INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 8, Issue 3, July-September 2017: 475-484 www.ijcs.uaic.ro

WILDFIRE RISK ZONATION IN A TROPICAL FOREST DIVISION IN KERALA, INDIA: A STUDY USING GEOSPATIAL TECHNIQUES

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Abstract

The forests of the Western Ghats in India are often affected by wildfires. Such forest fires are potential hazards seriously damaging the environment. Wildfire occurrence in an area is influenced by environment, terrain, and climatic conditions, alongside with human activities. The records on previous forest fire data show that the present study area is also prone to fires. The present study aims to delineate and map wildfire risk zones in Thenmala forest division, a part of the Western Ghats, using Remote Sensing (RS) and Geographic Information System (GIS) techniques. Factors such as land use/land cover (LU/LC) type, slope, aspect, distance from settlement, distance from road, and elevation are selected for this study. All these factors have direct or indirect influence on fire occurrence. A Modified Fire Risk Index method has been used to prepare the fire risk zone map. The prepared fire risk zone map of Thenmala forest division has classified the area into five zones viz., very low, low, moderate, high, and very high. Finally, the risk zone map is validated with the fire incidence points, which shows that 75% of the fires have occurred in the high and very high risk zones. This shows the effectiveness of the present methodology and can be used for entire Western Ghats region. The study shows that the majority of fires are induced by humans. The officials of the forest departments can use this risk zone map to easily locate areas under high and very high fire risks and take effective preventive and mitigation measures. This can reduce loss of life and precious forest wealth.

Keywords: *Wildfire; Modified Fire Risk Index; Incidence points; Western Ghats*

Introduction

Forests, being one of the most important natural resources are primarily responsible for the conservation of climate, soil, water, ecology, and biodiversity. This natural resource is under the threats of fires, droughts, insect infestations, diseases, encroachments and unplanned settlements [1]. Fires are the most frequented disturbance among these. They can occur due to

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the influence of natural forces as well as humans [2]. Wildfire occurrence in an area is influenced by environment, terrain, and climatic conditions, along with human activities. It can cause serious damage to forests and human lives regardless of whether it is caused by natural forces or human activities [3]. Forest fires can lead to atmospheric emissions, soil erosion, biodiversity loss, and drainage alterations [4]. The present study area is a part of the Western Ghats, a biodiversity hotspot in Southwest India. Most of the forests in this fragile eco-sensitive zone are under serious threat from fires [5-13]. Thus, proper evaluation and understanding of the factors contributing to fire risks is essential.

Geospatial techniques are increasingly applied in disaster management, as they require less manpower, cost and time. A large number of studies have been carried using these techniques to demarcate the disaster prone areas [11, 14-52]. *R.N. Manavalan and S. Jayalakshmi* [53] prepared a fire risk zone map of Nilgiri district forest area using RS and GIS tools. Factors such as roads, settlements, NDVI, NDWI, temperature, slope and aspect were used for the study. *R.P. Singh and K. Ajay* [54] used the same techniques to prepare a fire risk zone map of Chitrakoot area (Madhya Pradesh) in India. The factors selected were fuel type, elevation, slope, and aspect. *Y. Hai-wei et al.* [55] generated a forest fire risk zone map of Da Hinggan Mountains considering factors such as vegetation type, settlement buffer, slope, altitude, and aspect and *X. Dong et al.* [3] prepared a forest fire risk zone map of Baihe Forestry Bureau in China taking into consideration factors like vegetation, slope, aspect, altitude, distance from roads, farmlands, and from settlements.

The purpose of this study is to demarcate and map the wildfire risk zones in Thenmala forest division using RS and GIS techniques. The factors that are relevant to fire risks have been derived from satellite images and topographic maps. Factors such as LU/LC type, slope, aspect, distance from settlement, distance from road, and elevation are selected for this study. In order to delineate the risk zones, a Modified Fire Risk Index (MFRI) method has been used.

