire risk zone map provides crucial data for understanding the forest fire problem and may serve as an effective tool for the Ministry of Forests and Environment, provincial and local governments, and other relevant authorities. The planning, prevention, and mitigation of forest fires will be made easier with the use of this data, improving risk management.

Keywords: GIS, Madhesh province, RS, VIIRS

1. Introduction

Forest fires occur at different scales around the globe every year. They cause social, economic, and environmental loss and damage (Pandey et al., 2022). Forest fires are considered a potential hazard with significant physical, biological, ecological, and environmental impacts (Somashekar et al., 2009). During 2000s forest fire frequency increased in many areas of the globe with major incidents occurring in Asia. Forest fires are one of the major natural hazards, becoming a serious threat to the environment. Globally, 350 million hectors of forest land are burned annually (Giglio et.al, 2013). Around 0.4% of the global land surface is reportedly burned every year, covering approximately 30 to 46 million km2 (Randerson et al., 2012). During forest fires, significant amounts of gaseous and particulate matter pollutants will get emitted into the atmosphere. On the other hand, forest fires can also have some positive impacts. Forest fires facilitate natural regeneration process by stimulating the germination of certain species, clearing space for the invasion and growth of others, and releasing a periodic flush of nutrients into the soil (Dawson et al., 2001).

Spatial and temporal distribution of forest fires in Madhesh Province and to know the fire risk zones is aim to study because research conducted by Bhujel et al. (2022) shows that the Terai and Siwalik regions of Nepal experience a higher incidence of forest fires compared to other physiographic regions. In this province forest fires are considered as a one of the major causes of forest degradation, especially in protected areas, along with illegal harvesting and the presence of unwanted species (Acharya et al., 2011). These fires pose a serious threat to forest resources, wildlife, and the environment, and they can also have direct and indirect impacts on human health and livelihoods (Ajin et al., 2017; Stephenson et al., 2013). Despite their increasing ecological and economic impacts, forest fires have not yet received sufficient priority in government policies, and research and fire management strategies remain limited (Somlai et al., 2018). Therefore, developing fire hazard maps and conducting further studies on fire occurrence, risk factors, and spatial distribution are essential for improving forest fire prevention and management in Nepal.

In Nepal, rising temperature and changes in precipitation are reliable shreds of evidence of increasing fire incidences (Negi et al., 2012). The declining pattern of precipitation and a long spell of rain off days are the shreds of evidence of severe wildfires in the coming days (Wang et al., 2013). In Nepal, forest fires are thought to be one of the main causes of forest degradation, particularly affecting protected areas, in addition to other factors including illicit harvesting and the introduction of undesired species (Acharya et al., 2011). Forest fires are the one of the most common hazards occurring in the forests and are considered as a serious threat to the forest resources, environment, and wildlife (Ajin et al., 2017). The increasing trend of forest fire in Nepal are affecting natural vegetation as well as causing major destruction of human settlements (Parajuli et al., 2020). Though the impacts of forest fires are relatively low compared with other major disasters, but it has direct and indirect impacts that include death as well as an adverse effect on people's health (Stephenson et al., 2013). Frequent forest fires destroy non-timber forest products, seriously harm seedlings, prevent their growth and regeneration, and may even promote invading species. (MoFSC, 2013).

Even though during the period of last decade unusual precipitations along with high temperature levels have been impacting the fire risk, these two variables represent just some of the possible causes of forest fires. Fire risk depends on several regional specific factors, human attitudes, and weather patterns (Pausas & Fernandez-Munoz, 2012). The combination of all of these aspects is responsible for generating such a type of scenario of forest fire as danger. Several types of natural disasters including landslides, hailstorms, floods, drought and fires are vulnerable in Nepal. According to projections, the quantity and intensity of these events will increase with climate change (MoAC, 2011). Remote Sensing (RS) and Geographic Information System (GIS) techniques can be effectively used in forest fire risk zonation mapping. Many researchers delineated forest fire risk zones using RS and GIS techniques (Chuvieco & Salas, 1996; Chuvieco et al., 1999; Singh, 2014; Thakur & Singh, 2014). MODIS data have been widely in use to map fire severity and burnt area (Chu et al., 2016) and develop danger forecasting models (Chowdhury & Hassan, 2015).

Additionally, it's critical to investigate and forecast the areas and times where fires are most likely to occur. This knowledge is essential for understanding what causes forest fires, devising methods to limit and manage the sources of ignition, and identifying high-risk areas (Parajuli & Haynes, 2016). That is why, the development of an integrated forest fire risk zone can help to decide the problems by taking into consideration the human and biophysical factors that are needed.

Considering the limitations associated with the detection of fire events in Madhesh Province between 2012 and 2022 using VIIRS satellite hotspot data, particularly uncertainties caused by satellite overpass timing and cloud cover, this study was conducted in response to the increasing concern about wildfire occurrences in the region. The research aimed to identify and model areas with high wildfire susceptibility and to examine their spatial variability. Multiple environmental variables were incorporated using remote sensing and GIS based techniques, drawing on factors commonly applied in previous wildfire susceptibility studies and supported by local knowledge. Primary field data were not included in the development of the fire risk zoning or in the spatial temporal analysis of fire distribution. Despite these limitations, the results provide useful insights for stakeholders and authorities involved in forest fire management and mitigation planning. However, the generated models should primarily be applied for awareness and preventive planning, as additional local-scale factors may influence wildfire risk that are not fully captured in the model are vegetation conditions, human activities, and micro-climatic variations.

So, this study is an attempt to exploit the capabilities of RS and GIS techniques to suggest an appropriate methodology for forest fire risk zone (FFRZ) mapping and analyzing the spatial and temporal distribution of forest fires in Madhesh Province. The active fire data acquired by MODIS and VIIRS devices on NASA’s Terra and Aqua satellites can be used for mapping and analyzing wildfire incidences. Timely and accurate detection of fires has become an issue of considerable importance. In this study, VIIRS S-NPP fire data from March 2012 to April 2022 have been used for spatiotemporal analysis of forest fire in the study area and to validate the forest fire risk map. Increased forest fire in Nepal in recent years has contributed to the destruction of forest health and carbon emission in all physiographical regions.

Such maps will help forest officials and other concerned authorities to prevent or minimize fire risk activities within the forest and take proper action when a fire breaks out (Chuvieco & Sales, 1996).

