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Research Article

Remote Sensing and GIS Based Forest Fire Vulnerability Assessment in Dachigam National Park, North Western Himalaya

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Abstract

Background and Objective: Dachigam National Park in Kashmir, India is the only habitat in the world to critically endangered species, Kashmir Stag (*Cervus hanglu*). One of the reasons of its dwindling population has been associated with the frequent fires that occur in dachigam national park. Besides, the forest fires have also been associated with ecological disturbance in the area. This study assessed the forest fire vulnerability of this area using remote sensing and Geographical Information System (GIS) in order to prioritize the area into different forest fire vulnerability zones. **Materials and Methods:** The data used included, (1) Advanced spaceborne thermal emission and reflection radiometer, digital elevation model (ASTER GDEM, 30 m), (2) Indian Remote Sensing (IRS) LISS-III data (23.5 m), (3) Survey of India (SOI) topographical maps of 1967 (1:50000 scale) and (4), Moderate resolution imaging spectroradiometer (MODIS) fire product. These datasets were used to generate topographic, land use; vegetation and other biophysical parameters to classify the study area into four fire vulnerability zones using GIS based multicriteria analysis model. **Results:** It was found that out of the total 164.55 km^2 area of the park, 24.95 km^2 (15.16%) of area falls in very high vulnerability zone, 89.67 km^2 (54.49%) of area falls in high vulnerability zone, 44.51 km^2 (27.05%) of area falls in medium vulnerability zone, whereas 5.42 km^2 (3.29%) of area falls in low vulnerability zone. The results were validated with the Moderate Resolution Imaging Spectro-Radiometer (MODIS) satellite-based fire information product and the observational data. **Conclusion:** The study concluded that more than 50% area of the national park is very highly vulnerability to forest fires. In this context, the study shall guide in mitigating the causes behind the forest fire in the area through proper planning and management to minimize their frequency.

Key words: Moderate resolution imaging spectro-radiometer, geographic information system, vulnerability, dachigam national park, Kashmir stag, hangul, vulnerability zonation

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Forest fires are recognized as one of the most serious environmental hazards causing huge damage to forest fauna and flora, including soil inhabitants[1,2]. Soil nutrient availability, plant community development, biological diversity and atmosphere get heavily influenced by forest fires resulting in huge economic impacts in the region[3,4]. Forest fire incidences can also adversely affect human health[5,6]. Forest fires release huge amounts of pollutants such as particulate matter, carbon monoxide and oxides of nitrogen, sulphur dioxide and organic compounds. Particulate matter, $PM_{2.5}$ has potentially detrimental health effects as they penetrate deep into the human lungs causing respiratory and cardiovascular diseases[7,8].

Incidences of fire are greatly affected by weather pattern and land use practices[9-11]. Forest fires by emitting ash and invisible gases like carbon monoxide, carbon dioxide and small quantities of nitrogen oxides to atmosphere, contributes to air pollution and reduces the visibility in an area[12,13]. In tropical regions, the number of forest fire incidents is high in summer due to higher levels of water stress[14,15]. The increased temperature and drought periods acts as accelerating factors for forest fires[16,17]. The severity and spread of forest fires is dependent on factors like state and nature of fuel (proportion of live or dead vegetation, species type, density and moisture content), physical environment (weather conditions and topography) and causal factors (human and natural related)[18-23]. Land use has been credited as one of the major factors in the regions where population is put at risk due to fires[24].

Globally, the increase in the frequency of forest fires has been associated with climate change[15,25-27]. It has been observed that there has been an increase in the annual number of fires[28] from 1970-2006. Climatic models also indicate the forest fires will likely lengthen and intensify fire season as there are changes in the temperature, humidity and timing of precipitation[14,15,29-31].

Forest fires can be intentional as well as unintentional[32]. Most of them are human induced, which are caused intentionally[33]. Burning of forest floor for agriculture purposes, burning of wild grass for animal search, firing by offenders are some causes of intentional fires[34-36]. Unextinguished campfires of trekkers, unextinguished bidis, matchsticks and cigarette butts, spark of fire from railway engines, burning of agricultural fields near to forest areas etc., are some causes of un intentional fires which are caused due to human carelessness[37]. Lighting, rolling stones and volcanic eruptions are some causes of natural fires[38].

With the development in the field of geoinformatics, monitoring and mapping of forest fires is more feasible for managing, analysing and depicting statistical and geographic data[39-42]. The increased availability of satellite data has helped in better understanding of fires globally[43,44]. Advanced Very High-Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS) and Indian Remote Sensing Satellite Advanced Wide Field Sensor (IRS AWiFS) are some sources of data which are used for active forest fire detection[45-47]. The Advanced Very High-Resolution Radiometer (AVHRR) fire data was studied to characterize global patterns of fire seasonality and their relationship with climate[48,49]. Recently, a new generation of satellite sensors have advanced capabilities of fire monitoring, which helps in identification of burned area and fire hotspots at a regional or global scale[50-54]. Information of vital nature can be generated on habitat loss, habitat evaluation, species habitat suitability, corridor mapping, deforestation, landscape fragmentation, carrying capacity and forest fire risk zonation in the protected areas using Geoinformatics technology[55-57]. Remotely sensed data provides the synoptic view and can be used to determine the presence and distribution of areas affected by fires within a protected area[58,59].

The GPS is readily used in land surveys to note the precise coordinates of boundaries of areas affected during a forest fire[60,61]. Precise measurement of these locations is one of the fundamental elements of land surveying, GPS has become a valuable tool as it provides more accuracy over a large area than other conventional methods of surveying[62]. Surveyors have traditionally relied on landmarks that can be destroyed or moved over time. The GPS uses exact coordinates rather than relational landmarks. The GPS points can be taken at photo points in the field and then the photos can be uploaded as a point layer of forest fire locations into the GIS database. Geoinformatics technology has a great potential in forest fire mapping, monitoring and management and can be effectively used for mapping active and burnt areas as well as for forest fire prone area mapping (fire risk/vulnerability zonation)[63-66].