Materials and methods

Study Area

The present study has been carried out in Thenmala forest division, which lies between 76º58’0”E and 77º12’0”E longitude, and between 8º52’0”N and 9º2’0”N latitude. This forest division comprises two forest ranges namely Aryankavu and Thenmala. The study area is bordered by the state of Tamil Nadu to the East, Punalur forest division to the West, Shenduruny Wildlife Sanctuary to the South, and Achankovil and Punalur forest divisions to the North. This division covers an area of around 159.47km^2. The location of study area is shown in Figure 1.

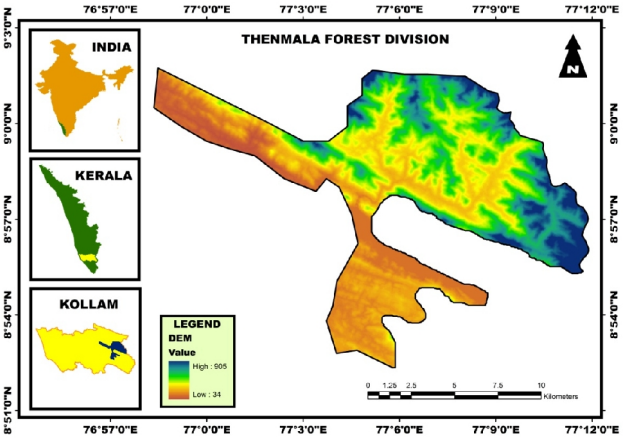

Fig. 1. Study area map

The present study area is included in the Survey of India (SOI) topographic maps numbered 58 C/16, 58 D/13, 58 G/4, and 58 H/1 in 1:50,000 scale. The thematic maps were prepared using ArcGIS 9.3 and ERDAS IMAGINE 9.2 software tools. The LU/LC type map was derived from the Landsat ETM+ imagery of 30m resolution. ERDAS Imagine software was used for the supervised classification of the satellite imagery. The road networks and human settlements were digitized from the SOI topographic maps and Google Earth. The distance from settlement and distance from road map layers were prepared from the digitized data using ArcGIS spatial analyst tools. The contour data was extracted from the Cartosat DEM of 30m resolution. The slope, aspect and elevation map layers were prepared from the 20m interval contour data using ArcGIS spatial analyst and 3D analyst tools. A MFRI model developed during this study was used to prepare the risk zone map. The thematic map layers were reclassified using the Natural Breaks (Jenks) method. An index was assigned to each class of these factors according to their sensitivity to fire or their fire inducing capability. The class wise index was calculated from the rank and weight (Index = Rank X Weight) and is shown in Table 1. The wildfire risk zone map was prepared by overlaying the index map layers using ArcGIS tools. Finally, the risk zone map was validated with the fire incidence data collected from the records of Forest Survey of India (FSI).

Table 1. Rank, Weight and Index assigned for different factors

Factor	Class	Rank	Weight	Index
Land use/land cover	Water body	1	30	30
	Built-up area	2		60
	Agricultural land	3		90
	Evergreen forest	4		120
	Forest plantation	5		150
	Deciduous forest	6		180
Slope (degree)	0 – 6.22	1	22	22
	6.22 – 12.45	2		44
	12.45 – 19.00	3		66
	19.00 – 26.03	4		88
	26.03 – 40.72	5		110
Aspect	Flat (-1)	1	18	18
	North (0-22.5)	2		36
	Northeast (22.5-67.5)	3		54
	East (67.5-112.5)	3		54
	Southeast (112.5-157.5)	4		72
	South (157.5-202.5)	5		90
	Southwest (202.5-247.5)	5		90
	West (247.5-292.5)	3		54
	Northwest (292.5-337.5)	3		54
	North (337.5-360)	2		36
Distance from settlement (m)	0 – 388	5	12	60
	388 – 832	4		48
	832 – 1373	3		36
	1373 – 2080	2		24
	2080 – 3537	1		12
Distance from road (m)	0 – 210	5	12	60
	210 – 480	4		48
	480 – 784	3		36
	784 – 1256	2		24
	1256 – 2149	1		12
Elevation (m)	40 – 208	1	6	6
	208 – 337	2		12
	337 – 470	3		18
	470 – 616	4		24
	616 – 877	5		30

