Forest fire risk assessment using geospatial techniques: a study in Mannarkkad Forest Division of Palakkad District, Kerala, India

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Abstract. Forests are invaluable natural resources for the sustenance of terrestrial as well as atmospheric environment. Forests are often threatened by factors like deforestation and global warming. Past records have shown that one major cause of loss of forests is fires. A forest fire whether natural or human induced can pose serious threat to the fragile ecological and environmental stability of a region. The present study area, Mannarkkad forest division in Kerala is a part of the Western Ghats and is prone to forest fires. In this study, an attempt has been made to delineate and map the fire risk zones in Mannarkkad forest division using Remote Sensing and Geographic Information System techniques. Thematic layers such as vegetation type, road networks, human settlements, and contours were derived from satellite images and topographic maps. The Fire Risk Index method is used for the delineation of risk zones. The study area is divided into five risk zones ranging from 'very low' to 'very high'. The prepared forest fire risk zone map is validated with the fire incidence data. The result of the study is found to be in strong agreement with actual fire affected sites. The study shows that most of the fires are due to natural forces. This risk zone map can serve as a valuable data for the officials of forest and disaster management departments to take effective preventive and mitigation measures for better fire risk management.
Key Words: forest fire, Fire Risk Index, risk zones, Western Ghats.

Introduction. Forests are invaluable natural resources for the sustenance of terrestrial as well as atmospheric environment. Forests are often threatened by factors like deforestation and global warming. Past records have shown that one major cause of loss of forests is fires. Forest fires can occur due to natural forces as well as anthropogenic activities (Adab et al 2013). A forest fire whether natural or anthropogenic can pose serious threat to the fragile ecological and environmental stability of a region. Fires of natural origin are largely related to climatic conditions such as temperature, wind speed and direction, and the moisture content in soil and atmosphere. The impacts of forest fires on the environment are high carbon emissions, loss of biodiversity, soil erosion, forest degradation, and emission of large amount of toxic gases. Fires can result in deforestation and desertification (Hernandez-Leal et al 2006). Forest fires are one of the major natural hazards in the Western Ghats, which is a biodiversity hotspot in southwest India. To assuage the frequently occurring forest fires causing irrecoverable losses, a more appropriate approach of prevention and mitigation is necessary to enhance the efficiency of forest fire fighters and forest department. There is need for critical assessment and planning. Our ability to assess and map forest fire risk zones need refinement and modernization.

Remote Sensing (RS) and Geographic Information System (GIS) techniques can be effectively used to locate the forest fire risk zones. Many researchers (Dong et al 2005; Chavan et al 2012; Ghobadi et al 2012; Malik et al 2013; Manavalan & Jayalakshmi 2013; Singh & Ajay 2013; Ajin et al 2016a; Ajin et al 2016b; Ajin et al 2016c; Ajin et al 2016d; Ajin et al 2016e; Vinod et al 2016; Ajin et al 2017) demarcated forest fire risk zones using RS and GIS techniques. Ajin et al (2014a) demarcated forest fire risk zones of Peppara wildlife sanctuary in Kerala using RS and GIS techniques. The factors selected were land use/land cover, distance from settlement, distance from road, slope, and elevation. Singh (2014) prepared forest fire risk zone map of Raipur range in

India using geospatial techniques. Various climatic, seasonal, environmental, and anthropogenic factors were used for the study. Sowmya & Somashekar (2010) delineated forest fire risk zones of Bhadra wildlife sanctuary using RS and GIS techniques. Factors such as vegetation, slope, distance from roads, and distance from settlements were used for the study.

In the present study, an attempt has been made to delineate and map the forest fire risk zones in Mannarkkad forest division using RS and GIS techniques. The Fire Risk Index (FRI) method has been used for the delineation of risk zones. The factors selected for the present study are vegetation type, slope, settlement density, road density, and elevation.

Material and Method. The present study area, Mannarkkad forest division lies between longitudes of 76°17′30″ E and 76°48′00″ E and latitudes of 10°52′30″ N and 11°14′00″ N. The study area is bordered by the state of Tamil Nadu to the east and north, Nilambur South forest division to the west, and Palakkad forest division to the south. The Mannarkkad forest division comprises three forest ranges, namely Mannarkkad, Attappady, and Agali. This forest division covers an area of around 1113.95 km^2. The study area map is shown in Figure 1. The present study covers a time span of 4 months from February to May 2016.

