# Estimation of Forest Fire Spread by Modeling in GIS Platform

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## Abstract

Fire has been a source of disturbance for thousands of years. It has been found through research that forest fires mostly happen due to human interactions with the forests. The disturbances from humans mostly affect the forest areas that are nearer to the human habitations and roads. Statistical estimates infer that Tamil Nadu is one of the Indian states which is also frequently disturbed by forest fires. A spatial extent of about 4230.94 km<sup>2</sup> of Tamil Nadu is vulnerable to human interventions from all the roads and settlements that can cause forest fires. This means that, no afforestation practice in future should be carried out within these areas. Instead, such practices in future could be encouraged in areas wherein there is 'zero' risk due to anthropogenic threats. This is essential to ensure the safer survival of any artificial plantations. If 'Forest Fire Spread Model' is prepared for these areas, the same will prove to be helpful in finding out the direction of fire in the event of a fire-spread from a spot. For any forest area, the factors that is responsible for the spread of a fire are, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Aspect, Slope, and Land Surface Temperature (LST). **Objective:** To prepare a 'forest fire spread model' that could be used for predicting the direction of fire movement and estimating the area of fire spread after a stipulated time. Method: In this research, firstly a 'Fire reach susceptibility index' map has been prepared which could then be fed to a model that has be prepared using Python customizing facility in QGIS, to estimate the 'forest fire spread' in a course of time. The factors that have been considered in this study were Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Aspect, Slope, and Land Surface Temperature (LST). Findings: The 'FRSI' Map preparation phase considers all the necessary factors as suggested by the previously conducted researches. The hence prepared map has also been undergone through 'accuracy assessment' to ensure its reliability in its usage for the estimation of forest fire spread. This has been done by checking the correlation between the number of fire incidences and each district's corresponding average FRSI value. This map and the number of fire incidences have a correlation coefficient of '0.94', thereby making this map to achieve an accuracy of 97.43%. Thus, the average FRSI value and the number of fire incidences are relevant, which means that the prepared FRSI map is reliable. With the help of this map, 'fire spread model' has been prepared from which it has been estimated that, for a safer region in Tirunelveli district, the fire could spread to an extent of 38.56 km<sup>2</sup> in 9 hours. Application: The 'Forest Fire Spread Model' prepared for these areas would prove to be helpful in finding out the direction of fire in the event of a fire-spread from a spot. Hence, this model could be useful to 'Tamil Nadu Forest Department' in predicting the most expected spot of arrival of fire in a time duration. This could ensure that plantations nearby are safeguarded from any possible adverse effects of human interventions.

Keywords: Forest-fire spread, FRSI, LST, NDVI, NDWI

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## 1. Introduction

Forest and wild land fire has been taking place historically, shaping landscape structure, pattern and ultimately the species composition of ecosystems<sup>1</sup>. The ecological role of fire is to influence several factors such as plant community development, soil nutrient availability and biological diversity<sup>2</sup>. Forest and wild land fire are considered as the vital natural processes initiating natural exercises of vegetation succession<sup>3</sup>. However uncontrolled fire can cause tremendous adverse impacts on the environment and the human society<sup>4</sup>. India has a forest cover of about 20.55 % of its geographical area. It is enriched with an ample diversity of forests bloomed with a rich array of floral and faunal life forms<sup>5</sup>. The ecological and socio-economic consequences of wild land fire in India include- Loss of timber, biodiversity, wildlife habitat, global warming, soil erosion, fuel-wood and fodder, damage to water and other natural resources, natural regeneration etc<sup>6</sup>.

Forest fires are caused by Natural as well as Man-made processes.

- i) Natural causes: It includes lightning, high atmospheric temperature and low humidity<sup>7</sup>.
- ii) Man-made causes: Fire is caused when a source of fire like naked flame, cigarette or bidi, electric spark or any other source of ignition comes into contact with inflammable material.

A combination of edaphic, climatic and human activities account for the majority of wild land fire<sup>8</sup>. High terrain steepness along with high summer temperature supplemented with high wind velocity and the availability of highly flammable material in the forest floor can contribute to forest fire. The contribution of natural fires is insignificant in comparison to number of fires started by humans<sup>9</sup>. In the mountain area, along with elevation raising, temperature will become lower and humidity will increase, so the probability of forest fire reduces<sup>10</sup>. Abrupt slope allows faster surface runoff, dries the surface fuel and exacerbates the fire spread. Aspect and the received solar radiation are partly correlated.

It is self-evident that any afforestation practice in future should be confined to the areas which have 'zero' anthropogenic risk (Figure 1.). But any subsequent and unexpected natural or artificial fire in these areas could result in heavy losses of tree resources therein. To prevent such occurrence, it will be optimal to put off the fire at the most expected spot of arrival of fire spread, with the help of aerial vehicles fitted with fire extinguishers. For such a scenario, a 'Forest Fire Spread Model' could prove to be useful in finding out the most probable direction of fire, in case of a fire spread from a spot<sup>2</sup>.