This study used remote sensing and GIS based approach for assessing the vulnerability of dachigam national park, Jammu and Kashmir, India to forest fires. The latterlies in the zabarwan range of the western Himalayas, about 22 km^2 from Srinagar city[67,68]. The rationale behind the work is because, this park is one of the five national parks of the state of Jammu and

Kashmir, that is frequently damaged due to forest fires[69]. Forest fires not only damages fragile ecosystem of this region but also higher frequency of these, is a direct threat to the critically endangered species, Kashmir Stag (*Cervus hangul*). The park is the only remaining habitat of this species in the world. According to the latest survey (2017), the Hangul population in this park stands at 182. Earlier population estimates ranged from 197 in 2004 to 186 in 2015. Wildlife experts have attributed the dwindling population of the Hangul to the increasing incidences of forest fires in the park over the last decade in addition to some other factors[70]. The main causal factors behind forest fires are the concurrent dry spells and the occurrence of lightning events. Lightning strokes act as sources of ignition, besides, there are also anthropogenic factors responsible for such incidents. To formulate the concrete prevention strategy to save the endemic and unique biodiversity of this national park from disastrous effects of fires, the forest fire vulnerability zonation is very important. This study is part of the comprehensive wildland fire assessment system (WFAS) created for the dachigam national park by the state authorities to identify and manage highly vulnerable zones of the park to avoid the occurrence the fires by taking appropriate steps.

MATERIALS AND METHODS

Study area: The state of Jammu and Kashmir which is the northern most state of India and is known for its biodiversity. The state is endowed with rich flora and fauna which flourish in its varied natural habitats[71-73]. There are total 57 protected areas in the state of Jammu and Kashmir, which includes 5 national parks, 15 wildlife sanctuaries and 37 conservation reserves. It is also very much famous for the rare and critically endangered Hangul or Kashmir Stag, an official state animal of Jammu and Kashmir state of India[69]. It covers an area of 164.55 km^2 and is situated between 34°04' 46.214" to 34°10' 54.756" N latitude and 74°54' 11.782" to 75°08' 58.077" E longitude (Fig. 1). Its altitude ranges from 1665-4319 m.

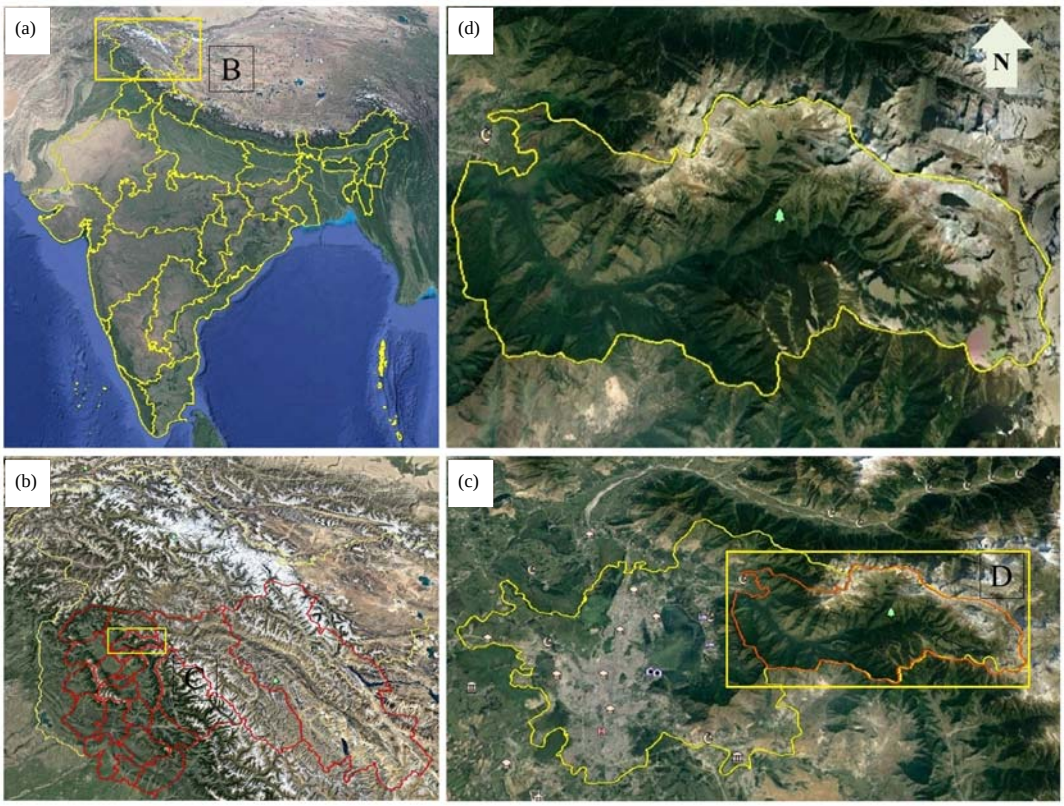

Fig. 1(a-c): Location of the dachigam national park

The upper left inset in the main map shows the location of the state of Jammu and Kashmir (J and K) with respect to India. The location of the park with respect to J and K is shown in the left bottom inset. The location of the park w.r.t Srinagar is shown in the right bottom inset. The map coordinates are in the UTM 43 (north) World Geodetic System (WGS-1984) reference system

Different datasets used in the present study include the following: (1) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM (Digital Elevation Model) with a spatial resolution of 30 m downloaded from USGS (Earth Explorer). The ASTER DEM was used to generate topographical parameters for the study area, (2) Indian Remote Sensing (IRS) LISS-III data of 2011 with a spatial resolution of 23.5 m. The Linear Imaging Self Scanning (LISS-III) data of October 2011 was used to generate land cover and vegetation layers for the study area, (3) Survey of India (SOI) topographical maps of 1967 (1:50000 scale) from survey of India (SOI) were used to generate road and settlement layers for this study area. To correlate the generated fire risk assessment map, moderate resolution imaging spectroradiometer (MODIS) fire product (MCD14DL) was used for validation.

The overall methodology adopted in the present study to accomplish the research objective is presented in Fig. 2.

The performance of models that use slope and aspect as inputs is dependent on the accuracy of slope and aspect measures. The DEM resolution is one of the important factors which influence the topographical and hydrological parameters. The topographical data created from fine resolution DEMs (ASTER 30 m resolution) is expected to give greater amounts of details as compared to coarse resolution DEMs such as SRTM 90 m resolution[74]. As a result, ASTER DEM was preferred over SRTM DEM for the present study. Topographical parameters (slope, aspect and elevation) are important parameters which can influence occurrence and spread of forest fires. In the present study topographical parameters were generated from ASTER DEM. The DEM was clipped with the help of vector layer boundary of study area. The clipped DEM of the study area was used to generate slope, aspect and elevation parameters. The generated topographical parameters (slope, aspect and elevation) were reclassified.

