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The Risk Assessment Study of Potential Forest Fire in Idukki Wildlife Sanctuary using RS and GIS Techniques

Ajin R.S.[1], Ana-Maria Loghin[2], Mathew K. Jacob[3], Vinod P.G.[1] and Krishnamurthy R.R.[4]

[1]Geomatics Division, GeoVin Solutions Pvt. Ltd., Thiruvananthapuram, Kerala, India
[2]Faculty of Hydrotechnical Engineering, Geodesy and Environmental Engineering, Gheorghe Asachi Technical University of Iasi, Romania
[3]Department of Geology, Sree Narayana College, Sivagiri, Kerala, India
[4]Department of Applied Geology and Centre for Environmental Sciences, University of Madras, Chennai, India

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Abstract In recent years, forest fires have become a major disaster in many countries of the world because of their impact on biodiversity, landscape, health, environment, ecology and economy. Forest fires are one of the major natural hazards occurring in the forests of the Western Ghats, a biodiversity hotspot in India. The present study aims to demarcate the risk zones of potential forest fire in Idukki Wildlife Sanctuary using integrated Remote Sensing (RS) and Geographic Information System (GIS) techniques. Every year, during March-May months, the forests in this area are affected by severe fires. In order to generate the fire risk zone map of the study area, a thematic study was carried out on each of the influencing factors *viz.* land cover type, slope, distance from settlement, distance from road, and elevation. A Fire Risk Index method was used to prepare the risk zone map. The area of the final map was grouped into five different categories of risk zones, *viz.* very low, low, moderate, high, and very high. Finally the risk zone map was validated with the fire incidence data for the last 10 years. Results of this study show that the most important factors which contribute to fire ignition are the human induced factors, also known as the anthropogenic factors. The resulting map of forest fire risk zone can be of great benefit for understanding the fire problem and will offer a more effective database for the preparation and control of forest fires.
Keywords *Fire Risk Index; Natural Hazards; Biodiversity; Western Ghats*

1. Introduction

Forest fires are one of the major natural hazards, becoming a serious threat to the environment. Forest fires are considered to be a potential hazard with physical, biological, ecological, and environmental consequences (Somashekar et al., 2009). It typically occurs during periods of increased temperature and drought (Tatli and Türkeş, 2014). The major causative factor inducing forest fires is the climate change, along with the anthropogenic activities. The causes of forest fire are varying throughout the world. There are two different types of forest fires, depending on the causative factors. Thus, in some parts, there are naturally occurring fires, which are climate induced, in most

cases by lightning, and secondly, in other zones, there are human induced fires. Forest fires can cause extensive damage to the biodiversity, ecosystem, landscape, and endangers human and animal life. It can also cause atmospheric pollution. During forest fires, significant amount of gaseous and particulate matter pollutants will get emitted into the atmosphere (Lazaridis et al., 2008). On the other hand, forest fires can also have some positive impacts. In many ecosystems, forest fires help the natural regeneration process by stimulating the germination of certain species, clearing space for the invasion and growth of others, and releasing a periodic flush of nutrients into the soil (Dawson et al., 2001). The effects of fire on forests vary, depending upon weather, topography, and fuel type (Podur and Martell, 2009). Fires occur in forest areas from all over the world. This phenomenon also occurs in the Indian forests, and is a major cause of degradation. It is estimated that the proportion of forest areas prone to fires annually ranges from 33% in some states to over 90% in others (Roy, 2003). Forest fires are frequent in Kerala, in the forests of the Western Ghats, a biodiversity hotspot in southwest India. The study area is represented by the Idukki Wildlife Sanctuary, which is a part of the Western Ghats. This area was affected by fires especially during the months from March to May. The risk of forest fire will be severe in ecologically sensitive area like the Western Ghats, which can adversely affect the wildlife, micro climate, and forest regeneration.

