Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 11 [9] August 2022 : 67-87

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
ORIGINAL ARTICLE **OPEN ACCESS**

Assessment of Forest Fire Vulnerability Zones in Nilgiris District, Tamilnadu, Using Remote Sensing and GIS

S. Latha
Guest Lecturer, Department of Geography, Bharathidasan University,
Tiruchirappalli 620 024, Tamil Nadu, India
Email: lathapala2017@gmail.com

ABSTRACT
Forests are one of the vital natural resources as it plays an important role in maintaining the environmental balance. The health of a forest of any area is a true indicator of the ecological conditions prevailing in that domain. One of the major environmental issue is the occurrence of forest fires, which affect forest preservation, that results in economic and ecological damage and human suffering. Hence it is essential to be aware of the forest fire vulnerability zones of any region, especially the forest areas. The present study will assess the forest fire vulnerability zones in Nilgiris district, Tamil Nadu, using remote sensing and GIS, for 2021.The study area covers 2457.036 sq.km. The assessment is done through analysing various parameters like Elevation, Slope, Aspect, Wind Speed, Rainfall, Landuse/Landcover, Normalized Difference Index (NDVI), Land Surface Temperature (LST), Normalized Burn Ratio (NBR), Road and Settlement in Nilgiris district, for 2021, using software- ArcGIS and ENVI. After the preparation of thematic maps, the weightage and rank are assigned with the aid of fire influence intensity of each parameter. The Weighted Overlay Analysis is used to prepare the final Forest Fire Vulnerability Zones, with 4 classes-the Very Low Vulnerability zone covers 68.93sq.km (2.81%), Low Vulnerability occupies 1127.16sq.km (45.87%), High Vulnerability envelopes 1237.56sq.km (50.36%) and Very High Vulnerability zone encloses 23.38sq.km (0.95%). The high and very high forest fire vulnerability zones that totally covers 1260.94sq.km (51.31%), is an alarming condition in the study area. The forest fire vulnerability zones map provides valuable data for planners and decision makers for effective resource management and protection.
Keywords: *Forest Fire Vulnerability, Normalized Difference Vegetation Index, Land Surface Temperature, Normalized Burn Ratio, Weighted Overlay Analysis.*

Received 21 .04.2022 Revised 20.06.2022 Accepted 13.07.2022

INTRODUCTION

Forests are one of the vital natural resources that provide food, water, shelter, and nutrients and play a fundamental role in conserving soil and biodiversity[1]. Forests are vital in maintaining the environmental balance, and its health is a true indicator of the ecological conditions prevailing in that domain [2]. One of the major environmental issue is the occurrence of forest fires, that causes imbalances in nature and endangers biodiversity by reducing faunal and floral wealth, generating damage to human health from smoke, loss of biological diversity, release of greenhouse gases, and destruction to recreational values and infrastructure[3]. Global attention to forest fires has increased in recent years due to their major long and short term risks to property and human lives [4]. Forest fires are perceived as one of the most significant environmental hazards causing huge damage to forest fauna and flora, including soil inhabitants[5]. In recent times, forest fires in India have acquired greater attention because of their ecological, economic, social, climatic, and political impacts [6]. Fire is considered to be a major cause of forest degradation in India [7] and approximately 64% of the total forest area is commonly affected by forest fires[8]. According to the Indian Forest Service, 3.73 million hectares of forest area are affected by wildfires, every year [9]. Forests' vulnerability to fire is defined as a combination of sensitivity of forests to natural or man-made fire and assessing its spread as it is a pre-requisite for advance planning and preparation to combat fire [3].Forests' vulnerability to fire is described as a combination of sensitivity of forests to natural or man-made fire and its spread varies from place to place depending upon the type of vegetation, topography and the climate [3].Vulnerability assessment is a pre requisite for a pre planning and preparation to combat fire [10]. Fire vulnerability may be assessed based on long-term history of fire occurrence, locality characteristics with reference to vegetation cover and type, climate, topography and biotic pressure andfire proneness and its spread potential are the main components of vulnerability assessment [3].The degree of forest fire vulnerability analysis and frequency of fire incidents are very important factors for adopting preventive measures and post fire degradation assessment [11]. Tamil Nadu covers 22,877 sq. km of forests which constitutes 17.59% of the total geographical area of the State[3]. In India, Tamil Nadu ranks tenth in terms of area under forest cover that is grouped into four canopy density classes namely- Dry deciduous, Savannas, Semi ever green and Southern thorn [12]. Tamil Nadu Forest Department experimented an overlay analysis using forest type group cover of Tamil Nadu with SNPP-VIIRS (Suomi National Polar-orbiting Partnership- Visible Infrared Imaging Radiometer Suite), incorporating the forest fire incidents that happened between 2012 and 2016, to detect the sensitive forest type groups[3]. A study by the Geomatics centre of Tamil Nadu Forest Department reveals that nearly 56% of the forests are either highly or very highly and 30% are moderately vulnerable to fire[10]. In Tamil Nadu, Moderately Dense Forests are more prone to forest fire followed by Open Forests and Scrub Forests and it has been observed that 37.5% of fire incidents were recorded in Moderately Dense Forests, 26% in Open Forests and 25% in Scrub forests and only 12% of fire incidents in Very Dense Forests[13]. When comparing vulnerability of forest types, it is reported that Tropical Dry Deciduous Forests are more prone to fire with 46.5% of fire incidents recorded followed by Grasslands with 25.75% of fire incidents[10]. The crucial period of forest fire in Tamil Nadu is from 02nd Feb to 10th June [14]. The fire incidences reported by FSI in Tamil Nadu in the year 2008-09 are 276, 148 during 2009-10, and 34 between 2010-11[12]. Forest fire is a reappearing episode in the state leading to disastrous proportions during the decade 2006-2015, where 8649 fire incidents were detected within the geographical area ofTamil Nadu (SDM). Of this, 3272 fire incidents were detected within the Notified forests of the State and on an average 327 fire incidents in 74 fire days per annum were detected during the period, with maximum fire incidents during 2009[15]. Nilgiris district covers Very Dense Forest (496.72 sq.km) (with canopy density more than 70%), Moderately Dense Forest (596.85 sq.km) (with canopy density between 40-70%), Open Forest (627.44 sq.km) (with canopy density between 10-40%), and Scrub (4.85 sq.km) (with canopy density below 10%)[16]. Some major events of forest fire occurred in different parts of India during 1990-2011 states that, in Tamil Nadu, 10 hectares of Reserved Forests are affected by forest fire in Nilgiris district[12]. Tamil Nadu Forest Department is divided into 12 Territorial Forest Circles and 5 Wildlife Circles for administration, and Mudumalai Tiger Reserve in Nilgiris is one among them [10]. The Circle wise Forest fire risk zone reports that, in Mudumalai Tiger reserve wild life circle, 52.249(very high), 69.884 (high), 57.100 (moderate), 46.899 (low), and 180.007 (very low)area (in hectares) are noticed to be under threat of forest fire [13]. The Fire sensitive Beat locations over the notified forests of Tamil Nadu during 2006-2015 were analysed and the results show that more than one fourth of annual average fire incidents had been detected in 15 forest divisions, where Nilgiris district is one among them [15]. The data received by the Moderate Resolution Imaging Spectrometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) detected fire incidents from 2006 to 2015 were overlaid with beat map of the State to assess the frequency of fire occurrence in different beats anda minimum of one fire incident had been detected in 638 beats, and based on number of fire detections in the beats the sensitivity is classified into five classes' viz. Very Low, Low, Moderate, High and Very High[15]. In Nilgiris district, Beatsthose are sensitive to forest fire are Singararange, Bokkapuram, beat number 52,that fall under Very high sensitivity and Sngara-Segur south,Beat number 41, comes under high sensitivity to forest fire [10].

PREVIOUS STUDIES

The significance of the damage generated by fire depends on local climatic conditions [17]. The importance of spatial fire prediction mapping is locating where a forest fire will likely occur locally in any region [18]. Regional risk mapping is necessary for formulating forest polices and legislation [19]. Local risk maps has an important role in land management, wildfire risk communication, and emergency planning, at the municipal or local community level [20]. Incidences of fire are greatly affected by weather pattern and land use practices [21][22][23]. The increased temperature and drought periods act as accelerating factors for forest fires [24][25]. In addition, topographical factors (slope, aspect and elevation), roads, built-ups and drainageplay an important role in forest fire vulnerability [26]. The vegetation types, slope, proximity to settlements, and distance from roads are used to predict fire risk in Madhya Pradesh in India[27].The neural networks and knowledge-intensive systems are used to predict forest fires based on temperature, humidity, rainfall, and fire history in Galicia[28].The comparison of 2013 and 2015 digital elevation models to observe the changes of terrain characteristics by analyzing parameters like elevation, slope, aspect and contour was done in Nilgiris District [29]. The higher post-fire LST of the burned areas was observed in field data [30] and there are studies that explore the relationships between burn severity, NDVI and LST [31][32]. In many studies, common variables like-slope, aspect, elevation, distance from road, distance from settlement, and land use cover are used to create forest fire risk maps [33][34][35][36][37][38][39].The evolution of dynamical trend of time series of NDVI and NBRd obtained from MODIS data, from 2000 to 2009, has been compared and analyzed for two test sites, located in Southern Italy [40].The forest-fire vulnerability is related to vegetation density, distance from roads, residential areas, streams and lake, physiographic features (slope and aspect), and climatic variables (temperature and amount of precipitation)[41][42][43]. The parameters data such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), surface temperature, and air temperature are used to determine the forest and land fires vulnerability using Landsat-5 TM data in Jambi Province [44]. The elevation, slope, aspect, road distance, settlement distanceare considered as indicators of the likelihood of a forest fire occurrence in Melghat Tiger Reserve forest[45]. An accurate risk zone mapping is essential to abate the possible effects of fires in the forest [27]. With the development in the field of geoinformatics, monitoring and mapping of forest fires is more feasible for managing, analysing and depicting statistical and geographic data[46][47][48][49]. The increased availability of satellite data has helped in better understanding of fires globally [50][51].Remotely sensed data provides the synoptic view and can be used to determine the presence and distribution of areas affected by fires within a protected area [52][53]. The utilization of remote sensing data and GIS technique in natural resource and forest management can be very useful [54]. Techniques like Geographical Information System (GIS) and Remote Sensing (RS) have been used widely to assess and predict the fire frequency [55].The use of LiDAR data to map the fuel types is a subject of current research [56].Satellite sensors are widely used in wildfire research [57]. Global estimation of burned area are studiedusing MODIS active fire observations [58]and Potential global fire monitoring from EOS-MODIS[59]. Burned area mapping was analysed using multi-temporal moderate spatial resolution data–a bi-directional reflectance model-based expectation approach[60]. The post-fire LST-severity relationship was assessed using multitemporal MODIS imagery for a two-year period after fire, detecting an increase in post-fire LST up to 8.4 °C for a conifer forest by [61]. Advanced Very High-Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS) and Indian Remote Sensing Satellite Advanced Wide Field Sensor (IRS AWiFS) are some sources of data which are used for active forest fire detection[62][63][64].Forest fire vulnerability map are prepared using remote sensing data, GIS and AHP analysis by[34]. Slope, aspect and the altitude are important topographic parameters that can help identify potential areas for forest fire and the forest risk map was created by performing a multi-criteria analysis in Turkey [65]. Forest fire risk mapping in two major landscapes of Nepal was prepared, using remote sensing and GIS [66]. The Remote sensing and GIS techniques are used in various forest fire studies carried in Iran [67]and India [68][69][70]. Many studies have been implemented to produce forest fire maps using geographic information systems (GIS) and remote sensing (RS) techniques [71][72][73][74][75][76][77][78][79] [80][81][82][83][84][85].