The survey of India (SOI) topographic map of study area was corrected for geometric errors using geo-referencing. The geo-referenced topographic map was used to generate road network and settlement layer using onscreen digitization. Buffers were created around the roads and settlements to create buffer zones of roads and settlements within the study area. The vector buffer zones of roads and settlements were converted to raster format using feature to raster conversion technique.

Land use and vegetation layers were generated using Indian Remote Sensing (IRS) LISS-III satellite image with a spatial resolution of 23.5 m of 2013, using supervised

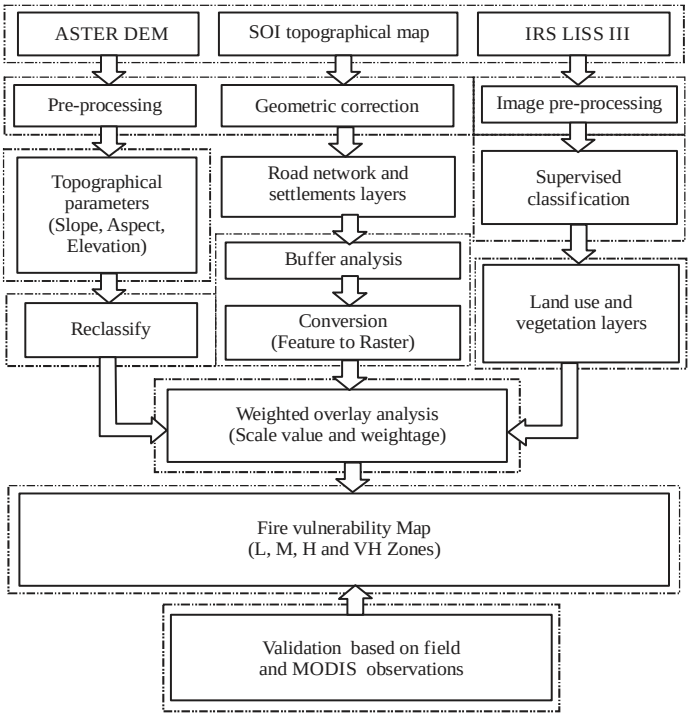

Fig. 2: Flow chart of the methodology used in modelling the fire vulnerability zones of the dachigam national park

classification technique. The IRS LISS-III data was first corrected for geometric errors at 1:50000 scale using suitable Ground Control Points (GCP) with an RMSE of 0.49. The corrected satellite data was then separately used for classifying land cover and vegetation. The maximum likelihood supervised classification technique was used in the classification of both land cover classes as well as vegetations types[40,75,76]. The land use and vegetation classes were created in relation to their behaviour towards a fire incident. The various land use classes generated included forest, scrub, pasture, agriculture, built up, barren rocky and water, whereas following vegetation types were generated fir kail forest, silver fir forest, blue pine forest, broad leaved forest, birch forest, built up, agriculture, scrub, alpine pasture, rocky cliffs and water.

For accuracy assessment of land use and vegetation maps, a detailed field work was carried out and 140 field verification points were taken. Kappa coefficient for the classified maps was calculated using the below equation[74,77]:

$$\frac{\left\{N\sum_{i=1}^{r}X_{ii}-\sum_{i=1}^{r}(X_{+i}.X_{i+})\right\}}{N^2-\sum_{i=1}^{r}(X_{i+}.X_{+i})}$$

where, r is the number of rows in error matrix, X_{ii} is the number of observations in row i and column i (elements on the main diagonal), X_{i+} is the total of the observations in row I, X_{+i} is the total of observations in the column i and N is the total No. of observations considered for the matrix.

In the weighted overlay analysis, each class of the final raster thematic layers (land use, vegetation, slope, aspect, elevation, road and settlement) was assigned a scale value on a common measurement scale (Table 1). Higher scale values were assigned to cells which are more vulnerable to fire and lower values were given to cells which are less vulnerable to fire. Cells representing areas of water bodies were restricted. Finally, weights (percentage of influence) were given to each of thematic layers according to their vulnerability to fire to get the final fire vulnerability map of study area.

RESULTS AND DISCUSSION

The present study was a knowledge driven modelling framework wherein understanding of scientific knowledge of a phenomenon is converted into numerical value[40,74,78]. Ajin *et al.*[79] carried out a study of potential forest fire in idukki wildlife sanctuary using multi criteria analysis in a GIS environment to categorise the sanctuary in different zones of fire vulnerability. Similarly, Malik *et al.*[57] used multi criteria analysis for forest fire risk zonation of Kansrao forest range Uttarakhand.

Land use: Land cover is the collection of abiotic and biotic components on the earth's surface[80]. Land cover is what covers the earth's surface and land use describes how land is being utilized by human beings[81]. Land use is one of the important parameters which affects the occurrence and spread of fire[82]. The dense and dry vegetation is more susceptible to fire than the moist and sparse vegetation. The different land use classes identified in the study area are forest, agriculture, built up, scrub, pastures, barren and water bodies (Fig. 3a). To check the overall accuracy of the land use classification, ground truthing was carried out. In total 148 ground samples were used for accuracy assessment. The overall accuracy of land use generated was 94.59%. The value of kappa coefficient was 0.93 (Table 2).

The highest scale value of 9 was given to forest class (highly vulnerable to fire) due to that fact that it has the highest percent area equal to 40.41%, followed by scrub class that was given 8 (39.45%). The least scale value of 1 was given to barren (18.22%), being least vulnerable to fire. The land use classes agriculture (0.1%), built up (0.08%) and pasture were given scale values of 4, 3 and 3, respectively. Water bodies were masked in the analysis. After analysis an overall weightage of 15% was imbibed to land use parameter.

Vegetation type: It is the collection of plant species and the ground cover and is among one of those important parameters the greatly affect spread and persistence of fire[83]. Vegetation of the terrain is the fuel required for catching fire and its survival[84]. The different types of forest are classified by their grade of inflammability and fuel value or calorific value[32,85,86]. The different vegetation types have different moisture content that has a direct influence on breaking out forest fire[87]. Coniferous forest has higher chances for fire risk than deciduous, because they contain less water and high oiliness[88].

