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Forest Fire Simulation Modeling using Remote Sensing & GIS

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Abstract: Forest fire is one of the major hazards causing destruction to biodiversity, environment and humans in the Taradevi forest of Himachal Pradesh (India). The study was carried out for forest fire spread analysis and loss assessment using simulation modeling techniques. Knowledge of the factors which includes forest types, canopy cover, meteorological status, topographic feature accelerating forest fire were taken into considerations. The parameters derived from remote sensing data and Geographical Information System (GIS) were used to generate input files for forest fire *simulation modeling* using *FARISTE*. Finally, a fire spread maps and fire areas were predicted in this simulation, where relative importance is given to each theme built based on GIS and climate parameters. The study aims to develop a simulation method to find out fire spread and direction according to the climate data like wind direction, wind speed, rainfall, forest fuel type & density, canopy cover and other maps required for it. Findings of the research are helpful in development of forest fire management. Fast and appropriate direction will be used by the management to stop the spread of fire effectively. It helps to provides effective means for protecting forests from fires as well as to formulate appropriate methods to control and manage forest fire damages and its spread.

keywords: GIS, Forest Fire, Simulation, Farsite, Fire Perimeter.

I. INTRODUCTION

Wild land fires are those fires which burns the vegetative cover [1, 2]. It causes disturbance in terrestrial ecosystems and nearly six million sq. km. loss of forest worldwide in less than 200 years [3]. Worldwide estimation of the total number of wildfires and forest area burnt becomes complicated and difficult due to insufficient and unavailability of reliable data for many regions. The estimate given by the 10th World Forestry Conference (Paris, September 1991) of more than 10 million hectares or 0.3% of the total wild land does not reflect the frequency of fires. Numerous models like fire occurrence model and fire damage model [4], etc. for assessing fire risk and its effects have been developed. While the earliest models were non-spatial, recent advances in GIS have allowed for the development of spatial fire risk models [5, 6, 7]. Mapping methods using remote sensing and geographic information systems (GIS) that contain topography, vegetation, land use, population, and settlement information have been used to study forest fire risk zone (FFRZ) [8,9,10,11]. At the global level, forest fires are common in Australia, Western Cape of South Africa, the hills of South Asia, Indonesia and the forested areas of the United States and Canada. About 50 % of Indian forests are fire prone (FSI 2003) and forest fires are a major factor of degradation of Indian forests, along with various other factors [12, 13]. The deciduous, seasonally dry forests of the lowlands and the coniferous (pine) forests in the higher elevations are regularly burned. While statistical data on fire loss are weak, it is estimated that the proportion of forest areas prone to forest fires annually ranges from 33% in some states to over 90% in others. In this study simulation method has been used to locate spread of fire and get knowledge about affected area. Simulation modeling is an adequate tool to estimate risk when actual risk data are limited or unavailable. For planning firefighting strategies, this would help fire management team to equip themselves to control fire effectively using direction of spread so as to minimize damage. FARSITE simulation is effective in predicting the fire spread using spatial and weather inputs. FARSITE (Fire Area Simulator) is a two-dimensional deterministic fire growth simulation model for spatially and temporally simulating the spread and behavior of fires under conditions of heterogeneous terrain (i.e., elevation, slope, and aspect), fuels, and weather which uses spatial information on topography and fuels along with meteorological data. To do so, FARSITE incorporates existing fire behavior models of surface fire spread [14], crown fire spread [15,16] spotting, point-source fire acceleration (Forestry Canada Fire Danger Group 1992), and fuel moisture with GIS data. Fire risk was estimated as the proportion of simulation runs that burned a particular point and was accumulated over the entire area of Taradevi forest. In recent years forest fire has become disaster for Taradevi range, Shimla forest division because of its impact on bio-diversity, scenic ad landscape beauty, tourism and economic losses. Deciduous forest types are most susceptible to forest fires and accounts for around 40% of all the forest fires in India [17, 18]. Forest fire destroy hundreds of hectares, forest in Himachal Pradesh. The fire devastated almost 2,000 hectares of the reserve forest area in Shimla and Solan Districts of the state. The greatest danger from forest fire occurs during the months of April, May and June until the south west monsoon breaks in the early July. In India forest fire are mainly due to human induced factors, like slash and burn agricultural practices, controlled burning, deforestation, tourist activities (camp fire), and fire-wood burning causing loss of about INR 440 crores [19]. Forest fires are generally known as natural phenomenon in the ecosystem, whereas in Indian context forest fires considered as an event due to anthropogenic activities [20, 21]. FARSITE (Fire Area Simulator) was developed to describe the temporal and spatial differences of fire behavior and spread [22,23]. Weather, vegetation and topographical features have mutual impact in forest fire occurrences. Here in this paper 'FARSITE (Fire Area Simulator)' used to study forest fire areal spread and behavior using various parameters i.e. topographical, forest parameters (type, density, height, DBH etc.), meteorological parameters [24, 25]. Using these spatial and non spatial data forest fire intensity and spread day-wise and type-wise was calculated for mainly four months in which maximum forest fire incidents were recorded i.e. (March, April, May and June). Since the weather data along-with topographical data and forest data were used for the forest fire simulations and modeling. IRS LISS-III data of 2009 along with SRTM (Shuttle RADAR Topographic Mission) were used for assessing the forest fire spread.