2. Material and methods

2.1 Study Area

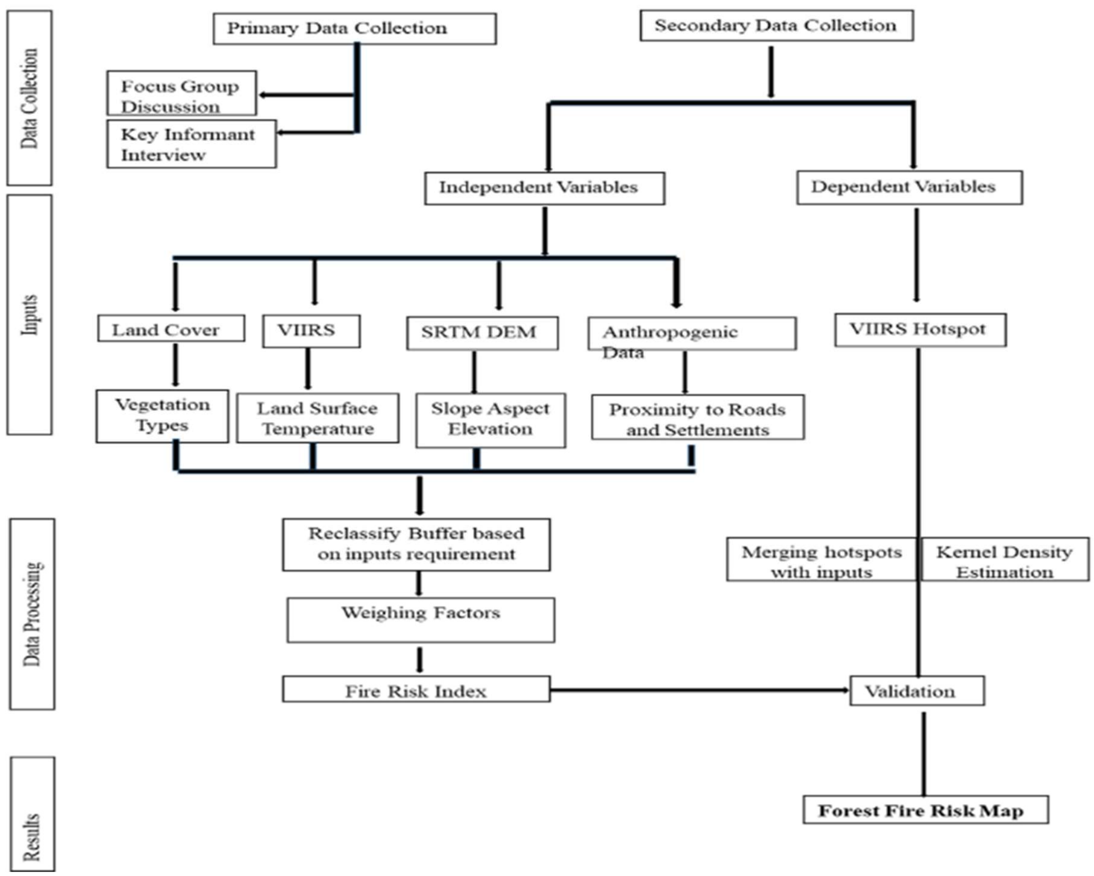
The study was carried out in Madhesh province. There are eight districts in Madhesh Province. The Province lies between 84°27′ to 86°54’30” East longitude and 26°23’38” to 27°28’17” North latitude. It covers 9,661 sq.km area and that is 6.56% of the total area of the country. Within the area 27.29% land is covered by forest. Topographically, the province can be divided into four main regions starting from the North, are the Chure Region, the valley basin is also called Dun, the Inner Terai also called as the Bhavar region, and the Low Plain region. Chure region of Madesh provenance occupies 1,52,339 ha (15.88%) of the total Province land surface area. There are climatic variations, which are associated with the diverse natures of its topography and altitude pronounced by dry and wet monsoon seasons.

During the summer temperature raised up to 40 degrees Celcius where as in winter it decreased up to 5 degrees Celsius. Madhesh province is smallest province by area among the in Nepal. As per census of 2021 the population of the provenance was 6,126,288, listed as highest populated province of Nepal. As per Economic Survey (2019/20), this Province contributes 14% to national GDP. Measuring GDP by provinces, it is estimated to have a growth rate of 2.3% in that fiscal year.

2.1 Research Framework

After the literature review and research gap, Madhesh Province was selected as the study site. The literature review was carried out to understand forest fire risk mapping, selection of methodology, and forest fire affecting factors like Slope, Aspect, Elevation, Vegetation types, and so on. Here is a flowchart of the methodology as in figure 1 was adopted for fire risk zonation which includes data collection, data processing and presenting results.

Figure 1: *Research Framework*



2.2 Data collection

Data were collected using the following methods:

2.2.1 Primary data collection

Primary data were collected by using the following tools. Key informant interviews and focus group discussions were used to gather primary data and information.

Key informant interviews (KIIs): To gain a thorough understanding of forest fire status, distribution and management approach of the region 17 KIIs were conducted in 2023 with forest officials/ Forestry experts at each Division Forest office and Parsa National Park (PNP).

Focus group discussion (FGD): 7 focus group discussions were carried out during the research in a very high, high and medium risk zone. This conversation helped us to learn more about the overall situation in the past and present as well as the perception toward forest fire cause, status, management and the support from various agencies and pieces of training they have about forest fire.

2.2.2 Secondary Data Collection

According to a report by HMGN/MFSC (2002), there is no systematic and complete record of the occurrence of forest fires and affected areas in Nepal. Thus, the historical data were taken through NASA's Fire Information for Resource Management System (FIRMS). The EOSDIS Archive Data Tool's archive fire spots were used in this study, and a polygon encompassing the study area and temporal data from 2012 to 2022 was created. In the study area from 2012 March to 2022 April, forest fire found in agricultural and water bodies detected by VIIRS was eliminated.

3. Data Analysis

For the analysis of data, MS Excel and ArcGIS 10.8 were used. Especially under ArcGIS other than basic function, buffering, kernel density function, and weighted overlay were used for analyzing different variables and results. All the data were extracted and encoded in an Excel sheet for better analysis and interpretation.

3.1 Parameters for Forest Fire Risk Model

The seven factors that are directly associated with fire occurrences are aspect, slope, elevation, land cover vegetation type, land surface temperature. Proximity to the road network, and proximity to settlement have been regarded as independent variables in accordance with the literature reviews for the forest fire risk model. The following inputs were selected in order to create the Madhesh Province forest fire risk potential map.

Land Cover: Land cover change is a major issue of concern with rapid population growth and expansion of urban centers, scarcity of land needed for more production (Manjan & Shrestha, 2024). In the forest vegetation is the source of fuel for the fire and the spread of the fire depends on the type of vegetation cover, stock of fuel, spacing of fuel, etc. (Nikhil et al., 2021).

Land Surface Temperature: Increasing air temperature has a great effect on the possibility of forest fire occurrence (Zivanovic et al., 2020).

Slope: It is thought that there is a decrease in the risk of fire as the slope increases (Baltaci et al., 2020).

Elevation: Elevation has a significant effect in fire propagation since it is a critical physiographic characteristic that is linked to wind behavior and, as a result, influences fire capability (Jaiswal et al., 2002).