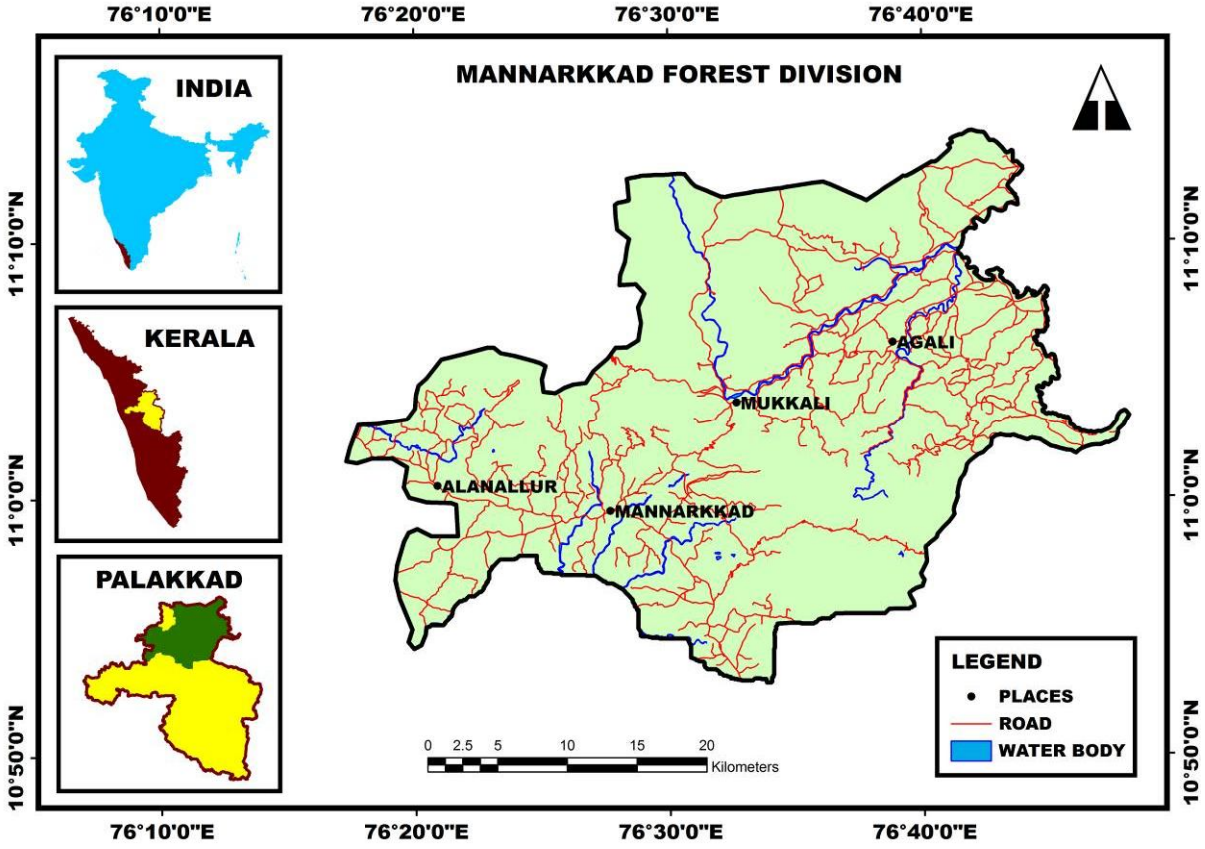

Figure 1. Study Area map.