II. STUDY AREA

Taradevi forest range of Shimla forest division (Himachal Pradesh) having spatial extent between 76º52′9.66″ E to 77º11′16.96″ E and 31º01′15.59″ N to 31º 10′45.42″ N covering an area of 1564.90 (ha) is the study area opted for the current study (Figure-1). The forest range has three forest blocks named taradevi block, Jubarhatti block and Tutu block. Major forest types in the area are chil (*Pinus roxburghii*), blue pine (*Pinus wallichiana*), Ban Oak (*Quercus leucotrichophora*), and Deodar (*Cerdus deodara*) with variety of broad leave trees along with shrubs and grasses. The area has hilly terrain with the elevation ranging between 900-2200 m and relative humidity around 80%. Temperature ranges from 15^0C-22^0C. The average total annual precipitation is 1520 mm.

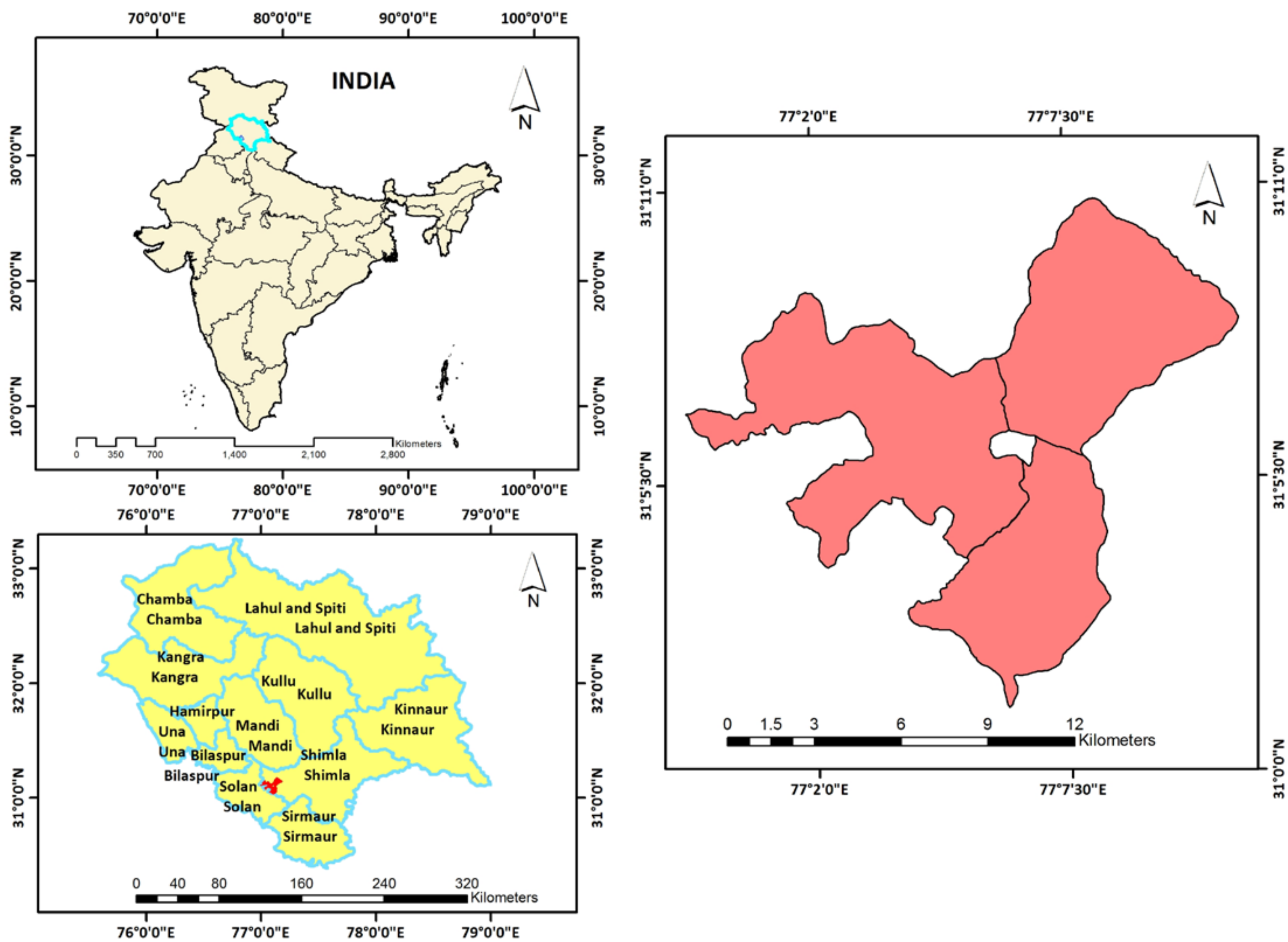


Figure 1: Study Area

III. MATERIALS AND METHODOLOGY

Satellite and ancillary data used in the study

Satellite imagery IRS-P6 LISS-III of November 2009, SRTM data (90m) and SOI Toposheets on 1:50000 scale were used for this research work along with Fire management plan of taradevi forest range which was procured from the forest range office. Satellite images were visually interpreted with ground truth validation to produce forest type and density map and land use maps. All thematic data preparation tasks were carried out using Arc GIS software. Topographic maps (slope, elevation and aspect) were generated from SRTM data using Arc GIS software to be used as input in FARSITE software for simulation. The complete methodology was categorized into two parts which are:

Preparation of thematic maps in Arc GIS

All thematic maps, topographic maps and climate data were used to generate input parameter in FARSITE as .LCP file. Forest cover, type density maps, topographic maps are prepared in GIS environment.

FARSITE Simulation based on GIS themes and climate data

