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Forest fire occurrence, distribution and future risks in Arghakhanchi district, Nepal

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Abstract

Forest fire has proved to be a major uncontrolled disaster which causes imbalances in ecosystem and endangers the biodiversity but the research related to this is very limited so far in Nepal. Thus, this study was objectively carried out to identify the occurrence and distribution of forest fire and its drivers and risk zone applying spatial analysis. MODIS hotspot satellite data from 2002 to 2018 and other variables were integrated using geo spatial technique. The topographic and land cover related data archived from International Center for Integrated Mountain Development and Land Processes Distributed Active Archive Center from NASA official website. The forest fire point and burnt area related shape file archived from the MODIS data as data sources for this study. The layers of each variable were prepared and overlaid on it to assess the forest fire risk zone. Altogether 120 GPS points collected from field and 12 focus group discussion was done to find the fire risk zone. The collected data were analyzed using ArcGIS. The result shows those total 391 hotspots were recorded by MODIS satellite from 2002 to 2018. Out of this, the highest fire count was in Sitganga municipality with 284. Total 121 in forest fire occurrence was in 2016 but single event was recorded in 2002. It was about 2, 51, 722.31 ha area burnt between 2002 to 2018. The forest area close to settlement area and road less than 1000 m was more prone to the forest fire. Fire occurrence was the highest 168 in broadleaved closed forest. The highest 77 fire incidents were recorded in southern aspect. The highest fire incidents was recorded at higher than 35 degree but very less number of fires occurred in slope less than 5%. Temperature range greater than 33 °C is more prone to fire, which recorded about 106 in number. It showed that, Sitganga and Sharada municipality are at the highest risk of fire zone. This study will help to establish the baseline data for monitoring the forest fire.

Keywords: MODIS, kernal density estimation, people perceptions, fire management

Introduction

Forest fire has proved to be major uncontrolled disaster that occurs in nature which causes imbalances in ecosystem and endangers the biodiversity by reducing the floral and faunal wealth. Fires in forests and outside forest have strong influences on natural resources, human health, weather and climate (Eiji at el 2007) [32]. Fire is a major factor in shaping the history of vegetation in most of the terrestrial environment in the world and if properly used fire can be an ecological tool of great value (Odum and Barrett, 2010) [60] but when it uncontrolled it becomes too destructive. Especially wildfires are creating major risk to the biodiversity, forests and forest products. Fire and its impacts can be viewed as desirable or non-desirable, based on the compatibility with overall objectives (Wade & Lundsford, 1990) [83].

Department of Forest (DoF) and International Centre for Integrated Mountain Development (ICIMOD), jointly have developed a fire detection and monitoring system for Nepal using Moderate Resolution Imaging Spectroradiometer (MODIS) data with the support of United States Agency for International Development (USAID) and National Aeronautics and Space Administration (NASA) (ICIMOD, 2012) [50]. The Government of Nepal (GoN) has prepared Forest Fire Management Strategy (FFMS) 2010 aiming to proceed through the strategy and control forest fire incidence in the country. It also identifies that there is the lack of coordination between the concerned stakeholders (GoN, 2011).

Arghakhanchi district is recognized as the fire prone area in Nepal but there is no any research related to this so far. So, this study is an attempt to map fire-prone forest areas in Arghakhanchi district using Geographic Information System (GIS) and to assess the management practices and its success and failure. Incidence of forest fire in the district from 2002-2018were acquired from the Fire Information for Resource Management System (FIRMS) and ICIMOD Nepal, which integrates remote sensing and GIS technologies to deliver global MODIS hotspot fire location and fire risk zone information to natural resource managers and other stakeholders around the world. This study also utilized the data given by MODIS to find fire areas in forest so that effective ground verification was carried out on forest of Arghakhanchi district and data given by NASA is merged to obtain high accuracy and valid result.

Arghakhanchi district is highly threatened by fire and also it is one of the eighteen districts of Nepal with very high fire risk zone (Martin *et al*, 2017) [57]. In this case of Arghakhanchi until now no studies on fire behavior from forest fires have been conducted. Hence, this study will help to establish baseline data of forest fire information, understanding the causes of forest fire drivers, hotspot of fire risk zonation, seasonality and create fire risk zonation map and their temporal and spatial pattern that helps to local authorities.

Research Methodology

The study was carried out in whole area including (3municipalities and 3 rural municipalities) of Arghakhanchi district. The geographical location of the district is Latitude28^{0}00'1.80‘‘N latitude and 83^{0}14'28.80‘‘E longitude. Altitude varies from 305 m to 2515 m above mean sea level. The district can be broadly divided into two physiographic regions i.e. 68% Mahabharat hills and 32% Churia hills. Hot season exists between March to June with maximum temperature 40 °C and this season is the fire occurring season. Forest covers 62.05% of the total land area of the district. Majority of the forest area is dominated by Sal (*Shorea robusta*), forest. Saj (*Terminalia elliptica*) and Bajh (*Quercus leucotrichophora*) are the major plant species but Katush (*Castanopsis tribuliodes*), Rhododendron (*Rhododendron ferrugineum*), Uttis (*Alnus nepalensis*), Chuire (*Aesandra butyracea*), Koiralo (*Bauhinia variegata*), etc. are also available in district.

Primary data collection: The primary information was collected by using PRA tools like Focus Group Discussion and direct field observation at the selected high forest fire prone area of study area.

Focus Group Discussion: Total 12 focus group discussion with different community forest groups alone with the representative from local government was carried out in the district. Purposive sampling was done to select the sites and groups. To select it, at first MODIS data was overlayed in the district and on the basis of frequency of occurrences of forest fire provided by the MODIS data, five risk categories will be made, i.e very high, high, medium, low and very low. 2 focus group discussion was made on each risk categories.