Aspect: South and southwest aspects receives higher solar radiation which creates lower humidity and higher fuel and soil temperature that makes favorable for fire to start and spread in the area (Pyne et al., 1996; Chavan et al., 2012)

Proximity to Road: Any physical activity by man, animal or vehicle on the road can cause an unwanted fire. Thus, proximity to the road plays a vital role in the chance of fire.

Proximity to Settlement: Because of increased human activity, the occupancy makes the forest extremely susceptible to forest fire. Because building density and the number of people living close to the forest might create accidental fires, the forested area around homes and villages are more likely to experience fire ignition. (Jaiswal et al., 2002).

3.2 The weightage assigned to the parameters for the forest fire risk model

The seven characteristics that were chosen are land use (forest type), temperature, slope, distance to roads, closeness to civilization, elevation, and aspect were reclassified and given a fire risk value. Each variable was graded according to its fire potential, and weight was assigned based on a review of the literature in order to obtain a useful result and prevent model error (Jaiswal et al., 2002). The score was assigned using the scenario of forest fire frequency linked to each of the seven characteristics and comprehensive literature reviews conducted on related topics. Because land cover contributes significantly to fire stimulation through fuel flammability, it was given the greatest weight. Since greater temperatures increase the risk of fire, they were listed as the second most critical variable. Slope, road distance, and settlement closeness were ranked third, while aspect and elevation were given a 5% ranking. Each variable was graded according to its fire potential, and weight was assigned based on various publications in order to arrive at an efficient conclusion and prevent model errors. Every variable that had separate classes was given a unique name, ranging from 1 to 5, according to how each class affected forest fires. A score of one denotes a higher risk of forest fire, while a score of five suggests a reduced risk. The elements under consideration were then weighted according to the percentage of their influence, as the table 1 below illustrates.

Table 1: *Weight, value assigned and rating assigned to different parameter classes*

Variable	Weight (%)	Class	Value Assigned	Fire Rating Classes
Land Cover		Tropical Sal and Mixed Broad-Leaved Forest	1	Very High
		Hill Sal Forest	2	High
		Grassland/OWL	3	Medium
	40	Cropland	4	Low
		River bed/Bare soil/ Build-Up	5	Very Low
		Water bodies	No Data	No Risk
Temperature Degree C		>33	1	Very High
		31-33	2	High
	20	29-31	3	Medium
		27-29	4	Low
		<27	5	Very Low
Slope (%)		<5	1	Very High
		15-25	2	High
	10	15-25	3	Medium
		25-35	4	Low
		>35	5	Very Low
		<1000	1	Very High

Distance to Road (M)		1000-2000	2	High
	10	2000-3000	3	Medium
		3000-4000	4	Low
		4000-5000	5	Very Low
		<1000	1	Very High
Proximity to Settlement (M)		1000-2000	2	High
	10	2000-3000	3	Medium
		3000-4000	4	Low
		>4000	5	Very Low
		<200	1	Very High
		200-400	2	High
Elevation(M)	5	400-600	3	Medium
		600-800	4	Low
		>800m	5	Very Low
		Flat/South	1	Very High
		East/South East/ South West	1	High
Aspect	5	West	3	Medium
		North West/ North East	4	Low
		North	5	Very Low

3.3 Determining the risk model

In the literature, a number of indices have been presented to evaluate fire hazards utilizing anthropogenic and biophysical factors, such as vegetation, humidity, elevation, slope, and aspect. (proximity to settlements and roads) parameters (Jaiswal et al., 2002; Saglam et al., 2008; Adab et al., 2013; Mohammadi et al., 2014; Sivrikaya et al., 2014; Zhang et al., 2014). The fire risk model was prepared by a weighted linear combination of these parameters. The weightage of these parameters was calculated by the Analytical Hierarchy Process (AHP) using pairwise comparisons (Saaty, 1987). The scales used for pairwise comparison are shown in the Table, from Saaty (1987). The relative weights for variables were chosen (Jaiswal et al., 2002) and hence the risk model was developed with the equation given below.

FRI= 40% LC+20% LST+10%S+10%PR+10%PS+5%A+5%E

Where, FRI = Fire Risk Index, LC = Land Cover, LST = Land Surface Temperature, S = Slope, PR = Proximity to the Road, PS = Proximity to the Settlement, A = Aspect and E= Elevation.

Finally, a fire risk zone map was produced based on the analyses of parameters. Various weights were allocated based on the significance of the specific variable. Because fuel contributes to the greatest extent due to the inflammability factor, the LC was given the highest weight because it reflects the kind of forest, fuel load, and its accumulations. Due to the strong correlation between temperature and forest fire, LST was assigned the second-highest weight. Slope, road distance, and settlement proximity were assigned the third-highest weights. Higher slopes facilitate convectional preheating, making it easier for fires to start and spread. Additionally, being close to populated areas and accessible by road makes it possible for visitors, grazers, and locals to enter the forest and start fires. Subsequently, elevation and aspect are important because the fuel becomes drier and more combustible when exposed to direct sunlight, and because human infiltration reduces with altitude. Their risk potential was used to provide a rating, ranging from high to low. Following the determination of each weight, the Weighted Overlay Tool was used to overlay all of the layers in Arc Map 10.8.

3.3 Model Validation

Two methods were applied in this study to validate the Forest Fire Risk Model. Assuming that greater fire counts correspond to the higher risk rating assigned category, the first validation procedure involved integrating the forest fire counts in each fire risk zone. The second method was the KDE method which was used to validate the fire risk model developed. VIIRS hotspot was used as an input for this model. KDE was widely used for hotspot analysis and detection. The objective of KDE is to produce a smooth density surface of point events over space by computing event intensity as density estimation (Serra-Sogas et al., 2008).

4. Result

4.1 Spatial distribution of forest fire

4.1.1 Distribution of Forest Fire in Madhesh Province

Table 2: *District wise forest area, fire count and fire density from March 2012 to April 2022*

S.N.	District	Forest Area (ha.)	Forest Fire Incidents	Fire Density
1	Parsa	17,224	10,842	0.63
2	Bara	46,132	4,526	0.10
3	Rautahat	26,083	2,455	0.09
4	Sarlahi	25,578	2,797	0.11
5	Mahottari	22,061	2,214	0.10
6	Dhanusha	26,862	2,138	0.08
7	Siraha	18,028	1,335	0.07
8	Saptari	20,234	2,312	0.11
	Grand Total	**202,202**	**28,619**	**0.14**

Spatial and temporal distributions of forest fire in the study area were investigated on a monthly and yearly basis from VIIRS S-NPP 375m: Temporal Coverage of March 2012 to April 2022 AD and the monthly changes was studied for each year. Fire Density was expressed as the number of fires per unit area. Altogether 28,619 having fire density 0.14 forest fires per hectare fire counts were found with 2838 fire incidents per year and 237 fire incidents per month. The distribution of forest fire in districts of Madhesh Province is shown in Figure 3 to 11 and the Total forest fire occurrence in Madhesh Province from March 2012 to April 2022 years is shown in Figure 2. From Table 2 Parsa district had the highest fire count followed by Bara district while Siraha district had the lowest fire count.