The calorific value of a tree is the amount of heat energy released during the combustion of its tissues. The average

Table 1: Percentage of area, scale values and weightages of different parameters used in the GIS based fire vulnerability model for dachigam national park

Raster layer	Classes	Area (km^2)	Area (%)	Weights (%)	Scale value	Fire sensitivity
Land use	Forest	66.58	40.47	15	9	Very high
	Agriculture	0.17	0.10		4	Medium
	Built up	0.13	0.08		3	Medium
	Scrub	64.92	39.45		8	High
	Pasture	1.83	1.11		3	Low
	Barren rocky	29.98	18.22		1	Very low
	Water body	0.94	0.57		Restricted	Nil
Total		164.55	100.00			
Vegetation	Silver fir forest	4.95	3.01	15	8	Very high
	Fir kail forest	5.68	3.45		9	Very high
	Birch forest	5.96	3.63		7	Very high
	Broad leaved forest	8.95	5.44		7	Very high
	Blue pine forest	52.19	31.78		8	Very high
	Alpine	4.59	2.79		3	Low
	Scrub	51.85	31.51		6	High
	Agriculture	0.15	0.09		4	Medium
	Built up	0.13	0.08		3	Low
	Water	0.85	0.52		Restricted	Medium
	Rocky cliffs	29.26	17.72		Restricted	Very low
Total		164.55	100.00			
Aspect	Flat	0.01	0.01	10	1	Low
	North	18.01	10.95		1	Very low
	North east	18.08	10.99		2	High
	East	13.30	8.08		5	High
	South east	13.22	8.03		8	Very high
	South	27.13	16.53		9	Very high
	South west	29.66	17.99		3	Low
	West	26.35	16.01		2	Very low
	North west	18.78	11.42		1	Low
Total		164.55	100.00			
Slope (degrees)	0-10	12.81	7.78	10%	2	Very low
	10-15	34.59	21.02		4	Low
	15-25	54.62	33.10		6	Medium
	25-35	56.18	34.24		8	High
	35-90	6.34	3.86		9	Very high
Total		164.55	100.00			
Elevation (m)	1665-2165	22.92	13.93	10	9	Very high
	2165-2765	37.22	22.62		7	High
	2765-3365	46.88	28.53		5	Medium
	3365-3965	49.40	29.99		2	Low
	3965-4319	8.13	4.94		1	Very low
Total		164.55	100.00			
Proximity to settlements (m)	0-500	6.53	3.97	20	9	Very high
	500-1000	13.01	7.91		7	High
	1000-1500	14.52	8.83		5	High
	1500-2000	15.15	9.21		3	Medium
	2000-3500	45.18	27.46		3	Low
	3500-6000	52.09	31.65		2	Very low
	6000-9000	18.07	10.98		1	Very low
Total		164.55	100.00			
Proximity to roads (m)	0-500	64.11	38.96	20	9	Very high
	500-1000	36.91	22.43		7	High
	1000-1500	23.86	14.50		5	High
	1500-2000	17.07	10.38		3	Medium
	2000-2500	11.87	7.21		3	Low
	2500-3000	7.02	4.27		2	Very low
	3000-4000	3.71	2.25		1	Very low
Total		164.55	100.00			

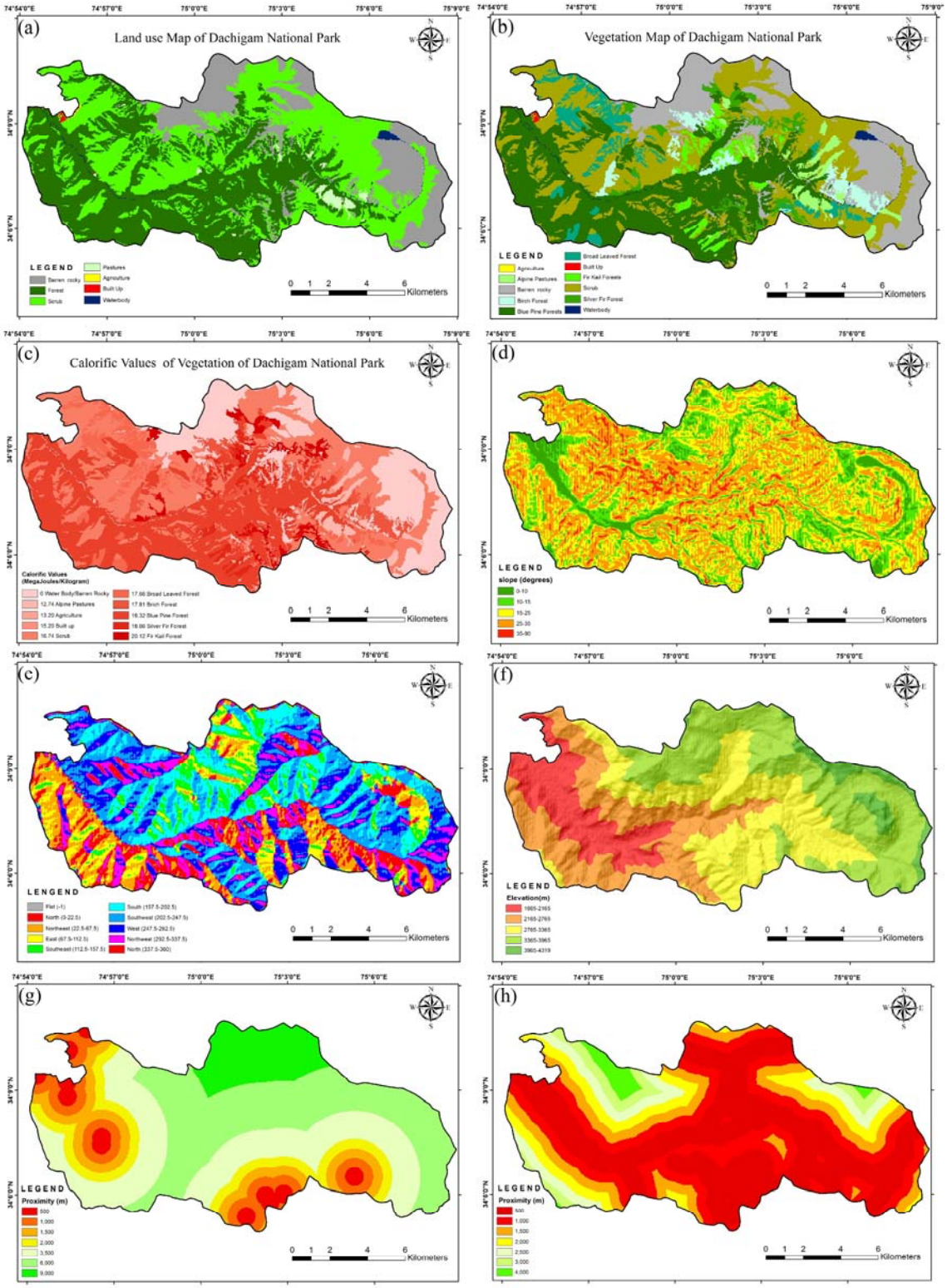

Fig. 3(a-h): (a) Land use map of study area, (b) Vegetation map, (c) Calorific values parameter of the fire vulnerability model, (d) Slope parameter of the fire vulnerability model, (e) Aspect parameter of the fire vulnerability model, (f) Elevation parameter of the fire vulnerability model, (g) Proximity to settlements parameter of the fire vulnerability model and (h) Proximity to roads parameter of the fire vulnerability model