Ground Truth Verification: To check the accuracy of the MODIS data, random fire points from different community forest along with the attributes like fire occurred date, time and month was recorded.

MODIS data: Information for Resource Management System (FIRMS) provides information on active fires using the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on board NASA‘s Aqua (evening) and Terra (morning) Satellite (NASA/University of Maryland, 2002). Furthermore, ICIMOD also provides the information of active forest fire in Nepal. MODIS data from NASA‘s Terra (Afternoon) and Aqua (Morning) earth monitoring satellites, and provides the processed data to universities and research institutes as part of the academic frontier project. The MODIS active fire product detects fires in 1km x 1km pixels that are burning at the time of overpass under relatively cloud-free conditions (Giglio *et al*., 2003; Giglio, 2007) [48, 49]. In concern to Nepal, it does not have own reliable information, tools and technology for the detection and monitoring due to which MODIS vector data will be downloaded from NASA‘s official website. The forest fire point and burnt area related shape file archived from the MODIS data as data sources for this study.

Required data for fire risk zone model: The data which was necessary were obtained from different websites, institutions and organizations. Historical fire data of the Arghakhanchi district was selected from NASA forest fire data. Land cover (2010) and Road Network were obtained from ICIMOD, Forest type and settlements of Arghakhanchi district were obtained from Department of Forest Research and Survey (DFRS). District boundary was obtained from Department of Survey; ASTER Digital Elevation Model (DEM) was obtained from LP DAAC NASA‘s website and Slope and Aspect was prepared from ASTER DEM using ArcGIS 10.5. These data was used for fire risk zone modeling.

Ground verification: Data given by NASA (MODIS active historical fire data) was verified by doing random verification in certain areas of the district for the valid result. Altogether 120 GPS points collected from field.

Desk review: The collected related district annual management plans, progress reports and related literatures published on various journals were reviewed through desk review process. The other relevant information was collected from Divisional Forest Office, District Coordination Committee, Department of Forest, previous records, maps, publications, reports of other line agencies, published or unpublished and other relevant literatures from websites was reviewed as secondary data for better understanding, interpretation, and analysis of the research.

Fire sensitive or risk zonation: Kernel density model was used to find out the high, medium and low risk or sensitive zone of the district. It is necessary to estimate density to know where the fire incidence is more concentrated. Kernel density calculates magnitude per unit area from point using kernel function to fit smoothly tapered surface to each point.

Fire risk modeling involved several steps: Several studies have proposed the integration of variables into a single fire model (Hernandez *et al*., 2006; Carrão *et al*., 2003; and Jaiswal *et al*., 2002) [53]. Several types of factors and parameters are required for forest fire risk zone modeling. In delineating forest fire risk zone mapping, all seven thematic layers of parameters such as slope, landcover, aspect, distance from roads, distance to settlements, and elevation. Chuvieco and Congalton (1989) [17] suggest a hierarchical scheme of fire rating which was followed in this study. Layers of importance from highest to lowest were as follow: land cover, vegetation, slope, aspect, temperature, Proximity to roads, proximity to settlements and elevation (Chuvieco and Congalton, 1989) [17].

These all parameters were correlated to historical fires data. Aspect of the DEM (digital elevation model) and Euclidean distance of road to forest fire occurrence in the study area were calculated. Based on the MODIS active fire historical fire data from 2002 to 2018, the classes of the different cause factors (distance of settlement, aspect, and land cover) were reclassified based on the risk they represent. To rank the classes of the input layers according to their importance to their importance as being vulnerable to fire, the forest fire hotspot and the reclassified data were overlaid to identify classes of particular layer with more frequent fire incidents. Classes with high fire occurrence were assigned a higher rank and classes with less positive relation to fire occurrence were ranked lowest. The classes of each dataset were ranked in a scale of 1-5, particualry1 being the highest ranking, 2 as high; 3as medium; 4as low and 5as the very low. Once all layers were reclassified and each assigned a rank, a model was developed to overlay this data according to defined weights in order to produce a fire risk map of Arghakhanchi district. Using the Spatial Analyst (Weighted Overlay) tool in ArcGIS model builder the input layers have been given weights that all add up to 100%. In order to obtain effective and more accurate conclusions mathematical operations in GIS analysis formed. The fire risk model can be summarized in the following equation:

$$FFRZ = 40LC + 20LST + 10S + 10DR + 10DS + 5A + 5E$$

Where FFRZ are forest fire risk zone index, where LC indicates land cover variables with 5 class, S indicates slope variables with 5 classes. A indicates aspect variables 5 classes, E indicates elevation variables of distance from roads and settlement .Finally, a FFRZ map was produced based on these analyses by using ARC GIS software. The relative weights for variables were chosen based on the literature (Chuvieco and Congalton 1989; Jaiswal *et al*. 2002; Saglam *et al*. 2008; Adab *et al*. 2013; Sivrikaya *et al*. 2014) [17, 53, 76] and ratings among the different classes within each variable were chosen based on historical data analysis. Based on literature review, advisor‘s advice, consultant suggestion, land cover was weighted the highest, followed by slope, aspect, elevation and distance to roads, settlements. Each layer was assigned a scale starting with 1, 2, 3, 4 and 5 with 1 being the highest risk and 5 as the lowest risk.

Land cover was evaluated first as an estimate of fuel available for a fire. Weighting of the classes in the land cover layer were determined by the moisture; the dryer the vegetation, the higher the risk of flammability. Temperature layer was evaluated .It was divided into five categories. Temperature greater than 33 °C was given the highest weight 31-33 °C was given the high rank, temperature 30-31 °C was ranked as medium group. Temperature between 28-30 °C was ranked as low group and finally temperature less than 28 °C was given the very low category.