RS and GIS are effective techniques, which can be used in forest fire risk zonation. Many researchers delineated forest fire risk zones using RS and GIS techniques (Ajin et al., 2015; Singh, 2014; Thakur and Singh, 2014; Veeraanarayanaa and Ravikumar, 2014; Rajabi et al., 2013; Singh and Ajay, 2013; Assaker et al., 2012; Chavan et al., 2012; Ghobadi et al., 2012; Mahdavi et al., 2012; Sowmya and Somashekar, 2010; Dong et al., 2005; Chuvieco et al., 1999; Chuvieco and Salas, 1996). Ajin et al. (2014a) delineated forest fire risk zones of Peppara Wildlife Sanctuary in Thiruvananthapuram district using RS and GIS techniques. The factors selected for the study are land use/land cover, distance from settlement, distance from road, slope, and elevation. Gangapriya and Indulekha (2013) demarcated forest fire risk areas in Thiruvananthapuram Reserve Forest using GIS techniques. The factors selected are vegetation type, proximity to human settlements, distance from roads, and slope. Somashekar et al. (2009) mapped burnt areas in Bandipur National Park using LISS III data, and RS and GIS techniques. The factors such as vegetation type, historical data, slope, and road are used. Eskandari et al. (2013) demarcated fire risk areas of Northern forests in Iran using GIS techniques and Dong model. The factors such as vegetation type, vegetation density, slope, aspect, elevation, and distance from road, distance from settlement, and distance from farmland are used for the study.

The objective of this study is to delineate the forest fire risk zones of Idukki Wildlife Sanctuary in Kerala using RS and GIS techniques. In order to generate the fire risk zone map of the study area, five important influencing factors such as land cover type, slope, distance from settlement, distance from road, and elevation are selected. A Fire Risk Index (FRI) method is used for the delineation of the identified risk zones.

2. Materials and Methods

2.1. Study Area

The present study area, the Idukki Wildlife Sanctuary is located in the Thodupuzha and Udumbanchola taluks of Idukki district. The sanctuary spans approximately an area of 105.364 sq. km, bounded within 76˚52’00” and 77˚7’00”E longitudes and 9˚43’00” and 9˚51’00”N latitudes. This is one of the most nature rich areas in Kerala, with steep mountains and undulating hills and valleys. The major rivers flowing through the area are Periyar and Cheruthoniar. The importance of this area is increased by the world famous Idukki arch dam; built on the Periyar River, with a length of 365.85 m. Located at an altitude of 167.68 m, it is one of the highest arch dams in Asia, and the third tallest (168.91 m) arch dam in the world. This dam was constructed along with two other dams, *viz.* Cheruthoni and Kulamavu. Together these three dams form the Idukki reservoir of 33 sq. km. In the

sanctuary, the temperature varies from 13˚C to 29˚C; the warmest period is March-April. The annual average rainfall in this area is about 3800 mm. The forest types include West Coast tropical evergreen forests, semi-evergreen forests, moist deciduous forests, hill shoals, and grasslands. The major tree species are *Dipterocarpus indicus*, *Palaquium ellipticum*, *Calophyllum polyanthum*, *Vernonia arborea*, *Mesua ferrea*, *Hopea parviflora*, *Persea macrantha*, *Artocarpus hirsutus*, *Lagerstroemia microcarpa*, *Cinnamomum zeylanicum*, *Tectona grandis*, *Dalbergia latifolia*, *Terminalia paniculata*, *Terminalia bellirica*, *Grewia tiliaefolia*, *Pterocarpus marsupium*, etc. The common animals found are Elephant, Sambar deer, Barking deer, Mouse deer, Bonnet macaque, Nilgiri langur, Malabar giant squirrel, Wild dog, Wild boar, Porcupine, Jackal, etc; and also various species of snakes including Cobra, Viper, Krait and numerous non-poisonous ones are found. Birds include Grey junglefowl, Malabar grey hornbill, several species of Woodpeckers, Bulbuls, Flycatchers, etc. The study area map is shown in Figure 1.