Table 2: Accuracy assessment of land use classification

Class	F	SH	PS	A	BU	BR	W	Row total	Accuracy
F	35	2						37	94.59
SH	2	20						22	83.33
PS			20					20	100.00
A				10	2			12	83.33
BU					15			15	100.00
BR				2		30		32	93.75
W							10	10	100.00
Column									
Total	37	22	20	12	17	30	10	148	
Accuracy	94.59	83.33	100.00	83.33	88.23	100.00	100.00		

Overall accuracy [(35+20+20+10+15+30+10)/148]×100 = 94.59%, F: Forest, SH: Scrub, PS: Pasture, A: Agriculture, BU: Built up, BR: Barren Rocky, W: Water

gross heat combustion or calorific value of fir kail forest, silver fir forest, blue pine forest, broad leaved forest, birch forest, built up, agriculture, scrub, alpine pasture 18.66, 20.12, 18.32, 17.66, 17.81, 15.20, 13.2, 16.74, 12.74 MJ kg^{-1}, respectively[89]. The vegetation map of the study area is given in Fig. 3b. Based on the calorific value, each vegetation class was assigned the scale value (Table 1, Fig. 3c). The highest scale value of 9 was given to fir kailforest, followed by 8 given to silver fir and blue pine. Broad leaved and birch forest was given a scale value of 7 each followed by scrub which is given a scale value of 6. Agriculture was given a scale value of 4. The least scale value of 3 were given to built-up and alpine pasture each. The land use parameter was given an overall weightage of 15%.

Slope: Slope is the measurement of steepness of terrain. It is the ratio of vertical rise to horizontal distance which is expressed in degrees of an angle or percentage[90]. A high slope indicates the steep inclination. For the present study, slope information was derived from ASTER DEM[91,92]. The slope is one of the fundamental parameters that affect the speed of fire spread[93].

Forest fires always spread faster on steep slopes[94]. This approach of high vulnerability to high slope range class and low vulnerability to low slope range class is widely adopted by researchers of this field[95]. The following five slope range classes were used in the present study 0-10° (Flat), 10-15° (Gentle), 15-25° (Medium slope), 22-35° (Steep slopes) and 35-90° (Very Steep slopes) (Fig. 3d). The slope parameter in the present study was given an overall weightage of 10%. The scale values were given ranging from 9-2 (Table 1). The highest scale value 9 was given to (35-90°) slope class with high vulnerability to forest fires and the lowest scale value 2 was given to (0-10°) slope class with least vulnerability to forest fires. Scale value of 8, 6 and 4 were assigned to 22-35°, 15-25° and 10-15°, respectively.

Aspect: Aspect is defined as the direction of maximum slope. It identifies the down slope direction of maximum rate of change in value from each cell to its neighbouring cells[96]. The physical significance of the parameter lies in the fact, that it gives relationship of terrain with sunlight and wind and thus greatly influences fire ignition and spread[32]. The south facing slopes experience higher temperatures due to excess time of sunlight, strong winds and low humidity making the south facing slopes more vulnerable to forest fires[97,98]. Higher temperature leads to dryness of vegetation which makes the area prone to fires[99]. East facing aspects experience more ultraviolet and direct sunlight than the west aspects[100,101]. The north facing slopes experience lower temperatures due to less time of sunlight making the north facing slopes least vulnerable to forest fires[102]. The present study area was classified into 9 aspects classes (Fig. 3e). The highest scale value of 9 was given to south aspect direction as it highly vulnerable to forest fires, followed by 8 to south east aspect. North, north west and flat aspect directions being least vulnerability to forest fires were given a lowest scale value of 1 each (Table 1). The scale values of 5, 3, 2 and 2 were given to east, south west, west and north east respectively. In the present study the overall weightage given to aspect parameter is 10%.

Elevation: It is the altitude of a place above mean sea level and is closely linked to temperature and precipitation, hence making it an important parameter which controls forest fires[98]. There is an increase in precipitation as the elevation increases, hence less chances of forest fire[83,103,104]. Five elevation zones were classified (Fig. 3f). Higher elevation ranges were given low scale values and the vice versa. The highest scale value of 9 was given to lowest elevation range 1665-2165 m as this elevation range is highly vulnerable to forest fires, followed by 7 to range 2165-2765 m. The least scale value of 1 was given to highest range 3965-4319 as this elevation range is least

vulnerable to forest fires (Table 1). Scale value of 3 and 5 were assigned to range 3365-3965 m and range 2765-3365 m, respectively. Moreover, the overall weightage given to elevation parameter was given 10%.

Proximity to settlements: Proximity to settlements is also one of the important parameters that needs to be considered for forest fire vulnerability analysis. The population living near forests can play positive as well as the negative role in this phenomenon. Human population living within the forest area and on the periphery (generally tribals) more often is a source of forest fire. Tribals cause forest fire intentionally or unintentionally. The present study area was divided into seven zones depending on the distance from the settlements (Fig. 3g). Zone near to settlements experience more threats of forest fires as compared to zones which are farther from settlements[79,57]. Higher scale values were given to zones close to settlements being highly vulnerable to forest fires whereas low scale values were assigned to zones situated farther from settlements, being least vulnerable to forest fires. The highest scale value of 9 was given to 0-500 m zone, followed by 7 to zone 500-1000 m (Table 1). The least scale value of 1 was given to zone 6000-9000 m. Scale value of 6, 5, 3 and 2 were assigned to zones 1000-1500, 1500-2000 , 2000-3500 and 3500-6000 m, respectively. In the present study the parameter (Proximity to settlements) was given an overall weightage of 20%.