Slope was the third factor to be evaluated. Weighting was determined by the fact fire travels more rapidly up slope. The slope layer was divided into five groups: less than 5% as very low risky, slope 5%-15% as a low, slope range 15% to 25% (medium), slope 25% to 35% (High) and slope greater than 35% (very high risky).

The distance from roads was evaluated since nearby areas have a higher risk of a fire. The buffer layer was divided into five groups. The areas within a Euclidean distance of less than 1000 meters was noted as very high, between 1000 to 1500meters was assigned high risk, between 1500 to 20000 meters was noted medium risk, between 2000 to 2500meter was assigned low risk and areas with a distance greater than 2500 meters were identified as very low risk. The fifth layer evaluated was proximity analysis. Proximity to settlements had a similar weighting as the distance from settlement. Proximity was divided into five groups. Areas less than 1000m as very high risk, 1000m to 1500m as high, 1500m to 2000m as medium, 2000m to 2500m as low and areas within a distance greater than 2500 meters as very low risk.

Elevation layer was evaluated. This layer was divided into Four categories. Areas with an elevation less than 1000m was assumed as very high risk and areas between (1000-1500)m was assumed as high, elevation 1500m to 2000m where assumed as medium and. Finally Elevation greater than 2000m was assummed as very low.

Aspect layer was evaluated. It was divided into seven categories. South aspect was given the highest weight due to a higher insolation. Southeast and South west was weighted as high risk, while East and West were weighted as medium risk, Northwest and Northeast where weighted as low risk and Northeast and North where weighted as very low risk.

The following table shows different risk classes with different values range of different parameters. These tables are used in the reclassification of different risk maps in the models (Table 1).

Table 1: Variables in forest fire risk zone modeling, their weightage

Land Cover	Temp ^{0}C	Slope percent	Distance to Road (m)	Proximity to Settlement (m)	Elevation (m)	Aspect
Broad leaved Closed Forest	>33 (1)	>35 (1)	<10000 (1)	<1000 (1)	<1000 (1)	South (1)
Broadleaved Open Forest	31-33 (2)	25-35 (2)	1000-1500 (2)	1000-1500 (2)	1000-1500 (2)	South west and south east (2)
Grassland	30-31 (3)	15-25 (3)	1500-2000 (3)	1500-2000 (3)	1500-2000 (3)	West and East (3)
Shrub Land	28-30 (4)	5-15 (4)	2000-2500 (4)	2000-2500 (4)	>2000 (5)	North west and North east (4)
Barren Land	<28 (5)	<5 (5)	>2500 (5)	>2500 (5)		North (5)

Note: Values in parentheses indicates fire rating classes. They are 1, 2, 3, 4 and 5 for very high, high, medium, low and very low respectively.

Results

Spatial and Temporal Distribution Pattern of Forest Fire Occurrence and Burnt Area: The result shows those total 391 hotspots were recorded by MODIS satellite from 2002 to 2018. Out of total detection, about 362 fires were recorded with greater than 30% confidence. Fire distribution pattern for the last 17 year are presented which shows that Sitganga municipality accounted to have highest fire count with about 284 and it was followed by Bhumekasthan municipality and Panini rural municipality which is 27 and

26 in numbers. Sandhikharka municipality accounted about 13 and Malarani rural municipality account about 9 numbers of fire incidents in District. whereas the least fire count is seen in Chhatradev rural municipality which is about 3 in numbers which is shown in fig 1.

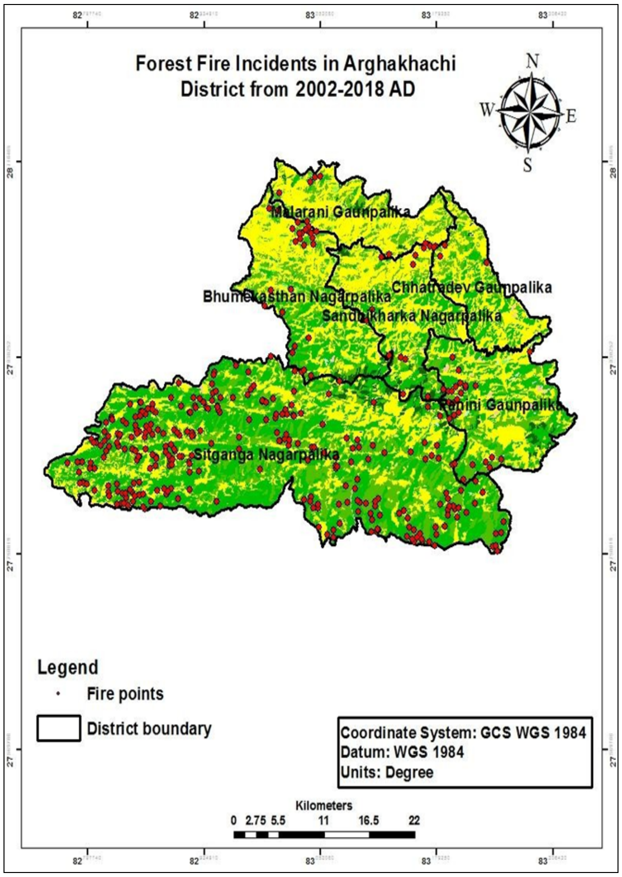

Fig 1: Spatial and temporal distribution of forest fire occurrence

Year wise fire incidents and Month wise fire incidents

Temporal changes of fire frequency for the Arghakhanchi district were investigated on a monthly and yearly basis from 2002-2018. From feature classes created, it was possible to obtain data on the number of fires per month in the Arghakhanchi district since 2002-2018 AD. Total 121 in forest occurrence was in 2016 but these events were 35,37,46 and 41 in 2009, 2010, 2012 and 2014 respectively. In 2002 only a single fire occurrence was observed.