To analyse various parameters like Elevation, Slope, Aspect, Wind Speed, Rainfall, Landuse/Landcover, Normalized Difference Index (NDVI), Land Surface Temperature (LST), Normalized Burn Index (NBR), Road Buffer and Settlement Buffer in Nilgiris district, for 2021.

-To assess Forest Fire Vulnerability Zones in Nilgiris district, using Weighted Overlay Analysis, for 2021.

-To register the Forest Fire Control Measures devised in Nilgiris district.

Study Area

Nilgiris district is located between 11°42'9.426''N to 11°11'15.407''N and76°27'24.516''E to 76°30'32.147''E, covering an area of 2457.036 sq.km (Fig 1), with a total population of 735,394 as per 2011 census[86]. The total coverage of forest in Nilgiris district accounts for 6.7% of the total state forest area[87]. The Nilgiris fall under the hilly and high-altitude climatic zone and due to its altitudes, the climate remains at a maximum of 2 ^{0}C to 25^{0}C and the minimum of 10^{0}C to 12^{0}C in summer, and to the maximum of 16^{0}C to 21^{0}C. and a minimum of 2^{0}C, in winter [87].The positivity of the climate is appropriate for horticultural and plantation crops like tea, coffee, pepper, fruits, vegetables and the district is known for its leisure tourism activity, scenic beauty, rich flora and fauna [87].

MATERIAL AND METHODS

The data for elevation, slope, wind speed and aspect are collected from SRTMDEM. The slope and elevation maps are prepared from the 10 m interval contour data. Landsat 8 OLI data is used to prepare Landuse/Landcover ,Land Surface Temperature, Normalized Burn Ratio and Normalized Difference Vegetation Index maps. The Landsat 8 consists of Operational Land Imager which contain nine spectral bands with a spatial resolution of about 30 m for Bands 1 to 9. The resolution for Band 8 is 15 meters. Additionally, it holds two Thermal IR bands with a spatial resolution of about 100m (later resampled into 30m). Normalized Difference Vegetation Index map is prepared using band 4 Near Infrared and band 5 Red. The boundary and road map are prepared using Google Earth Pro. The distance from road and settlement are prepared from the digitized data using ArcGIS spatial analyst tools. The thematic maps are prepared using ArcGIS 10.1 and ENVI 5.1 software tools. The ENVI software was used for the supervised classification of the Landsat 8 OLI image. The thematic layers are reclassified using the Equal Interval method. Ranks are allocated to each class of the thematiclayers and weightages are assigned to each thematic map layer according to the vulnerability potential. The forest fire vulnerability zone map was prepared using the Weighted Overlay Analysis, using Arc GIS tools.

Fig 1 Study Area

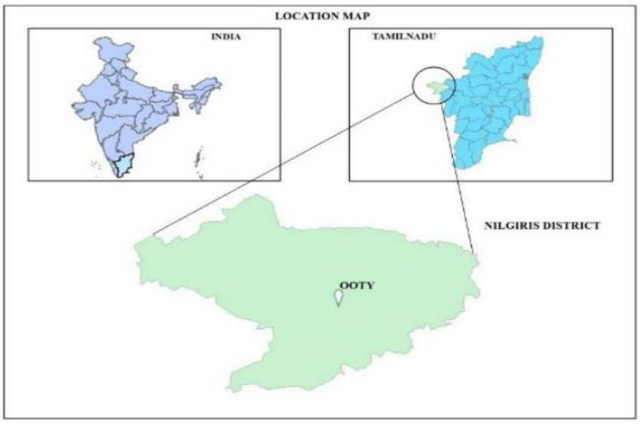
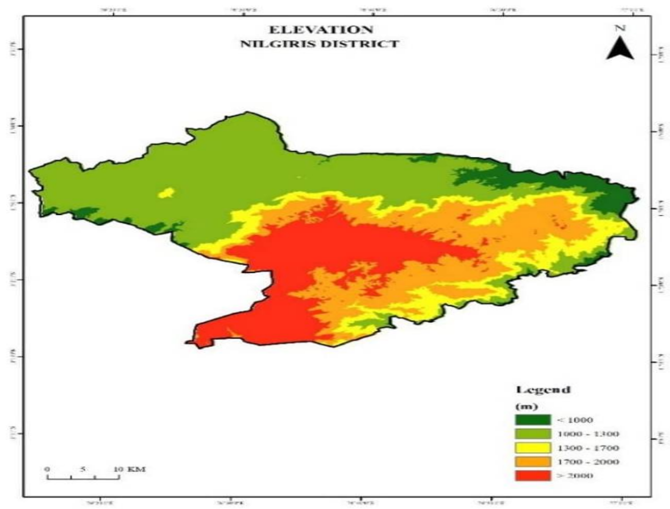


Fig 2 Elevation



RESULTS AND DISCUSSION

Thematic Layers - Weightages and Classes

Elevation

Elevation is an important physiographic factor that is related to wind behaviour and hence affects fire proneness and typically, a deminishing trend in forest fires is evident with rising elevation owing to lower temperatures and higher humidity, as vice versa to the regions located at a lower elevation [88]. It is the altitude of a place above mean sea level and is closely linked to temperature and precipitation, hence making it an important parameter which controls forest fires[38]. There is an increase in precipitation as the elevation increases, hence less chances of forest fire [89][90][91]. Higher elevation ranges were given low scale values and the vice versa as there is less risk of fire at higher altitudes [92].Nearly 40% of the fire incidences were recorded within 1 km of a road with 65% of the fires in the areas below the elevation of 1000 m[93]. The elevation map of the study area is prepared from SRTM DEM with 30m resolution data and is shown in figure 2. The Elevation classes (in mts) are <1000 (very low), 1000-1300 (low), 1300-1700 (moderate), 1700-2000 (high), and >2000 (very High).The weightage assigned for elevation parameter is 10%.The highest weightage (5) is assigned for areas falling under <1000 meters, in the study area.

Slope

Fires usually move faster uphill than downhill [88] [94]. The steeper the slope, the faster the fire travels in the direction of the ambient wind, which usually flows uphill [3]. And additionally the fire is able to preheat the fuel further up the hill because the smoke and heat are rising in up-slope direction[3]. Steeper slopes are more susceptible to forest fire and slope morphology significantly influences the rate of upward and downward spread of forest fires [95]. The slope is one of the fundamental parameters that affect the speed of fire spread [96]. The slope map of Nilgiris is prepared from SRTM DEM with 30m resolution data and is shown in figure 3. The Slope classes (in degrees) are <8 (flat), 8-16 (gentle), 16-26 (medium), 26-40 (steep), and >40 (very steep). The weightage assigned for slope parameter is 10%. The highest weightage (5) is assigned for areas falling under >40 degree, in the study area.

Aspect

Aspect is interpreted as the direction of maximum slope[97]. It can be described as the direction of the maximum rate of change in elevation and as the southern aspect receives more sunlight, it faces a very high risk of forest fire [98]. Aspect gives relationship of terrain with sunlight and wind and thus greatly influences fire ignition and spread[27]. In the northern hemisphere, the slopes that face south is more vulnerable to fire than north facing slope and this is because the south facing slopes are exposed to sun radiation throughout the day and are hence drier than north facing slopes [3]. The south facing slopes experience higher temperatures due to excess time of sunlight, strong winds and low humidity making the south facing slopes more vulnerable to forest fires [99][67]. The north facing slopes experience lower temperatures due to less time of sunlight making the north facing slopes least vulnerable to forest fires [100]. East facing aspects experience more ultraviolet and direct sunlight than the west aspects[101][102][103]. The slope map of Nilgiris is prepared from SRTM DEM with 30m resolution data and is shown in figure 4. The Aspect classes are identified and the weightage assigned for this parameter is 10%. The highest weightage (9) is assigned for areas with wind direction facing South, in the study area.

Wind Speed

The rate of spread of a wildfire swells distinctly when a wind escalates [104]. Ambient wind conditions also play a indispensable role in fire spread, fire intensity and flame features [105]. An examination on the wind flow and fire spread in a sloped terrain was conducted [106].Wind probably has the biggest impact on the behaviour of the forest fire and hence the stronger the wind blows, the velocity of wind would be high in higher elevations that influence the spread [3]. Also, the high temperature and strong winds together place the area at high risk of fire [107]. The wind speed map of the study area is prepared from SRTM DEM with 30m resolution data and is shown in figure 5. The Wind Speed classes (in mts/sec) are <3 (very low), 3-5 (low), 5-6 (moderate), 6-7 (high), and >7 (very high). The weightage assigned for wind speed parameter is 10%. The highest weightage (5) is assigned for areas falling under >7mts/sec, in the study area.

Rainfall

Rain and other types of precipitation raise the amount of moisture, which suppresses any potential fires from breaking out and reduced precipitation could increase the risk of forest fires[3].The areas with high rainfall faces fewer fire incidents due to the high moisture content and the amount and duration of rainfall played a crucial role in the physiological growth of vegetation and influenced the formation of forest fire in Brazil [108]. The rainfall map of the study area is shown in figure 6. The Rainfall classes (in mm) are <1500 (very low), 1500-2000 (low), 2000-2500 (moderate), 2500-3000 (high), and >3000 (very high). The weightage assigned for rainfall parameter is 10%. The highest weightage (5) is assigned for areas falling under >1500 mm of rainfall, in the study area.

Land Surface Temperature (LST)

Temperature play a key role in a forest fire, as high temperature helped to the rising rate of evapotranspiration that results in the seasonal drying of fuel, such as needles, leaves, twigs, and dead trees, which ultimately leads to the explosion of fire [109]. Higher temperature leads to dryness of vegetation which makes the area prone to fires[110]. High temperature is directly related to the relative humidity and moisture content of the fuels [111]. Warmer and increasing temperature affects the sparking and ignites faster burning, adding to the rate at which a fire spreads in the forests (Tamil Nadu Forest Department 2019). The higher the temperature, higher is the risk of forest fire[112].LST is the key variable in understanding the amount of change in a burned area with respect to the pre and post fire conditions [113] [114] [115] [116]. The spatio-temporal patterns of land surface temperature and fire severity in the Las Hurdes wildfire of Pinus pinaster forest,Spain, is assessed from a time series of fifteen Landsat 5 TM images corresponding to 27 post-fire months and the differences in LST values between burn severity categories in each image are highly correlated[117].72% of the fire incidences are noticed in areas where the temperature was above 30^{0}C, in Nepal [118]. The Land Surface Temperature of Nilgiris district is identified using Landsat 8 OLI data and the resulted map is given in the figure 7. The LST classes (in^{0}F) are <60 (very low), 60-70 (low), 70-80 (moderate), 80-90 (high), and >90 (very high). The weightage assigned for rainfall parameter is 10%. The highest weightage (5) is assigned for areas falling under >90^{0}F of temperature, in the study area.

Landuse/Land cover

Land use is one of the important parameters which affects the occurrence and spread of fire [119]. Landuse dynamics are mostly accelerated by human activities which caused many changes those affect various forests and environment ecosystem[120]. In current decades, remotely sensed data have been popularly used to collect the details of land use and land cover and other details like degradation level of forests and wetlands, rate of urbanization, intensity of agricultural activities and human-induced changes[121]. Land use is considered to be the critical factor for spreading fire and has high weightage for influencing the risk [122]. A study using GIS Multi-Criteria Analysis for Identifying and Mapping Forest Fire Hazard, showed that land use is an important paramount in forest fire modelling[123].The floor of deciduous forests is covered with dry fallen leaves and is prone to catch fire during dry season [3]. The highest forest fire occurrence in a deciduous forest in India, where dry vegetation was more susceptible to fire[124]. The Landuse/Landcover of the study area is identified using Landsat 8 OLI data and the resulted map is given in the figure 8. The Landuse/Landcover classes are Water bodies, Fallow, Agriculture, Forest plantation and Deciduous. The weightage assigned for Landuse/Landcover parameter is 10%. The highest weightage (5) is assigned for areas falling under Deciduous (highly vulnerable to fire), in the study area.