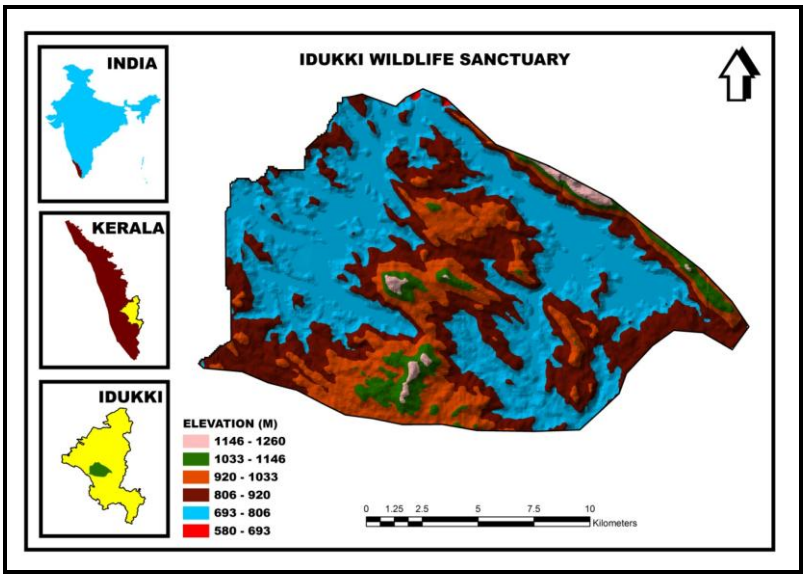

Figure 1: *Location Map of the Study Area*

2.2. Methodology

The flowchart of methodology used for the present study is shown in Figure 2. The study area was delineated from the Survey of India (SOI) topographic maps (58 C/13, 58 C/14, 58 G/1, and 58 G/2) of 1:50,000 scale. The thematic maps required for this study were prepared using ArcGIS 9.3 and ERDAS Imagine 9.2 software. The land cover type map was prepared from the IRS-P6 LISS-III image of 23.5 m resolution. The ERDAS Imagine software was used for the supervised classification of satellite image. The road networks and human settlements were digitized from the toposheets and Google Earth data/map, and the distance from road and distance from settlement maps were prepared from the digitized data using ArcGIS spatial analyst tools. The contour data was derived from the Cartosat 1 DEM of 30 m resolution. ArcGIS spatial analyst and 3D analyst tools were used to prepare the slope and elevation maps from the 10 m interval contour data. In order to demarcate the forest fire risk zones in the study area, a FRI method was used. The thematic map layers of the selected factors were reclassified using Equal Interval method. Different ranks were assigned to each class of the thematic layers, and also, different weights were assigned to each thematic layer, according to their sensitivity to fire or their fire-inducing capability. The index (Table 1) was derived from the weight and rank, being equal to the multiplication of weight with the corresponding rank (Index = Weight X Rank). In order to prepare the forest fire risk zone map, the index map layers were overlaid using ArcGIS tools. Field survey was conducted to collect the fire incidence points as well as

to check the accuracy of land cover type map. Finally the risk zone map was validated with the forest fire incidence points collected from the Forest Survey of India (FSI) and during the field survey and primary data collection.

Table 1: *Rank, Weight, and Index Assigned for Different Factors*

Sl. No.	Factor	Class	Rank	Weight	Index
1	Land cover type	Water body	1	10	10
		Built up area	2		20
		Wasteland	3		30
		Evergreen forest	4		40
		Forest plantation	5		50
		Grassland	6		60
		Deciduous forest	7		70
2	Slope (degree)	0 – 9.91	1	3	3
		9.91 – 19.82	2		6
		19.82 – 29.74	3		9
		29.74 – 39.65	4		12
		39.65 – 49.57	5		15
3	Distance from settlement (m)	0 – 895	5	2	10
		895 – 1791	4		8
		1791 – 2686	3		6
		2686 – 3582	2		4
		3582 – 4478	1		2
4	Distance from road (m)	0 – 922	5	2	10
		922 – 1845	4		8
		1845 – 2767	3		6
		2767 – 3690	2		4
		3690 – 4613	1		2
5	Elevation (m)	580 - 715	1	1	1
		715 – 850	2		2
		850 – 985	3		3
		985 – 1120	4		4
		1120 – 1255	5		5