The input includes the meteorological data like temperature, rainfall data, wind speed, wind direction and cloud cover with GIS themes. The GIS themes incorporate elevation, slope, aspect, fuel model, canopy cover. FARSITE is spatial, where we have to provide the spatial data to FARSITE. The spatial data in FARSITE are incorporated in a single landscape file (extension LCP). The Landscape (.LCP) File contains raster data which is obtained from a GIS for terrain and fuels. All raster data are incorporated in the form of ASCII grid format exported from Arc GIS. The weather file is required which include wind and rainfall data. The inputs were .LCP, .WTR, .WND which are necessary for displaying maps and point ignition for forest fire spread. Three points were selected from each forest beat of the taradevi forest range and fire was ignited at these points. Simulation was initiated with time duration to run for hours. The output maps were generated in the form of day-wise and fire type. Therefore, in this study the fuel type, canopy cover, topographic maps and climate data have been used to generate output maps indicating fire perimeter, fire spread area and graphs.

Table 1: Input parameters used for FARSITE software (Source: Kanga et al., 2014)

Input type	**Landscape (GIS layers)**	**Fuel**	**Climatic**	**Ignition probability**	**Misc.**	**Ignition point**
Input	-Latitude -Elevation map -Slope map -Aspect map -Fuel map -Vegetation map Cover map	-Adjustment -Fuel moisture	-Wind speed and direction -Relative humidity -Temperature	-Road probability map -Random percentage -Number of simulations	-Burn period	- Ignition point for fire point

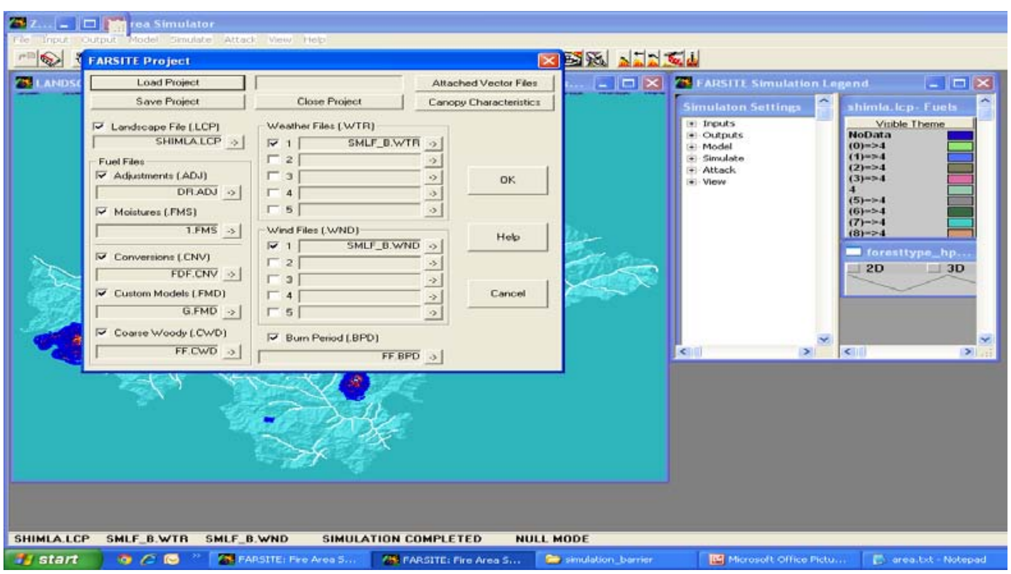


Figure 2: Inputs for FARSITE project (Source: Kanga et al., 2014)

After giving all the inputs required three ignition points from each forest beat of taradevi forest range has been taken to find out the fire growth and spread in the area. Drainage, settlement and road networks were used as a barrier for fire during creation of fire growth and spread model. It has been calculated for four months which are supposed to have maximum number of fire incidents as per historical evidences collected from the forest officials as well as from the local people of the area i.e. March, April, May, June. Three days time has been fixed to calculate the growth and spread in the area. After getting all the four models comparative analysis of all these have been done on the basis of field check and historic records of fire.