The study area was delineated from the Survey of India (SOI) topographic maps (58 A/8, 58 A/12, 58 A/16, 58 B/5, and 58 B/9) of 1:50,000 scale. The thematic maps required for the study were prepared using ArcGIS 9.3 and ERDAS Imagine 9.2 software tools. The vegetation type map was prepared from the IRS-P6 LISS-III image of 23.5 m resolution. The supervised classification of the pre-processed LISS-III images has been carried using ERDAS Imagine software tools. The Maximum Likelihood (ML) classification method was applied to classify different vegetation types. The accuracy of the classified image was ascertained based on the ground information data collected during the field work. The road networks and human settlements were digitized from the SOI topographic

maps and Google Earth. The road density and settlement density maps were prepared from the digitized data using ArcGIS spatial analyst tools. The 20 m interval contour data was also digitized from the topographic maps. ArcGIS spatial analyst and 3D analyst tools were used to prepare the slope and elevation maps from the contour data. The FRI method (Ajin et al 2014b; Ajin et al 2015) was used for the demarcation of forest fire risk zones. The thematic map layers were reclassified using the Natural breaks (Jenks) method. Ranks were assigned to each class of the thematic map layers and weights were assigned to each thematic map layer according to their sensitivity to fire or their fire inducing capability. The index was derived from the weight and rank (Index = Weight x Rank). A higher index indicates that the factor class has a higher influence on the fire risk. The index, rank, and weight details are shown in Table 1. The forest fire 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 for the past 11 years (January 2004 - December 2014) collected from the records of the Forest Survey of India (FSI). The flowchart of the methodology is shown in Figure 2.

Table 1

Rank, weight, and index assigned for the factors

Factor	*Class*	*Rank*	*Weight*	*Index*
Vegetation type	Water body	1	10	10
	Built-up area	2		20
	Barren land	3		30
	Mixed vegetation	4		40
	Evergreen forest	5		50
	Forest plantation	6		60
	Grassland	7		70
	Deciduous forest	8		80
Slope (degree)	0-5.05	1	3	3
	5.05-11.65	2		6
	11.65-18.90	3		9
	18.90-27.25	4		12
	27.25-56.05	5		15
Settlement density (km/sq. km)	0-2.50	1	2	2
	2.50-7.33	2		4
	7.33-13.50	3		6
	13.50-21.41	4		8
	21.41-40.51	5		10
Road density (km/sq. km)	0-0.28	1	2	2
	0.28-0.69	2		4
	0.69-1.07	3		6
	1.07-1.49	4		8
	1.49-2.60	5		10
Elevation (m)	40-344	1	1	1
	344-719	2		2
	719-1063	3		3
	1063-1537	4		4
	1537-2243	5		5