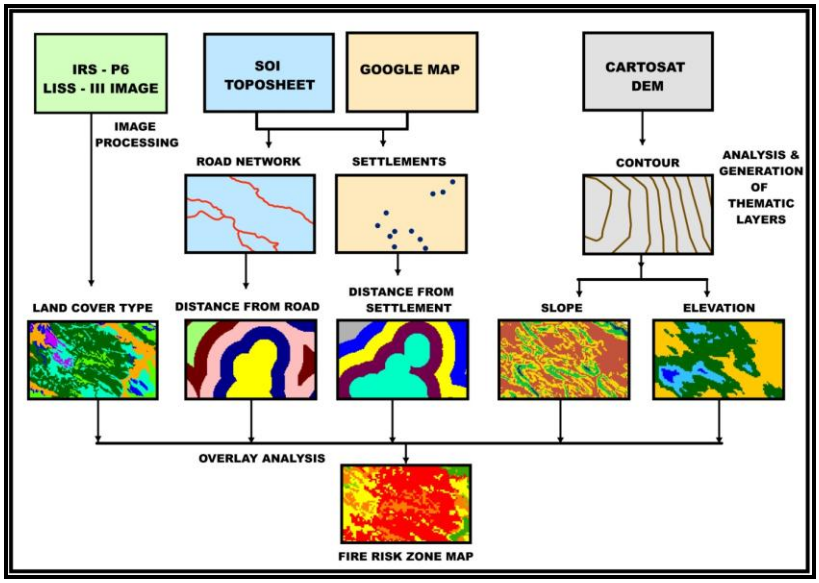

Figure 2: *Flowchart for Delineating the Forest Fire Risk Zones*

3. Results and Discussion

3.1. Land Cover Type

Land cover is represented by the physical material at the surface of the earth, which includes grass, trees, bare ground or water. The vegetative cover has the most significant influence on fire behaviour. For example, the areas with dry and dense vegetation are more susceptible to fire than those which are moist and sparse. The land cover types found in this sanctuary area are deciduous forest, grassland, forest plantation, evergreen forest, wasteland, built up area, and water body. In this sanctuary, the areas which are more susceptible to wild fire are deciduous forest and grassland. The deciduous forests are found mainly in the central part of the study area, and most of the grasslands are found in the northwestern parts. The map representing the land cover types of the Idukki Wildlife Sanctuary is shown in Figure 3.

