FOREST FIRE RISK ASSESSMENT AND MANAGEMENT USING GEOSPATIAL TECHNOLOGIES

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ABSTRACT

Fire is a natural element present in all ecosystems and influencing many of its functions. The negative impacts include air and water pollution, loss of biodiversity, land degradation, desertification, soil erosion, impairment of human health and safety as well as loss of human life, forest flora and fauna throughout the world every year. Occurrences of forest fires and Ignition factors will be collected from various sources to construct from various sources to construct a GIS database, and then, validate the proposed model. The map will be done using ArcGIS 10.5 software to generate the maps of use and occupation, slope and aspect. Then use MCDM (Multi Criteria Decision Making) methodology in conjunction with fuzzy logic, in a participatory decision making framework to rank and prioritize the causative factors of fire risk in the study area. The study focuses on mapping of forest fire risk in the study area using GIS and remote sensing and then developing a forest fire management system based on topographic and meteorological factors. This mapping will serve as a tool for establishing public power as well as control measures in the areas of high susceptibility.

Keywords: *Forest fire mapping, GIS, Remote sensing, ArcGIS, Fuzzy logic, MCDM*

INTRODUCTION

Forests are an important part of human ecosystem. As per the present record, the world's total forest area is just over 3,999 million hectares (Global Forest Resources Assessment 2015). India has an estimated forest area of 7,08,273 sq. km that covers 21.54% of the total geographic area of the country. After taking into account the changes observed during two assessment periods i.e. ISFR 2015 (updated) and ISFR 2017, there has being an increase of 6,778 sq. km forest cover at the national level. Kerala state has contributed to an increase of 1,043 sq. km. As per the latest investigation done by FSI, about 36% of country's forests are prone to fires and of this; over 10% are severe fire prone areas. Forest fire can cause loss of ecosystem, depletion of wildlife, deforestation, global warming, and adverse health impacts (R.S.Ajin, 2016). The causes of forest fires can be divided into two broad categories. The first one is the '*Environmental',* which are beyond control and the second, '*Human related',* which are controllable (Ajin. R. S, 2014). Forest fires in our nation are generally of anthropogenic initiation and so preventable to a huge extent (FSI, 2019). A forest fire can pose serious threat to the fragile ecological and environmental stability of a region. Forest fires may be of three types (1) Surface fire, very fast moving fire, which consumes small vegetation and surface litter along with loose debris, (2) Crown Fire, the fastest way of spreading fire and most destructive for trees as well as wildlife, and (3) Ground fire, it spreads within, rather than top of organic matter. Unsustainable development and forest management practices could also contribute to enhanced forest fires (P Srivastava, 2013). The more accurate fire models require geospatial technology that is accomplished by remote sensing and Geographic Information Systems (GIS). The integration of field collected data along with the remote sensing data is necessary for current and accurate fire vulnerability mapping (Subin K. Jose, 2011). The combination of remote sensing with GIS will be helpful for the spatial assessment and management of forest fire**.**

In the present study, an effort has been made to delineate and map the forest fire risk zones in Mannamangalam forest division using GIS and RS techniques and to explore the possibility of fuzzy based multicriteria GIS analysis work for the identification of fire risk/ vulnerability zone and the corresponding fire management strategies. The factors selected for the present study are aspect, contour, elevation, slope, temperature, rainfall, humidity, vegetation type, settlement density, distance from road, and distance from stream.

MATERIALS AND METHODS

Mannamangalam reserve forest of Pattikad range in Thrissur District which lies in central Kerala, India, was selected as an intensive study area, which is situated between 10° 27' 0" N to 10° 34' 0" N latitude and 76° 16' 30" E to 76° 16' 30" E longitude, spanning an area of about 137.953 km^2, of which 113.283 km^2 is Administrative area and 24.67 km^2 is reserve area. The area has tropical humid climate. Types of forests in station area are tropical semi evergreen, tropical moist deciduous, tropical dry deciduous, and plantations.