Results and discussion

Land use/land cover

The land cover has significant influence on fire occurrence and spread. Forest fires are more frequent in areas covered with dry and dense vegetation. In the study area, the chance of fire occurrence is higher in areas covered by deciduous vegetations. The land use can influence the fire occurrence. The land use practices of inhabitants in and around the forests can lead to uncontrolled fires. For example: the fires created for the purpose of shifting cultivation can result in accidental forest fires. However, in the present study area, land use has given lesser preference, as shifting cultivation is not common in the forests of Kerala. The land use/land cover types in the present study area are deciduous forests, forest plantations, evergreen forests, agricultural land, built-up area, and water body. The land use/land cover type map is shown in Figure 2a.

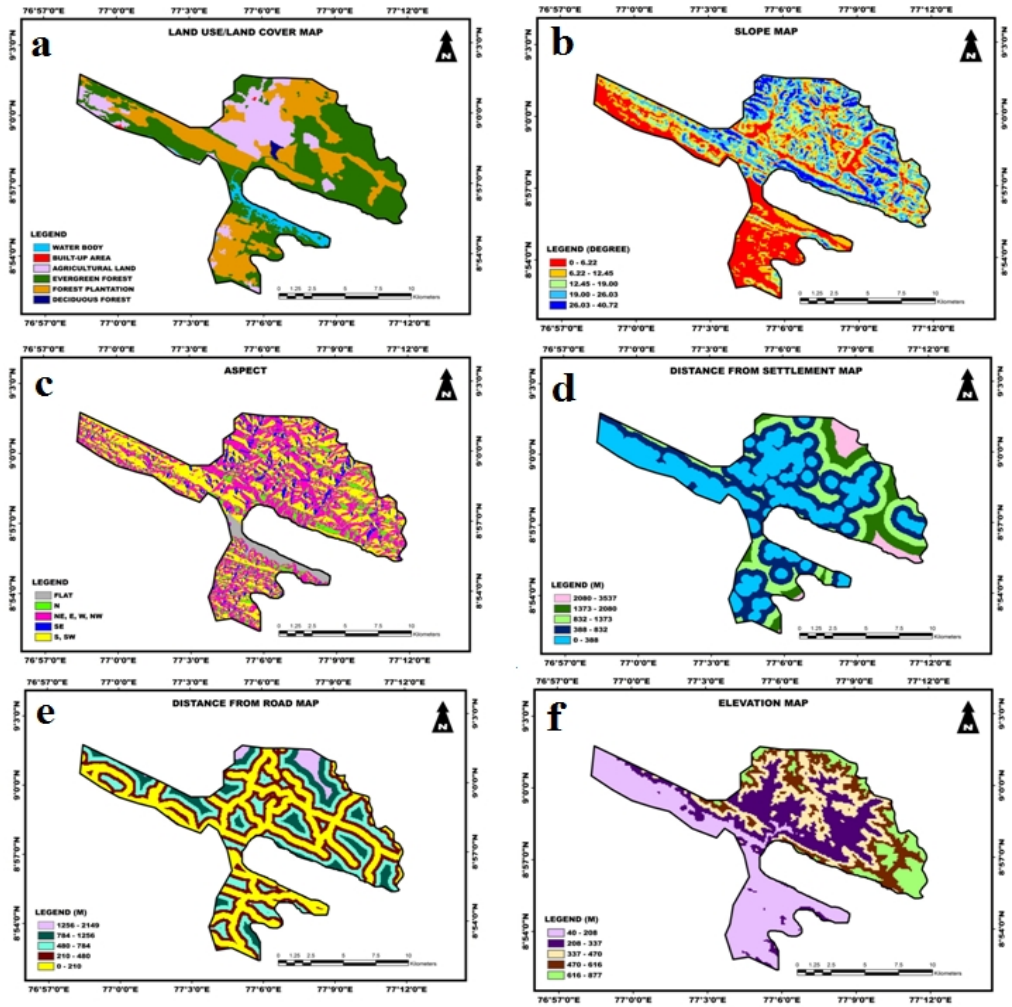

Fig. 2. Area maps: a - Land use/land cover; b - Slope; c - Aspect;
d - Distance from settlement; e - Distance from road; f - Elevation

Slope

The spread of forest fires is influenced by slope of the terrain. In upslope direction forest fire catches up much faster [56]. Fuel moisture and air humidity decreases as the slope increases. Mountain winds act as a catalyst in fire spread, if the ground slope is steeper. The upslope vegetation is easily heated and dried up by the fire advancing up the slope. The slope of this area has been grouped into five classes *viz.*, 0 – 6.22º, 6.22 – 12.45º, 12.45 – 19.00º, 19.00 – 26.03º, and 26.03 – 40.72º. The slope map is shown in Figure 2b.

Aspect

Aspect refers to the direction of the exposed surfaces of the slope with respect to the angle of incident heat energy from the sun [57]. The rate of fuel drying and spread of fire are very much related to aspect and exposure [58]. The southern exposures are subjected to greater solar and wind influences leading to wildfires [57]. The terrains receiving direct sunlight face the highest degree of fire risks due to higher insolation [19]. Because of the higher degree of desiccation, the fuels in the southern slopes are usually drier and less dense than those in the northern slopes [59]. Even though, the eastern aspects receive early heating from the sun and early slope winds, the western aspects, due to late but higher rate of heating and transitional wind flows create much more favorable condition for triggering wildfires [57]. Therefore western slopes are more vulnerable and are prone to fires. The aspect of this area has been categorized into nine classes *viz.*, Flat, North, Northeast, East, Southeast, South, Southwest, West and Northwest. The aspect map is shown in Figure 2c.