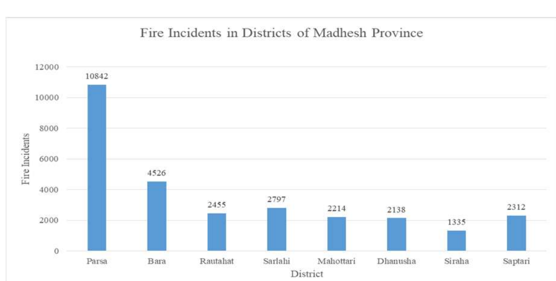


Figure 2: *Total forest fire incidence from March 2012 to April 2022*

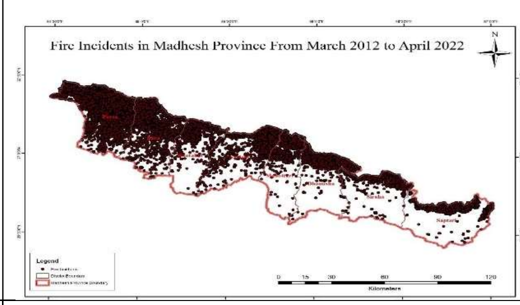
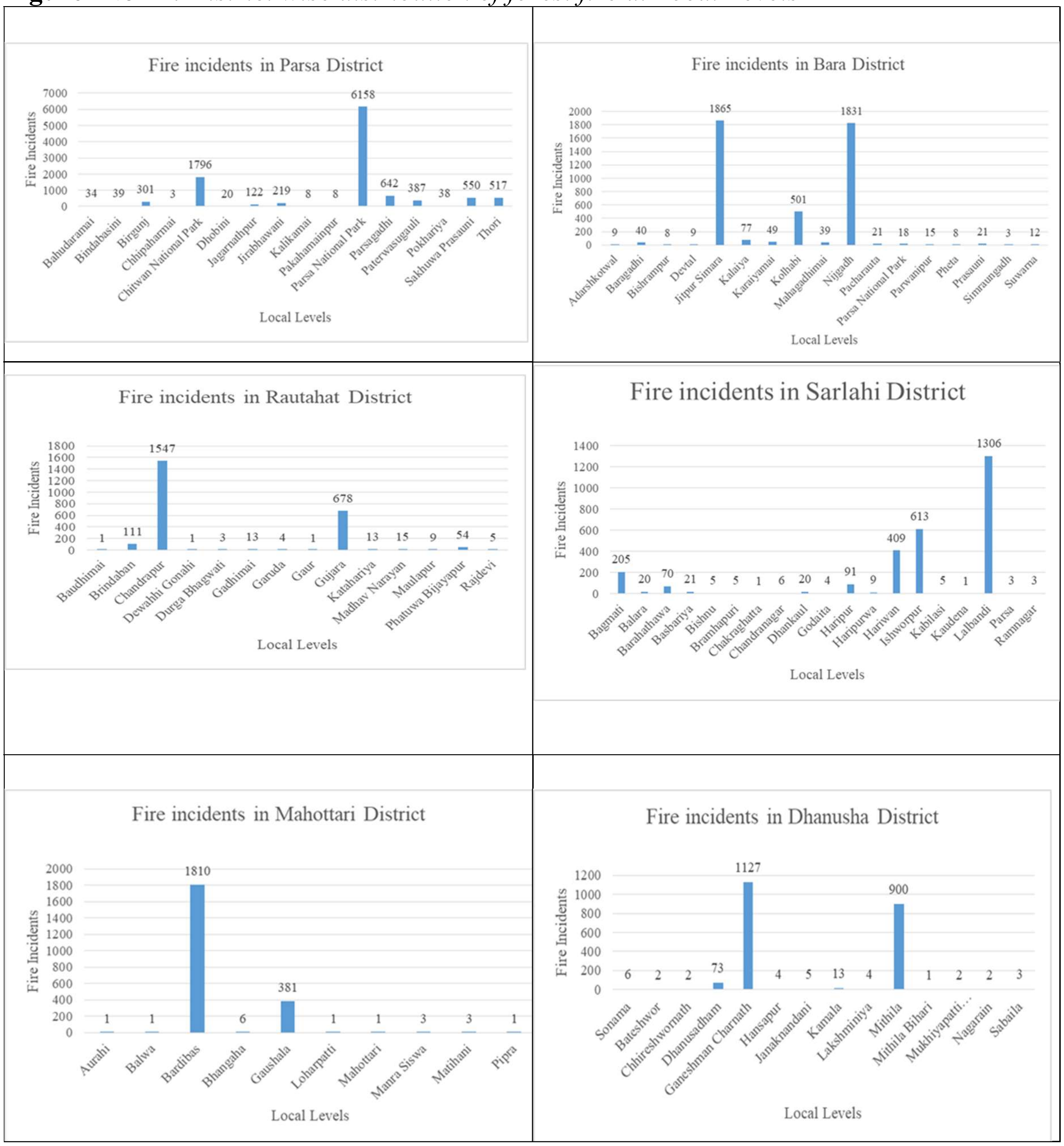
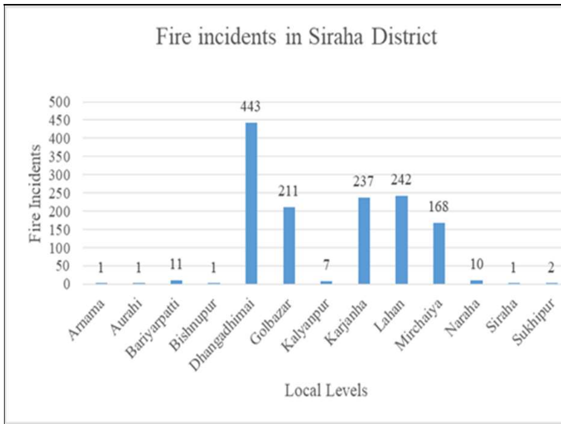


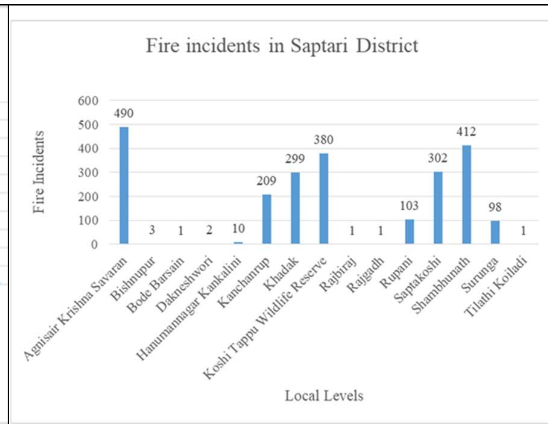
Figure 3: *District wise distribution of forest fire incidents*