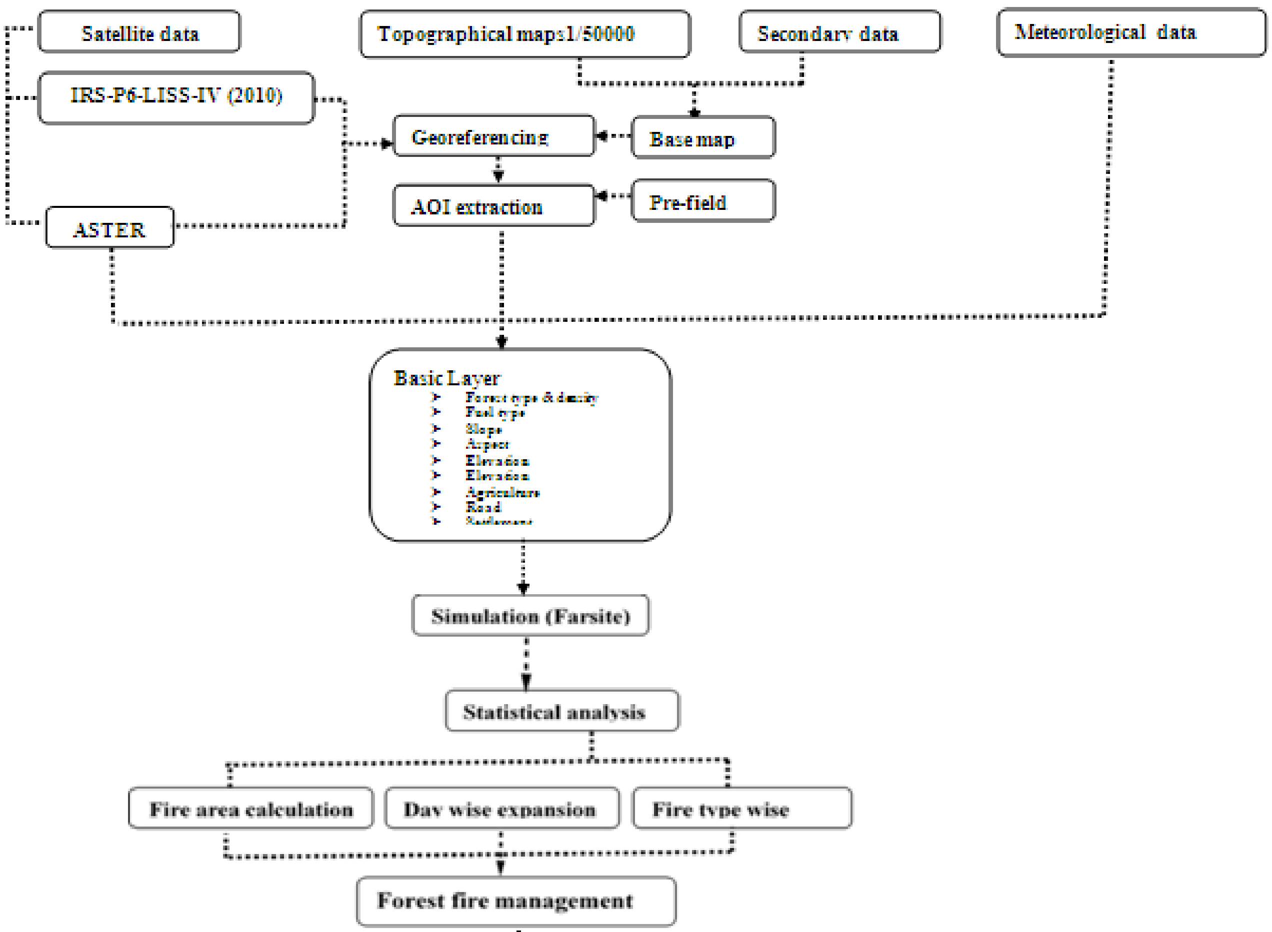


Figure 3: Adopted Methodology

After giving all the inputs required three ignition points from each forest beat of taradevi forest range has been taken to find out the fire growth and spread in the area. Drainage, settlement and road networks were used as a barrier for fire during creation of fire growth and spread model. It has been calculated for four months which are supposed to have maximum number of fire incidents as per historical evidences collected from the forest officials as well as from the local people of the area i.e. march, april, may, june. Three days time has been fixed to calculate the growth and spread in the area. After getting all the four models comparative analysis of all these have been done on the basis of field check and historic records of fire.

