Identification of Forest Fire Zone in Junnar Forest Division, Pune District of Maharashtra

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Abstract
The Junnar division is a critical area for forest fires every year. March, April and May are the three months when most forest fires occur. Most of these fires are artificial. Grazing, smoking and collecting firewood are some examples. Therefore, we must face all the problems of the environment, humans and pollution on a large scale. The amount of forest in this area has been greatly reduced due to the annual fires. Therefore, the people here must face natural and economic problems like tiger attacks, shortages of wood, heavy rains and heat. Forest area is 5319 sq. km. Present study therefore aims to monitor the conditions of the study area using GIS and remote sensing methods, to locate forest fire hotspots and to investigate the effects of these fires on both the environment and people using parameters such as the Normalized Difference Vegetation Index, land use land cover, forest density distance from habitation, distance from road, slope and aspect map and elevation map. These thematic layers were weighted according to their importance and forest fire hotspots were identified.

The total number of forest fire alerts is high. The final fire risk map created indicates that the low-risk area is 1848 sq. km. The moderate-risk area is 3372 sq. km. The high-risk area is 100 sq. km. Therefore, there is a need for proper management of forest fires. The proposed work focuses on assessing detailed processes such as forest fire impacts on the human living environment, using geospatial tools. Also, it is helpful for a sustainable environment in the study area.

Keywords: Risk of forest fires, Sentinel 2, GIS, Junnar forest division.

Introduction

Forest fire is a global environmental issue which is a very significant problem in today's world. Any uncontrolled, unplanned burning or combustion of plants in a natural environment such as a forest, grassland, brush land, or tundra, that consumes the natural fuels and spreads depending on environmental factors (such as wind and topography), is referred to as a wildfire, also known as a forest, bush, or vegetation fire. Forests are regarded as vital natural resources because they support corroborative economic activity, preserve environmental equilibrium, control climate and manage the carbon cycle[19]. The Junnar division is a critical area for forest fires every year. March, April and May are the three months when most forest fires occur. Forest fires originate and spread primarily during the summer, but dryness creates ideal conditions for them to occur[5]. Most of these fires are artificial. Grazing, smoking and collecting firewood are some examples. The majority of current wildfires are caused by humans. Fire has a significant impact on many ecological factors such as changing the structure of plant populations, conserving water, improving soil quality and increasing biodiversity[29]. There are three different forms of forest fires: crown, surface and ground fires. The ground fire rages on for a very long period. The surface fire grew quickly. The most damaging type of fires are crown fires.

Ground fire is the most common type of forest fire in India. It is estimated that humans are responsible for 95% of forest fires. Fires are typically set to encourage new growth of grasses, to collect small forest products, or to prepare land for agriculture. Fires affect about 3 5 million hectares of forest every year[17]. The woodland is frequently on fire in the summer. As a result, the forest area is rapidly getting smaller. Therefore, the people here must face natural and economic problems like leopard attacks, shortages of wood, heavy rains and heat. Precious forests have been destroyed by fire over the years. Many researchers have worked on the topic of forest fires.

Across the globe, authorities employ various techniques to detect forest fires, with satellite detection being the most widely used method[8]. Remote sensing-based forest fire assessment involves identifying and mapping burned areas[26]. Deep learning can effectively analyze satellite images for forest fire classification and detection, identifying areas likely to be affected by fires[14]. Remote sensing is crucial for detecting active forest fire locations using fire signals from the MODIS sensor aboard the Terra and Aqua satellites[2]. Almost all fires happen during the driest months, which are December through March[10]. Forest fire zones are identified using geospatial techniques. The integration of remote sensing data, GIS, and simulations enhances fire risk assessment over large areas by incorporating additional inputs[18].

Forest fires may result in deforestation and exacerbate the level of carbon dioxide in the atmosphere. Forest fires release carbon into the atmosphere. A complex mixture of particulate matter and greenhouse gases could potentially affect the climate. It can also affect the forest habitat and species population and distribution. Sometimes wildfires may cause large scale damage to people and property, particularly when these reach the tribal communities[3]. Complex terrain, inaccessible roads, high elevations and strong winds make firefighting challenging. This results in massive forest and ecosystem damage and loss of life[15].

Effective forest fire management and sustainable strategies, including the development of fire risk maps, are essential to reducing fire risk[28]. A forest fire zone map has been developed for the Junnar forest division of the Pune district of Maharashtra. Zones having the potential for fire or those where a fire might spread quickly, are known as high-risk fire zones. Factors considered are: land use, land cover map, normalized difference vegetation index, slope, aspect, elevation, proximity to water body, proximity to human settlements and closeness to road. Numerous studies have been carried out to enhance detection systems for early fire prediction and to create response plans at the scene. Forest fires and damage can be reduced by using appropriate protection and management measures.