Normalized Difference Vegetation Index

The Normalized DifferenceVegetation Index estimates the vegetation health, monitors the changes in vegetation cover, and detects live green plant canopies from the multispectral remote sensing data [2].The wide use of NDVI for vegetation monitoring arises because of its positive correlation with characteristics of plant status and abundance[30]. NDVI yields good results for burn severity assessment [125] [126] [127] [128]. NDVI, Advanced Very High Resolution Radiometer and GIS are used to create a Fire Risk Dynamic Index (FRDI) to study the fire incidence in Canary Islands, Spain[129].NDVI may represent fuel conditions, both in terms of the level of greenness of vegetation and the litter[130]. The NDVI of the study area is identified using Landsat 8 OLI data and the resulted map is given in the figure 9. The NDVI classes are <0.2 (very low), 0.2-0.3 (low), 0.3-0.4 (moderate), 0.4-0.5 (high), and >0.5 (very high). The weightage assigned for NDVI parameter is 10%. The highest weightage (5) is assigned for areas falling under >0.5, in the study area.

Normalized Burn Ratio

Normalized Burn Ratiois the most commonly used spectral index for assessing fire severity[131] and this outperformance other indices [132]. An adequate correlation has been found between ground estimates of burn severity and the Normalized Burn Ratio [133]. The Fire severity was assessed using Normalized Burn Ratio and Normalized Difference Vegetation Index, derived from Landsat TM/ETM images[134].A studysummarized NBR recovery trends, and investigated the influence of burn severity, post-fire climate, and topography on post-fire vegetation recovery via random forest (RF) analysis, through examining post-fire vegetation recovery with Landsat time series analysis in three western North American forest types[135].The Normalized Burn Ratio computed from Landsat NIR and SWIR bands has gained considerable attention in recent years for mapping burned areas [136][137][138][139][140][141]. NBR is used for identifying the forest fire in Alaska[142]. North American Boreal-forest region [143], and Siberia[144]. A study is made to compare burn severity assessments using Differenced Normalized Burn Ratio and ground data[145]. NBR is calculated using the following formula-NBR=(Band5-Band7)/(Band5+Band7). The NBR of the study area is identified using Landsat 8 OLI data and the resulted map is given in the figure 10. The NDVI classes are <0.3 (very low), 0.3-0.4 (low), 0.4-0.5 (moderate), 0.5-0.6 (high), and >0.6 (very high). The weightage assigned for NBR parameter is 10%. The highest weightage (5) is assigned for areas falling under >0.6, in the study area.

Roads

Road access is a remarkable contributing factor in the occurrence of human caused ignitions [146]. The 70% of forest fires happen close to main roads, at a distance of less than 500 m[147]. The proximity to the roads plays a vital role in the incidence of fire corresponding to the physical activity from tourists on roads, throwing unextinguished cigarette butts onto the dry litter, and heating bitumen/asphalt for road surfacing [27] [70] [93]. Accessibility of humans in areas near to roads are prone to fires due to human activities such as carelessly thrown burning cigarette butts or match sticks[148]. Anthropogenic parameters, especially roads in forests are areas where influence of human activity is involved [149]. Anthropogenic parameters have been used in many research studies[34],[38], [58]. Roads within the forest area are useful in fire suppression as fire fighter response team can travel in time to control and suppress the forest fire in time, so that damage caused by fires can be minimized[150] [151]. Human activities are strongly associated with the event of forest fire and, thus, the proximity to urban areas and roads should be considered elementary for forest fire risk mapping [152]. The roads of the study area are identified using Google earth Pro and the resulted map is given in the figure 11. The Road classes are 0-2,2-4, 4-8, 8-10, 10-12, 12-15, 15-18 and 18-20 km. The weightage assigned for road parameter is 5%. High scale values were given to zones close to roads as these zones are highly prone to forest fires whereas low scale values were assigned to zones situated farther from roads, being least prone to forest fires.The highest weightage (8) is assigned for areas falling under 0-2 km, in the study area.

Settlements

Proximity to settlements, rivers and accessibility to roads are important factors that must be considered in fire risk assessment [153]. Distance to a road and settlements can be a useful tool to identify the risk areas where maximum human activities occur [121]. A study indicates that the fire scars were high in the area closer to roads, settlements and rivers due to increased movements which contributed to the fires [111]. The settlements of the study area are identified using Google earth Pro and the resulted map is given in the figure 12. The Settlement classes are 0-2, 2-4, 4-8, 8-10, 10-12, 12-15, 15-18 and 18-20 km. The weightage assigned for road parameter is 5%. High scale values were given to zones close to settlements as these zones are highly prone to forest fires whereas low scale values were assigned to zones situated farther from settlements, being least prone to forest fires. The highest weightage (8) is assigned for areas falling under 0-2 km, in the study area.

Weightage Techniques

Knowledge base weights to the classes of all the layers according to their sensitivity to fire or their fire-inducing capability was assigned to delineate forest fire risk hazard zones[154]. A knowledge-based methods in combination with GIS is applied [39].A study used fuzzy sets and semi-triangular membership function in order to perform long-term prediction of forest-fire risk based on fire history and drought cycles[155].The AHP method lessen complex decisions into a series of simple comparisons, called pairwise comparison, between elements of the decision hierarchy[156], GIS and AHP analysis forZarivar Lake and its surrounding areaare prepared by[34].The technique of the weighted linear combination was applied to pinpoint the forest fire risk zones using analytical hierarchy process and earth observation datasetsin the mountainous terrain of Northeast India[157]. Fire hazard mapping was performed using knowledge based and analytic hierarchy process for assessing the forest fire hazards vulnerability and risk assessment in Himachal Pradesh[158]. The authors have used varied techniques to analyse the forest fire like-logistic regression in North eastern China[159], analytic hierarchy process [160][161], fuzzy logic [162], goal programming (GP) and analytical network process [163], artificial neural networks [164] and random forest [165]. The criteria weights that guide to fire risk were computed by using analytic hierarchy process that was applied to two datasets located in NW Spain[152]. In the weighted overlay analysis, each class of the final raster thematic layers like-land use, vegetation, slope, aspect, elevation, road and settlement, was assigned a scale value on a common measurement scale[166]. In the present study, the thematic layers of various parameters like Elevation, Slope, Aspect, Wind Speed, Rainfall, Landuse/Landcover, Normalized Difference Index (NDVI), Land Surface Temperature (LST), Normalized Burn Ratio (NBR), Road and Settlement in Nilgiris district, for 2021, are added to Arc GIS. The weightage and rank are assigned with the aid of fire influence intensity of each parameter (Table 1), and the Weighted Overlay Analysis is used to generate the Forest Fire Vulnerability Zone map for Nilgiris district, with 5 classes- Very Low Vulnerability, Low Vulnerability, High Vulnerability and Very High Vulnerability zones and is shown in figure 13. The Very Low Vulnerability zone covers 68.93sq.km (2.81%), Low Vulnerability occupies 1127.16sq.km (45.87%), High Vulnerability envelopes 1237.56sq.km (50.36%) and Very High Vulnerability zone encloses 23.38sq.km (0.95%). The high and very high forest fire vulnerability zones that totally covers 1260.94sq.km (51.31%), is an alarming condition in the study area.

Forest Fire Control Measures in Nilgiris District

The greatest pressure on forest is by way of forest fire, wherethe human for their own greed, intentionally,setting fire every year in one or the other part of Nilgiris district, which retards the growth of existing standing vegetation and does not allow new recruits to emerge out on the forest floor [167].The local cattle grazers often set ablaze the grazing areas in the hope of getting new shoots, the head loaders destroy vegetation to create pathway through the forests,the encroachers set fire to forest in order to clear the land for agricultural purpose and the careless tourists throwing away lighted matches and cigarette butts start fire are the major causes for the occurrence of forest fire in Nilgiris district [168]. The forest department of Nilgiris district has developed fire-line-scrapping, wherein they will remove vegetation for six meters surrounding every block of 10 hectares, in Nilgiris forest division, to curb the spread of forest fire and this method was successfully tried out in Korakundha forest area that caught fire in February, 2020[169]**.** The annual fire management plans had been carried out in the forest area, which involved local communities through Joint Forest Management committees by the Forests and Wildlife Department and non-governmental organisations (NGOs), using the fire frequency maps that helps to develop conservation strategies for forest regeneration[170].

The Crisis Management Plan for Forest Fire Prevention and Management, 2017 [13] has formulated Preventive measures for forest fire in Nilgiris district and those include-

- Priority was given to High and Very High vulnerability areas of forest fire, for fire line clearing, with intensified patrolling.
- Mobilizing of Fire-fighting equipment and kits, for pre and post fire operations, are procured and supplied to all officials.
- Fire observation post/Watch towers, with Fire watchers to spot forest fire, are installed in Nilgiris district.
- Satellite based near real time fire information through SMS/email/whatsapp/fax/wireless network are revealed swiftly to the officials and field workers.
- The fire preventive measure like formation of fire-fighting crews and Rapid Response Teams are kept prepared, for the immediate support, especially during summer, the sensitive period.
- Creating awareness to public by broadcasting, telecasting and distribution of pamphlets and engaging volunteers ofNon-Government Organizations, to explain the importance of forest.
- Fire preventive committee, including skilled youth from the Tribals and abutting villages to monitor the fire occurrence and fire-fighting, is framed.
- Fire-fighting demonstration at forest fringe villages is performed through Fire service personnel.
- Training regarding the modern and counter fire-fighting techniques are offered to the officers and local volunteers.
- In the case, when forest fire spreads outside the forest, caution zone will be declared in and around the human habitation and necessary evacuation procedures will be followed.

CONCLUSION

In the present study an attempt to assess the forest fire vulnerability zones in Nilgiris district, Tamil Nadu, using remote sensing and GIS. The various parameters that contribute to forest fire like Elevation, Slope, Aspect, Wind Speed, Rainfall, Landuse/Landcover, Normalized Difference Index (NDVI), Land Surface Temperature (LST), Normalized Burn Ratio (NBR), Road and Settlement in Nilgiris district, for 2021 are prepared. The thematic maps are given weightages and rank and using Weighted Overlay Analysis, the forest fire vulnerability zone map is derived for the study area. The results shows that the Very High Vulnerability and High Vulnerability classes covers nearly 1260.94sq.km (51.31%), of the study area. These identified zones should be critically monitored to reduce the intensity of forest fire, in future. This study would help us for planning and adopting the sustainable forest conservation practices in the study area. This study shall help the wildlife department in mitigating the fire prone areas that are associated with the human settlements. At the same time, fire vulnerability zone map helps transport managers and practitioners to develop and adopt fire emergency plans. Thus, the result of this study would be useful for future research, planning, mitigation, conservation and management practices for forest fire in the study area.