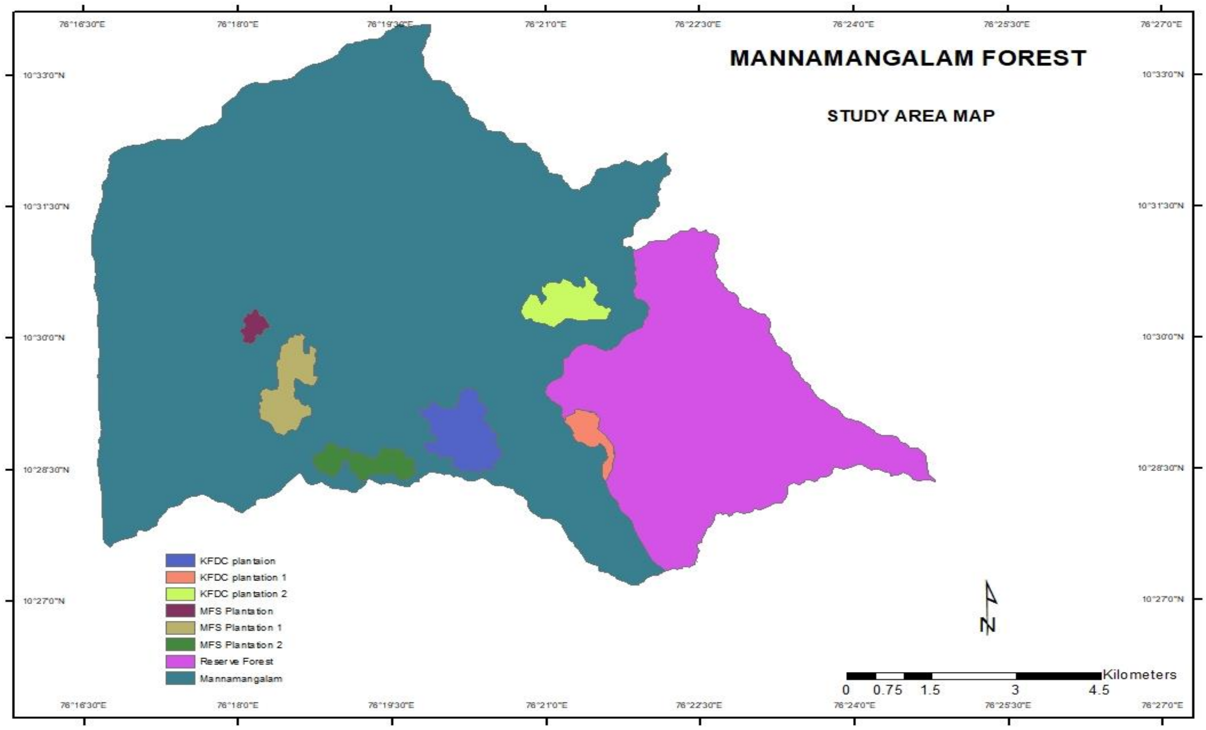

Fig 1: Location map of study area

The elevational range in the forest extends from 10m to 689m above mean sea level and the terrain is undulating. The annual rainfall in the area ranges from 59cm to 846cm, most of which occurs during May - September under the influence of SW Monsoon. December to April is the dry season. The wind speed is 5.1m/s towards West direction. Relative Humidity was always more than 70%.

The Mannamangalam forest study area was delineated from the Survey of India (SOI) Open series maps (Map numbers: C43K2, C43K3, C43K6, and C43K7) of 1:50,000 scale. Geospatial data were collected from Survey of India (SOI) topographic map sheets of 1:50,000 scale and Indian Remote sensing Satellite (IRS) satellite imageries and Linear imaging Self Scanning Sensor (LISS). The SOI maps were useful to create a number of basic thematic layers like contour, drainage, settlements, trek paths and water body. The thematic maps required for the study were prepared using ArcGIS 10.5 and ERDAS 9.2 software tools. The vegetation type map was prepared using IRS-1C LISS-IV digital image of 5.60 m resolution, acquired on 29 April 2016. The accuracy of the classified image was verified based on the ground information data collected during field trip and was found to be accurate. The contour data of 20 m interval was also digitized from the SOI topographic maps. ArcGIS spatial analyst tool was used for the preparation of the slope and elevation maps from the contour data. Each class of the thematic maps were considered and ranks were assigned to each of them and weights also were assigned to each of the thematic map layer according to the reactivity to fire or their fire igniting capacity. Details regarding trek path, settlement boundary and fire lines inside the forest were collected during field visit. Data regarding the history of forest fire during the last few years in the study area were collected from the forest department and field visit and then the graph was plotted.