Month wise fire incidents

There was a large variation in the monthly pattern of fire occurrence; with April being the most significant having highest numbers of fire. Generally, two months April and May are the peak months of fire occurrence in the district while March has significantly few fires than January and June and the remaining months have no fire occurrence, however the district has not seen fire in the months February, July, August, September, October and November (Figure 2 & 3).

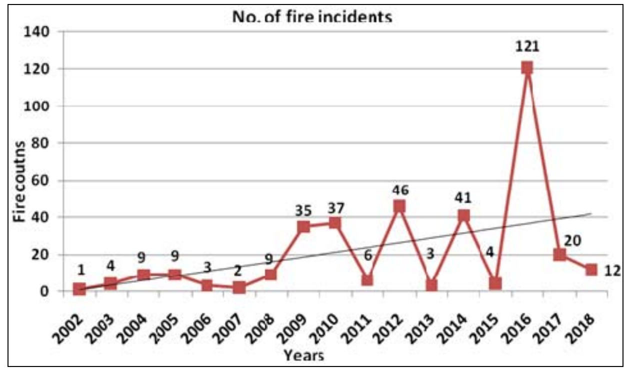

Fig 2: Year wise fire incidents in District

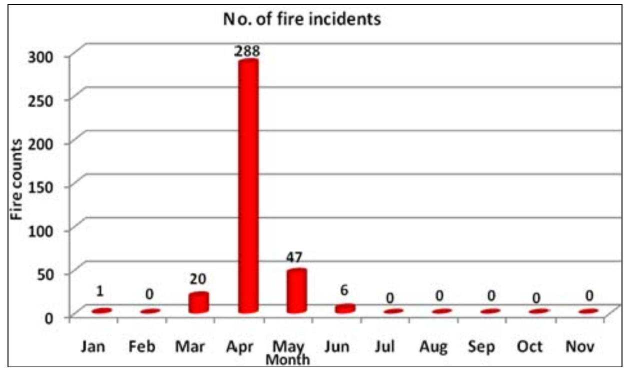

Fig 3: Fire occurrence per month

Spatial and temporal distribution of burnt area

Result showed that, a total of 251,722.31 ha area was burnt throughout the study period. The maximum number of forest fire was in 2016. The area was burnt extremely higher in 2016 covering 94.37% (figure 4).

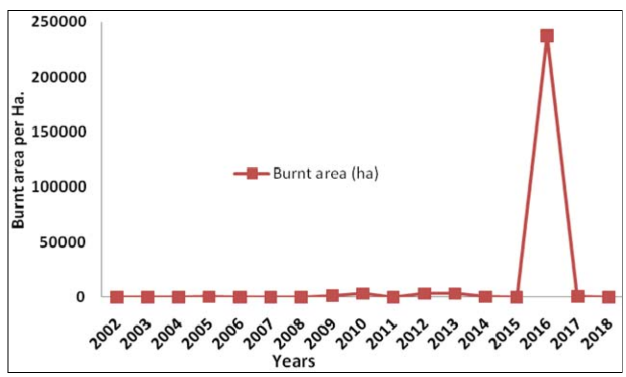

Fig 4: Total area burnt per year

Driving Factors of Wildfire Incident:

Distance from settlement map: Anthropogenic variable such as increased proximity to settlement has been identifies as increasing the risk of forest fire ignition (Sowmya and Somashekar, 2010). Here, the result too shows the same. The forest area close to settlement area less than 1000 m was more prone to the forest fire than the forest of distance with 1000m far. It is so because the settlement areas act as promoter and barrier of the fire. This study also shows that the forest, close to the settlement area was more prone of fire (figure 5).