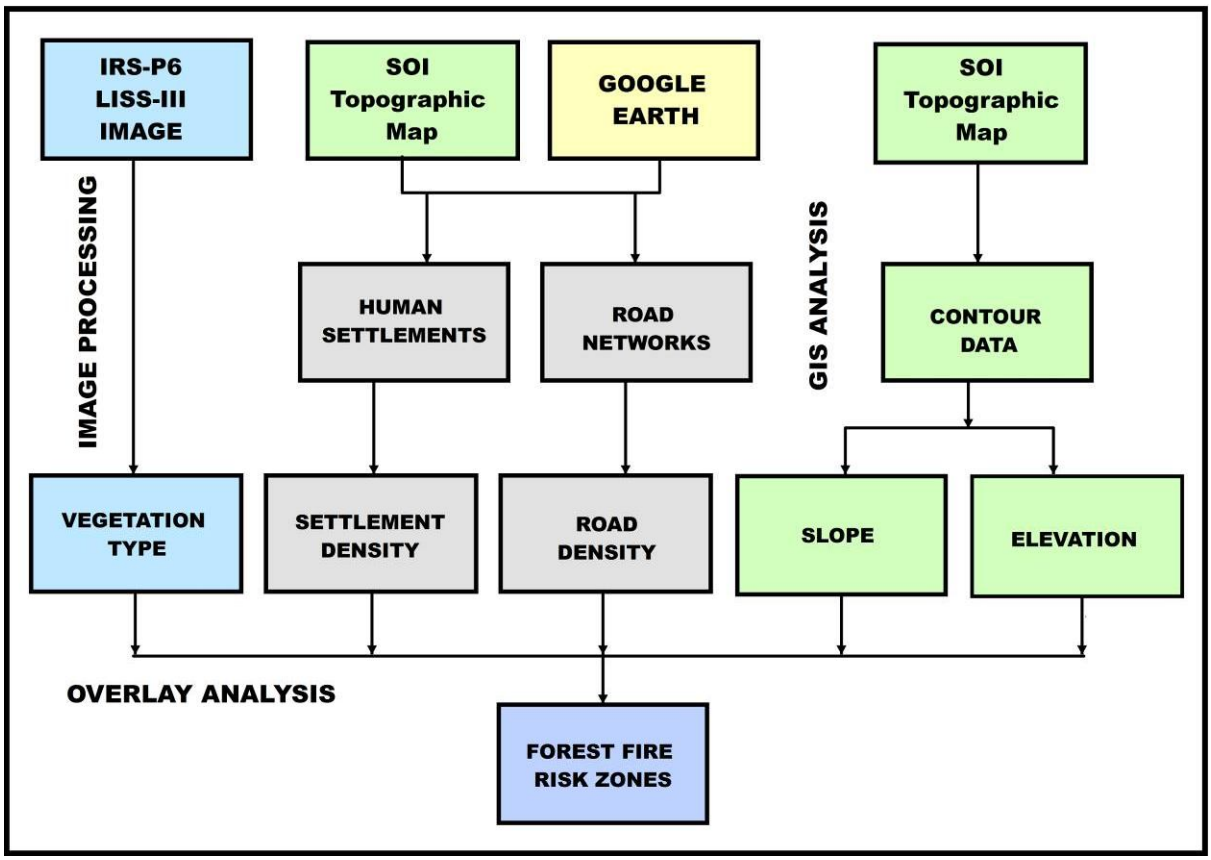

Figure 2. Flowchart of the methodology.

Results and Discussion. The present study on forest fire risk assessment has taken into account five factors; namely vegetation type, slope, settlement density, road density, and elevation. Their influence and impact characteristics are briefly discussed below.

Vegetation type. Fire initiation requires suitable fuels. The fuels include the combustible materials such as trees, leaves, roots, grasses etc. The most important factor that helps in fire spread is the continuous availability of suitable fuels. The areas covered with dry vegetation are more prone to fires. In the present study area, deciduous forest and grasslands are more susceptible to forest fire. Deciduous forest and grasslands constitutes major portion of the highland area. The major portion of grassland area is covered by bamboo. Forest fires can also occur due to the friction in dry bamboo stems (Saxena 2012). The vegetation type map is shown in Figure 3.

Slope. Most forest fires are influenced by geomorphology. The upward drifting of forest fires is faster and more intense than its downslope movement (Rothermel 1972). In steeper slopes, rate of fire spread may rise, since flames are angled closer to the surface of ground and wind effects can augment the process of heat convection for the fire produced (Zhong et al 2003). The northern part of the study area is steep, whereas the southwestern part is almost plain. Based on slope angle, the area has been grouped into five classes *viz.* 0-5.05°, 5.05-11.65°, 11.65-18.90°, 18.90-27.25°, and 27.25-56.05°. The slope map is shown in Figure 4.

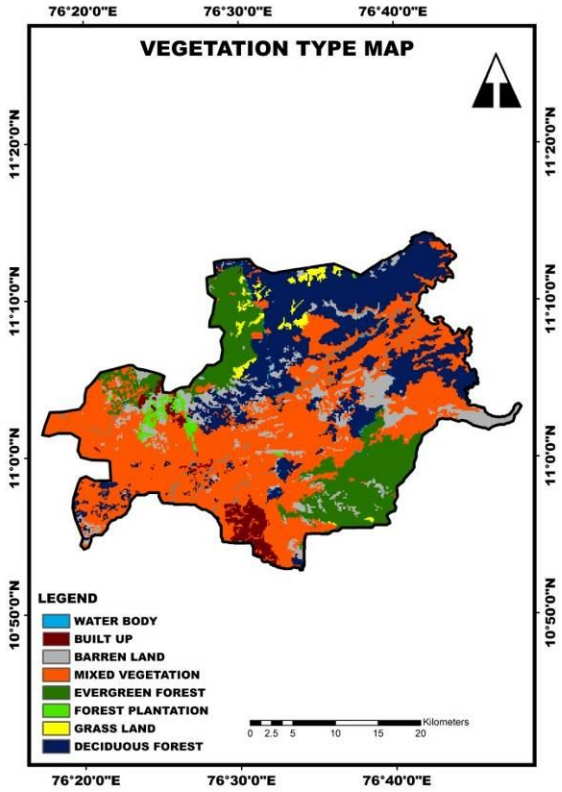

Figure 3. Vegetation type map.