Proximity to roads: Roads within the forest area are used to travel to a specific destination. Roads within the forest area are useful in fire suppression as fire fighter response team can travel in time to control and suppress the forest fire in time, so that damage caused by fires can be minimized[105,106]. Roads in forests are areas where influence of human activity is involved[21]. Accessibility of humans in areas near to roads are prone to fires due to human activities such as carelessly thrown burning cigarette butts or match sticks[37]. Further, the vehicular movement creates air flow which helps in spread of fire in areas near to roads. Depending upon the distance from roads the study area has been grouped into seven zones (Fig. 3h). High scale values were given to zones close to roads as these zones are highly prone to forest fires whereas low scale values were assigned to zones situated farther from settlements, being least prone to forest fires (Table 1). The highest scale value of 9 was given to 0-500 m zone, followed by 7 to zone 500-1000 m. The least scale value of 1 was given to zone 3000-4000 m. Scale value of 6, 5, 3 and 2 were assigned to zones 1000-1500, 1500-2000 m, 2000-2500 and 2500-3000 m, respectively. In the present study the parameter (distance from settlements) was given an overall Weightage of 20%.

GIS based fire vulnerability model: To find the collective contribution of the factors towards the fire vulnerability, all the generated layers were integrated in a fire vulnerability model to find the overall fire vulnerability of the study area (Fig. 4). Land use, vegetation, slope, aspect, elevation, proximity to settlements and proximity to roads were assessed for forest fire vulnerability of the study area, each class of all the different layers included were assigned a scale value and final weights were attributed to each layer. Final weights (influence (%)) were given to each of the thematic layers according to their fire influencing properties and finally, using GIS based model, final fire vulnerability map of study area was produced. The study area has been divided into four vulnerability zones (Fig. 5). Analysis of the scale values and weightage (influence (%)) revealed by means of final forest fire vulnerability map of the study area, that out of total area of 164.55, 24.95 km^2 falls in the very high vulnerable zone of forest fire and needs immediate attention to minimize the damage, 89.67 km^2 falls in the high vulnerable zone of forest fire, 44.51 km^2 falls in the medium vulnerable zone of forest fire and 5.42 km^2 falls in low vulnerable zone.

Validation: To validate the final fire vulnerability map of the study area, forest fire data from the near real time moderate resolution imaging spectro-radiometer (MODIS, MCD14DL) between 2005-2016 and the recorded field-based fire events that happened in the dachigam national park between 2001 and 2016 were related with the final fire risk vulnerability map. The two vector point shape files of fire data from MODIS and field observations were overlaid on the final fire vulnerability map.

The overlay analysis (Fig. 6a) revealed that out of the total fire incidents of 49 of MODIS fire locations data, 14 fire incidents has occurred in the very high vulnerable zone, 33 fire incidents in the high vulnerable zone, 2 fire incidents in medium vulnerable zone. It is also observed from the satellite-based fire incidents that not a single incident of fire has occurred in low vulnerability zone of the present study area from the year 2001-2016. Further, the overlay analysis (Fig. 6b) revealed that out of the total fire incidents of 33 of satellite fire locations, 14 fire incidents has occurred in the very high vulnerable zone, 18 fire incidents in the high vulnerable