Fig 3 Slope

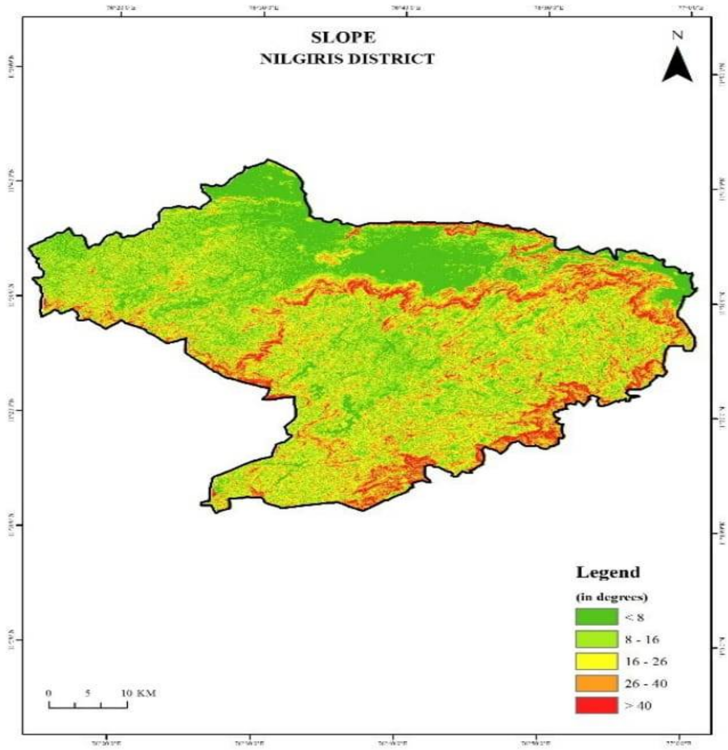


Fig 4 Aspect

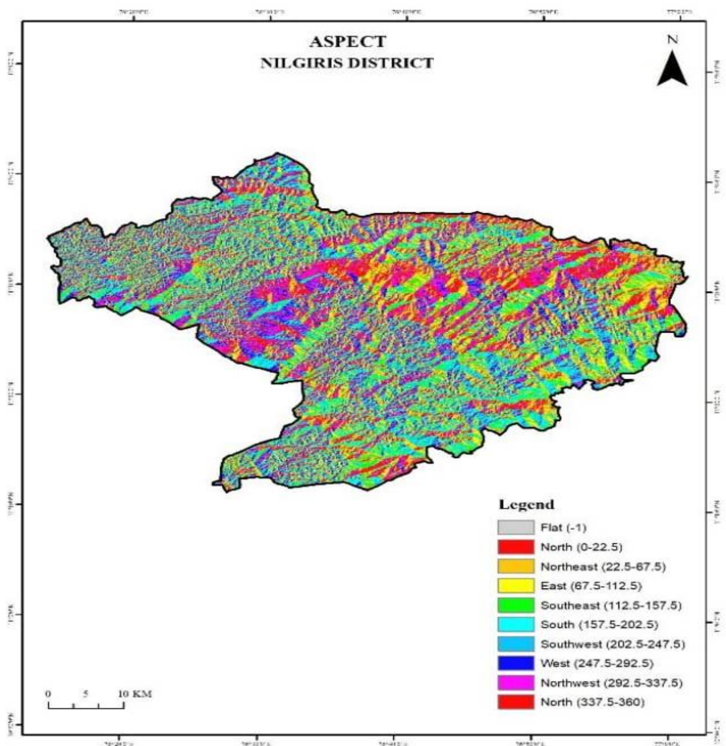


Fig 5 Wind Speed

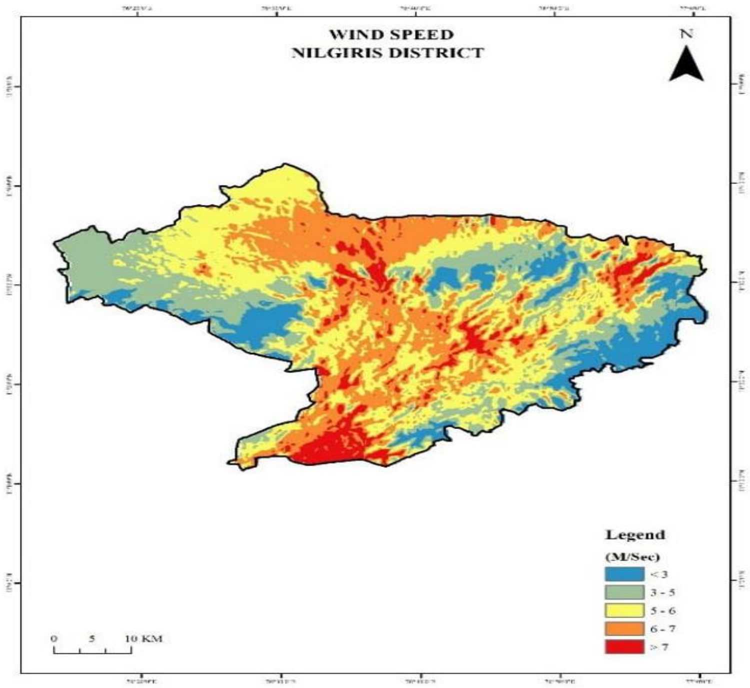


Fig 6 Rainfall

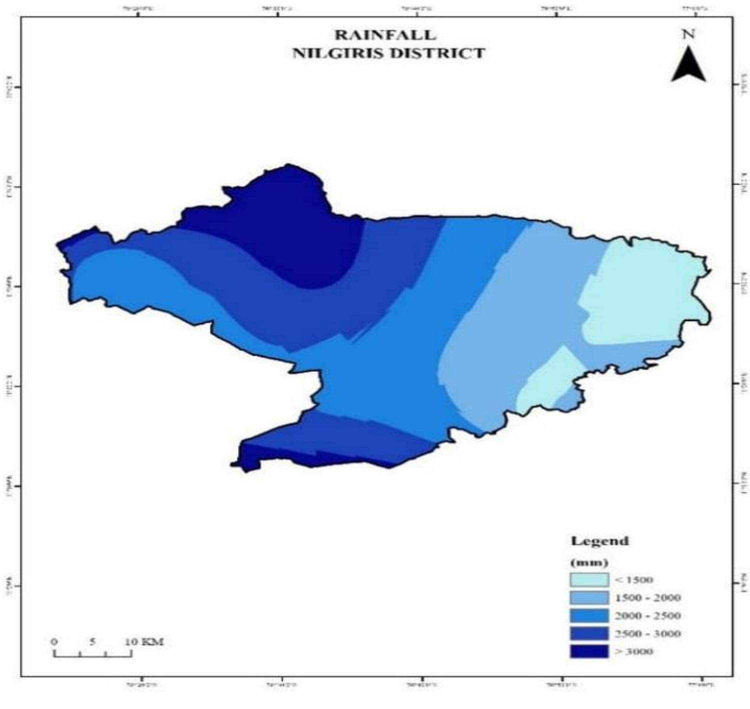


Fig 7 Land Surface Temperature

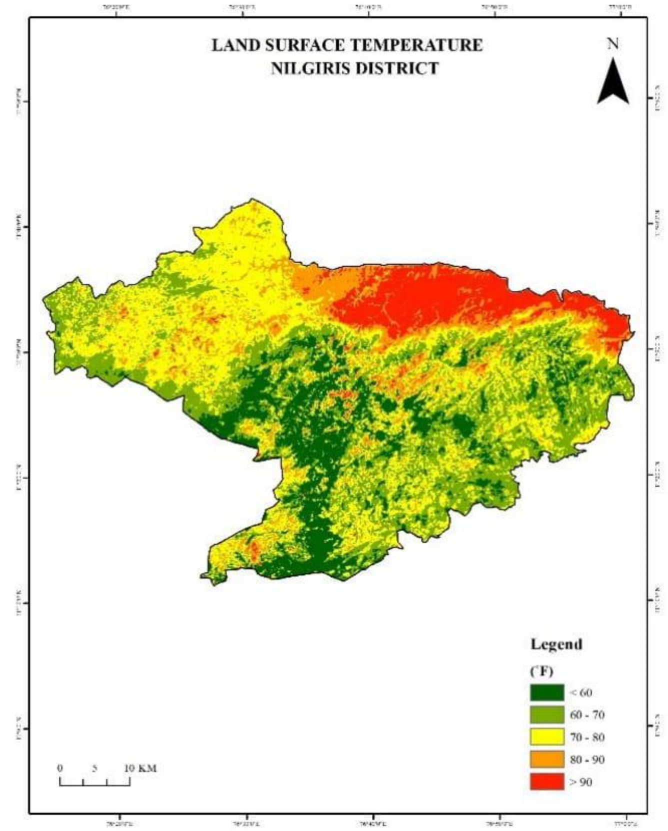


Fig 8 Landuse/Landcover

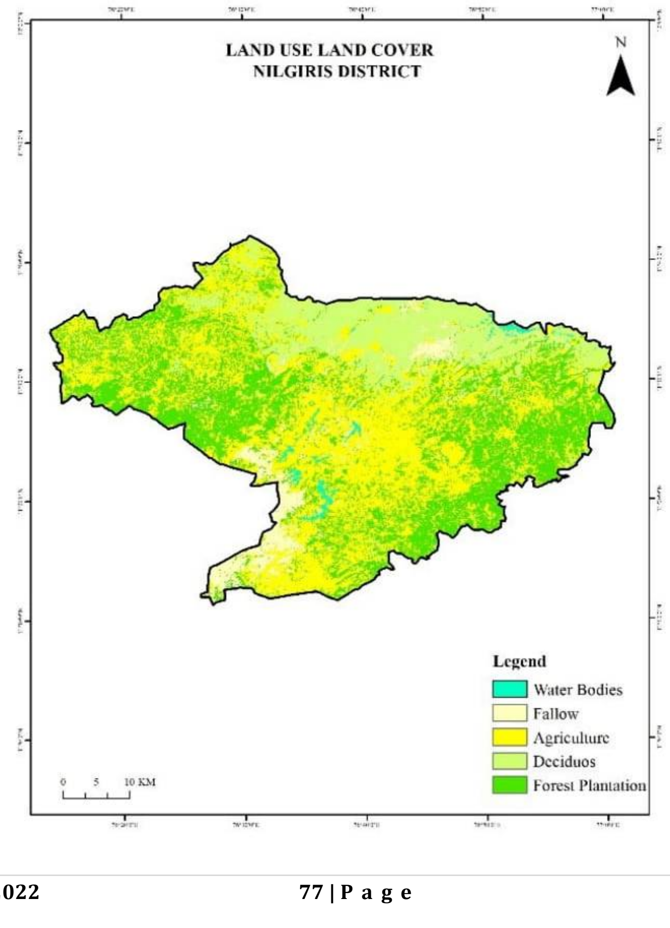


Fig 9 Normalized Difference Vegetation Index

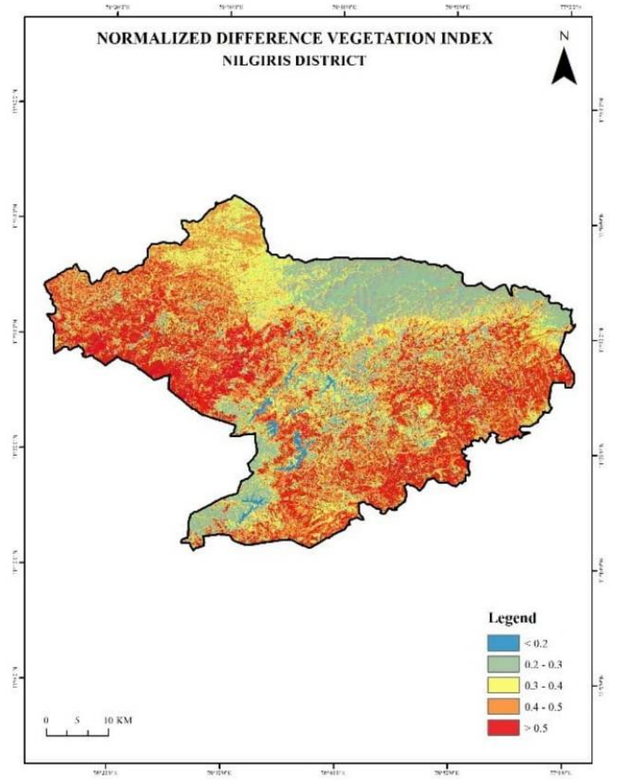


Fig 10 Normalized Burn Ratio

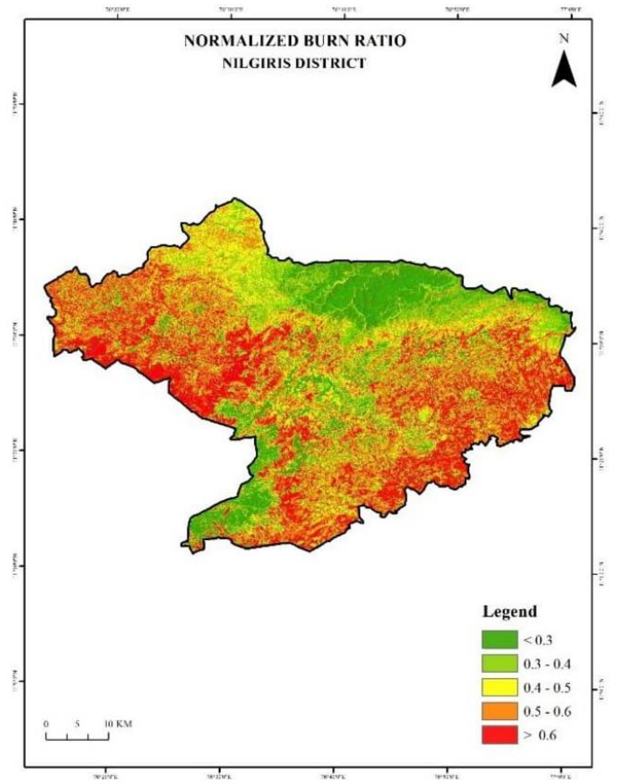


Fig 11 Roads

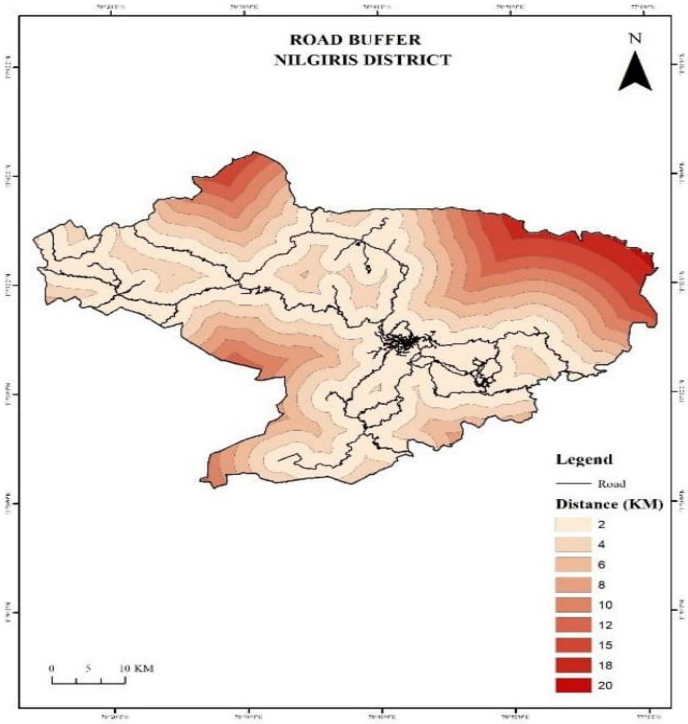


Fig 12 Settlements

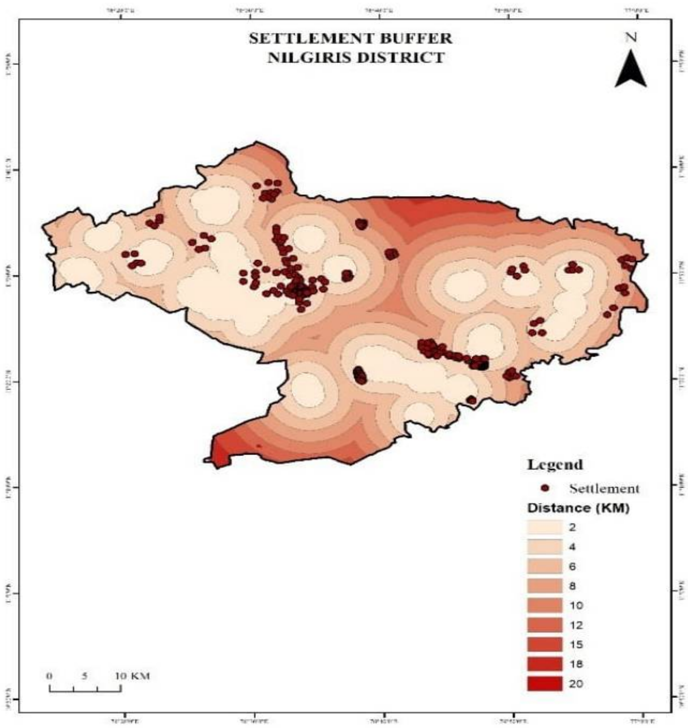


Fig 13 Forest Fire Vulnerability Zone

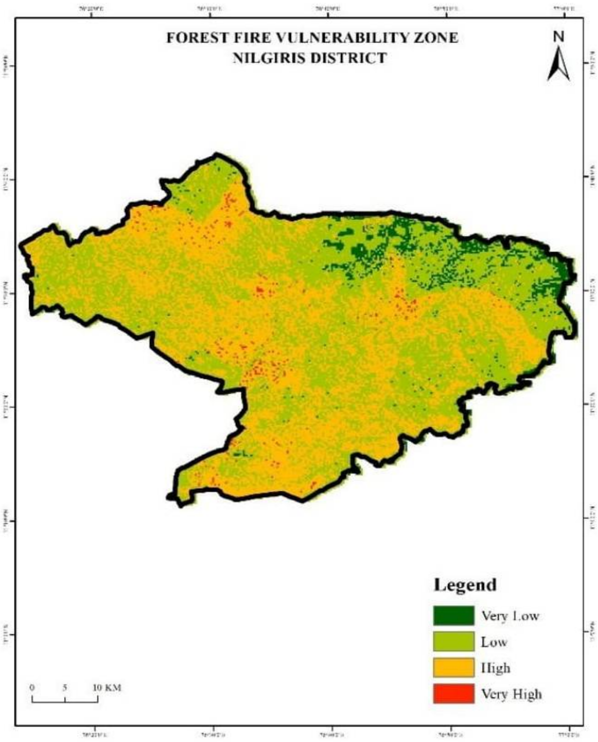


Table 1 Weightage

Parameters	Ranges	Rank	Weightage	Parameters	Ranges	Rank	Weightage
LULC	Water Bodies Fallow Land Agricultural Land Plantation Forest Deciduous Forest	1 2 3 4 5	10	Rainfall	< 1500 1500-2000 2000-2500 2500-3000 >3000	5 4 3 2 1	10
Slope	< 8 8-16 16-26 26-40 >40	1 2 3 4 5	10	NDVI	<0.2 0.2-0.3 0.3-0.4 0.4-0.5 >0.5	5 4 3 2 1	10
LST	< 60 60-70 70-80 80-90 >90	1 2 3 4 5	10	Elevation	< 1000 1000-1300 1300-1700 1700-2000 >2000	5 4 3 2 1	10
NBR	< 0.3 0.3-0.4 0.4-05 0.5-0.6 >0.6	1 2 3 4 5	10	Wind speed	< 3 3-5 5-6 6-7 >7	1 2 3 4 5	10
Road	2 4 8 10 12 15 18 20	8 7 6 5 4 3 2 1	5	Settlement	2 4 8 10 12 15 18 20	8 7 6 5 4 3 2 1	5
Aspect	Flat (-1) North (0-22.5) Northeast (22.5-67.5) East (67.5-112.5) Southeast (112.5-157.5) South (157.5-202.5) Southwest (202.5-5.247.5) West (247.5-5.292.5) Northwest (292.5-337.5) North (337.5-360)	1 1 2 5 8 9 3 2 1 1	10				

REFERENCES

1. David Morales-Hidalgo, Sonja N. Oswalt, &Somanathan, E. (2015). Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment. Forest Ecology and Management, 352:68-77.
2. Balaguru Navammuniyammal, Vidhya, &Sathyavathi. (2018). Assessing forest fire prone area in Kurangani, Tamil Nadu using remote sensing and GIS. International Journal of Applied Engineering Research, 13(7):264-269.
3. Tamil Nadu Forest Department (2019), GIS based multi variable analysis to assess forests' vulnerability to fire. Funded by State Planning Commission.
4. United Nations (2015), Sendai Framework for Disaster Risk Reduction 2015–2030; General Assembly, United Nations: Geneve, Switzerland.
5. Ahlgren, I. F. (1998). Ecological effects of forest fires. The Botanical Review, 26:483-533.
6. Krishna Prasad Vadrevu, Anuradha Eaturu, &Badarinath. (2010). Fire risk evaluation using multi-criteria analysis-a case study. Environmental Monitoring Assessment, 166:223-239.
7. Bahuguna. (2002). Fire Situation in India, International Forest Fire New. No.26. http://www.fire.uni-freiburg.de/iffn/ country/in/in5.htm (30.09.02)
8. Forest Survey of India, (2003). State of forest report, Ministry of Environment, Forest and Climate Change. http://www.fsi.nic. in/sfr2003
9. Srivastava & Garg, (2013). Forest Fires in India: Regional and Temporal Analyses. Journal of Tropical Forest Science, 25:228-239.
10. Guidelines on Forest alert, (2018). Tamil Nadu Government, India. https://www.forests.tn.gov.in/app/ webroot/img/document/legislations/fire%20alert%20guidelines.pdf
11. Roy, P.S. (2003). Forest Fire and Degradation Assessment Using Satellite Remote Sensing and Geographic Information System-Indian Institute of Remote Sensing (NRSA) Dehra Dun. Satellite Remote Sensing and GIS Applications in Agricultural Meteorology, 361-400.