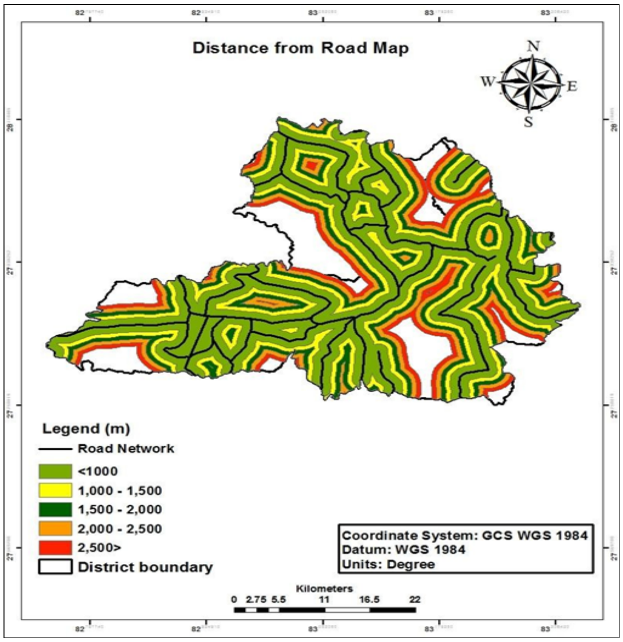

Fig 5: Distance from road map

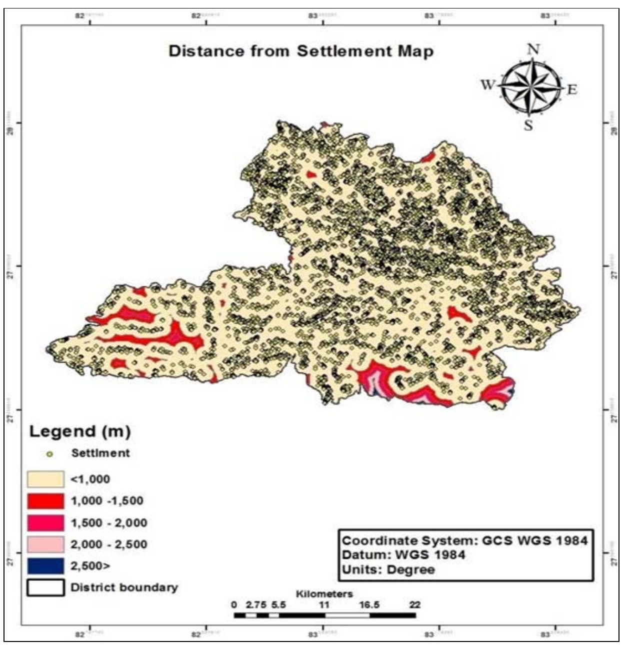

Fig 6: Distance from settlement map

Distance from Road map: One of the major factors of forest fire is anthropogenic factor which include road distance . Most of forest fire is human induced. Road distance less than 1000m is more risk to forest fire. It is so because the road works both as promoter and barrier of the fire. The area close to the road has more chances of disturbance from the user in the form of cigarettes and other inflammable material (figure 6).

Slope Map: Slope is an extremely important factor among topographic factor which effects largely on fire specially when it is spreading (Goldammer & de Ronde, 2004; Yakubu *et al*., 2015) Fire generally travels faster in up-slope and low in downslope (Chuvieco and Congalton, 1989; Whelan, 1995; Kushla and Ripple, 1997; Trollope *et al*., 2002; Jaiswal *et al*., 2002; Vadrevu *et al*., 2006; Yakubu *et al*., 2015) [17, 53]. Hence for slope study, DEM was used and slope was extracted using GIS. The surface slope in this study ranges varies from less than 5 degree to greater than 35 degree so this area is high prone to fire (Figure 7).

Aspect Map: Aspect was generated using DEM and has been classified into nine classes such as shown in figure. South and southwest aspects are said to be favourable for fire to start and spread as it receives higher solar radiation which creates lower humidity and higher fuel and soil temperature(Pyne *et al*., 1996, Chavan *et al*., 2012, Yakubu *et al*., 2015 *et al*., 2012, Yakubu).

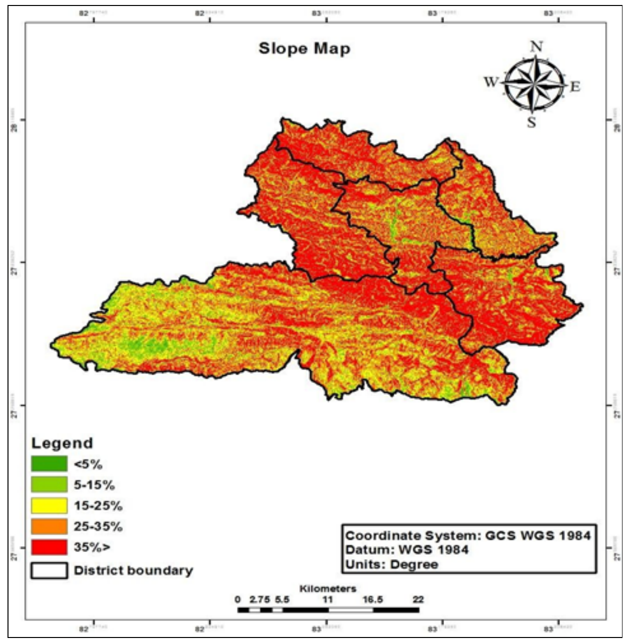

Fig 7: Slope Map

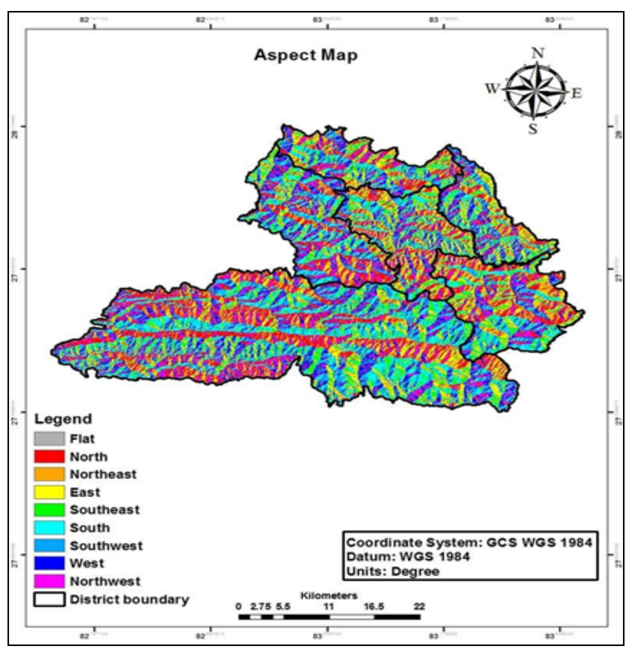

Fig 8: Aspect Map

Elevation Map: Elevation factor has been used by Chuvieco and Congalton (1989) [18] to generate the risk model. Hence elevation in this model has been used assuming that it has direct relation with humidity and fuel combustion. In this study the elevation ranges from 1000m to 2000m (figure 9).