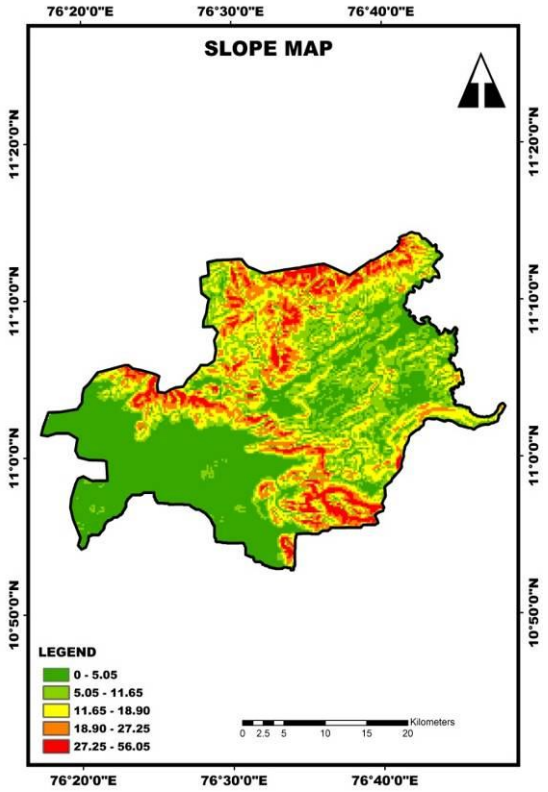

Figure 4. Slope map.

Settlement density. Recent decades have seen greater pressure upon forest fringe zones due to human encroachment of forest land. Forests are source of subsistence for the tribal communities. Local inhabitants close to the forest sometimes create minor fires for gathering fire wood, clearing forest path, hiding illicit felling, driving away wild animals, practicing tribal customs/rituals, etc. Very often such fires grow to uncontrolled forest fires resulting in serious fire hazard. There is high density of settlements within the study area. On the basis of settlement density, the area has been grouped into five classes *viz.*, 0-2.50 km/sq. km, 2.50-7.33 km/sq. km, 7.33-13.50 km/sq. km, 13.50-21.41 km/sq. km, and 21.41-40.51 km/sq. km. The settlement density map is shown in Figure 5.

Road density. Human settlements have developed narrow roads into the peripheral zones of forests. The incidence of forest fire is more near such roads. The movements of humans and vehicles on forest roads can increase the chances of forest fire occurrence. Accidental forest fires often begin from negligent human activities like throwing unextinguished cigarette butts, leaving behind burning fire woods after wayside cooking or setting campfires by travellers. On the basis of road density, the area has been grouped into five classes' *viz.*, 0-0.28 km/sq. km, 0.28-0.69 km/sq. km, 0.69-1.07 km/sq. km, 1.07-1.49 km/sq. km, and 1.49-2.60 km/sq. km. The road density map is shown in Figure 6.

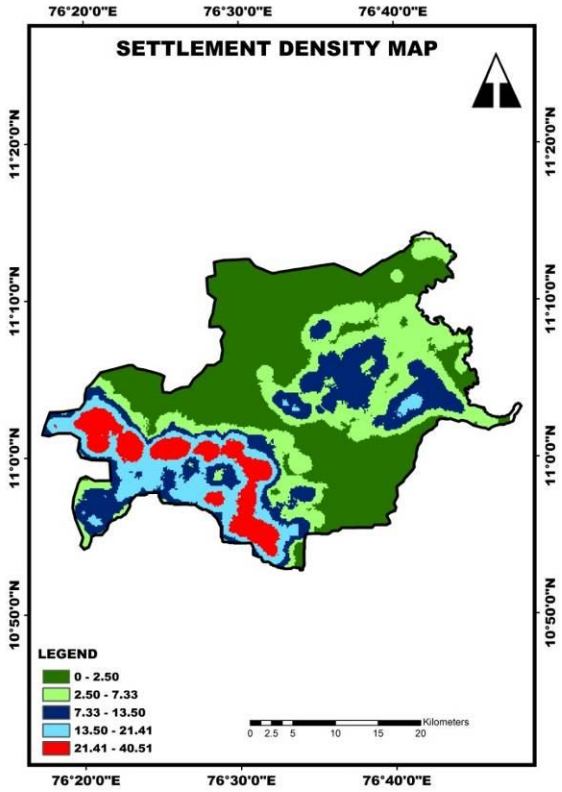

Figure 5. Settlement density map.