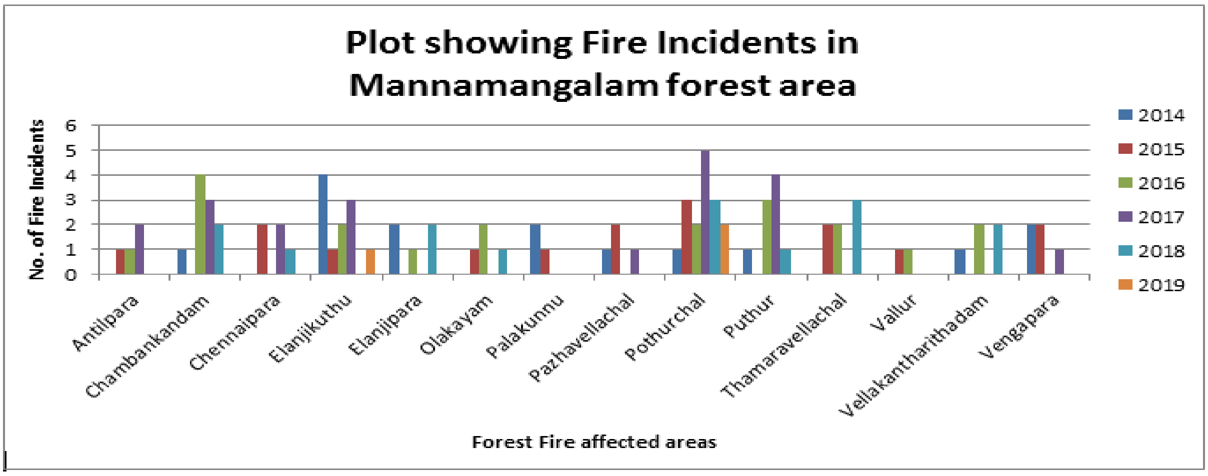

Fig. 2: Plot showing history of forest fire in the study area

Temperature and humidity data were collected from the forest department meteorological stations, Indian Meteorological Department (IMD) station. Extensive field trips were carried out during the different stretch of the study. GPS (Global Positioning System) was used to collect he real world coordinates. The various data collected were processed and put into the Arc GIS 10.5 software package. In this study, we used a MCDM (Multi Criteria Decision Making) methodology in conjunction with fuzzy logic, in a participatory decision making framework to rank and prioritize the causative factors of fire risk in the study area. The methodology consisted of four different components: (1) Classification of each parameter into different classes (2) Assigning ranks to each class (3) Assigning weights to each parameter (4) Determining the index. For evaluating the fire risk in the study area topographic, vegetation, climatic, and socioeconomic parameters were used. These data were arranged in raster-based maps for further analysis.

The thematic map layers were reclassified using the Natural breaks (Jenks) method. Ranks were assigned according to their sensitivity to fire. The Index was calculated using the formula, Index = Weight x Rank. A higher index indicates that the factor class has a higher influence on the fire risk.

Then the forest fire risk zone map was prepared by overlaying the index map layers using ArcGIS tools.