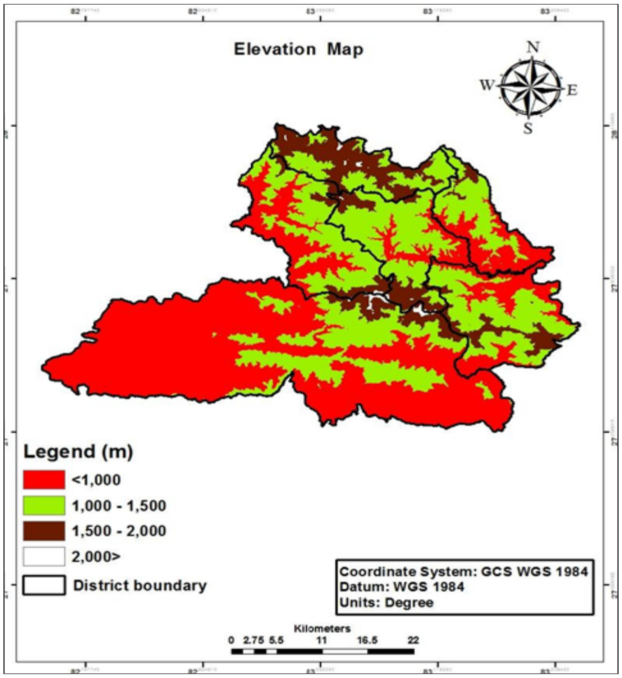

Fig 9: Elevation map

Temperature Map: Meteorological inputs like temperature has been used in different studies. When the temperature is high it has direct relation with relative humidity and the moisture content of the fuels which creates difficulty in (Hussin *et al*., 2008) whereas low temperature has inverse relation with the moisture content (Goldammer & de Ronde, 2004) .The temperature map shows the variation in surface temperature area (figure 10).

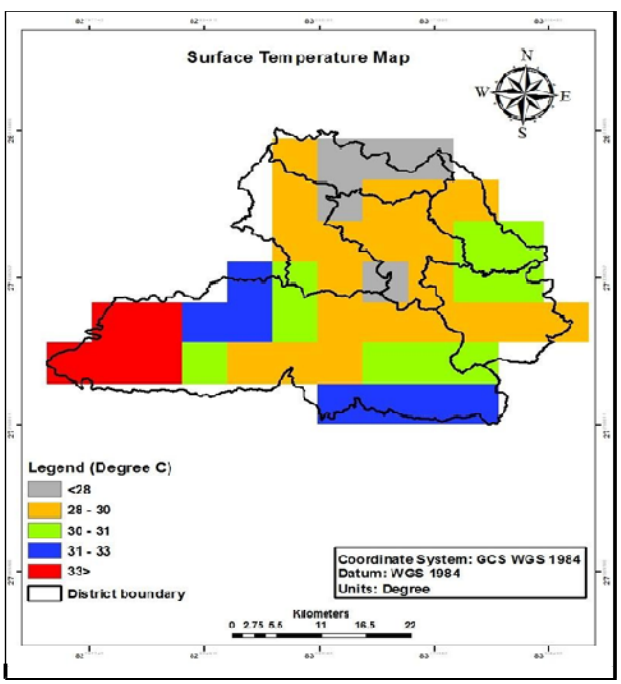

Fig 9: Elevation map

Forest Fire Incident in Different Land Classes: Result shows that, forest fires occur higher in broadleaved closed forest followed by broadleaved open forest. Out of 362 fire incident in District, about 168 fire was observed in broadleaved closed forest, 95 fire was observed in broadleaved open forest. Grassland account about 89 fire, which is followed by needle leaved open forest which is 6 in number. Agriculture and shrub land account 1 in number. This is because the tropical broadleaved forest experiences heavy leaf fall during summer (i.e. March–June) which results in the accumulation of a large amount of leaf litter, fuelling frequent and prolonged occurrences of fire during summer.

Forest Fire Incident in Topographic Features and based on elevation: The results show that a large number of fire incidents were in southern aspect which is 77 in numbers which is followed by south east and south west which is 55 in number. Higher number of forest fires occurred in area range below 1000m elevation. About 81.76% of the fires were recorded in the areas below the elevation of 1000m, whereas 18.23% of the incidences occurred in areas from 1000m to 2000 m . 0% of forest fire occurred above 2000m (msl). Hence comparatively lower elevation has more prone to forest fire than higher elevation which is shown in fig 11 and 12.

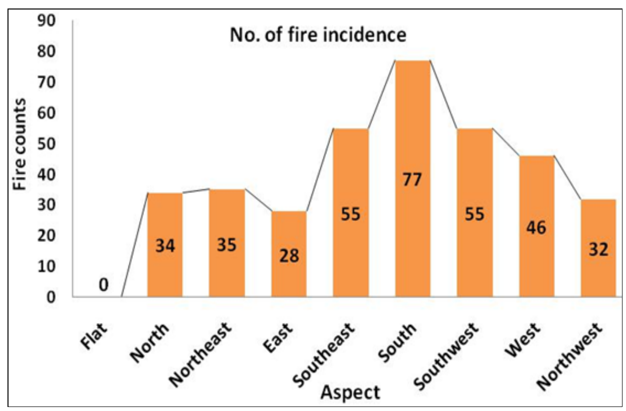

Fig 11: Fire occurrence in aspect

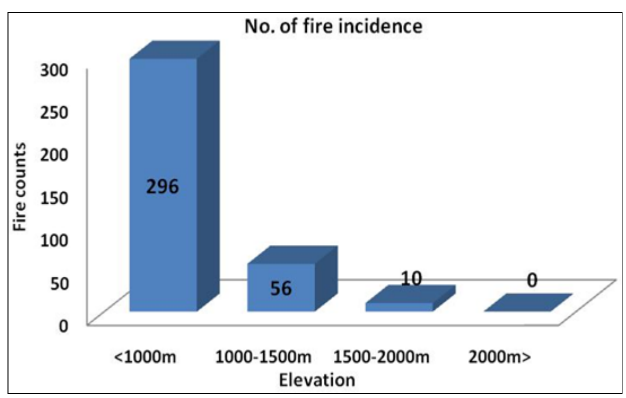

Fig 12: Fire occurred based on elevation

Forest fire incident in Slope And based on Temperature: Result shows that, Number of fire incidents received higher in slope greater than 35% degree and Very less number of fires occurred in slope less than 5%. Hence, Forest fire is more in upslope than lower slope.