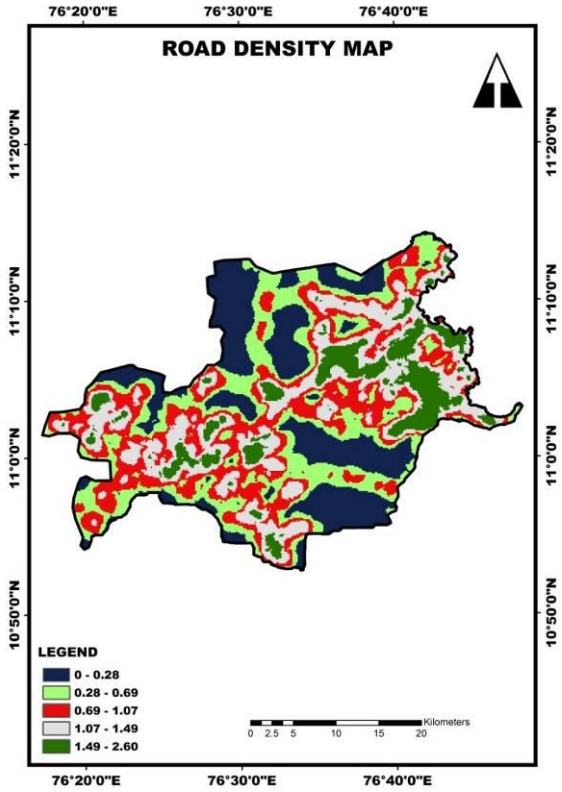

Figure 6. Road density map.

Elevation. Elevation or relief characteristics of this area have significant influence upon forest fires, especially with respect to fires caused by lightning strikes. Lightning is one of the major causes of forest fires of natural origin (Saxena 2012). Further at higher elevations, the uphill convective movement of warm air enhances the rate of desiccation of organic matter and hence can provide potential fuel for the escalation of fire. The elevation of this area has been grouped into five classes *viz.* 40-344 m, 344-719 m, 719-1063 m, 1063-1537 m, and 1537-2243 m. The elevation map is shown in Figure 7.

Forest fire risk zones. The forest fire risk zone map of the study area is prepared by combining the index map layers of factors such as vegetation type, slope, elevation, road density, and settlement density using GIS tools. The study area is grouped into five fire risk zones *viz.*, very low, low, moderate, high, and very high. The map showing the fire risk zones is shown in Figure 8. The risk zone map is validated with the fire incidence points for the past 11 years collected from the records of the FSI. From the risk zone map it is observed that, out of the 66 forest fires, 53 (80.30%) occurred in the high and very high risk zones. This shows that the present methodology is reliable and can be effectively used in the delineation of forest fire risk zones. Most of the fires have occurred in the higher elevation and steeper slope areas, where the road networks and human settlements are relatively less. This underlines the natural/environmental origin of fires.

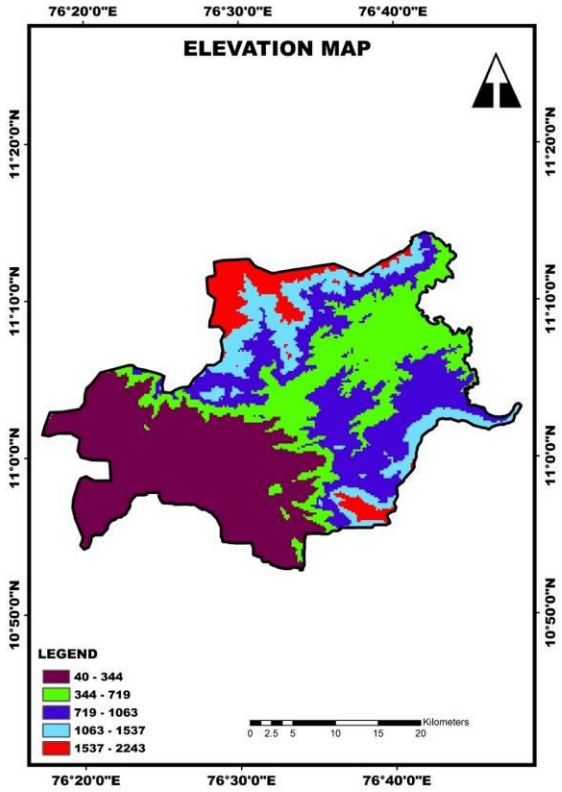

Figure 7. Elevation map.