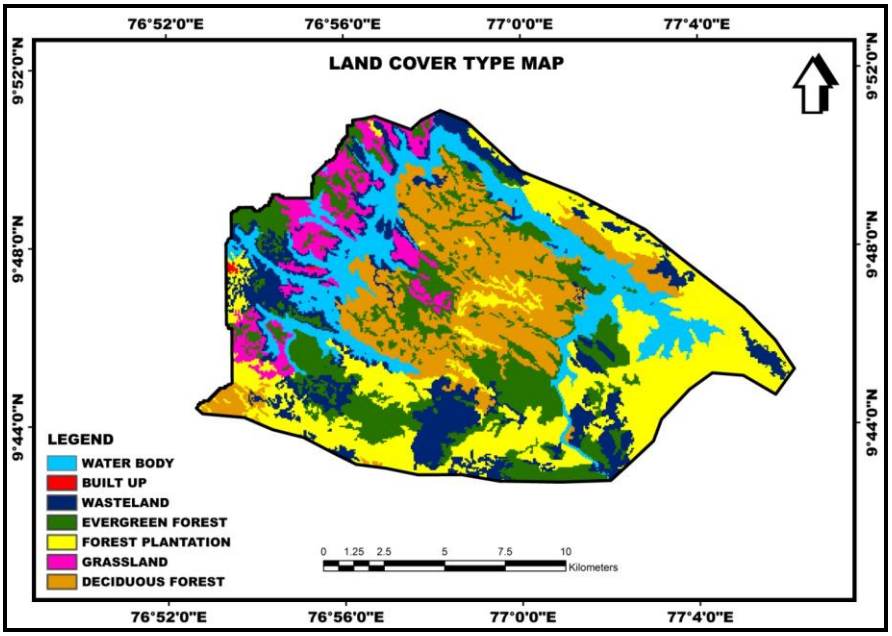

Figure 3: *Land Cover Type Map*

3.2. Slope

Slope represents the degree of inclination of the land surface, the measure of steepness, has great influence on fire behaviour. This is a natural factor which affects the rate of fire spread and also has significant influence on fire intensity. Fire moves most quickly up slope and least quickly down slope (Rothermel and Richard, 1972). The rate of fire spread is higher in the areas with steeper slopes, because the fire flames are angled closer to the ground surface and the effects of the wind supplies the process of heat convection (Zhong et al., 2003). Generally, currents of wind move upslope, and this phenomenon pushes the heat flames to newer areas and also to newer fuels. Thus, the rate of fire spread increases with slope steepness. The steeper the terrain, the faster is the fire spreading. The areas with steeper slopes, found in the central and northeastern parts of the sanctuary are more susceptible to forest fire. In this study, the slope of the area is grouped into five classes, *viz.* 0 – 9.91˚, 9.91 – 19.82˚, 19.82 – 29.74˚, 29.74 – 39.65˚, and 39.65 – 49.57˚. The slope map is shown in Figure 4.

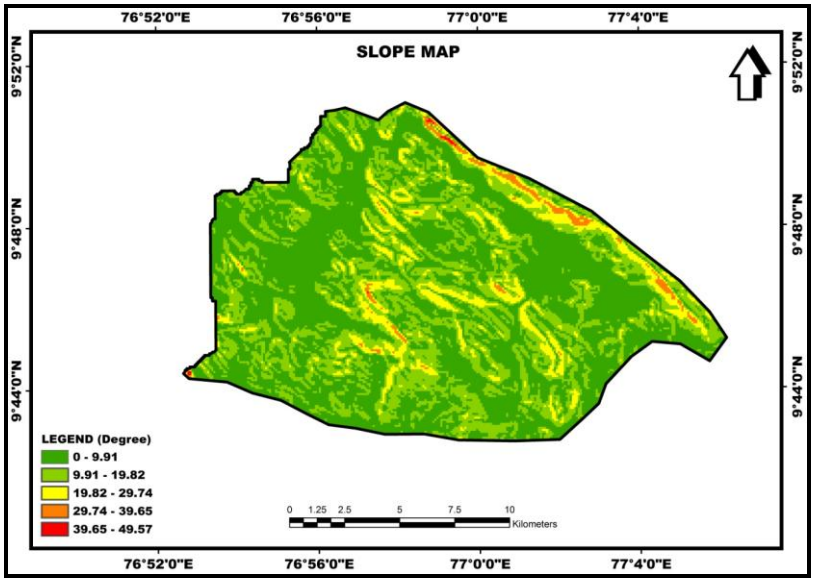

Figure 4: *Slope Map*

3.3. Distance from Settlement

Forest peripheral human settlements and tribal settlements within the forest**,** both in fact are very potential threats to forest. The tourists travelling through the area or the tribal population living there can cause fire intentionally or unintentionally. In the first case, they often set fire with some intentions like: clearing forest paths, hiding illicit felling of trees, encroachment upon forest land. They also set fires as a part of tribal customs/rituals, for the collection of Non Timber Forest Products (NTFP) like honey, etc. Secondly, they set the fire unintentionally; for example, carelessly throwing lighted cigarette butts, improper setting of campfires, leaving behind lighted fire woods recklessly, etc. Therefore the areas closer to human settlements are more prone to forest fires. Depending on the distance from settlements, the study area of Idukki Wildlife Sanctuary has been grouped into five classes' *viz.* 0 – 895 m, 895 – 1791 m, 1791 – 2686 m, 2686 – 3582 m, and 3582 – 4478 m. The map showing the distribution of all these classes is represented in Figure 5.