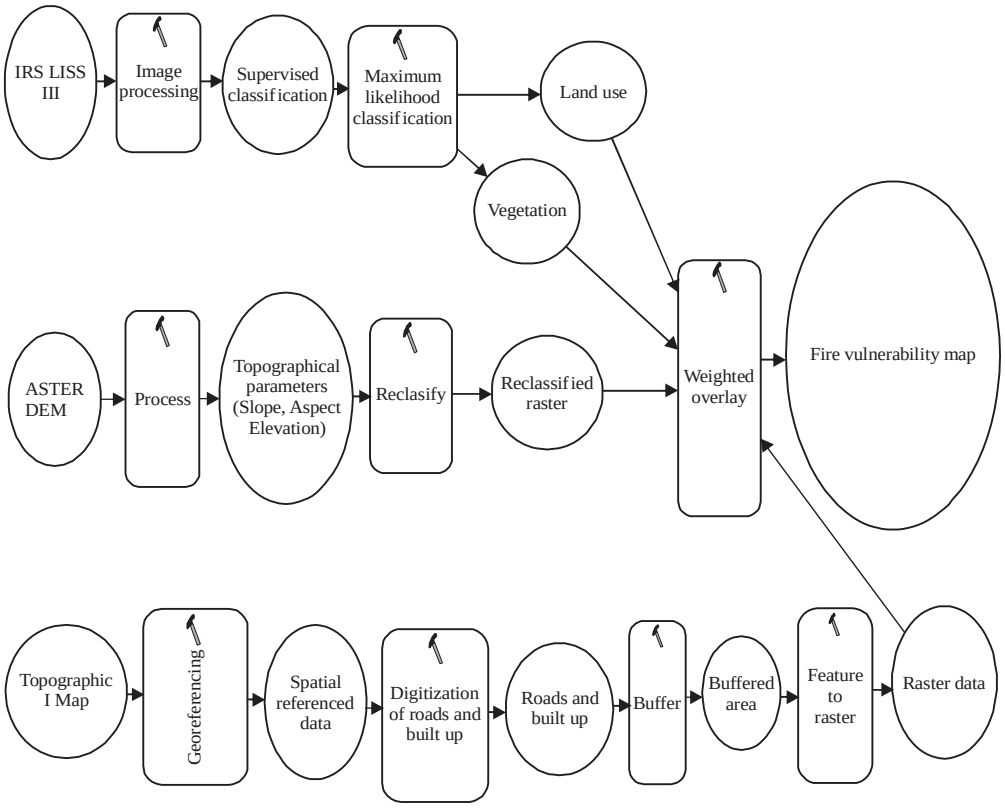

Fig. 4: GIS based fire vulnerability model for the dachigam national park

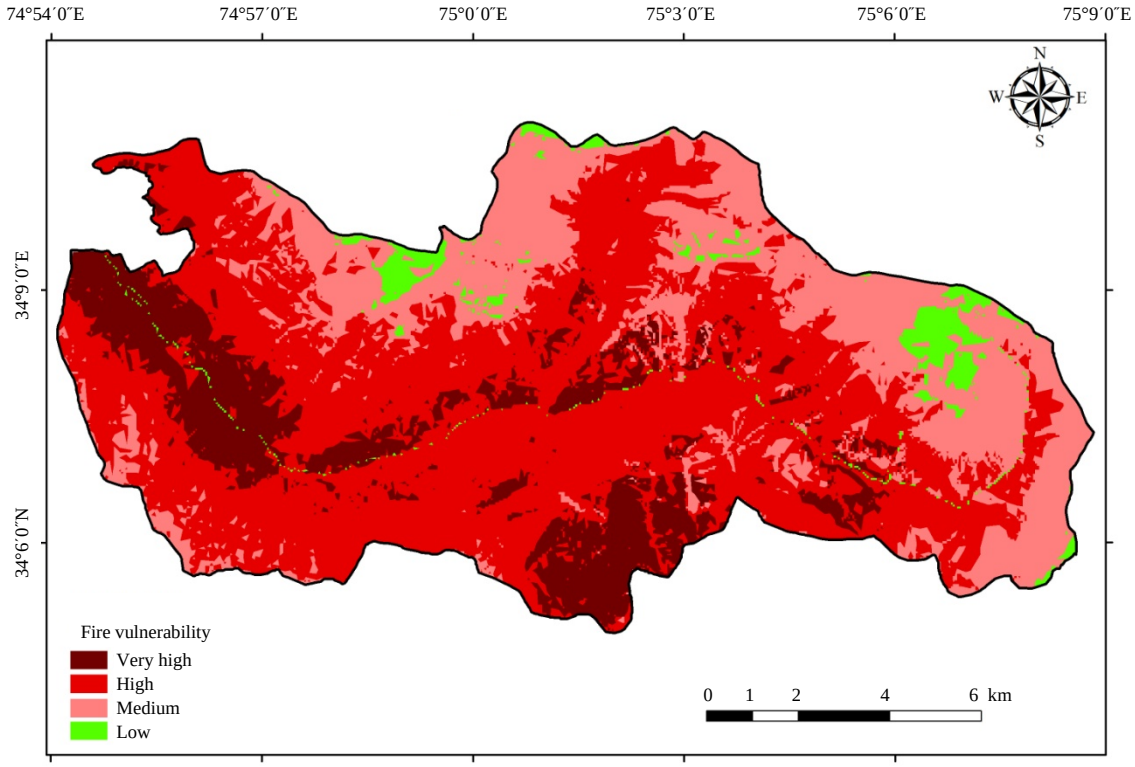

Fig. 5: Fire vulnerability map of study area

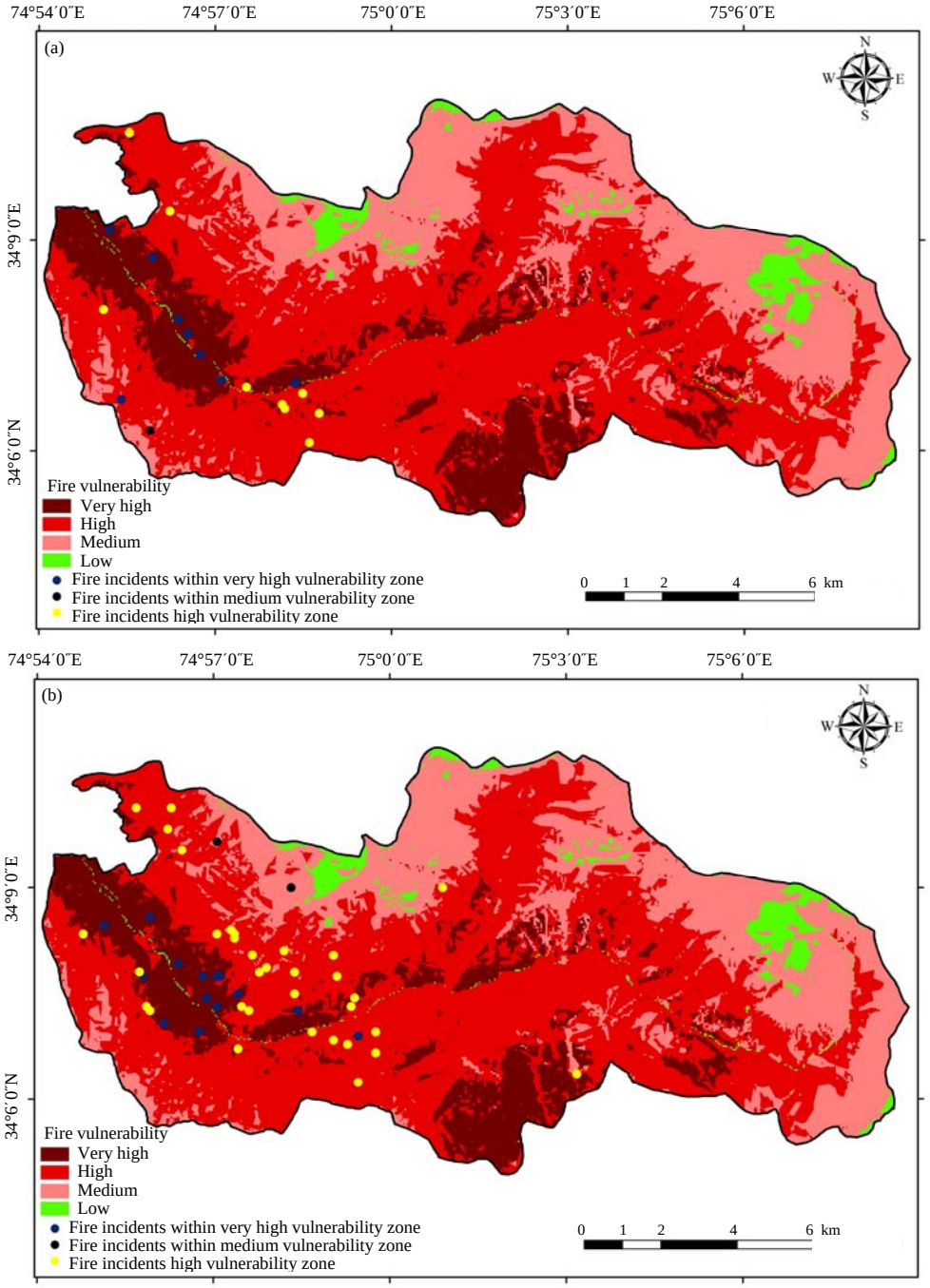

Fig. 6(a-b): (a) MODIS data fire incident locations within study area and (b) Field data fire incident locations within study area

Table 3: Fire incidents in different vulnerability zones

Fire vulnerability zone	MODIS data fire incidents (2001-2016)	Field data fire incidents (2004-2016)
Very High	14	14
High	33	18
Medium	2	1
Low	0	0

zone, 1 fire incident in medium vulnerable zone. It was observed that not a single incident of fire has occurred in low vulnerability zone of the present study area from the year 2005-2016. Table 3 shows the distribution of fire incidents in different vulnerability zones of the present study area.