4.1.2 District wise distribution of forest fire at Local Levels

Figure 4 to 11: *District wise distribution of forest fire at Local Levels*





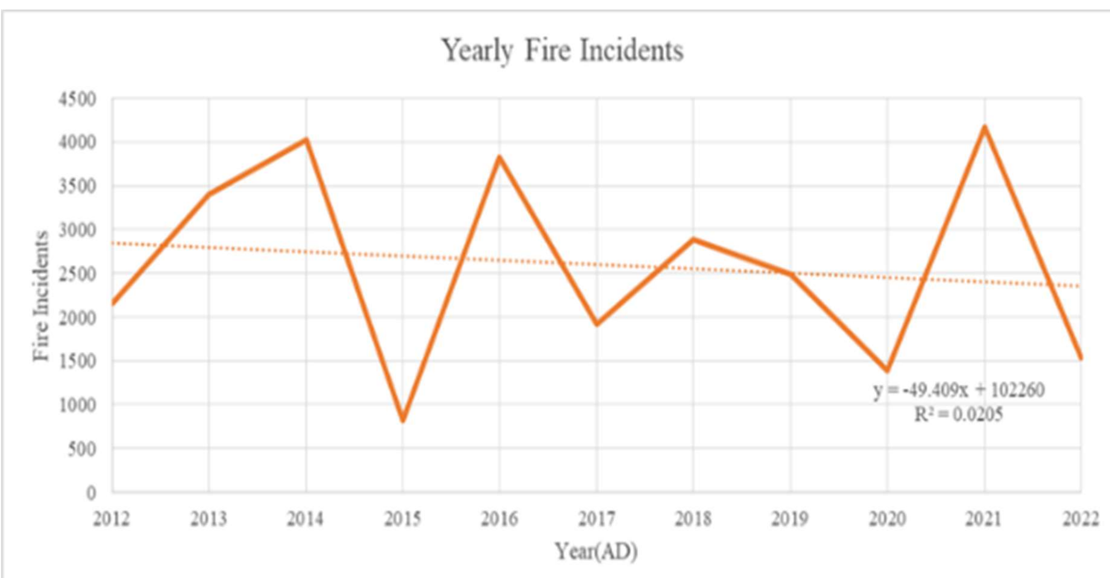


4.2 Temporal distribution of forest fire

4.2.1 Annual Trends of forest fire in Madhesh Province

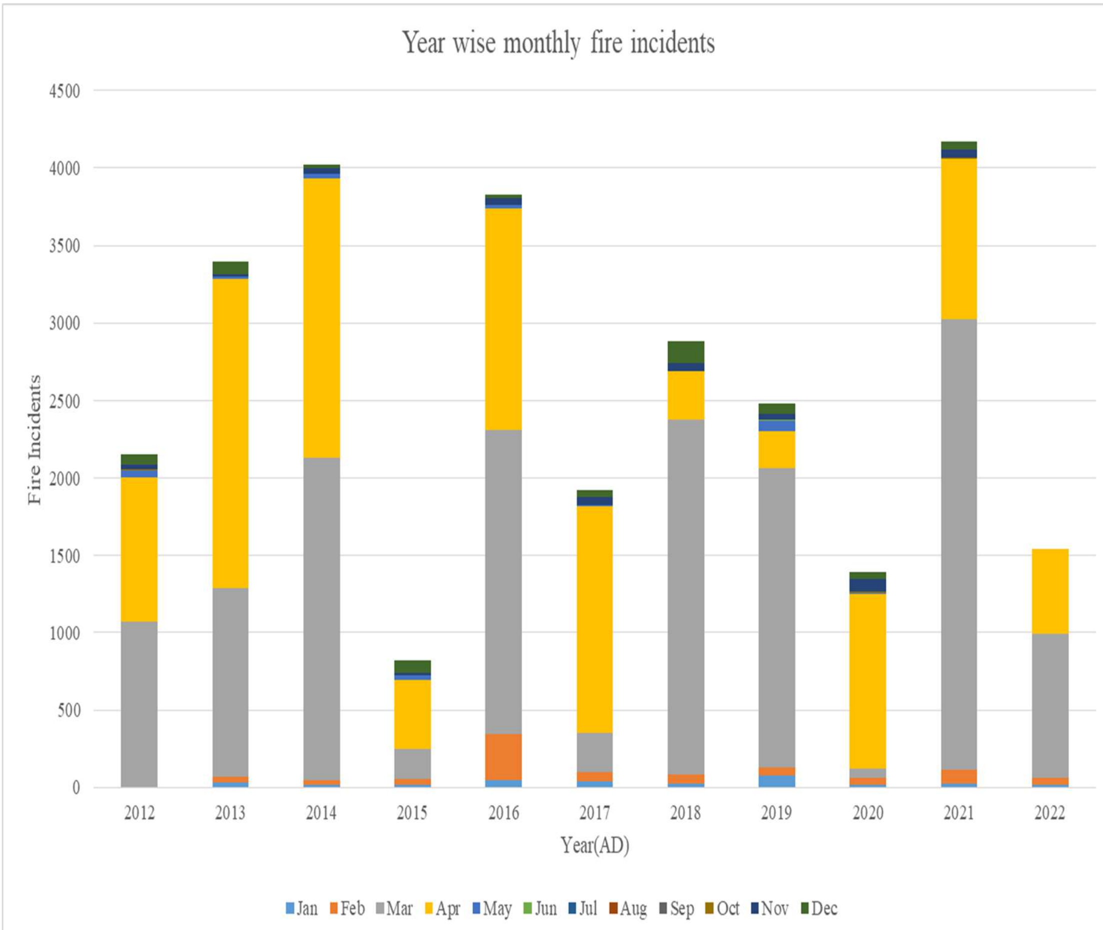
Analyzing the forest fire incidents from March 2012 to April 2022 from VIIRS S-NPP fire data, an average of 2,838 fire incidents observed minimum counted 2151 in the year 2012 and maximum counted 4173 in the year 202 followed by counted 4020 in the year 2014 and 3828 counted in the year 2016 within the study area, as shown in Figure 12. Annual trends of fire in Madhesh Province show that there was alternatively decrease and increase i.e. if there were highest fire incidents in the year 2014 then decreased in the year 2015, and after this increase in the year 2016, this was due to a decrease in fuel availability after highest fire incidents in that year then decreased in next year. As we conducted 17 KIIs and 7 FGD with government officials and stakeholders in Madhesh Province 90 % of respondents agreed with the trends of forest fire but in the year 2020 there is a decrease in fire incidents from the year 2018 to 2020 this was due to the corona pandemic as movement and outdoor activities of human were low during that period. As the trend is increasing but there was low fire incidents in year 2015 and 2020, It might be due to the less movement and low activity of peope due to earthquake in 2015 and corona pandemic in 2020.