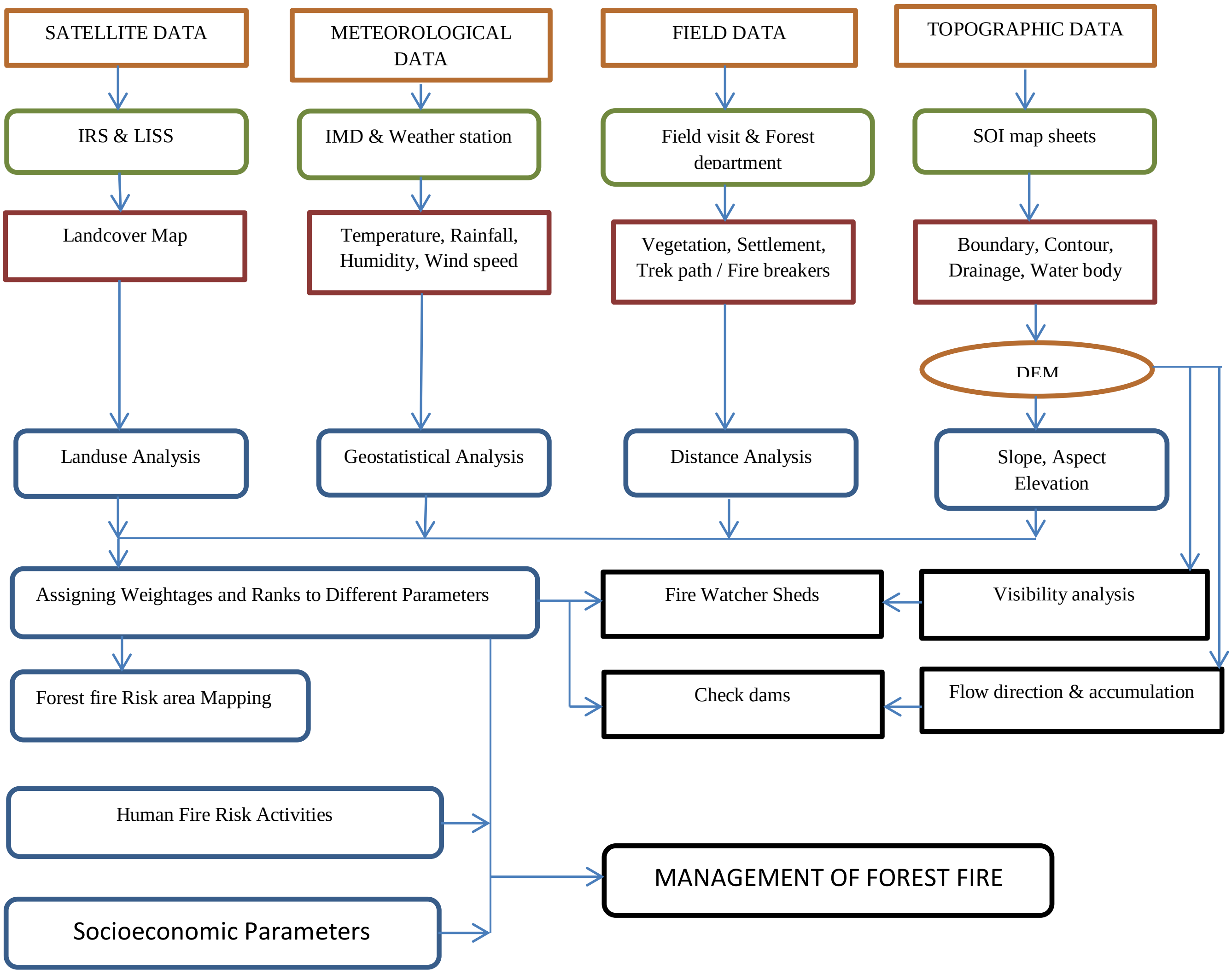

Fig. 3: Flow chart of forest fire risk area identification and their management

Thematic maps

Different thematic maps (parameters) that are involved for the identification of fire risk area in Mannamangalam reserve forest include Aspect (Fig.4), Road map (Fig.5), Stream network map (Fig.6), Contour map (Fig.7), Elevation (Fig.8), Meteorological sampling point (Fig.9), Humidity (Fig.10), Rainfall (Fig.11), Temperature (Fig.12), Land cover (Fig.13), and Slope (Fig.14).