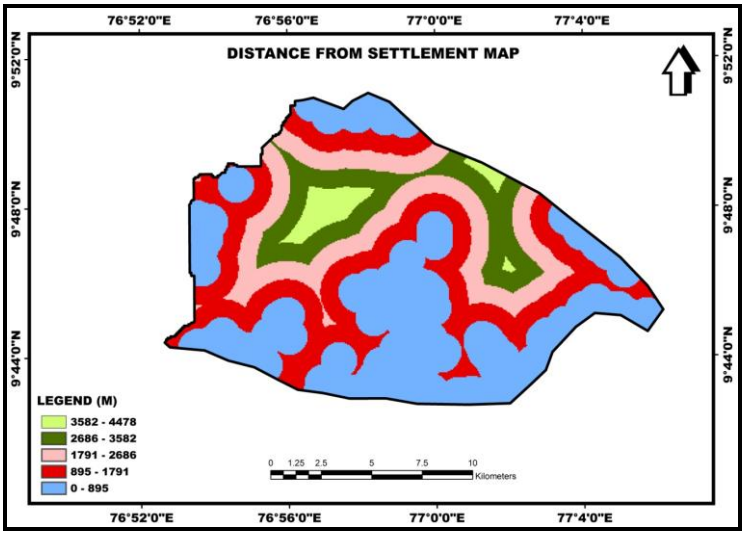

Figure 5: *Distance from Settlement Map*

3.4. Distance from Road

Wildlife sanctuary, bird sanctuary, and National parks are attracting lots of tourists every year. The study area, Idukki Wildlife Sanctuary is also a famous tourism destination, having a rich biodiversity that attracts lots of people every year. Also, the world famous Idukki arch dam is located within this sanctuary. To promote ecotourism, some of the traditional forest foot paths have been broadened for vehicular access to take tourists well into the forests. Ecotourism attractions in the forest can be a waterfall or any other geomorphological features. The movement of tourists through these roads can cause accidental forest fires, due to carelessly thrown burning cigarette butts or match sticks, way side food making by lighting stoves, burning tar for road making, etc. Therefore the forest areas closer to the roads are more prone to fires. Depending on the distance from roads, the study area has been grouped into five different classes *viz.*, 0 – 922 m, 922 – 1845 m, 1845 – 2767 m, 2767 – 3690 m, and 3690 – 4613 m. The distance from road map is shown in Figure 6.