12. Forest Fire Disaster Management, National Institute of Disaster Management, Ministry of Home Affairs, Government of India, 2014.
13. Crisis Management Plan, Tamil Nadu State for Forest Fire Prevention and Management, Tamil Nadu Forest Department, Chennai, 2016-2017. FSI, State Forest Report, 2009. https://fsi.nic.in/forest-report-2009
14. State Disaster Management Perspective Plan 2018-2030, Tamil Nadu State Disaster Management Authority Government of Tamil Nadu. https://tnsdma.tn.gov.in/app/webroot/img/document/SDMP-29-08.pdf
15. Tamil Nadu State of Forest Report, ISFR, 2019.
16. Jazireie, M.H. (2005). Forest maintenance. First Edition, Publishing and Printing Institute of Tehran University, Tehran, Iran, 231.
17. Carrara, A&Guzzetti, F. (2013). Geographical Information Systems in Assessing Natural Hazards. Springer Science & Business Media: Berlin/Heidelberg, Germany.
18. Modugno, S., Balzter, H., Cole, B., &Borrelli, P. (2016). Mapping regional patterns of large forest fires in Wildland-Urban Interface areas in Europe. J. Environ. Manag., 172:112-126.
19. Schoennagel, T., Balch, J.K., Brenkert-Smith, H., Dennison, P.E., Harvey, B.J., Krawchuk, M.A., Mietkiewicz, N., Morgan, P., Moritz, M.A., &Rasker, R. (2017). Adapt to more wildfire in western North American forests as climate changes. Proc. Natl. Acad. Sci., USA, 114:4582-4590.
20. Laurance, W.F., (1998). A crisis in the making: Responses of Amazonian forests to land use and climate change. Trends in Ecology and Evolution, 13:411-415.
21. Fernandes, P.M., & Botelho, H.S. (2003). A review of prescribed burning effectiveness in fire hazard reduction. Int. J. Wildland Fire., 12:117-128.
22. Ryan, K.C., Knapp, E.E., & Varner, J.M. (2013). Prescribed fire in North American forests and woodlands: History, current practice and challenges. Frontiers in Ecology and the Environment, 11:15-24.
23. Hanson, P.J. & J.F. Weltzin, J.F. (2000). Drought disturbance from climate change: Response of United States forests. Sci. Total Environ., 262:205-220.
24. Tatli, H. & M. Turkes, (2014). Climatological evaluation of Haines forest fire weather index over the Mediterranean Basin. Meteorological Application, 21:545-552.
25. Forest fire assessment in NE India, Under North eastern Regional Node for disaster, Risk Reduction Program, NE Space Application centre, Dept of Space, Govt of India. Meghalaya, 2014.
26. Jaiswal, R.K., Mukherjee, S., Raju, K.D., &Saxena, R. (2002). Forest fire risk zone mapping from satellite imagery and GIS. International Journal of Applied Earth Observation and Geoinformation, 4: 1–10.
27. Alonso-Betanzos, A., Fontenla-Romero, O., Guijarro-Berdiñas, B., Hernández-Pereira, E., Inmaculada Paz Andrade, M., Jiménez, E., Luis Legido Soto, J., &Carballas, T. (2003), An intelligent system for forest fire risk prediction and fire-fighting management in Galicia. Expert Syst. Appl., 25: 545-554.
28. Nagalakshmi&DebanjanPakrasi. (2017). Comparative analysis of terrain characteristics of Udhagamandalam, Nilgiri District. Tamil Nadu R. Eco. Env. & Cons., 23(2):1154-1160.
29. Montes-Helu, M., Kolb, T., Dore, S., Sullivan, B., Hart, S., Koch, G., &Hungate, B. (2009), Persistent effects of fire-induced vegetation change on energy partitioning and evapotranspiration in Ponderosa pine forests. Agric. For. Meteorol., 149:491-500.