IV. RESULTS AND DISCUSSIONS

The forest fire simulations generated outputs in the form of maps, vector files, graphs and tabular sheets. The output shows day-wise fire spread maps, fire intensity, fire combustion rate (graphical and tabular) for the months of March to June. The fire simulation helped in the assessment of the fire spread throughout the forest regions. These simulations were favored by many factors and suppressed by other factors depending upon the conditions. Historical fire incidents in the range for last 20 years were taken into consideration for the demarcation of fire ignition points. Information collected from the forest officials and local people of the area reveals that the fire ignition generally took place for a maximum of three days. Accordingly a three days temporal stretch was selected for fire spread simulation viz.

spread at day one, day two and day three on hourly basis. Fuel types and density, topographical characteristics and meteorological parameters are found to play dominant role in fire ignition and spread. The calculated statistics on day-wise forest fire spread in terms of area, perimeter and combustion rate supports the above conclusions (Figure-4 to Figure-9 followed by Table-2). Generally, as the duration increases the fire advances in the regions. Sometimes fire happens to be associated only with either flame or smoke and sometimes it is accompanied by both of them. These affect the fire intensity or spread rate as well as the fire combustion rate too. These ultimately affect the rate of fire spread in the region.

Simulation was performed with all inputs parameters and calculated for three days for the months of March to June as in these months there are maximum chances of forest fires. Fire spread was observed 4.16 km2 in the month of March, 4 km2 in April, 3.95 km2 in May and in the month of June it was 3.63 km2. Fire spread was also calculated for each day which is shown in figure-8 and table-2.Depending upon the weather conditions forest fire may be accumulated at a place or it may advances towards a particular direction. According to result outcome, fire intensity was very high up to 2-4 meter reaching up to 20710-22715 Kilo Joule and the intensity of heat almost cover whole of the region up to the periphery of 0.1 km. The figure shows the amount of fuels which were consumed at the rate of 380 mg/hr within 12 hours and during fire time total of 625 mg of total fuel in 32 hours was consumed by fire hazards for the month of March and there was very little variations found in the months of April and month wgeras it was decreased in the month of June. Fuel losses were 218 mg/hrs to 600 mg/hrs. Flame and smoke together is making its way simultaneously and both consuming fuel at the same rate but with passing by time fuel consumption by flame decreased as compared to smoldering. This pattern is followed in March to May and in the month of June is comparatively different. This behavior is totally with in favor of fire spread.

Table 2: Day- wise fire spread

Day	**Mar**	**Apr**	**May**	**June**
1st	0.62	0.66	0.81	0.42
2nd	1.07	1.14	0.79	0.94
3rd	2.47	2.19	2.34	2.27
Total	**4.16**	**3.99**	**3.95**	**3.63**