**Figure 1.** Distributions of safer areas from anthropogenic threats in Tamil Nadu.

#### 1.1 Study Area

Research<sup>1</sup> shows that a spatial extent of about 4230.94 km<sup>2</sup> in Tamil Nadu (India) is vulnerable to human interventions from all the roads and settlements therein. The distributions of these areas has been illustrated in Figure 1. The aggregate of these areas is the study area in this research.

The factors that are responsible for the spread of a forest fire from an ignited area are Normalized Difference Vegetation Index (NDVI), Normalized DifferenceWater Index (NDWI), Aspect, Slope, and Land Surface Temperature (LST)<sup>11</sup>.

# 1.2 Normalized Difference Vegetation Index (NDVI)

NDVI helps in numerically assessing whether the studyarea of concern contains live green vegetation or not, by utilizing the visible and Near-Infrared (NIR) bands of the electromagnetic spectrum<sup>12</sup>. It is closely linked with tree attributes such as the percent of vegetative cover in theterrain, amount of biomass and the leaf area index<sup>13</sup>. Scientists from the Remote Sensing Centre of Texas AandM University, were the first people to use NDVI. NDVI is calculated with the help of Equation 1, which finds the difference of NIR and Redreflectance values and then, divides the difference computed with the sum of NIR and red bands.

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \tag{1}$$

Theoretically, NDVI and NDWI values are represented as ratioswhose values range from -1 to 1.

# 1.3 Normalized Difference Water Index (NDWI)

NDWI, calculated with Equation 2, is an index formulated from satellite measurements in the NIR and Short Wave Infrared (SWIR) channels. The SWIR reflectance is related to the changes in both the water content of the floral cover and the porous inner tissue structure of the tree canopy<sup>14</sup>. The NIR reflectance is influenced by the leaves' dry matter content. SWIR reflectance is inversely proportional to the leaves' moisture content<sup>15</sup>.

$$NDWI = \frac{(NIR - SWIR)}{(NIR + SWIR)}$$
(2)

#### 1.4 Land Surface Temperature (LST)

Due to greater LST in some areas, the trees therein get heated more, when compared with the trees in other areas with lesser LST. In addition, LSTaffects the direction of wind movement<sup>11</sup>.

### 1.5 Slope

Slope is the steepness of the relief features on the land surface. Thisgradient of the terrain features influences both the direction and rate of the firespread. Fires, generally move faster up along the slope of a hill than along thedown-slope of the hill. Hence, greater is the slope angle, higher is the rate offire movement<sup>11</sup>. This is because:

- i. Along the upslope, the flames are nearer to the combustiblebranches of the trees,
- ii. Wind generally moves up along the slope of a hill tending to push the fire blaze higher,
- iii. Heat, transferred through convection, usually surges along theslope causing incremented rate of fire-spread.

### 1.6 Aspect

Aspect is the direction the land faces, which may be north, south, east or west. The aspect of a slope affects the fire-spread in the followingways<sup>11</sup>.

- i. Relief features with eastern aspects, endure more heat from the sun, tending to demoisturize the floral cover of the terrain,
- **ii.** The east-facing gradient of the land surface usually experiencestronger winds with lesser amount of water vapour and lowermoistures in the trees.

These are all the conditions needed for a rapid rate of fire spread.

## 2. Methodology

The GIS software used for all operations and analyses in this research are ArcGIS 10.4 and QGIS.For preparing the NDVI and NDWI map of the study-area, satellite images of AWiFS (Advanced Wide Field of View) sensor aboard Resourcesat-1 satellite, was used in this research. The date of capture of these satellite images is 16/02/2014. 'Fire Spread Model' is prepared by assigning 'Fire ReachSusceptibility Index' to all pixels, in the concerned raster image of the study area. 'Fire Reach Susceptibility Indices' (FRSI) are influenced as shown in Table 1. Thus, FRSI values with respect to NDVI, NDWI, Slope and LST,are assigned proportionately (Table 1) to the respective factor values. FRSIvalues, with respect to aspect, are also assigned as per Table 1.

Now, the mean values of all the FRSI values for each pixel arecalculated. Thus, the final FRSI map is obtained.A 'step number' withrelation to consecutive steps in time is assigned to each pixel. This is based onthe wind direction and the final FRSI value of the same. This is done forplotting the spread of fire from the starting point of ignition. This means that, if latitude and longitude of a point is given as input to the python console of QGIS, fire spread model can be prepared. The Customizing ability of QGIS for Python scripts has been utilized in this research for the preparation of the final model.