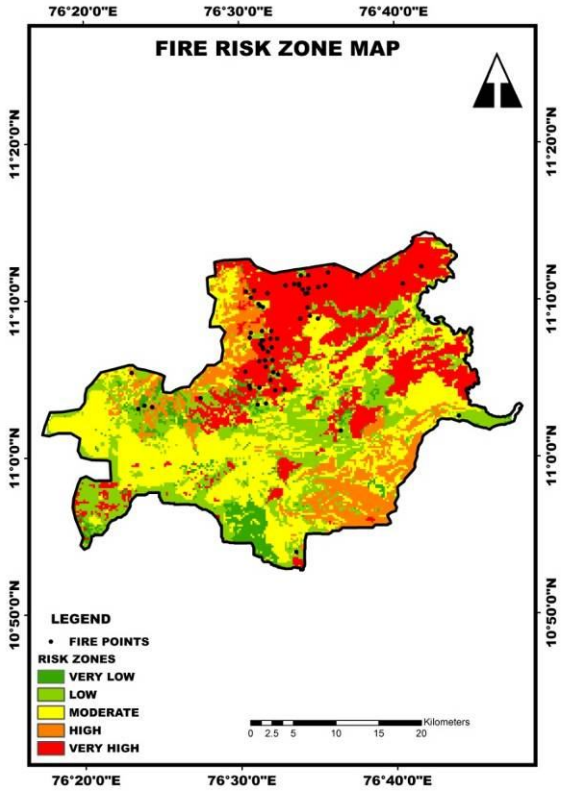

Figure 8. Fire risk zone map.

Conclusions. The present study is confined to the Mannarkkad forest division of Kerala, which is a part of the Western Ghats. This forest zone has considerable eco-geo-environmental significance. This forest cover is the abode of an impressive biodiversity. This area is often affected by forest fires of varying intensities. This study concludes that the number of forest fires is significantly high in the northern parts, where the slope as well as elevation are higher. This confirms that most of the fires have a natural origin.This area is also characterised by high wind velocity. Further forest fires of such areas can cause much more serious and irrecoverable damage to the rich and unique biodiversity here. This study highlights the extreme importance of preventing incidence of forest fires in this segment of the Western Ghats. The study shows that more than 80% of the fires have occurred in the high and very high risk zones. This shows the effectiveness of the methodology. This risk zone map can serve as a valuable data for the officials of forest and disaster management departments to take effective preventive and mitigation measures for better fire risk management.

References

Adab H., Kanniah K. D., Solaimani K., 2013 Modeling forest fire risk in the Northeast of Iran using remote sensing and GIS techniques. Natural Hazards 65:1723-1743.

Ajin R. S., Jacob M. K., Menon A. R. R., Vinod P. G., 2014a Forest fire risk analysis using geo-information technology: A study of Peppara Wildlife Sanctuary, Thiruvananthapuram, Kerala, India. Proceedings of the 2nd Disaster Risk Vulnerability Conference, Thiruvananthapuram, India, pp. 160-165.

Ajin R. S., Vinod P. G., Menon A. R. R., 2014b Forest fire risk analysis using GIS and RS techniques: an approach in Idukki Wildlife Sanctuary, Kerala, India. Proceedings of the 24th Swadeshi Science Congress, Malappuram, India, pp. 406-413.

Ajin R. S., Ciobotaru A. M., Vinod P. G., Jacob M. K., 2015 Forest and wildland fire risk assessment using geospatial techniques: a case study of Nemmara forest division, Kerala, India. Journal of Wetlands Biodiversity 5:29-37.

Ajin R. S., Loghin A. M., Jacob M. K., Vinod P. G., Krishnamurthy R. R., 2016a The risk assessment of potential forest fire in Idukki Wildlife Sanctuary using RS and GIS techniques. International Journal of Advanced Earth Science and Engineering 5(1): 308-318.