30. Harris, S., Veraverbeke, S., &Hook, S. (2011). Evaluating spectral indices for assessing fire severity in chaparral ecosystems (Southern California) using MODIS/ASTER (MASTER) airborne simulator data. Remote Sensing, 3:2403-2419
31. Veraverbeke, S., Harris, S., &Hook, S. (2011). Evaluating spectral indices for burned area discrimination using MODIS/ASTER (MASTER) airborne simulator data. Remote Sensing of Environment, 115:2702-2709.
32. Vallejo-Villalta, I., Rodríguez-Navas, E., & Márquez-Pérez, J. (2019). Mapping Forest Fire Risk at a Local Scale-a case study in Andalusia (Spain). Environments, 6:30.
33. Rasooli, S.B., Bonyad, A.E., & Pir Bavaghar, M. (2018). Forest fire vulnerability map using remote sensing data, GIS and AHP analysis (Case study: Zarivar Lake surrounding area). Caspian Journal of Environmental Sciences, 16:369–377.
34. Kayet, N., Chakrabarty, A., Pathak, K., Sahoo, S., Dutta, T., &Hatai, B.K. (2020). Comparative analysis of multi-criteria probabilistic FR and AHP models for forest fire risk (FFR) mapping in Melghat Tiger Reserve (MTR) forest. Journal of Forestry Research, 31:565-579.
35. Pandey, K & Ghosh, S.K. (2018). Modelling of parameters for forest fire risk zone mapping. International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences, 5: 299-304.
36. Gheshlaghi, H.A. (2019). Using GIS to Develop a Model for Forest Fire Risk Mapping. Journal of the Indian Society of Remote Sensing, 47:1173-1185.
37. Adab, H., Kanniah, K.D., &Solaimani, K. (2013). Modelling forest fire risk in the northeast of Iran using remote sensing and GIS techniques. Natural Hazards, 65:1723-1743.
38. Abedi Gheshlaghi, H., Feizizadeh, B., &Blaschke, T. (2020). GIS-based forest fire risk mapping using the analytical network process and fuzzy logic. Journal of Environmental Planning and Management. 63:481-499.
39. R. Lasaponara, R., Montesano, T., Desantis, F., &Lanorte, A. Pre and Post Fire Vegetation Behavioral Trends from Satellite MODIS/NDVI Time Series in Semi-natural Areas. Conference: Computational Science and Its Applications – ICCSA-International Conference, Santander, Spain, June 20-23, 2011, Proceedings, Part II.
40. Mohammadi, F., Shabanian, N., Pourhashemi, M., &Fatehi, P. (2010). Risk zone mapping of forest fire using GIS and AHP in a part of Paveh forests. Iranian Journal of Forest Research, 18:569-586.
41. Mohammadi, F., Pir Bavaghar, M., &Shabanian, N. (2013). Forest fire risk zone modelling using Logistic Regression and GIS: An Iranian case study. Small-scale Forestry, 13:117-125.
42. Amalina, P., Prasetyo, L.B., &Rushayati., S.B. (2016). Forest fire vulnerability mapping in Way Kambas National Park. Journal of Procedia Environmental Science, 33:239- 252.
43. AnnisaNurdianaa&IdungRisdiyanto. (2015). Procedia Environmental Sciences, 24:141-51.
44. Kayet, N., Chakrabarty, A., Pathak, K., Sahoo, S., Dutta, T., &Hatai, B.K. (2020). Comparative analysis of multi-criteria probabilistic FR and AHP models for forest fire risk (FFR) mapping in Melghat Tiger Reserve (MTR) forest. J. For. Res., 31:565-579.
45. Adinarayana, J., (2003). Spatial decision support system for identifying priority sites for watershed management schemes. Proceedings of the 1st Interagency Conference on Research in the Watersheds (ICRW), October 27-30, Arizona, Benson, 405-408.
46. Altaf, S., Meraj, G., &Romshoo, S.A. (2014). Morphometry and land cover based multi-criteria analysis for assessing the soil erosion susceptibility of the Western Himalayan watershed. Environ. Monitor. Assess.,186:8391-8412.
47. Bhat, S.A., Meraj, G., & Pandit. A.K. (2016). Assessing the influence of stream flow and precipitation regimes on water quality of the major inflow stream of Wular Lake in Kashmir Himalaya. Arabian J. Geosci., 9(1).
48. Meraj, G., Romshoo, S.A., Ayoub, S., & Altaf, S. (2017). Geoinformatics based approach for estimating the sediment yield of the mountainous watersheds in Kashmir Himalaya, India. Geocarto Int., 33:1114-1138.
49. Giri, C., Pengra, B., Long, J., & Loveland, T.R. (2013). Next generation of global land cover characterization, mapping and monitoring. Int. J. Applied Earth Observ. Geoinform., 25:30-37.
50. Pettorelli, N., Laurance, W.F., O'Brien, T.G., Wegmann,M., Nagendra, H., & Turner, W. (2014). Satellite remote sensing for applied ecologists: Opportunities and challenges. J. Applied Ecol., 51:839-848.
51. Maselli, F. (2004). Monitoring forest conditions in a protected Mediterranean coastal area by the analysis of multiyear NDVI data. Remote Sens. Environ., 89:423-433.
52. Kennedy, R.E., Yang, Z., Cohen, W.B., Pfaff, E., Braaten, J., & Nelson, P. (2012). Spatial and temporal patterns of forest disturbance and regrowth within the area of the North west forest plan. Remote Sens. Environ., 122:117-133.
53. Adab, H., Nokhandan, M., MirzaBayati., R &AdabiFiroozjani, A. (2008). Mapping fire risk in forests of Mazandaran Province using Molgan Precautionary Index and GIS. Abstracts of 1st International Conference on Climate Change and Botany in Caspian Ecosystem, Iran. 178-189.
54. Bonazountas, M., Kallidromitou, D., Kassomenos, P.A., & Passas, N. (2005). Forest Fire Risk Analysis. Hum. Ecol. Risk Assess. Int., J., 11:617-626.
55. Huesca, M., Riaño, D., &Ustin, S.L. (2019), Spectral mapping methods applied to LiDAR data: Application to fuel type mapping. Int. J. Appl. Earth Obs. Geoinf., 74,159-168.
56. Chuvieco, E., Cocero., D., Riaño, D., Martin, P., Martínez-Vega, J., de la Riva, J., & Pérez, F. (2004). Combining NDVI and surface temperature for the estimation of live fuel moisture content in forest fire danger rating. Remote Sens. Environ., 92:322-331.
57. Abedi Gheshlaghi, H., Feizizadeh, B., &Blaschke, T. (2020). Atmos. Chem. Phys., 6(4):957-974.
58. Chris Justice. (2006). Potential global fire monitoring from EOS-MODIS. J. Geophys. Res., 103(24):32215-32238.

59. Giglio, L., van der Werf, G.R., Randerson, J.T., Collatz, G.J, &Kasibhatla, P. (2006). Burned area mapping using multi-temporal moderate spatial resolution data–a bi-directional reflectance model-based expectation approach. Remote Sens. Environ. 83(1-2):263-286.
60. Vera Verbeke, S.,Verstraeten, W.W., Lhermitte, S., van de Kerchove, R.,&Goossens, R. (2012). Assessment of post-fire changes in land surface temperature and surface albedo, and their relation with fire–burn severity using multitemporal MODIS imagery. Int.J. Wildland Fire. 21:243-256.
61. Calle, A., Casanova, J.L., & Romo, A. (2006). Fire detection and monitoring using MSG Spinning Enhanced Visible and Infrared Imager (SEVIRI) data. J. Geophys. Res. Biogeosci.,111:(4).
62. Badarinath, K.V.S., Sharma, A.R., &Kharol, S.K. (2011). Forest fire monitoring and burnt area mapping using satellite data: A study over the forest region of Kerala State, India. Int. J. Remote Sens., 32:85-102.
63. Kasischke, E.S., Hewson, J.H., Stocks, B., van der Werf, G., & Randerson, J. (2003). The use of ATSR active fire counts for estimating relative patterns of biomass burning-a study from the boreal forest region. Geophys. Res. Lett., 30:(18).
64. Özelkan, E.,Örmeci, C., &Karaman, M. Determination of the forest fire potential by using remote sensing and geographical information system, Case study- Bodrum/Turkey. Advances in Remote Sensing and GIS applications in Forest Fire Management From local to global assessments Jesus San-Miguel Ayanz, IoannisGitas, Andrea Camia, Sandra Oliveira -Editors. JRC Scientific and Technical Reports, Proceedings of the 8th International EARSeL FF-SIG Workshop Stresa (Italy), 2011, 20-21.
65. Ashok Parajuli, Ambika Prasad Gautam, Sundar Prasad Sharma, Krishna Bahadur Bhujel, Gagan Sharma, Purna Bahadur Thapa, Bhuwan Singh Bist&Shrijana Poudel, (2020). Forest fire risk mapping using GIS and remote sensing in two major landscapes of Nepal. Geomatics, Natural hazards and risk 11(1) 2569-2586.
66. . Adab, H., Devi, K., & Karim, K. (2013). Modelling forest fire risk in the northeast of Iran using remote sensing and GIS techniques. Nat. Hazards., 65:1723-1743.
67. 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. Int. J. Adv. Remote Sens., 2:86-95.
68. 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. J. Environ. Biol., 31:969-974.
69. Lambin, E., Goyvaerts, K., & Petit, C. (2003). Remotely-sensed indicators of burning efficiency of savannah and forest fires. Int. J. Remote Sens., 24:3105-3118.
70. Chuvieco, E., &Congalton, R.G. (1989). Application of remote sensing and geographic information systems to forest fire hazard mapping. Remote Sens. Environ., 29:147-159.
71. Chuvieco, E., & Salas, J. (1996). Mapping the spatial distribution of forest fire danger using GIS. Int. J. Geogr. Inf. Sci.,10:333-345.
72. Pradhan, B., Mohd Dini Hairi, B.S., &Mohamad Arshad, B.A. (2007). Forest fire susceptibility and risk mapping using remote sensing and geographical information systems (GIS). Disaster Prev. Manag., 16,344-352.
73. Dong Xu, Xu Dong, Dai Li-min, Shao Guo-fan, Tang Lei & Wang Hui. (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.
74. Li, Z.-L., Tang, B.-H., Wu, H., Ren, H., Yan, G., Wan, Z., Trigo, I.F., &Sobrino, J.A. (2013). Satellite-derived land surface temperature: Current status and perspectives. Remote Sens. Environ., 131:14-37.
75. GholamrezaIanbaz Ghobadi, Bahram Gholizadeh, &Osman Majidi Dashliburun. (2012). Forest fire risk zone mapping from Geographic Information System in Northern Forests of Iran Case study. International Journal of Agriculture and Crop Sciences, 4 12):818-824.
76. Singh and Ajay. (2013). Fire Risk Zone Assessment in Chitrakoot Area, Satna MP, India, Research Journal of Agriculture and Forestry Sciences, 1(5):1-4.
77. Ajin.R.S., Mathew.K. Jacob., Menon.A.R., &Vinod.P.G. Forest fire risk analysis using geo-information technology: A study of Peppara Wildlife Sanctuary, Thiruvananthapuram, Kerala, India, Proceedings of the 2nd Disaster Risk and Vulnerability Conference, Thiruvananthapuram, India, 2014, 160-165.
78. Ajin. R.S., Mathew.K. Jacob., Menon. A.R., &Vinod. P.G. Forest fire risk analysis using GIS and RS techniques: An approach in Idukki Wildlife Sanctuary, Kerala, India, Proceedings of the 24th Swadeshi Science Congress, Tirur, India, 2014, 406-413.
79. Ajin. R.S. (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.
80. Ali Ariapour& Mohamed Shariff. A.R. (2014). Rangeland fire risk zonation usingRemote Sensing and Geographical Information System Technologies in Boroujerd rangelands, Lorestan Province, Iran, Ecopersia, 2(4):805-818.
81. Chuvieco, Inmaculada, Marta Yebra, & Hector Nieto. (2010). Development of a framework for fire risk assessment using remote sensing and geographic information system technologies, Ecological Modelling, 221(1):46–58.
82. Robert E. Keane., Stacy Drury., &Eva C. Karau. (2010). A Method for Mapping fire hazard and risk across multiple scales and its application in fire management, Ecological Modelling, 221:2-1.
83. Amarnath Giriraj, Shilpa Babar, Anke Jentsch, Singuluri Sudhakar, &Manchi Ramachandra Murthy (2010). Tracking Fires in India Using Advanced Along Track Scanning Radiometer (A)ATSR Data, Remote Sensing, 2:591-610.
84. López García, M.J&Caselles, V. (1991). Mapping burns and natural reforestation using thematic Mapper data. Geocarto Int., 6, 31-37.