## 3. Results and Discussion

Figure 2 shows the Fire Reach Susceptibility Index (FRSI) Map of the Identified safer areas in Tamil Nadu. The Maximum and minimum FRSI values are 0.829 and 0.181 respectively.

Table 1. Factors	that influence	the	'Fire	Reach
Susceptibility In	.dex'			

Sl.	Factor	Influence			Citation
No.					
1.	NDVI	Higher the value higher is the Fire Reach Index value			Bui et al <sup>11</sup>
2.	NDWI	Lower the value higher is the Fire Reach Index value			
3.	Slope	Higher the value higher is the Fire Reach Index value			
4.	Aspect	Direction	N	Fire Reach	
		Value	00	Index = $0$	
		Direction	NE	Fire Reach Index decreases from 1 to 0	
		Value	0º to 90º	Fire Reach Index decreases from 1 to 0	
		Direction	E	Fire Reach Index = 1	
		Value	90°		
		Direction	SE	Fire	
		Value	90° to 180°	Reach Index decreases from 1 to 0	
		Direction	S	Fire	
		Value	180 <sup>0</sup>	Reach	
		Direction	S, SW, W, and NW	index = 0	
		Value	180° to 360°		
5.	LST	Higher the value higher is the Fire Reach Index value			



**Figure 2.** Fire Reach Susceptibility Index Map of the Identified safer areas in Tamil Nadu in 201

The mean of all the FRSI values is 0.591. This map helps in predicting the direction of fire flow due to ignition at any point in the hence-established artificial plantations. As illustrated, fire flows to the adjacent pixel that has a higher FRSI value. As seen in Figure 2, the lowest FRSI value is held by a place in THIRUVARUR district, while the highest FRSI value is held by a place in Tirunelveli district. The FRSI map (Figure 2.) has been undergone with 'accuracy assessment', to ensure its reliability in its usage for the estimation of forest fire spread. This has been done by checking the correlation between the number of fire incidences and each district's corresponding average FRSI value. The average FRSI value and the number of fire incidences in a sample of five districts is depicted in Figure 2. This map (Figure 2.) and the number of fire incidences have a correlation coefficient of '0.94' thereby making this map to achieve an accuracy of 97.43%. As seen in Figure 2, the average FRSI value and the number of fire incidences are relevant, which means that the prepared FRSI map is reliable.

If latitude and longitude are fed as inputs to the python script coded in QGIS platform, fire spread model could be prepared, which illustrates the flow of fire from the specified starting point of ignition. This could be helpful to the fire service men in the event of an ignition, by putting off the fire in the areas where it is moving, or by making appropriate arrangements in the incumbent areas at least, so that the flow of fire is stopped.

Figure 3 illustrates the Fire spread model in the event of a fire in the identified safer areas in Tirunelveli district. A place in Tirunelveli district has been chosen as the starting point of ignition because, this district hosts the largest area (903.88 km<sup>2</sup>) of safer regions (from anthropogenic threats) among other districts (Table 1.). Also, Tirunelveli is found with dense forests due to which there are chances of fire incidences in this district in future. The Starting point of ignition correspond to the input latitude of 8° 42' 3.6", and input longitude of 77° 13' 51.6". This Model depicts the flow of fire with the colour ramp changing from yellow to red, as the time progresses from 0 to 9 hours. The model has been prepared based on a research<sup>11</sup> which infers that fire spreads at the rate of 4.26 km<sup>2</sup> per hour. Thus, the burnt area covered in 9 hours, due to such ignition, is found to be 38.56 km<sup>2</sup>.



**Figure 3.** Fire spread model in the event of a fire in the identified safer areas in Tirunelveli district.

## 4. Conclusion

Forest fire leads to huge loss of tree resources. Mostly human interventions cause frequent forest fires. Such interventions are maximum at the areas that are nearer to human settlements and transportation networks. This infers that any artificial plantations such be practiced in the areas that are safer from any kind of anthropogenic threat so that minimal damage is just expected. Those safer areas form the study area in this research. But, in some unexpected scenarios, there is a likelihood for the spread of fire in these areas too. To inhibit the spread of fire in such cases, fire spread model could be prepared which would prove to be useful in prediction the probable direction of fire spread from a spot. In this regard, the same has been prepared in this research using Python scripting option in QGIS console. It has been estimated that for a safer region in Tirunelveli district the fire could spread to an extent of 38.56 km<sup>2</sup> in 9 hours. Hence this model would prove to be useful to Tamil Nadu Forest Department in predicting the most expected spot of arrival of fire in a time duration. This could ensure that plantations nearby are safeguarded from any possible adverse effects of human interventions. A limitation of this research could be the strict availability of coordinate information of the exact spot of fire ignition, at the lack of which, the spread estimation might be less accurate. Enhancement of accuracy even in this regard, forms the scope for further research.

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