1. Aspect

A slope with an east aspect will get direct sunlight earlier in the day than a slope with a west aspect. Southern aspects receive more direct heat from the sun, drying both the soil and the vegetation. The aspect map is shown in figure 4.

2. Road map

ArcGIS Spatial analyst tools was used to create the road map. The chance of fire ignition is high near to settlement and trekpath. The negligence from the tribal people also cause accidental occurrence of fire. Also, Fire set by people who express the revenge towards the forest officials will contribute to the occurrence of forest fire. The road map is shown in figure 5.

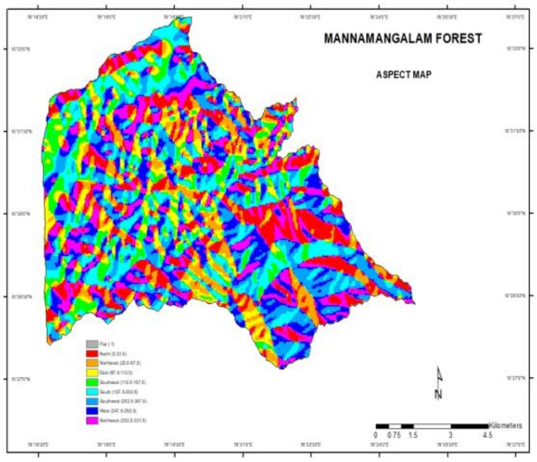

Fig.4 Aspect map of Mannamangalam forest.

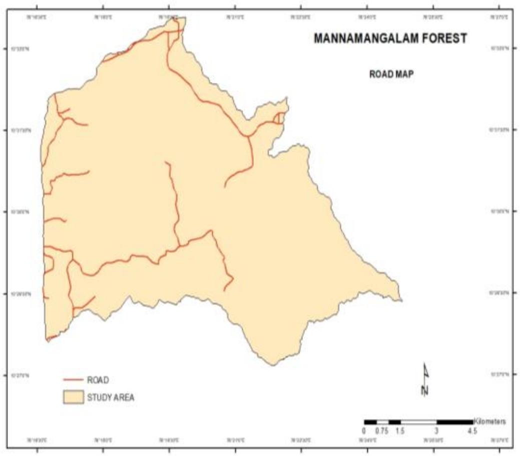

Fig.5 Road map of Mannamangalam forest.

3. Stream network map

The stream has negative influence in fire spread, that is, the chance of fire ignition is low near the stream, and the probability to fire keeps on increasing as the distance from the stream increases.

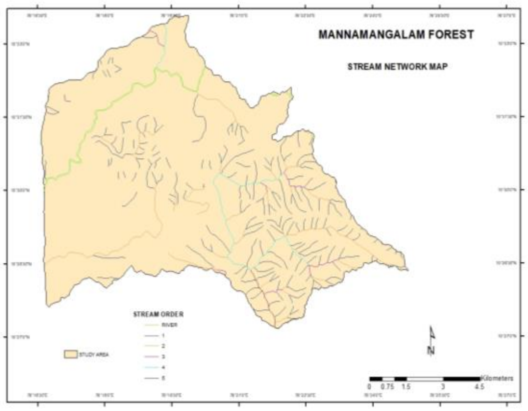

Fig.6 Stream network map of Mannamangalam forest.

4. Elevation

Elevation has a remarkable influence upon forest fires, particularly with respect to those fires which are caused by lightning strikes. Elevation also affects the seasonal drying of fuel. In lower elevations, fuels tend to dry out earlier in the year because of higher temperatures and lower precipitation. Elevation values (m) for fire pixels have been extracted from Survey of India (SOI) Toposheet contour lines. For the generation of elevation 20m contour lines are used. The elevation map is shown in figure 8.