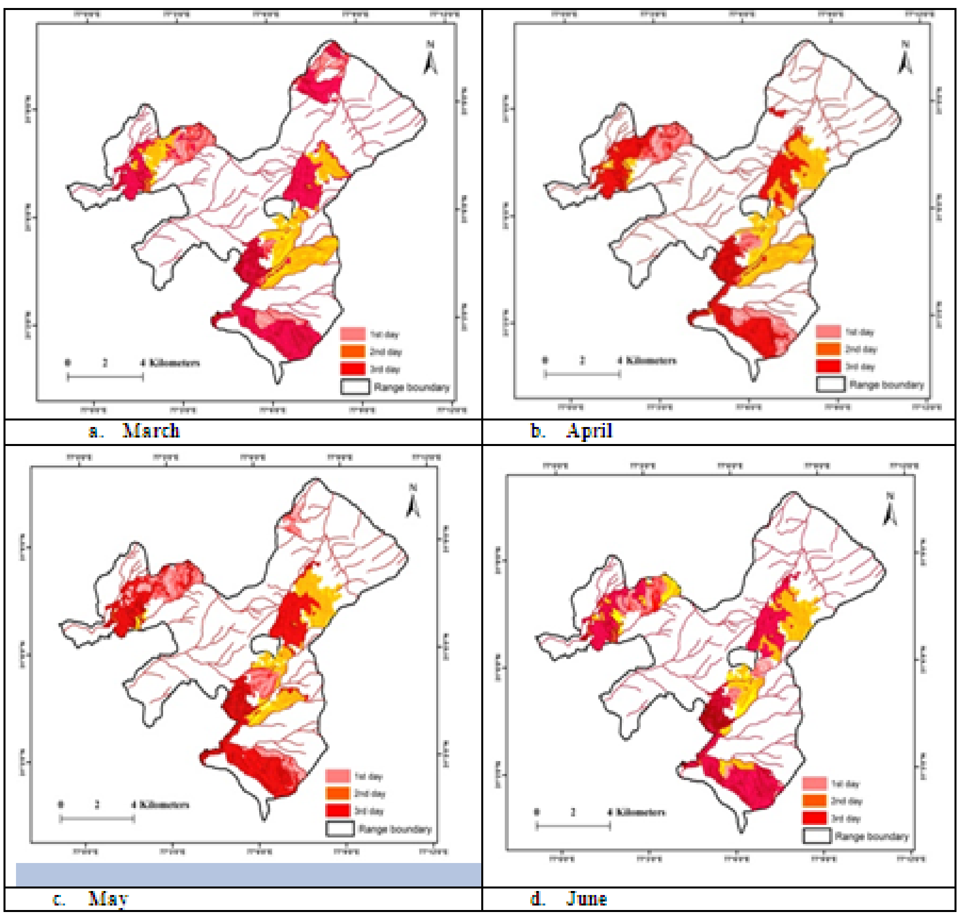
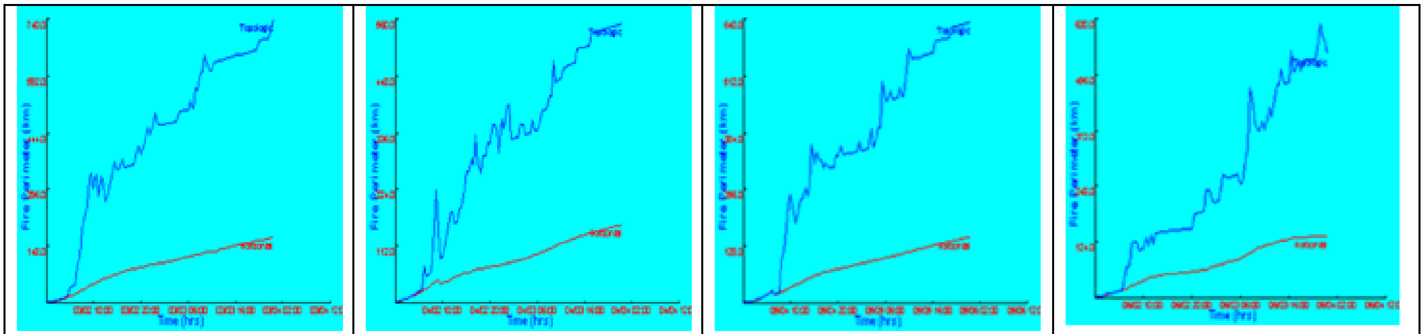
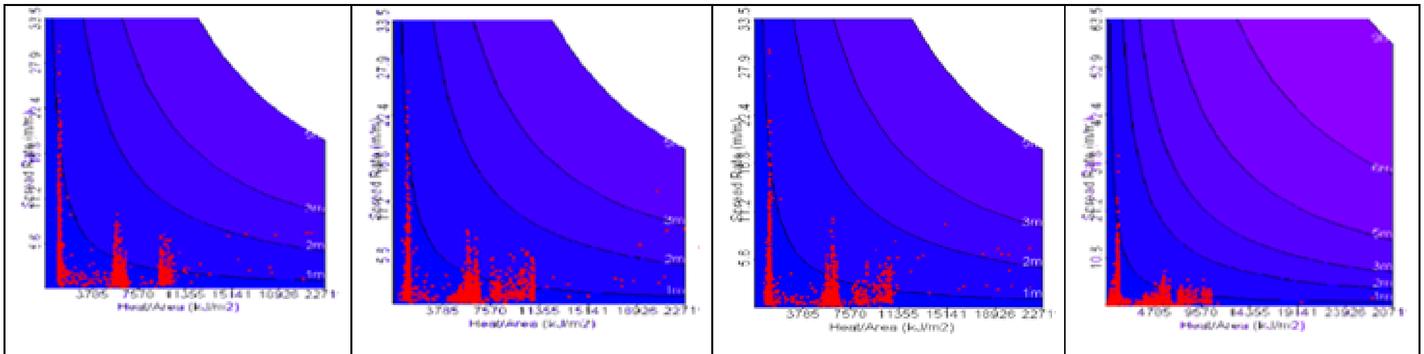