Distance from settlement

The forests located near human settlements are more prone to fires. The present study area has a large number of settlements. Forest fires due to human intervention may be intentional or unintentional. Attempting to burn a very limited area of forests for agriculture, habitation, and for protection come under intentionally induced forest fires. Sometimes such fires may grow out of control and spread out as wildfires. Accidental forest fires due to human intervention are typically due to reckless throwing of burning cigarette butts, match sticks, or due to wayside cooking or campfires. These types of accidental fires are caused more by travelers or visitors rather than peoples settled in forests for generations. The distance of forests from settlements has been grouped into five classes *viz.,* 0 – 388m, 388 – 832m, 832 – 1373m, 1373– 2080m, and 2080 – 3537m. This map based on the distance of forests from settlements is shown in Figure 2d.

Distance from road

The forests near roads are more prone to accidental fires. Thenmala is one of the ecotourism spots in Kerala. The movements of humans and vehicles through these forest roads can create intentional/unintentional fires. The geomorphological setting in the present study area is marked by scenic natural beauty enhanced by mist clad mountains, deep ravines, valleys and forest roads. The roads pass through parts of lesser slope with deciduous vegetation. Chances are very high for human induced forest fires due to careless disposal of burning materials by travelers. The distance of forests from roads has been grouped into five classes *viz.*, 0 – 210m, 210 – 480m, 480 – 784m, 784 – 1256m and 1256 – 2149m. This map based on the distance of forests from roads is shown in Figure 2e.

Elevation

In this study, higher preference was given to higher elevation areas, considering their association with wind behavior and lightning related ignitions. The incidences of lightning and related ignitions are more frequent at a higher elevation [9]. Incidences of previous forest fires show that the most dominant natural causative factor is lightning [60]. Areas of higher elevation are more affected by upslope moving convective winds. The speed of wind increases the rate of fuel drying and consequently increases the spread of fire. The elevation of this sanctuary ranges from 40 – 877m and has been grouped into five classes. The elevation map is shown in Figure 2f.