Climatic Factor Temperature: Temperature is one of the main factor causing the forest fire. With the increases in temperature number of fire incidents were also increases. Temperature range greater than 33 °C is more prone to fire, which recorded about 106 in number. The vice versa is also true, in case of less than 28 °C, fire records only 4 in (figure 13 and 14).

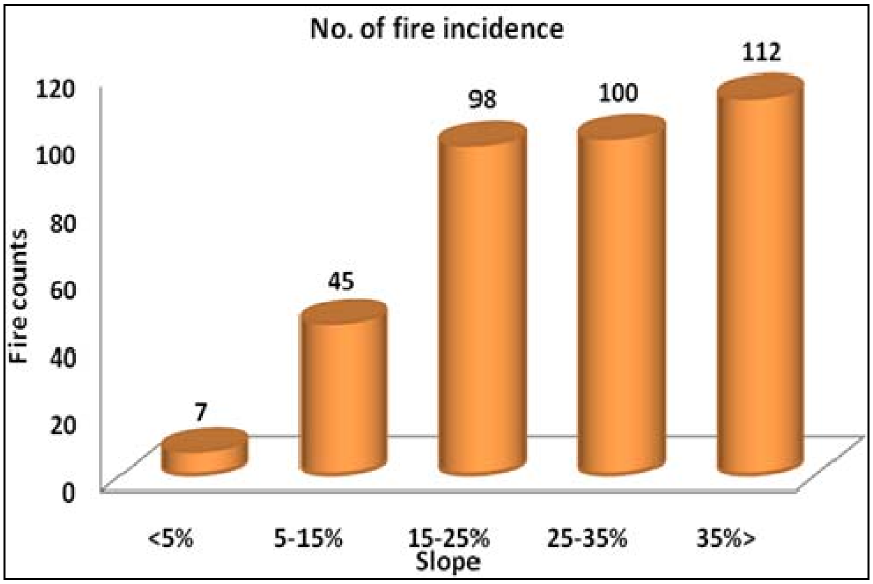

Fig 13: Fire occurrence distribution in slope

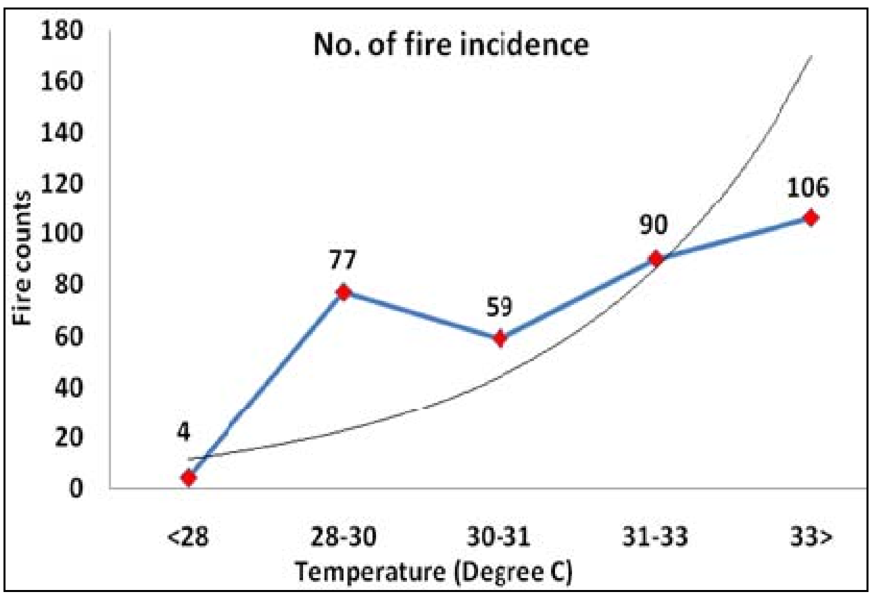

Fig 14: Fire occurrence with temperature

Forest Fire Risk Zone Map: The forest risk map is shown in the figure which shows that the whole area was characterized as very high, high, medium, low and very low fire risk areas. Both the highest and lowest concentration are scattered all over the district but Sitganga municipality Sharada municipality has the highest concentration making it very high risk, Bhumikasthan municipality has high risk, Panini rural municipality has medium, Sandhikharka municipality has low risk whereas Chhatradev rural municipality and Malarani rural municipality has the lowest concentration making it the least fire risk zone (figure 15).