Figure 4: Day-wise fire area spread for the months



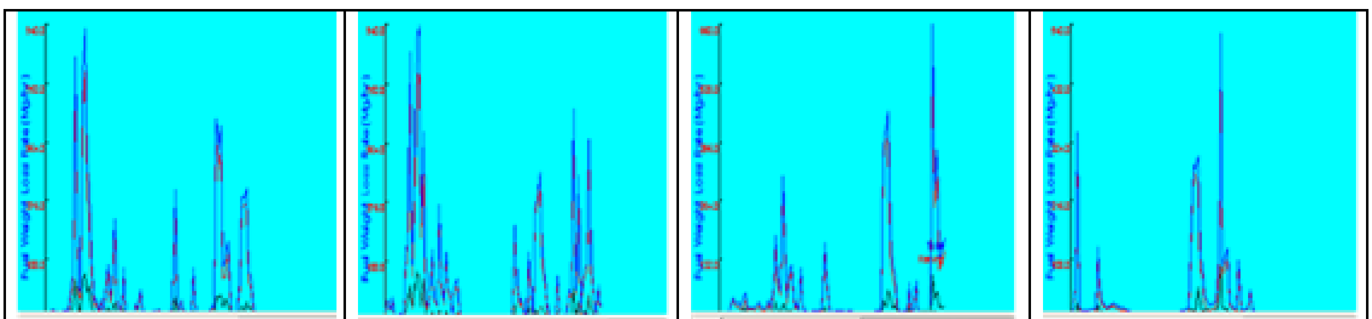
a. March b. April c. May d. June

Figure 5: Fire Perimeter speed (KM)



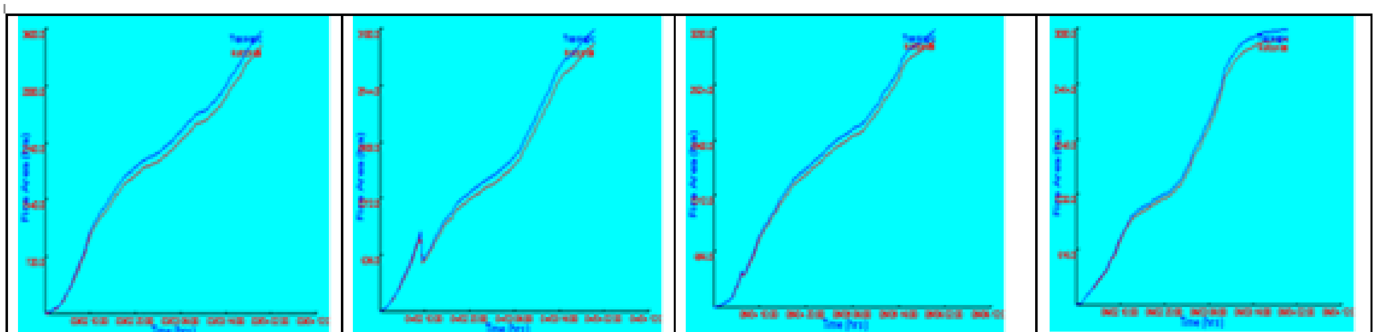
a. March b. April c. May d. June

Figure 6: Fire Intensity Chart



a. March b. April c. May d. June

Figure 7: Fuel Weight Loss Rate (Mg/hr)



a. March b. April c. May d. June

Figure 8: Fire area spread (Ha*le+01)

V. CONCLUSIONS

Major focus of the study is to analyses the forest fire risk with fire behavior in the region using simulation modeling technique. The simulations modeling is useful in fire risk assessment in larger areas with addition of more inputs and ground truth validations. Various parameters influencing the risk of fire and their relative importance was taken into consideration. The criteria used for fire risk modeling in the study proved that forest type and density along with various topographic and metereologic parameters. Whereas topological factors and horizontal factors affect the fire spread jointly and there was little change or displacement from its behavior. The application of remote sensing data and GIS with simulations is useful in fire risk assessment in larger areas with addition of more inputs. The cumulative fire risk along with its spread and perimeter, its intensity, fuel weight loss etc. were calculated. The results and recommendations from the study will be useful for further research on forest fire management. The study can be further be analyzed for suppression methods using models in future prospects. The result of the study will be useful for further research on forest fire management. As per the result of study the recommendations for future fire management is suggested for enhancement of existing conventional fire control measures.

REFERENCES

[1] Garner, M E, "Risk Mitigation of Wildfire Hazards at the Wildland Urban Interface", Master's Thesis, University of Arkansas, Fayetteville, 1989.

[2] Sharma, L K, Kanga, S, Nathawat, M S, Sinha, S and Pandey, P C, "Fuzzy AHP for forest fire risk modeling". Disaster Prev. Manag, Vol. 21, no.2, pp. 160-171, 2012.

[3] Dimopoulou, M, Ioannis G, "Towards an integrated framework for forest fire control", Eur. J. Oper. Res, vol. 152, pp. 476- 486, 2002.

[4] Olabarria, J R G, 2006. "Integrating fire risk into forest planning", Thesis, University of Joensuu. Finland, pp. 1-36.

[5] Hirsch, K, Kafka, V, Tymstra, C, McAlpine, R, Hawkes, B, Stegeehuis, H, Quintillo, S, Gauthier, S, Peck, K, "FIRE-smart forest management: a pragmatic approach to sustainable forest management in FIRE-dominated ecosystems", The Forestry Chronicles, vol.77, no.2, pp. 357-363, 2001.