Figure 12: *Annual trend of forest fire incidents in Madhesh Province*



4.2.2 Year wise monthly distribution of forest fire in Madhesh Province

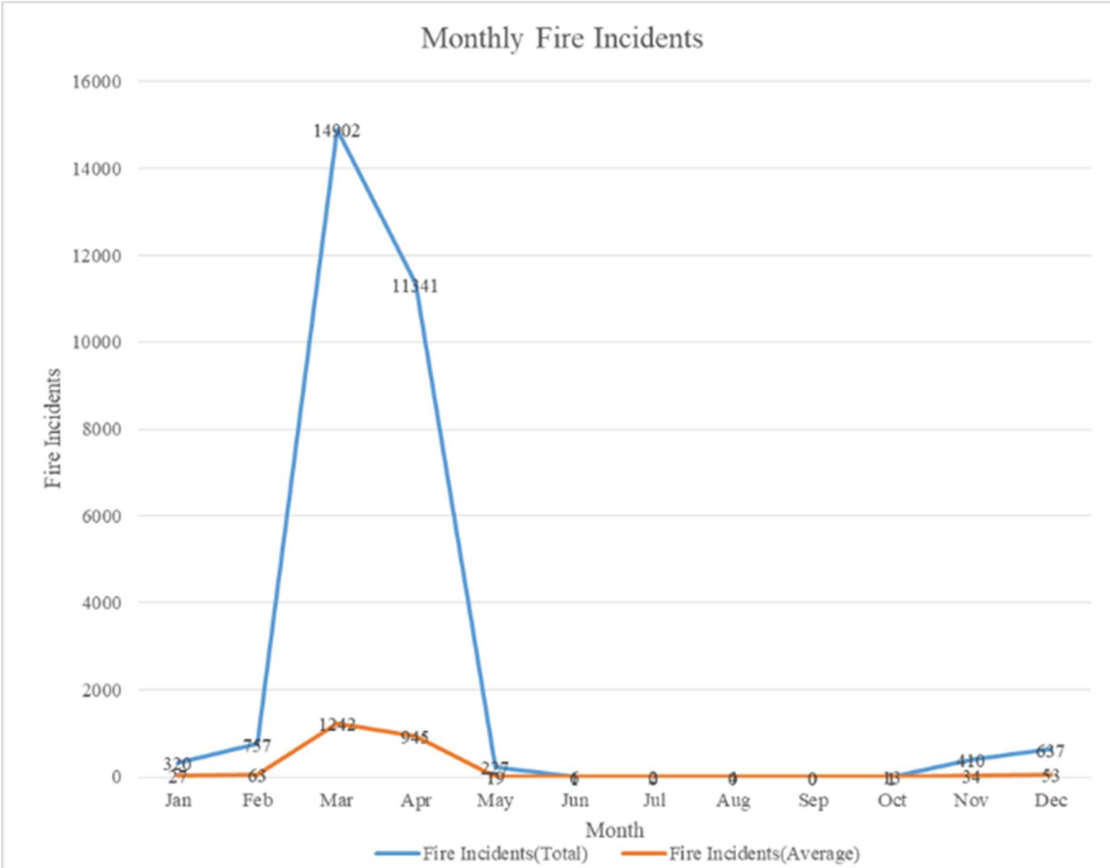
Counting forest fires incidence month wise counted maximum in two months from March to April were covering almost 91.70 % of forest fire of the year. The majority of these fires (approximately 93%) took place during the hot and dry season, from March to mid-June, with March alone accounting for about 52% of the incidents whereas the second most vulnerable month April comprised (36.63 %). There were no fires accounted in September month. The year-wise monthly data from March 2012 to April 2020 is shown in Figure 13.



4.2.3 Monthly distribution of forest fire in Madhesh Province

Pre-monsoon season especially April was recorded highest in the area as the studies carried out by Parajuli et al., (2020) and Thapa, (2021) observed April as the peak month for forest fire in Nepal. This study shows Madhesh Province recorded the highest in March which is shown in Figure 14. The more dry gasoline accumulates during this time, the more combustible the fuel becomes (Govender et al., 2006). There was a large inter-annual variation in average monthly patterns of fire occurrence but the majority of fires were observed during February, March, April and May. Among them the most significant being March, which had the highest average number of fires. Whereas from July to September fire activity gets lower because of the rainfall season and there were zero fire incidents in September month.

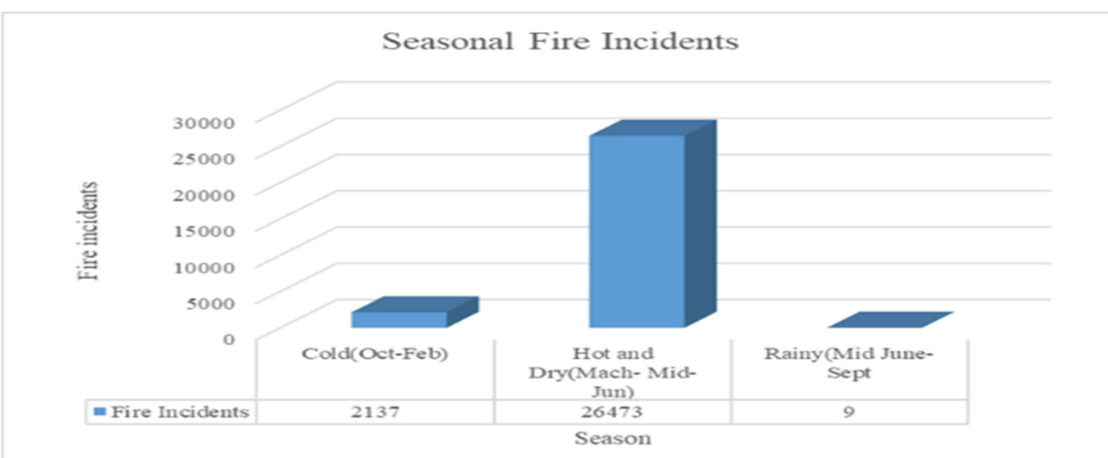
Figure 14: *monthly distribution of forest fire in Madhesh Province*



4.2.4 Seasonal distribution of forest fire in Madhesh Province

In the rainy season (Mid-June to September), there were very few (0.03%) forest fires due to heavy rain and enough moisture content available in an area. 7.47% of fire incidents were there in clod season (Oct-Feb). In the Hot and dry season (March to Mid-June) there were 92.50% of fire incidents when days were sunny and air humidity and fuel moisture were low, giving suitable conditions for fires. The seasonal distribution of fire incidents in Madhesh Province is shown in Figure 15.