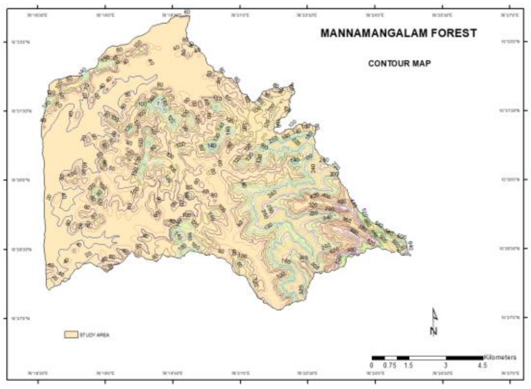

Fig.7 Contour map of Mannamangalam forest.

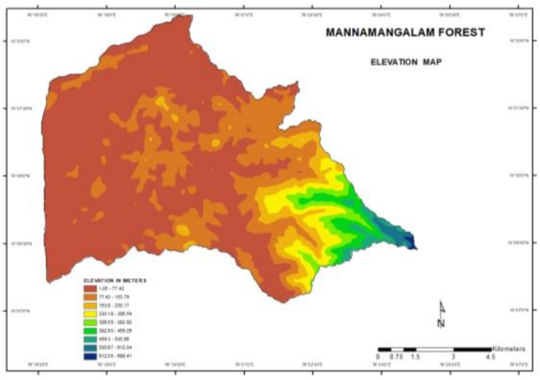

Fig.8 Elevation map of Mannamangalam forest.

5. Slope

The steepness of the slope affects both the rate and direction of the fire spread. Steeper the slope, the faster will be the fire movement. Fire travels most rapidly up slope and least rapidly down slope. The eastern part of the study area is steep.

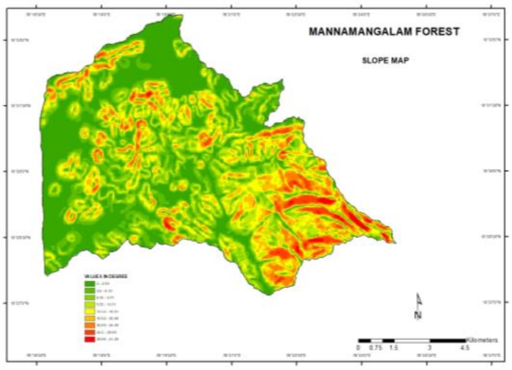

Fig.9 Slope map of Mannamangalam forest.

6. Climatic parameters

The meteorological data collected from the various stations were plotted with the help of GPS and these pointed data were interpolated using Inverse Distance Weighted (IDW) function in spatial analyst extension in Arc GIS with the assumption that things that are close to one another are more alike than those that are farther apart. It assumes that each measured point has a local influence that diminishes with distance.

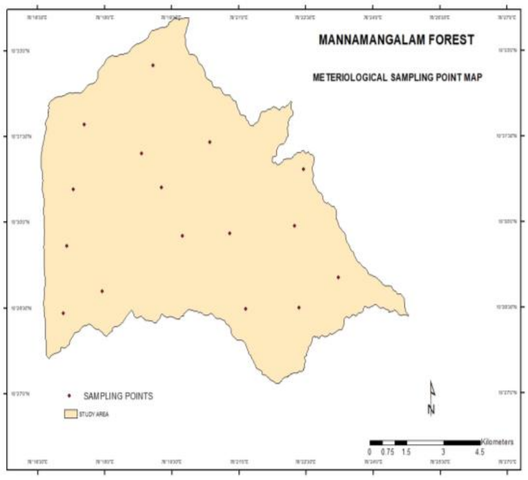

Fig.10 Map showing meteorological sampling point of Mannamangalam forest.