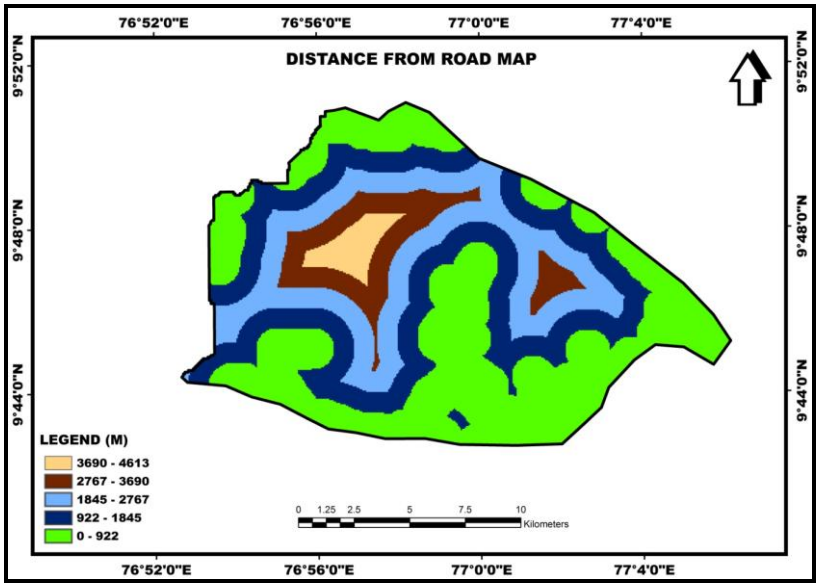

Figure 6: *Distance from Road Map*

3.5. Elevation

Another important factor which influences fire spreading is represented by the topographical factor of elevation. The elevation of the area influences fuel moisture and air humidity (Singh and Ajay, 2013). The humidity and temperature have higher influence on fire at higher altitude areas than lower ones (Thompson et al., 2000). Even though, the higher elevation areas of this sanctuary are more prone to forest fires. The regions with a higher elevation are more exposed to the prevailing winds, than the lower ones. During day time, the warm air rises and it will cause uphill draughts. In areas of higher elevation, the number of lightning strikes is usually more and hence a higher risk of lightning induced forest fire. These areas are found in the south, central, and northeastern parts of the sanctuary. The elevation of the study area, Idukki Wildlife Sanctuary is grouped into five different classes *viz.* 580 – 715 m, 715 – 850 m, 850 – 985 m, 985 – 1120 m, and 1120 – 1255 m. The elevation map is shown in Figure 7.

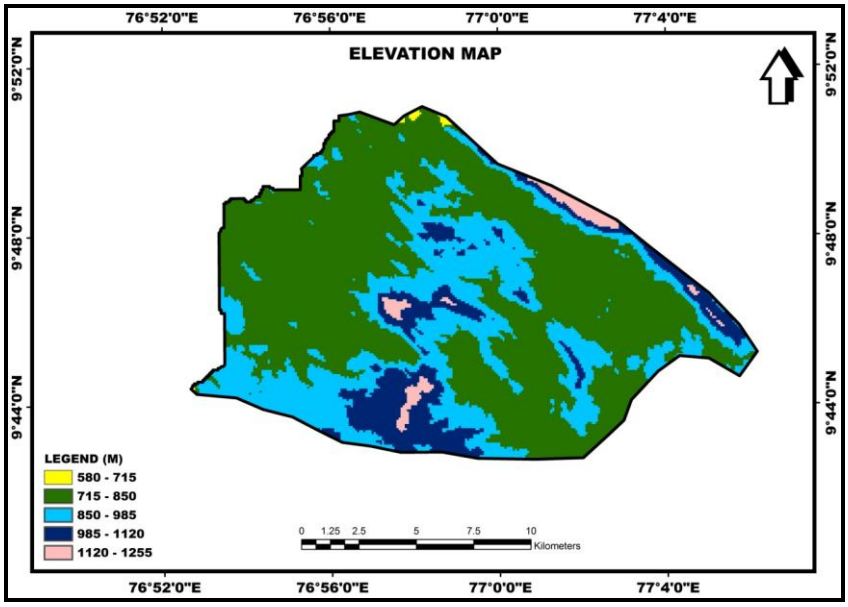

Figure 7: *Elevation Map*

3.6. Fire Risk Zones

The final forest fire risk zone map of the study area is generated by taking into account five influencing factors such as land cover type, slope, distance from settlement, distance from road, and elevation. During the process, there were assigned different weights to all these factors, according to their sensitivity to fire or their fire-inducing capability. The forest fire risk zone map is prepared by overlaying the index map layers using GIS tools. The study area is divided into five risk zones ranging from 'very low' to 'very high'. The risk zone map is validated with the fire incidence points for the last 10 years (2004 – 2014) collected from the FSI and during the field survey. In this study area of the Idukki Wildlife Sanctuary, a total of 35 forest fires have been recorded. Results show that out of the 35 fires, 29 (82.85%) forest fires occurred in the high and very high risk zones, 4 (11.42%) occurred in the moderate risk zone, and 2 (5.71%) occurred in the low and very low risk zones. The forest fire risk zone map is shown in Figure 8. Most of the forest fires occurred near the roads and settlements, which points out an anthropogenic origin (intentionally or unintentionally caused by humans). The result of this study is compared with the work done by Ajin et al. (2014b). They demarcated forest fire risk zones of Idukki Wildlife Sanctuary using Natural Breaks (Jenks) reclassification method. The result of that study reveals that 80% of the past forest fires occurred in the high and very high risk zones. Thus it is clear that the Equal Interval method will give more accurate result for the present methodology in this study area.