Figure 15: *Seasonal distribution of forest fire incidents in Madhesh Province*



4.3 Forest fire risk model of Madhesh Province

4.3.1 Forest fire risk zonation of Madhesh Province

Each parameter was assigned a weight according to its impact on forest fire, and GIS techniques were used to overlay the data; the study area was hence categorized into very low, low, medium, high and very high. The risk zone is shown in Figure 16 below and the area has been included in Table 3 which shows that very high-risk areas covered 1.96%, high-risk areas with 49.79%, medium at 47.70%, low at 0.55 % and very low with 0.0002%.

Figure 16: *Forest fire risk map of Madhesh Province*

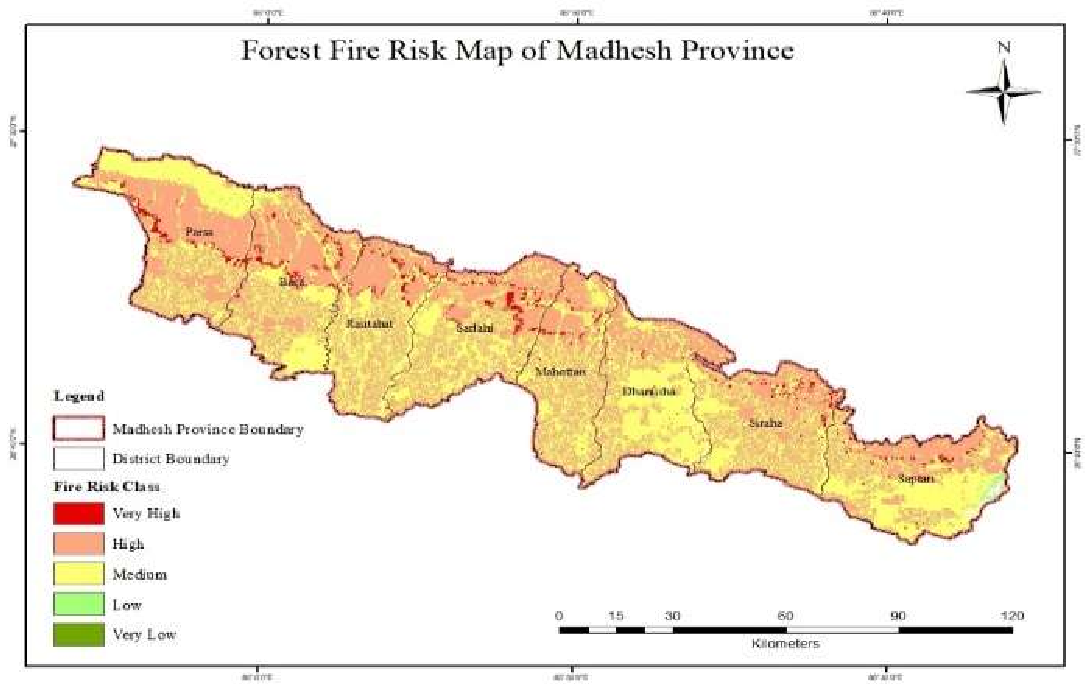


Table 3: *Area and percentage under forest fire risk zone in study area*

Risk Class	Risk Class Area (Ha.)	Risk Class Area (%)
Very high	18494.42172	1.96
High	469118.6895	49.79
Medium	449385.5839	47.70
Low	5144.778417	0.55
Very Low	1.559833	0.0002
Total	**942145.0333**	**100.00**

4.4 Model Validation

While carrying out any risk assessment model validation is vital. Once it is combined with a real-world dataset, the predictive power or accuracy will grow (Beguerıa, 2006). Two methods were used to validate the risk areas, one was the fire counts integration with the prepared risk zone maps and the other was the Kernel Density Model. For both validations, VIIRS S- NOSS hotspots count from March 2012 to April 2022 were taken as inputs.

4.4.1 Validation using forest fire counts on forest fire risk map

In addition to producing a consistent and comprehensive final risk digital map (Preisler et al., 2004), merging the fire risk map with fire occurrences enables the map to be incorporated into a coherent risk assessment procedure (Fairbrother & Turnley, 2005). Figure 17 shows the spatial distribution of forest fire incidence in a prepared fire risk zone map.

Figure 17: *Distribution of forest fire incidence in a prepared fire risk zone map*

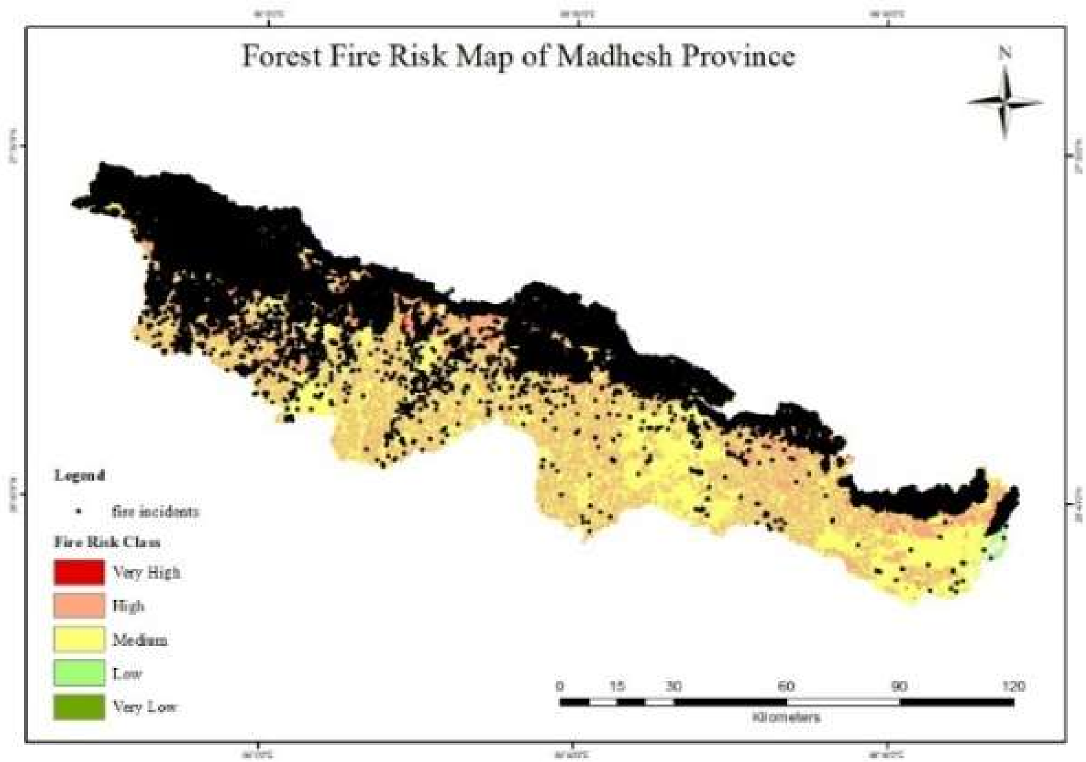


Table 4: *Percentage of fire counts in the prepared forest fire risk map*

Risk Class	Risk Class Area (Ha.)	Fire incidents	Risk Class Area (%)	Fire incident (%)
Very High	18494.42	727	1.96	2.5
High	469118.69	18601	49.79	65.0
Medium	449385.58	9022	47.70	31.5
Low	5144.78	269	0.55	0.9
Very Low	1.56	0	0.00017	0.0
Total	**942145.03**	**28619**	**100.00**	**100.0**