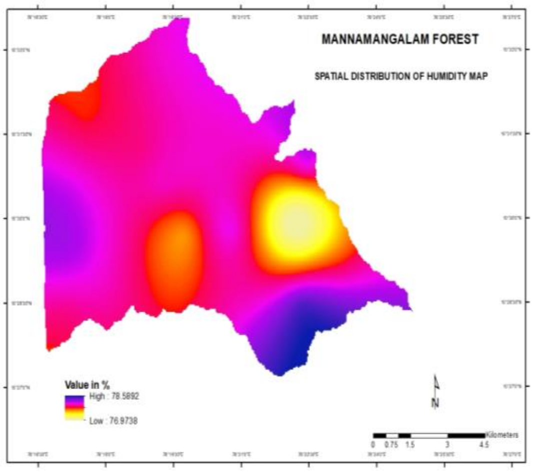

Fig.11 Humidity map of Mannamangalam forest.

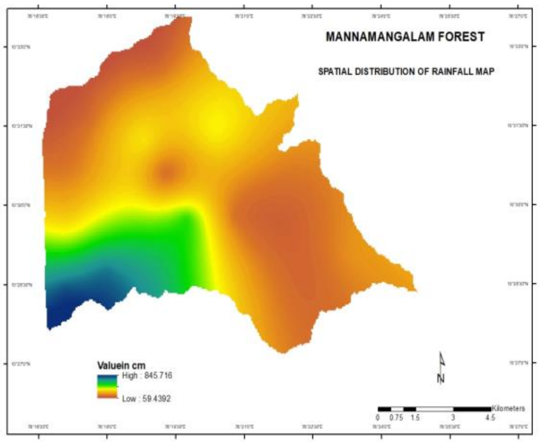

Fig.12 Rainfall map of Mannamangalam forest.

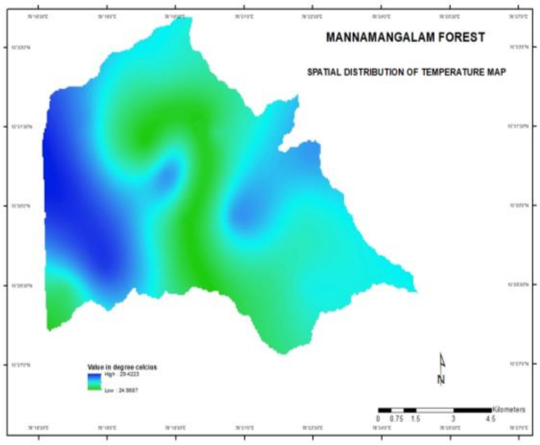

Fig.13 Temperature map of Mannamangalam forest.

7. Landuse

Vulnerability of the forest fuels to fire has been mapped based on vegetation type because some vegetation types are more flammable than others, thereby increasing the fire hazard. In forest vegetation type grassland and dry deciduous forest is more vulnerable to forest fire because they catch fire easily. Forest fire also occurs due to abrasion in bamboo plants. The vegetation map was prepared using IRS-1C LISS-IV digital image of 5.60 m resolution, acquired on 29 April 2016. For the preparation of land use map, ERDAS 9.2 image processing software was used.

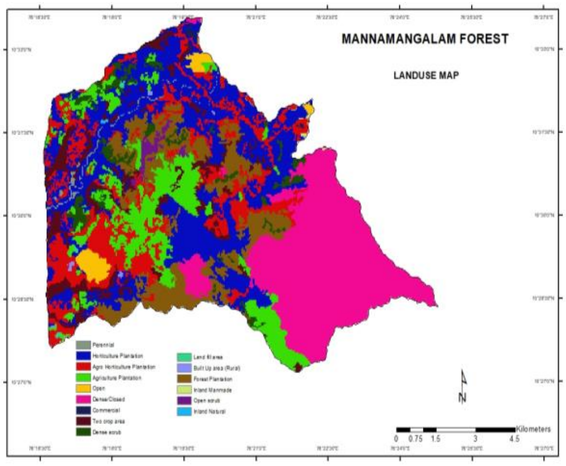

Fig.14 Landuse map of Mannamangalam forest.

RESULTS AND DISCUSSIONS

The forest fire risk area map of Mannamangalam forest is shown in the Fig.15 and the fire risk area is detailed in Table 1. The fire risk area map is classified into five classes as low, medium, moderate, high and very high areas. The very high and high fire risk area is mainly near to the east of reserve forest with dry mixed deciduous forest and grassland region.