85. Nilgiris District Census 2011. https://www.census2011.co.in/census/district/31-the-nilgiris.html.
86. District Diagnostics Study, Nilgiris district 2020. https://tnrtp.org/wp-content/uploads/2020/07/NILGIRIS-FINAL.pdf
87. Rothermel, R. C., Forest, I., & Station, R. E. (1983). How to predict the spread and intensity of forest and range fires: U. S. Dept. of Agriculture, Forest Service, Intermountain Forest and Range. Experiment Station,1-168.
88. Schwilk, D.W., J.E. Keeley., E.E. Knapp, J. McIver & J.D. Bailey et al., (2009). The national fire and fire surrogate study: Effects of fuel reduction methods on forest vegetation structure and fuels. Ecol. Applic., 19:285-304.
89. Castro, R. & E. Chuvieco. (1998). Modelling forest fire danger from geographic information systems. Geocarto Int., 13:15-23.
90. Sen, Z. & Habib. Z. (2000). Spatial precipitation assessment with elevation by using point cumulative semivariogram technique. Water Resourc. Manage., 14:311-325.
91. Jagpal Singh Tomar, Nikola Kranjˇci´c, Bojan Đurin, Shruti Kanga & Suraj Kumar Singh. (2121). Forest Fire Hazards Vulnerability and Risk Assessment in Sirmaur District Forest of Himachal Pradesh (India): A Geospatial Approach. ISPRS Int. J. Geo-Inf.,10:447. https://doi.org/10.3390/ijgi10070447
92. Ariapour A., & Shariff A. R. (2015). Rangeland fire risk zonation using remote sensing and geographical information system technologies in Boroujerd Rangelands, Lorestan Province, Iran. ECOPERSIA, 2(4):805-818.
93. Kushla, J. D., & Ripple, W. J. (1997). The role of terrain in a fire mosaic of a temperate coniferous forest. Forest Ecology and Management, 95:97-107. doi:10.1016/S0378- 1127(97)82929-5.
94. Rothermel. (2008). Fire Science Digest, Issue 2. https://www.firescience.gov/Digest/FSdigest2.pdf
95. Morandini, F., Santoni, P.A., &Balbi, J.H., (2001). The contribution of radiant heat transfer to laboratory-scale fire spread under the influences of wind and slope. Fire Saf. J., 36:519-543.
96. Wolock, D.M., & McCabe G.J. (1995). Comparison of single and multiple flow direction algorithms for computing topographic parameters in Top model. Water Resourc. Res., 31:1315-1324.
97. Mukherjee, S&Raj, K. Analysis of forest fire of Meghalaya using geospatial tools. In: 15th ESRI India user conference, 2014.
98. https://www.esri.in/~/media/esriindia/fles/pdfs/events/uc2014/proceedings/papers/UCP0053.pdf]
99. Iverson, L.R., Yaussy, D.A., Rebbeck, J., Hutchinson, T.F., Long R.P., & Prasad, A.M. (2004). A comparison of thermocouples and temperature paints to monitor spatial and temporal characteristics of landscape-scale prescribed fires. Int. J. Wildland Fire., 13:311-322.
100. Richard A. Shakesby., Chris Chafer, S.H., Doerr, W.H., Blake, P., Wallbrink, G.S., Humphreys & Harrington, B.A. (2003). Fire severity, water repellency characteristics and hydrogeomorphological changes following the Christmas (2001) Sydney Forest fires. Aust. Geogr., 34:147-175.
101. Anderson, H.E. (1982). Aids to determining fuel models for estimating fire behavior. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden UT. General Technical Report INT-122.
102. Bennie, J., Huntley, B., Wiltshire, A., Hill M.O., & Baxter, P. (2008). Slope, aspect and climate: Spatially explicit and implicit models of topographic microclimate in chalk grassland. Ecol. Modell., 216:47-59.
103. Wallbrink, G.S. Humphreys & Harrington, B.A. (2003). Fire severity, water repellence characteristics and hydrogeomorphological changes following the Christmas 2001 Sydney-forest fires. Aust. Geogr., 34:147-175.
104. Tom Beer (1991). The interaction of wind and fire. Boundary-Layer Meteorology, 54:287-308.
105. He, Y., Kwok, K.C.S., Douglas, G., & Razali, I.M. (2011). Numerical investigation of bushfire-wind interaction and its impact on building structure. Fire Saf. Sci., 10:1449-1462.
106. Abouali, A., Viegas, D.X., &Raposo, J.R. (2021). Analysis of the wind flow and fire spread dynamics over a sloped–ridgeline hill. Combust. Flame 234, 111724.
107. Rathaur, S. (2005). Fire risk assessment for tiger Preybase in Chilla Range and vicinity, Rajaji National Park using remote sensing and GIS. M.Sc. thesis, Indian Institute of Remote Sensing, ISRO, Dept. of Space, Govt. of India.
108. Eugenio, F.C., dos Santos, A.R., Fiedler, N.C., Ribeiro, G.A., da Silva, A.G., dos Santos, Á.B., Paneto, G.G., &Schettino, V.R. (2016). Applying GIS to develop a model for forest fire risk: A case study in Espírito Santo, Brazil. J. Environ. Manag., 173:65-71.
109. Bonora, L., Conese, C., Marchi. E., Tesi, E., &Montorselli, N.B. (2013). Wildfire occurrence: integrated model for risk analysis and operative suppression aspects management. Am. J. Plant Sci., 4(3A):705-710.
110. Van Wilgen, B.W., Higgins, K.B., &Bellstedt, D.U. (1990). The role of vegetation structure and fuel chemistry in excluding fire from forest patches in the fire-prone fynbos shrublands of South Africa. J. Ecol., 78:210-222.
111. Hussin, Y.A., Matakala, M., &Zagdaa, N. (2008). The Applications of Remote Sensing and GIS in Modelling Forest Fire Hazard in Mongolia.The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 37(B8).
112. Khanal, S. (2015). Wildfire trends in Nepal based on MODIS burnt-area data. BankoJanakari. Banko. 25(1):76-79.
113. De Santis, A., Chuvieco., &Geocbi. (2009). A modified version of the composite burn index for the initial assessment of the short-term burn severity from remotely sensed data. Remote Sens. Environ., 113:554–562.
114. Gitas, I.Z., Santis, A., & Mitri, G.H. (2009). Remote Sensing of Burn Severity. In Earth Observation of Wildland Fires in Mediterranean Ecosystems; (Eds. Chuvieco, E.) Springer: Berlin/Heidelberg, Germany, p.129-148.
115. Jimenez-Munoz, J.C., Cristobal, J., Sobrino, J.A., Soria, G., Ninyerola, M., & Pons, X. (2009). Revision of the single-channel algorithm for land surface temperature retrieval from Landsat thermal-infrared data. IEEE Trans. Geosci. Remote Sens., 47:339-349.