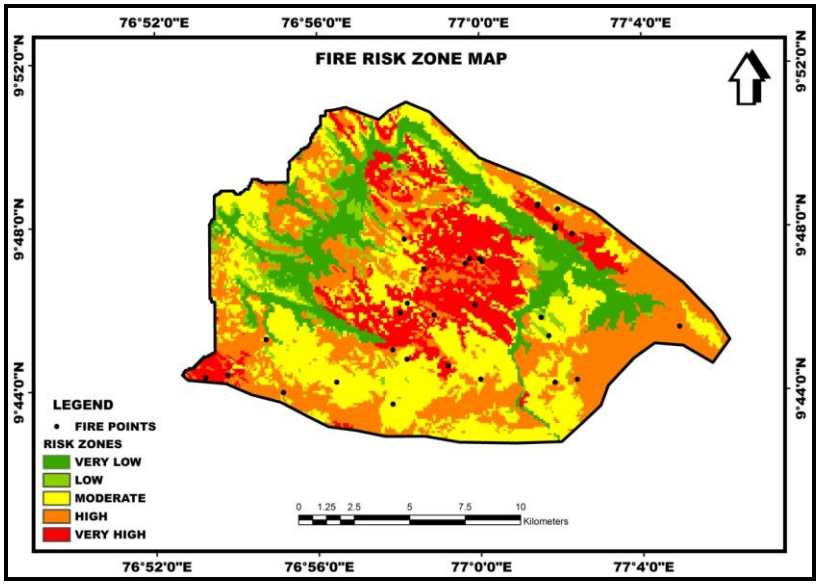

Figure 8: *Fire Risk Zone Map*

4. Conclusion

A method integrating RS and GIS techniques is used in this study. RS and GIS are effective techniques and which offer a great help in the monitoring and mapping of forest fire risk zones. A GIS is an optimal technique in forest fire research, because of the relation between fire occurrence and the spatial characteristics of the influencing factors. These factors have different influences and therefore, in the modelling process for the forest fire risk zonation of the study area, they were assigned different weights, according to their influence and capacity in inducing and spreading fire. The area of the sanctuary is grouped into five different risk zones, ranging from “very low” to “very high”. Results show that most of the fire incidence points fall spatially in the vicinity of roads and settlements. This fact points out that the forest fires have an anthropogenic origin, which means that they are induced by humans intentionally or unintentionally. The carelessly throwing lighted cigarette butts, fires set by the villagers for scaring away wild animals, unextinguished campfires set by the tourists, sparks of fire due to cooking food near the roads, and fire released during the heating of coal tar for road surfacing are some of the possible reasons for the occurrence of unintentional forest fires in this study area. On the other hand, the use of fire by the timber smugglers to hide the stumps of illicit felling, small fires set by the villagers to clear off forest path covered by tree branches and leaves, and the fires set for the collection of NTFP, etc are the causes of intentional forest fires in the sanctuary. This study confirms that 82.85% of the fire incidence points fall spatially over the high and very high risk zones. The present methodology gives good results, being suitable for forest fire risk zone mapping. The methodology presented in this paper is an excellent tool for the analysis, management, study and assessment of forest fires, in order to reduce their frequency and to avoid damage. With the help of fire risk zone maps, the forest fire managers can easily identify the risk zones and can take proper actions to minimize the impacts of fires for a better forest fire management.

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