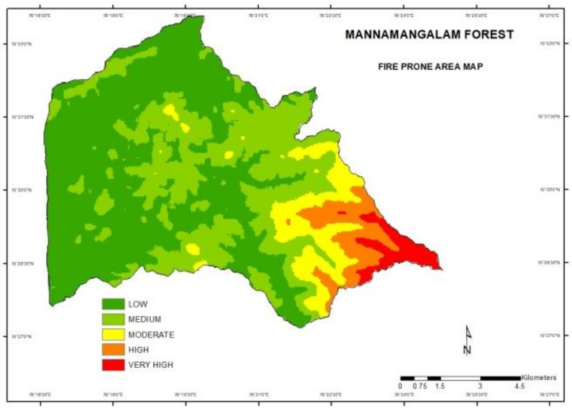

Fig.15: Forest fire risk area map of Mannamangalam forest.

Forest fire risk area – Mannamangalam Forest		
Fire risk class	Area (km^2)	Area percentage (%)
Low	50.25	35.89%
Medium	39.60	28.29%
Moderate	20.45	14.60%
High	16.20	11.57%
Very high	12.50	8.90%

Table 1: Forest fire risk area - Mannamangalam forest.

Very High Risk Areas: An area of 12.50 sq km (8.90%) in the Mannamangalam forest was identified as very high risk areas with respect to forest fire during peak seasons. This area is mainly closer to the settlements, trek paths where the vegetation is mostly open scrub, in the southwest and western aspects with steep slopes. This area is having high elevation, high slope, west and southwest aspect prevailing, and low humidity and rainfall.

High Risk Areas: 16.9 sq km area (11.57%) is identified as high risk areas. Areas near to the settlements, trek paths where the vegetation is moist deciduous, scrub dense and patches of semi evergreen in the south and southwest aspects with high degree slopes are mainly coming under this category.

Moderate Risk Areas: About 20.45 sq km area (14.60%) comes under this category. These are areas away from settlements, trek paths where the vegetation is mainly dense scrub, semi evergreen and open scrub in the east and southeast aspects.

Medium Risk Areas: 39.60 sq km (28.29%) comes under this category. These are areas away from settlements, trek paths where the vegetation is mainly dense scrub, semi evergreen and open scrub in the east and southeast aspects with varying degree of slopes.

Low Risk Areas: About half of the total area (39.60 sq km) is low risk areas and is located mainly in the evergreen and semi evergreen vegetation type and east and northeast faced gently sloppy areas.

Comparison of fire prone area map with Fire incidence map

The risk zone map is validated with the fire incidence points for the past 6 years collected from the records of the Mannamangalam Forest Division and from Pattikad Range office.

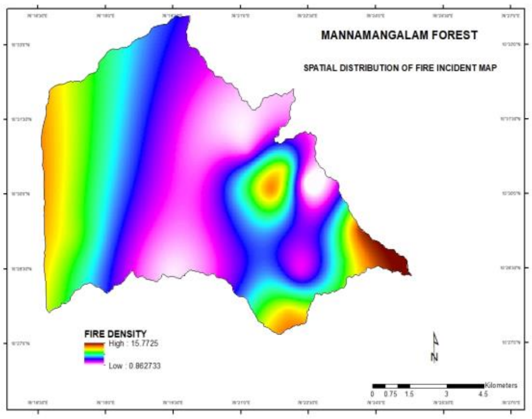

Fig.16 : Spatial Distribution of fire incident map of Mannamangalam forest.

From the risk zone map it is observed that, out of the 90 forest fires, 74 (82.22%) 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.

CONCLUSION

This study concludes that the number of forest fires is significantly high in the eastern parts, where the slope as well as elevation is higher. This confirms that most of the fires have a natural origin. This area is also characterized by high wind velocity. Further forest fires of such areas can cause much more serious and irrecoverable damage to the rich and unique biodiversity there.

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 area 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.

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