[6] Finney, M, "FARSITE- Fire area simulator. User's guide and technical documentation". Version 1.0. System for Environmental Management. Missoula. 1995.

[7] Loehle, C, "Applying landscape principles to FIRE hazard reduction". Forest Ecol. Manag, vol. 198, no. (1-3), pp. 261-7, 2004.

[8] Chuvieco, E, Congalton, R, "Application of Remote Sensing and Geographic Information Systems to forest fire hazard mapping". Remote Sens. Environ, vol. 29, pp.147-159, 1989.

[9] Chuvieco, E, Javier, S, "Mapping the spatial distribution of forest fire danger using GIS". Int. J. Geogr. Inf. Syst., vol. 10, pp. 333-345, 1996.

[10] Mariel, A, Marielle, J, "Wildland fire risk mapping using a geographical information system including satellite data: Examples of "Les Maures" forest, south east of France ". EARSeL Adv. Rem. Sen.vol. 4, no. 4, pp. 49-56, 1996.

[11] Jaiswal, R K, Mukherjee, S, Kumaran D R, Saxena, R, "Forest fire risk zone mapping from satellite imagery and GIS". Int. J. Appl. Earth Obs, vol. 4, pp. 1-10, 2002.

[12] Roy, P S, "Assessment of Forest Fires in India through Remote Sensing". Century status report in Project Planning Workshop on the "Scientific dimensions of forest fires" organized by International Council for Science Committee on Science and Technology in Developing Countries. Chennai during March, pp. 27-29, 2000.

[13] Kanga, S, Sharma, L K, Nathawat, M S, Sharma, S K, "Geospatial Approach for Forest Fire Risk Modeling: a Case Study of Taradevi Range of Shimla Forest Division in Himachal Pradesh, India". Ind. Forester, vol. 137, no. 3, 296-303. 2011.

[14] Rothermel, R C, "A Mathematical Model for Predicting Fire Spread in Wildland Fuels" Ogden, UT, USDA Forest Service, Intermountain Forest and Range Experiment Station, INT115, 1972.

[15] Rothermel, R C, "Some fire behavior modeling concepts for fire management systems". 12th Conference on Fire and Meteorology: Fire, Meteorology and the Landscape, Jekyll Island, GA, 28-28 October, 1993

[16] Van Wagner, C E,"Prediction of crown fire behavior in two stands of Jack Pine". Can. J. Forest Res, vol. 18, pp. 818-820, 1993

[17] Wikramanayake, E D, Dinerstein, E, Robinson, J G, Karanth, K U., Rabinowitz, A, Olson, D, Mathew, T, Hedao, P, Corner, M, Hemley, G, Bolze, D, "An ecology-based method for defining priorities for large mammal conservation: the tiger as case study". Conserv. Biol, vol. 12, pp. 865-878, 1998.

[18] Kanga, S, Sharma, L K, Pandey, P C, Nathawat, M S, "GIS Modeling Approach for Forest Fire Risk Assessment and Management". J. Adv. Rem. Sen. GIS Geography. Vol. 2, no. 1, pp. 30-44, 2014.

[19] Kanga, S K, Sharma P C, Pandey, P C, Nathawat, M S, Sinha, S, "Forest fire susceptibility mapping with GIS modeling". Inter. J. Ear. Sci. Eng, vol. 04, no. 3, 80-87, 2011.

[20] Kanga, S, Sharma, L K, Pandey, P C, Nathawat, M S, Sinha, S, "Geospatial Approach for Allocation of Potential Tourism Gradient Sites in a Part of Shimla District in Himachal Pradesh, India". J. GIS Trends. Vol. 2, no. 1, pp. 1-6, 2011.

[21] Kanga, S, Sharma, L K, Pandey, P C, Nathawat, M S, Sharma, S K, "Forest fir modeling to evaluate potential hazard to tourism sites using geospatial approach". Journ. Geomatics, vol. 7, no. 1, pp. 93-99, 2013.

[22] Rodgers, W A, Panwar, H S, Mathur, V B, "Wildlife Protected Area Network in India- A Review: Executive Summary", Wildlife Institute of India, Dehradun, India, 44, 2002.

[23] Kanga, S, Sharma, L K, Nathawat M S, "Himalayan Forest Fires Risk Management: A Geospatial Approach". Lambert Academic Publishing, pp 1-188, 2015.

[24] Kanga, S, "Forest cover and land use mapping using remote sensing and GIS Technology". SGVU Journal of Climate Change and Water, vol.1, no.2, pp.13-17, 2017

[25] Kanga, S, Tripathi, G, Singh, S K, "Forest Fire Hazards Vulnerability and Risk Assessment in Bhajji Forest Range of Himachal Pradesh (India): A Geospatial Approach". Journal of Remote Sensing & GIS, vol.8, no. 1, pp.1-16, 2017.