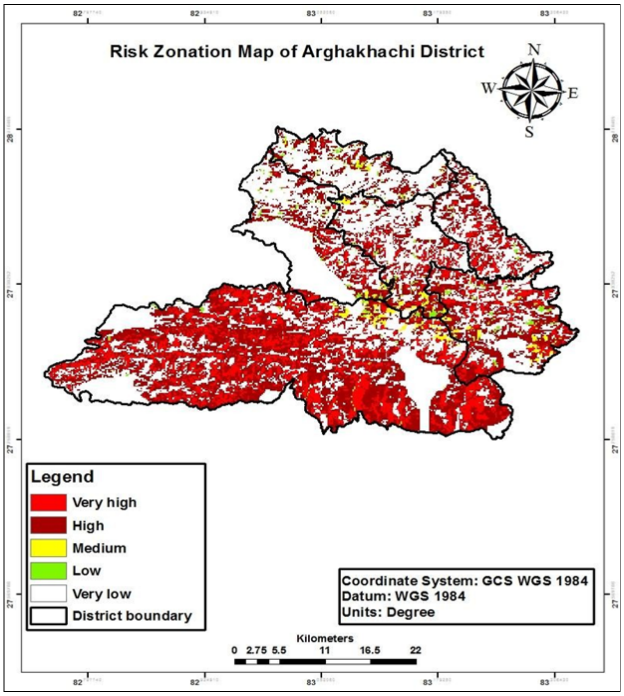

Fig 15: Risk Zonation Map of District

Discussions

The spatial and temporal distribution patterns of forest fire since 2002 to 2018 were analyzed. The result shows those total 391 hotspots were recorded by MODIS satellite from 2002 to 2018. Out of total detection, about 362 fires were detected with greater than 30% confidence. Research shows most of fire incidents during April followed by May which is consistent with previous study conducted by Ghimire, 2014 [47]. Bhatta (2014) has also observed increasing trend of fire incidents from 2001 to 2013. The fire events in this research from MODIS active fire data showed fire events from March to May making this consistent with previous studies in the country (Bajracharya, 2002 [9]; Sharma, 2006 [72]; Parajuli *et al*., 2015 [61] Also the reason for fire peak in March to May may be because of large fuel loads accumulation due to leaves shed by trees, weeds, undergrowth having low moisture content only because of high temperature, low relative humidity and precipitation and high wind velocity in this season (Van Wilgen *et al*., 2004) [82].

Result shows that, Forest fires occur higher in broadleaved closed forest followed by broadleaved open forest. Out of 362 fire incident in District, about 168 fire was observed in broadleaved closed forest, 95 fire was observed in broadleaved open forest.72.65% fires incidents count in broadleaved forest. 46.40% detected in broadleaved closed forest and 26.62% detected in broadleaved open forest. My result also shows that, highest number of forest fire was detected in broadleaved closed forest which coincides with previous study conducted by Martin *et al* 2017 [57]. Matin *et al*., (2017) also mentioned that the frequency of forest fire is more in broadleaved forest during March to May because broadleaved forest experiences heavy leaf fall resulting huge accumulation of fuels.

My research states that, higher number of forest fires occurred in area range below 1000m elevation. About 81.76% of the fires were recorded in the areas below the elevation of 1000m, whereas 18.23% of the incidences occurred in areas from 1000m to 2000 m (Fig.20). 0% of forest fire occurred above 2000m (msl). Hence comparatively lower elevation has more prone to forest fire than higher elevation which coincides with previous study conducted by Matin *et al* 2017. Elevation has straight relation with temperature which also motivates forest fire (Rothermel, 1983; Rothermel, 1991, Yakabu *et al*., 2015.

Result shows that, Number of fire incidents received higher in slope greater than 35% degree and Very less number of fires occurred in slope less than 5%. Hence, Forest fire is more in upslope than lower slope which is similar with previous study conducted by Adab *et al*., 2011.

The large no of fire were incident in southern aspect which is 77 in numbers which is followed by south east and south west which is 55 in number. Southern aspect experiences more sunlight resulting higher temperature but low fuel moisture and humidity. This creates the vegetation becomes parched on south facing slope than north facing slope while the east aspect receives more ultraviolet and direct sunlight hence it dries faster (Anderson 1982; Prasad *et al*., 2008). Because of that, drier fuels are more exposed to ignition (Noonan, 2003; Iwan *et al*., 2004). In addition, earlier in the day, east aspects get more ultraviolet and direct sunlight than west aspect. Consequently, east aspects become drier faster (Anderson, 1982 cited from Adab *et al*., 2012).. Hence, my result signifies that South facing aspect is more susceptible to forest fire which coincides with previous study conducted by Ghimire, 2014 [47].

Temperature is one of the main factor causing the forest fire. With the increases in temperature number of fire incidents increases .Temperature range greater than 33°c is more prone to fire, which records about 106 in number. With decreases in temp. no of fire also reduced and less than 28°c, fire records about 4 in number which is similar to Matin *et al*., (2017). It has been suggested that higher the temperature higher is the risk of forest fire (Hussien *et al*., 2008; Farukh *et al*., 2009; Miller *et al*., 2012; Khanal, 2015 [61]; Matin *et al*., 2017).

Result shows that, Forest fire occurs higher while settlement distance is in below 1000 m and very low while settlement distance is greater than 2500m. About 80.90% of forest fire occurred in below1000 m, 10.50% while settlement distance is in between1000-1500m and 0.60%when settlement distance is greater than 2500m. While making the fire risk zone it was predicted that the distance near to habitat for 1000m. The similar events were recorded by Hussien *et al*., (2008) where he argues that people usually know that forest fire is illegal hence to avoid charges they would rather start away from the settlement because they will know that no one will see them. Hence, my result signifies that, forest fire decrease with increase of distance from settlement which is consistent with previous study conducted by Saklani, 2008.

Result shows that the distance near to road is more vulnerable for forest fire which records about 43%,21% incident in area with distance of 1000-1500m and 8% incidence in area greater than 2500m.which is similar with the research conducted by Hussien *et al*.,(2008) In addition. Matin *et al*., (2017) stated that 40% of fires were recorded within the range of 1km in Nepal. Keeley and Fotheringham (2003) also cited that anthropogenic ignitions occur frequently along the road corridors and other areas where human activity is high. Out of the 18 vulnerable district, my studied area ranked in 9^th fire prone area which is similar to previous study conducted by Ghimire (2014) [47].

Conclusion and recommendations

The higher forest fire recorded in April month. It covers 79.5% of fire in month of April and it is followed by May. About 99.72% forest fire was detected in four months. Slope greater than 35% was more vulnerable to forest fire which record about 30.93%. With the decrease in slope, the occurrence rate of forest fire also decreased. On the basis of fire incidents, highest numbers of records were found in the Sitganga municipality (78.45%) followed by Bhumikasthan municipality (7.45%) and Panini rural municipality (7.18%) suggesting fires are typically high in the area near to Terai belt. With the increase in temperature, the rate of forest fire also inceases. Temperature greater than 33°c was more prone to fire according to the research. Complete and detailed record keeping and proper database is essential to mage the fire occurrence properly.

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