116. Chuvieco, E., Riaño, D., Danson, F.M., & Martin, P. (2006). Use of a radiative transfer model to simulate the postfire spectral response to burn severity. J. Geophys. Res. Biogeosci., 111.
117. Lidia Vlassova, Fernando Pérez-Cabello, Marcos Rodrigues Mimbrero, Raquel MontorioLlovería, & Alberto García-Martín. Remote Sens., 6:6136-6162.
118. Matin, M., Chitale, V., Murthy, S.R., Uddin, M., Bajracharya, K., Pradhan, & Sudip, B. (2017). Understanding forest fire patterns and risk in Nepal using remote sensing, geographic information system and historical fire data. Int. J. Wildland Fire. 26(4):276.
119. Yang, J., He, H.S., Shifley S.R., & Gustafson, E.J. (2007). Spatial patterns of modern period human-caused fire occurrence in the Missouri Ozark Highlands. For. Sci., 53:1-15.
120. Agarwal, C., Green, G.M., Grove, J.M., Evans, T.P., &Schweik, C.M. (2002). A review and assessment of land-use change models: dynamics of space, time, and human choice, Technical Report, U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Pennsylvania, USA, 1-67.
121. Kanga, S., Sharma, L.K., & Pandey, P.C., (2013). Forest Fire Modelling to Evaluate Potential Hazard to Tourism Sites using Geospatial Approach. J Geomat., 7:93–9.
122. Kumar, M., Denis, D.M., Singh, S.K., Szabó, S., &Suryavanshi, S. (2018). Landscape metrics for assessment of land cover change and fragmentation of a heterogeneous watershed. Remote Sens. Appl. Soc. Environ., 10:224233
123. Gigovi´c, L., Jakovljevi´c, G., Sekulovi´c, D., &Regodi´c, M. (2018). GIS Multi-Criteria Analysis for Identifying and Mapping Forest Fire Hazard: Nevesinje, Bosnia and Herzegovina. Teh. Vjesn., 25:891-897.
124. Ajin, R.S., Loghin, A.M., Vinod, P.G., & Jacob, M.K. (2016). Forest fire risk zone mapping using RS and GIS techniques: a study in Achankovil Forest Division, Kerala, India. J. Earth Environ. Health Sci., 2(3):109-115.
125. Díaz-Delgado, R., Lloret, F., & Pons, X. (2003). Influence of fire severity on plant regeneration by means of remote sensing imagery. Int. J. Remote Sens., 24:1751-1763.
126. Fox, D., Maselli, F., &Carrega, P. (2008). Using SPOT images and field sampling to map burn severity and vegetation factors affecting post forest fire erosion risk. Catena, 75, 326-335.
127. Petropoulos, G.P., Griffiths, H.M., &Kalivas, D.P. (2014). Quantifying spatial and temporal vegetation recovery dynamics following a wildfire event in a Mediterranean landscape using EO data and GIS. Appl. Geogr., 50: 120-131.
128. Kriegler, F.J., Malila, W.A., Nalepka, R.F., & Richardson, W. Preprocessing Transformations and Their Effects on Multispectral Recognition. In Proceedings of the Sixth International Symposium on Remote Sensing of Environment, Ann Arbor, MI, USA, 1969, 97-131.
129. Hernandez, P.A., Arbelo, M., & Gonzales Calvo, A. (2006). Fire Risk Assessment Using Satellite Data. Advances in Space Research 37:741-746.
130. Thoha, A. S. (2008). Usage of hotspot data in forest and land fires monitoring in Indonesia. Paper. Medan: Faculty of Agriculture, University of North Sumatera.
131. Verbyla, D., & Lord, R. (2008). Estimating post-fire organic soil depth in the Alaskan boreal forest using the Normalized Burn Ratio. Int. J. Remote Sens., 29:3845–3853.
132. Brewer, K.C., Winne, J.C., Redmond, R.L., Opitz, D.W., &Mangrich, M.V. (2005). Classifying and mapping wildfire severity: A comparison of methods. Photogrammetric Engineering and Remote Sensing, 71:1311-1320.
133. Van Wagtendonk, J.W., Root, R.R., & Key. C.H. (2004). Comparison of AVIRIS and Landsat ETM+ detection capabilities for burn severity. Remote Sensing of Environment, 92: 397-408.
134. Escuin, S., Navarro, R., & Fernandez, P. (2008). Fire severity assessment by using NBR (Normalized Burn Ratio) and NDVI (Normalized Difference Vegetation Index) derived from Landsat TM/ETM images. Int. J. Remote Sens., 29:1053-1073.
135. Benjamin C. Bright., Andrew, T., Hudak., Robert, E., Kennedy., Justin, D., Braaten., Azad HenarehKhalyani., & Bright (2019). Fire Ecology, 15:8.
136. Miller, J.D., &Yool, S.R. (2002). Mapping Forest Post-Fire Canopy Consumption in Several Overstory Types Using Multi-Temporal Landsat TM and ETM Data. Remote Sensing of Environment, 82:481-496.
137. French, N.H.F., Kasischke, E.S., Hall, R.J., Murphy, K.A., Verbyla, D.L., Hoy, E.E., & Allen, J.L. (2008). Using Landsat data to assess fire and burn severity in the North American boreal forest region: An overview and summary of results. Int. J. Wildl. Fire, 17:443-462.
138. Lutes, D.C., Keane, R.E., Caratti, J.F., Key, C.H., Benson, N.C., Sutherland, S., &Gangi, L.J., (2005). USDA Forest Service, Rocky Mountain Research Station: Ogden, UT, USA.
139. Key, C.H., & Benson, N.C. Landscape assessment: ground measure of severity, the Composite Burn Index; and remote sensing of severity, the Normalized Burn Ratio. Pages LA1-LA51. In FIREMON: fire effects monitoring and inventory system, (Eds. Lutes, D.C., Keane, R.E., Caratti, J.F., Key, C.H., Benson, N.C., Sutherland, S. &Gangi. L.J. Fort Collins: USDA Forest Service General Technical Report, RMRS-GTR164-CD, Rocky Mountain Research Station, (2006).
140. Hudak, A.T., Morgan, P., Bobbitt, M.J., Smith, A.M.S., Lewis, S.A., Lentile, L.B., Robichaud, P.R., Clark, J.T., & McKinley, R.A. (2007). The relationship of multispectral satellite imagery to immediate fire effects. Fire Ecol., 3:64-90.
141. Keeley, J.E. (2009). Fire intensity, fire severity and burn severity: a brief review and suggested usage. International Journal of Wildland Fire 18: 116-126.
142. Epting, J., Verbyla, D., &Sorbel, B. (2005). Evaluation of remotely sensed indices for assessing burn severity in interior Alaska using Landsat TM and ETM+. Remote Sensing of Environment, 96:328-339.

143. French, N.H.F., Kasischke, E.S., Hall, R.J., Murphy, K.A., Verbyla, D.L., Hoy, E.E., &Allen, J.L. (2008). Using Landsat data to assess fire and burn severity in the North American boreal forest region: An overview and summary of results. Int. J. Wildl. Fire,17:443-462.
144. Clement J. F., Delcourt., Alisha Combee., Brian Izbicki., Michelle C. Mack., TrofimMaximov., Roman Petrov., Brendan M. Rogers., Rebecca, C., Scholten., Tatiana, A., Shestakova., Dave van Wees., & Sander Veraverbeke. (2021). Evaluating the Differenced Normalized Burn Ratio for Assessing Fire Severity Using Sentinel-2 Imagery in Northeast Siberian Larch Forests, Remote Sens., 13:2311.
145. Allison, E., Cocke., Peter, Z., Fulé., & Joseph, E. (2005). Crouse, Comparison of burn severity assessments using Differenced Normalized Burn Ratio and ground data, International Journal of Wildland Fire, 14:189-198.
146. Ricotta, C., Bajocco, S., Guglietta, D., &Conedera, M. (2018). Assessing the influence of roads on fire ignition: Does land cover matter? Fire. 1(2):24. https://doi.org/10.3390/fire1020024
147. Ganteaume, A., Camia, A., Jappiot, M., San-Miguel-Ayanz, J., Long-Fournel, M., &Lampin, C. A. (2013). Review of the main driving factors of forest fire ignition over Europe. Environ. Manag., 51:651-662.
148. Gupta, A.K., & Kaushik, A.D. (2012). Managing Fire and Pests in Forestry: Approach to Ecosystem Health. In: Ecosystem Approach to Disaster Risk Reduction. (Eds. Gupta, A.K. & Nair, S.S.). National Institute of Disaster Management, New Delhi, India, p.121-136.
149. Chuvieco, E., Aguado, I., &Dimitrakopoulos, A.P. (2004). Conversion of fuel moisture content values to ignition potential for integrated fire danger assessment. Can. J. For. Res., 34:2284-2293.
150. Martell, D.L. (2007). Forest Fire Management. In: Handbook of Operations Research in Natural Resources. (Eds.Weintraub, A., Romero, C., Bjorndal, T., & Epstein, R.) Springer, Boston, 489-509.
151. Pyne, S.J. (2017). Fire in America: A Cultural History of Wildland and Rural Fire. University of Washington Press, USA.
152. Ana Novo., Noelia Fariñas Álvarez., Joaquin Martínez-Sánchez., &Henrique Lorenzo, (2020). Mapping Forest Fire Risk –a case study in Galicia, Spain, Remote Sensing, 12(22):3705.
153. 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.
154. Sharma, L.K., Kanga, S., &Nathawat, M.S. (2012). Fuzzy AHP for Forest Fire Risk Modelling. Disaster Prevent Manage., 21(2):160-171.
155. Iliadis, L.S. (2005). A decision support system applying an integrated fuzzy model for long-term forest fire risk estimation. Environ. Model. Softw., 20:613-621.
156. Yakubu, I., Mireku-Gyimah, D., &Duker, A.A. (2015). Review of methods for modelling forest fire risk and hazard. Afr. J. Environ. Sci. Technol., 9:155-165.
157. Ridalin Lamat., Mukesh Kumar., Arnab Kundu., & Deepak Lal. (2021). Forest fire risk mapping using analytical hierarchy process (AHP) and earth observation datasets: a case study in the mountainous terrain of Northeast India. SN Applied Sciences, 3:425.
158. Shruti Kanga., Gaurav Tripathi., & Suraj Kumar Singh. (2017). Forest Fire Hazards Vulnerability and Risk Assessment in Bhajji Forest Range of Himachal Pradesh (India): A Geospatial Approach, Journal of Remote Sensing and GIS, 8:25-40.
159. Deng, O., Su, G., Huang, Q., & Li, Y. Forest Fire Risk Mapping Based on Spatial Logistic Model of Northeastern China Forest Zone. In Proceedings of the International Conference on Geo-Informatics in Resource Management and Sustainable Ecosystem, Wuhan, China, 2013, 181–192.
160. Eskandari, S. (2017). A new approach for forest fire risk modelling using fuzzy AHP and GIS in Hyrcanian forests of Iran. Arab. J. Geosci., 10:190.
161. Akay, A.E &Erdo ˘gan, A. (2017). GIS-based multi-criteria decision analysis for forest fire risk mapping. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci., 25.
162. Pourghasemi, H.R., Beheshtirad, M., & Pradhan, B. (2016). A comparative assessment of prediction capabilities of modified analytical hierarchy process (M-AHP) and Mamdani fuzzy logic models using Netcad-GIS for forest fire susceptibility mapping. Geomat. Nat. Hazards Risk, 7, 861-885.
163. Ghorbanzadeh, O., Feizizadeh, B., &Blaschke, T. (2018). Multi-criteria risk evaluation by integrating an analytical network process approach into GIS-based sensitivity and uncertainty analyses. Geomat. Nat. Hazards Risk, 9:127-151.
164. Dutta, R.;,Das, A., &Aryal, J. (2020). Big data integration shows Australian bush-fire frequency is increasing significantly. R. Soc. Open Sci., 3: 150241.
165. Kim, S.J., Lim, C.H., Kim, G.S., Lee, J., Geiger, T., Rahmati, O., Son, Y., & Lee, W.K. (2019). Multi-temporal analysis of forest fire probability using socio-economic and environmental variables. Remote Sens., 11:86.
166. Muzamil Ahmad Rather., Majid Farooq., GowharMeraj., Mudasir Ahmad Dada., Bashir Ahmad Sheikh., &Ishfaq Ahmad Wani. (2018). Remote Sensing and GIS Based Forest Fire Vulnerability Assessment in Dachigam National Park, North Western Himalaya, Asian J. Applied Sci., (11)2: 98-114.
167. Srivastava, R.K. Forest fire and its prevention by generating environmental awareness in the rural masses-World Forestry Congress, Turkey, 1997.
168. UNDRR, Global Fire Monitoring Centre, Forest Fire and Biotic Interferences-A Great Threat to Nilgiri Biosphere, IFFN No. 26 – January 2002, 32-36. https://gfmc.online/iffn/country/in/in_7.html
169. The Times of India, February, 2020. http://timesofindia.indiatimes.com /article show/ 74216488.cms?utm_ source=contentofinterest&utm_medium=text&utm_campaign=cppst

170. Neha Jain, Decline in forest fires in Nilgiris Biosphere Reserve indicates management effectiveness, 20 September 2018. https://india.mongabay.com/2018/09/decline-in-forest-fires-in-nilgiri-biosphere-reserve-indicates-management-effectiveness/

CITATION OF THIS ARTICLE

S. Latha. Assessment of Forest Fire Vulnerability Zones In Nilgiris District, Tamilnadu, Using Remote Sensing & GIS. Bull. Env. Pharmacol. Life Sci., Vol 11[10] August 2022 : 67-87