Climate change and forest fires: Research shows that climate change, particularly prior snowmelt due to warming in the spring and summer, result in hot and dry conditions, that increase fire activity in some areas[107-110]. Climatologically, forest fire risk particularly depends on temperature and precipitation along with soil moisture[111,112]. These factors have strong direct or indirect ties to climate variability and climate change in the region[113]. In Jammu and Kashmir, huge number of forest fires have been reported in the last decade as is shown in the Fig. 7. The average forest fire incidents per year in Jammu and Kashmir between 2000 and 2016 are 311.

The changing trends in temperature and precipitation in Jammu and Kashmir is to some extent related to the increasing incidents of the forest fires since 2001 as is shown in the Fig. 7, though the relationship is not statistically significant. In many other regions of the World, forest fire incidents have been related with the increasing trends of temperatures and decreasing trends of precipitation and the relationship has been statistically significant[114,115]. Globally, there has been numerous studies that have similarly related forest fires with the changing climate. For example, in US. West, projections have shown that an average annual 1°C temperature increase shall increase the median burned area

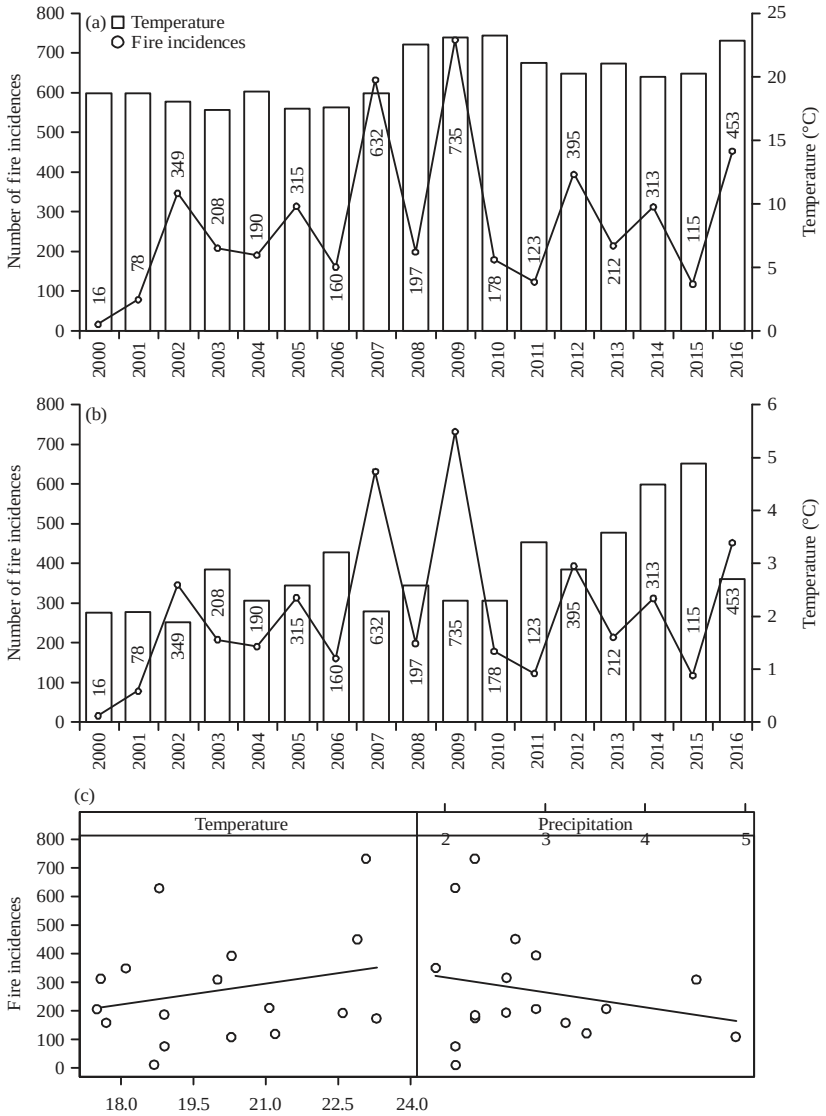

Fig. 7(a-c): (a) Graph of the number of fire incidences in the dachigam national park and changing temperature since 2001, (b) Graph of the number of fire incidences in the dachigam national park and changing precipitation since 2001 and (c) Scatterplot of the fire incidences vs. temperature and precipitation

per year as much as 600% in some types of forests[110,116,117]. In tropics, Goldammer and Price[118] have modelled the impact of climate change on the fire regimes of the tropics and have observed strong correlation between changing meteorological parameters and the occurrence of forest fires.

CONCLUSION

The present study used the integration of different land system layers (land use, vegetation, slope, aspect, elevation, proximity to roads and proximity to settlements) and multi criteria analysis in GIS environment for the assessment of forest fire vulnerability of the study area. Dachigam national park, J and K was prioritized for vulnerability to forest fires based on its biophysical factors so that necessary steps could be taken in advance to manage the regions that are comparatively more vulnerable forest fires. Four vulnerability zones had been designated as very high, high, medium and low vulnerable zones. Out of 164.55 km^2, high vulnerability zone occupied 54.49% area followed by medium (27.05%), very high (15.16%) and low vulnerability zones (3.29%). This study shall help the wildlife department in mitigating the fire prone areas that are associated with the human settlements. This study is part of the comprehensive Wildland Fire Assessment System created for the dachigam national park by the Government of Jammu and Kashmir and shall be useful in proper planning and hence in mitigating the damage caused by forest fires to this area.

SIGNIFICANCE STATEMENT

This study discovers, remote sensing and GIS based fire vulnerability model, that shall be beneficial for managing the most fire vulnerable areas in any forest. Fires create havoc to the flora and fauna of a forest, though they have their ecological significance too. This study shall help the researchers and planners to uncover the critical areas where management is required to ascertain why and how the fires could be stopped. Until now, this type of study has not been done in the dachigam national park and hence a new modelled theory on the collective causes of forest fires was arrived at.

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