Ajin R. S., Loghin A. M., Karki A., Vinod P. G., Jacob M. K., 2016b Delineation of forest fire risk zones in Thenmala forest division, Kollam, Kerala, India: a study using geospatial tools. Journal of Wetlands Biodiversity 6:139-148.

Ajin R. S., Loghin A. M., Vinod P. G., Jacob M. K., 2016c Forest fire risk zone mapping in Chinnar Wildlife Sanctuary, Kerala, India: a study using geospatial tools. Journal of Global Resources 3:16-26.

Ajin R. S., Loghin A. M., Vinod P. G., Jacob M. K., 2016d RS and GIS based forest fire risk zone mapping in the Periyar Tiger Reserve, Kerala, India. Journal of Wetlands Biodiversity 6:175-184.

Ajin R. S., Loghin A. M., Vinod P. G., Jacob M. K., 2016e Forest fire risk zone mapping using RS and GIS techniques: a study in Achankovil forest division, Kerala, India. Journal of Earth, Environment and Health Sciences 2(3):109-115.

Ajin R. S., Loghin A. M., Vinod P. G., Jacob M. K., 2017 The risk analysis of potential forest fires in a wildlife sanctuary in the Western Ghats (Southwest Indian Peninsula) using geospatial techniques. International Journal of Health System and Disaster Management 5(1):18-23.

Chavan M. E., Das K. K., Suryawanshi R. S., 2012 Forest fire risk zonation using remote sensing and GIS in Huynial watershed, Tehri Garhwal district, UA. International Journal of Basic and Applied Research 2:6-12.

Dong X., Li-min D., Guo-fan S., Lei T., Hui W., 2005 Forest fire risk zone mapping from satellite images and GIS for Baihe forestry bureau, Jilin, China. Journal of Forestry Research 16(3):169-174.

Ghobadi G. J., Gholizadeh B., Dashliburun O. M., 2012 Forest fire risk zone mapping from geographic information system in Northern forests of Iran (case study, Golestan Province). International Journal of Agriculture and Crop Sciences 4(12):818-824.

Hernandez-Leal P. A., Arbelo M., Gonzalez-Calvo A., 2006 Fire risk assessment using satellite data. Advances in Space Research 37:741-746.

Malik T., Rabbani G., Farooq M., 2013 Forest fire risk zonation using remote sensing and GIS technology in Kansrao forest range of Rajaji National Park, Uttarakhand, India. International Journal of Advanced Remote Sensing and GIS 2(1):86-95.

Manavalan R. N., Jayalakshmi S., 2013 Forest fire risk and degradation assessment using remote sensing and GIS. Journal of Geomatics 7(2):198-205.

Rothermel R. C., 1972 A mathematical model for predicting fire spread in wildland fuels. USDA Forest Service Research Paper INT - 115, Ogden, Utah, USA, pp. 1-40.

Saxena A., 2012 Wildfire risk management in India and the community. In: Wildfire and community: facilitating preparedness and resilience. Paton D., Tedim F. (eds), Charles C Thomas Publisher, Ltd., Springfield, Illinois, USA, pp. 129-149.

Singh D., 2014 Historical fire frequency based forest fire risk zonation relating role of topographical and forest biophysical factors with geospatial technology in Raipur and Chilla range. SSARSC International Journal of Geo Science and Geo Informatics 1(1):1-9.

Singh R. P., Ajay K., 2013 Fire risk zone assessment in Chitrakoot area, Satna MP, India. Research Journal of Agriculture and Forestry Sciences 1(5):1-4.

Sowmya S. V., Somashekar R. K., 2010 Application of remote sensing and geographical information system in mapping forest fire risk zone at Bhadra Wildlife Sanctuary, India. Journal of Environmental Biology 31(6):969-974.

Vinod P. G., Ajin R. S., Jacob M. K., 2016 RS and GIS based spatial mapping of forest fire risk zones in Wayanad Wildlife Sanctuary, North Kerala, India. International Journal of Earth Sciences and Engineering 9(2):498-502.

Zhong M., Fan W., Liu T., 2003 Statistical analysis on current status of China forest fire safety. Fire Safety Journal 38:257-269.

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