The table 4 indicates that the majority of fire incidence occurred in extremely high and very high-risk zones, accounting for 67.5% of fire counts, whereas area of the zone region represented 51.75% of all risk zones. As a very high-risk zone covered an area of 1.96% but 2.5% of fire incidents occurred in this class this shows higher accuracy of risk class thus validating the fire risk model.

4.4.2 Validation of forest fire risk map with KDE map

KDE has been widely used to produce the smooth density surface of fire points hence KDE method was applied to the historical dataset of VIIRS fire hotspots from March 2012 to April 2022. According to Zhang et al., (2017), Since KDE functions as a suitable decision support system development, it was employed as a tool for forest fire risk map validation procedures. Here we create smooth surface map using KDE tool in Arc Map and then classified into 5 classes of equal interval and area of each class were calculated. The comparison of danger areas identified by FRI and KDE is presented in Table 5, which demonstrates that while the high-risk zone had decreased and the low, very low-risk zone had expanded in KDE, the very high-risk and medium-risk zones in KDE are nearly identical to the area produced by the fire risk index map. Less concentrated fire spots in low and very low-risk areas might be the reason of this.

Figure 18: *Forest fire risk zone map from KDE*

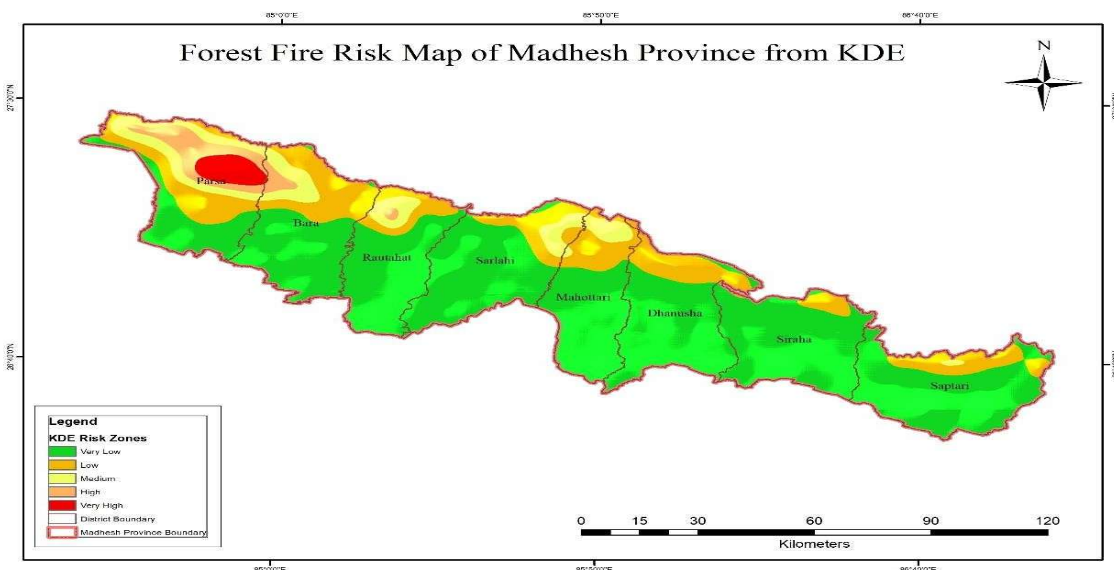


Table 5: *Comparison of risk areas with FRI and KDE*

Risk Zone	% of Risk Area from FRI	% of Risk Area from KDE
Very High	1.96	2.05
High	49.79	7.00
Medium	47.70	42.2
Low	0.55	15.35
Very Low	0.00017	42.5
Total	**100**	**100**

Hence, it can be said the fire risk index map has higher accuracy as it got almost similar results to KDE. Figure 18 shows the map generated by using the KDE method with the VIIRS fire points from March 2012 to April 2022.

4.5 Data Interpretation by Likert scale

The results obtained from Likert scale show that forest fires are on the rise. Forest fires exhibit the highest levels of surface fire. Lower tropical Shorea robusta and mixed broadleaf forests have the highest rates of forest fires. The highest number of fire incidents occurs in mid-March to the end of May (Chaitra-Baisakh). The majority of fire incidents occur in low lying locations. The southern side has the highest number of fire incidents. The highest number of fire incidents occurs at elevations up to 200 meters. The greatest distance at which a fire occurrence is noticed from a community is 1000 meters. The maximum distance at which a fire incident is viewed from the road is 1000 meters. Controlling forest fire incidents involves forest stakeholders very frequently. Regarding the findings from the secondary data, these primary data results appear to be comparable.

5. Conclusions and Recommendation

5.1 Conclusion

From March 2012 to April 2022, VIIRS fire hotspot data recorded 28,619 forest fire incidents in Madhesh Province, averaging 2,838 incidents per year. The highest number of fires occurred in 2021 (4,173 incidents), followed by 2014 (4,020 incidents). March and April were identified as the most critical months, accounting for 91.70% of total fire occurrences. March alone contributed 52.07% of the outbreaks, while April accounted for 39.63%. Overall, 92.50% of fires occurred during the hot and dry season (March to mid-June). Among the districts, Parsa District recorded the highest number of fire incidents (10,842), followed by Bara District (4,526) and Sarlahi District (2,797), while Siraha District (1,335) and Dhanusha District (2,138) recorded the lowest incidents. The forest fire risk map revealed that high and very high-risk zones cover 51.76% of the total area, with 67.5% of recorded fires overlapping these zones, validating the model's accuracy. The integrated analysis provides reliable support for forest fire management, planning, and mitigation strategies.

5.2 Recommendation

Climate change is likely to increase the frequency and severity, of forest fire in Madhesh Province. Understanding of environmental conditions, fire behavior, and human activities is essential for effective fire management. Federal and provincial authorities should strengthen preparedness, response, and recovery plans in high-risk areas of Parsa National Park. At provincial and local levels, clear communication systems, updated policies, training, proper firefighting equipment, advanced monitoring technologies, vegetation management, intensive research, and improved technology are necessary for fire weather prediction.

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