Wildfire risk zones

The wildfire risk zone map of Thenmala forest division is generated by combining the index map layers of factors such as land use/land cover, slope, aspect, distance from settlement, distance from road, and elevation using GIS techniques. The fire risk zones in this area are grouped into five classes' *viz.* very low, low, moderate, high, and very high. The wildfire risk zone map is shown in Figure 3. The area and percentage of each fire risk zones have been calculated and are shown in Table 2. The high and very high risk zones together constitute 43.24% of the study area. Finally the prepared risk zone map is validated with the fire incidence data for the past 11 years (2004 - 2014) collected from the records of FSI. A total of 12 forest fires have been recorded during the period considered for the present study. Result shows that out of the 12 fires, 9 (75%) occurred in the high and very high risk zones, 1 (8.33%) occurred in the moderate risk zone, and 2 (16.66%) occurred in the low and very low risk zones. Data collected during this study when analyzed show that the majority of the fire incidence points are close to the roads and human settlements, which reiterates the anthropogenic origin of forest fires.

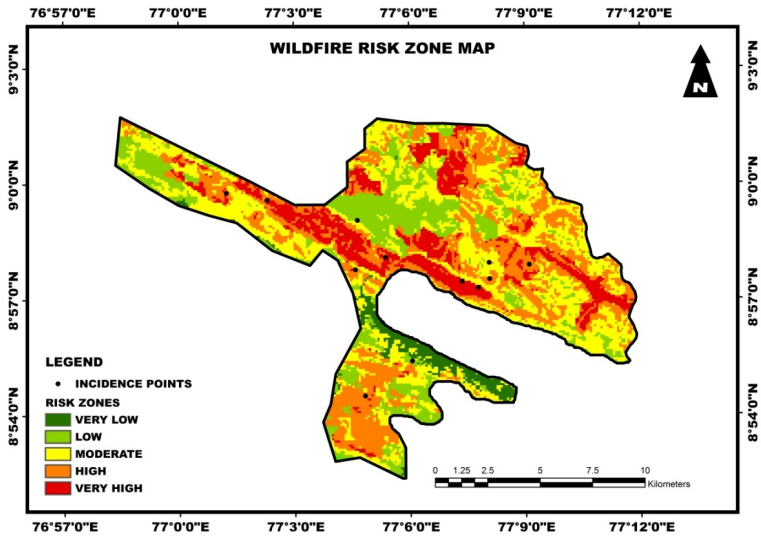

Fig. 3. Wildfire risk zone map

Table 2. Area and Percentage of the fire risk zones

Fire Risk Zones	Area (sq. km)	Percentage of the area of the fire risk zones
Very Low	5.89	3.70
Low	30.55	19.16
Moderate	54.06	33.90
High	46.73	29.30
Very High	22.24	13.94
Total	**159.47**	**100**

Conclusion

Forest fires are occasional hazards that threaten the conservation of the precious forest cover of the Western Ghats. The present study has delineated the potential fire risk zones in Thenmala forest division considering vegetation (land cover type), topography (slope, aspect, and elevation) and factors related to human intervention (distance from road, and distance from settlements). The thematic map layers generated from satellite imageries and topographic maps

formed the basis for above analysis. The study has shown that 75% of the forest fires have occurred in the high and very high risk zones. This proved the effectiveness of the methodology. Further, the GIS based study has found that the percentage of forest fires caused by human intervention is higher and in the zones demarcated as high and very high risks. This confirms that the majority of fires have an anthropogenic origin. The officials of the forest departments can use this risk zone map to easily locate areas under high and very high fire risks and take effective preventive and mitigation measures. This can reduce loss of life and precious forest wealth.

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Received: January 10, 2017
Accepted: August 30, 2017