The present study aims to detect the forest fire zone inside the study region by using remote sensing (RS) and GIS techniques. It is helpful for a sustainable environment in Junnar forest division.

Study area

Junnar division is the northern part of Pune district in Maharashtra; it comes under the Pune Forest Circle. Junnar, Otur, Ghodegaon, Manchar, Khed, Chakan and Shirur Talukas come under the Junnar Forest Division and it has a forest area of 5319 sq. km. It extends from 73°30'25" to 74°34'42" E and from 18°28'46" to 19°24'15" N in the northern part of the Pune district. Neighbouring districts of the research area include Thane and Ahmednagar. The Mina, Pushpavati, Kukadi, Ghod, Bhima and Bhama are among the rivers that originate in the study region. The study area's western portion is densely forested because it receives more rainfall than its eastern portion. In the hilly areas, especially the tribal settlements are fragmented and situated on the hill slopes. The study area is shown in figure 1.

Material and Methods

An identification of forest fire zones was conducted using a variety of mapping techniques including forest cover, aspect, slope, elevation, closeness to roads, proximity to settlements, proximity to water bodies, NDVI, land use and land cover maps and road maps. Thematic map layers are created using ArcGIS 10.8. The aspect, slope and elevation map were created by processing the DEM data and the resolution is 30 meters (Table 1). Data collected from the Copernicus Open Access Hub and the resolution is 10 meters. The Sentinel 2 images were used for NDVI and land use land cover classification. The road and water body data were collected from an open street map. Topographic maps are obtained from Survey of India (SOI) which will be useful for ground truth data. Fire damage assessment relies primarily on satellite imagery combined with ground observations to determine pre-fire vegetation conditions[29].

The toposheets for Junnar division are having scale 1:50000. Figure 2 flowchart represents the identification of the forest fire zone. A forest fire zone map was created of the study area. Each class was given a rank and the significance of each thematic layer was given a weight. A forest fire zone map was prepared.

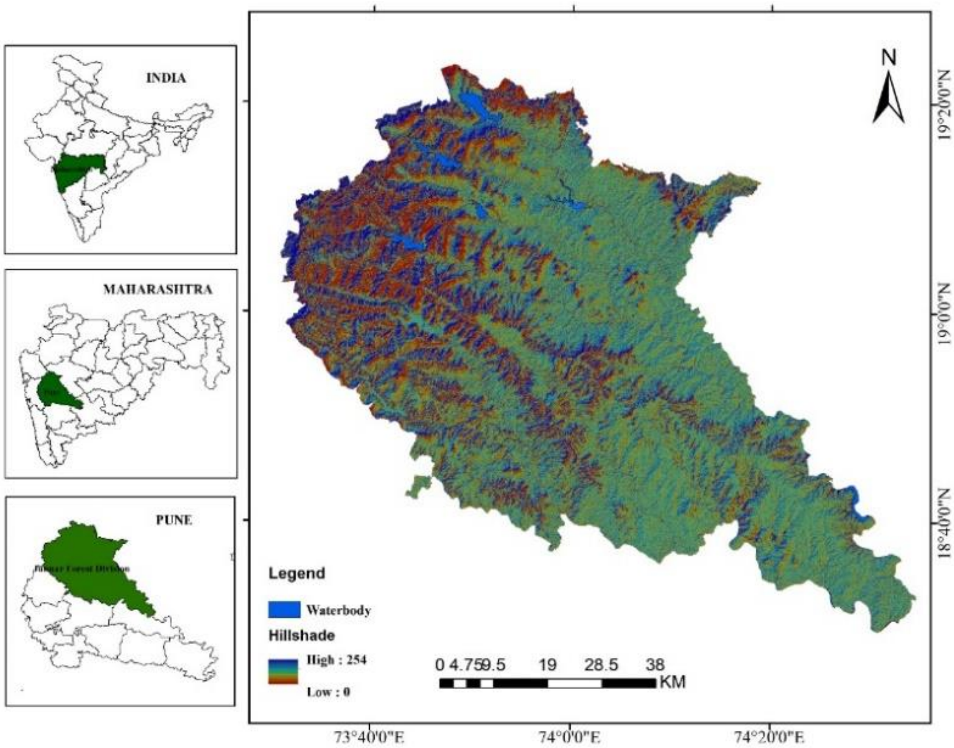

Figure 1: Location map of study area

Table 1
Data Source

Dataset Name	Source
Satellite Imagery- Sentinel 2 (2023)	Copernicus Open Access Hub
DEM Data	Bhuvan – NRSC
Road and Settlement Layers	Open Street Map
Toposheets	Survey of India. Scale 1:50,000.
Active fire Data (2023)	MODIS
Forest Division Boundry	Survey of India.

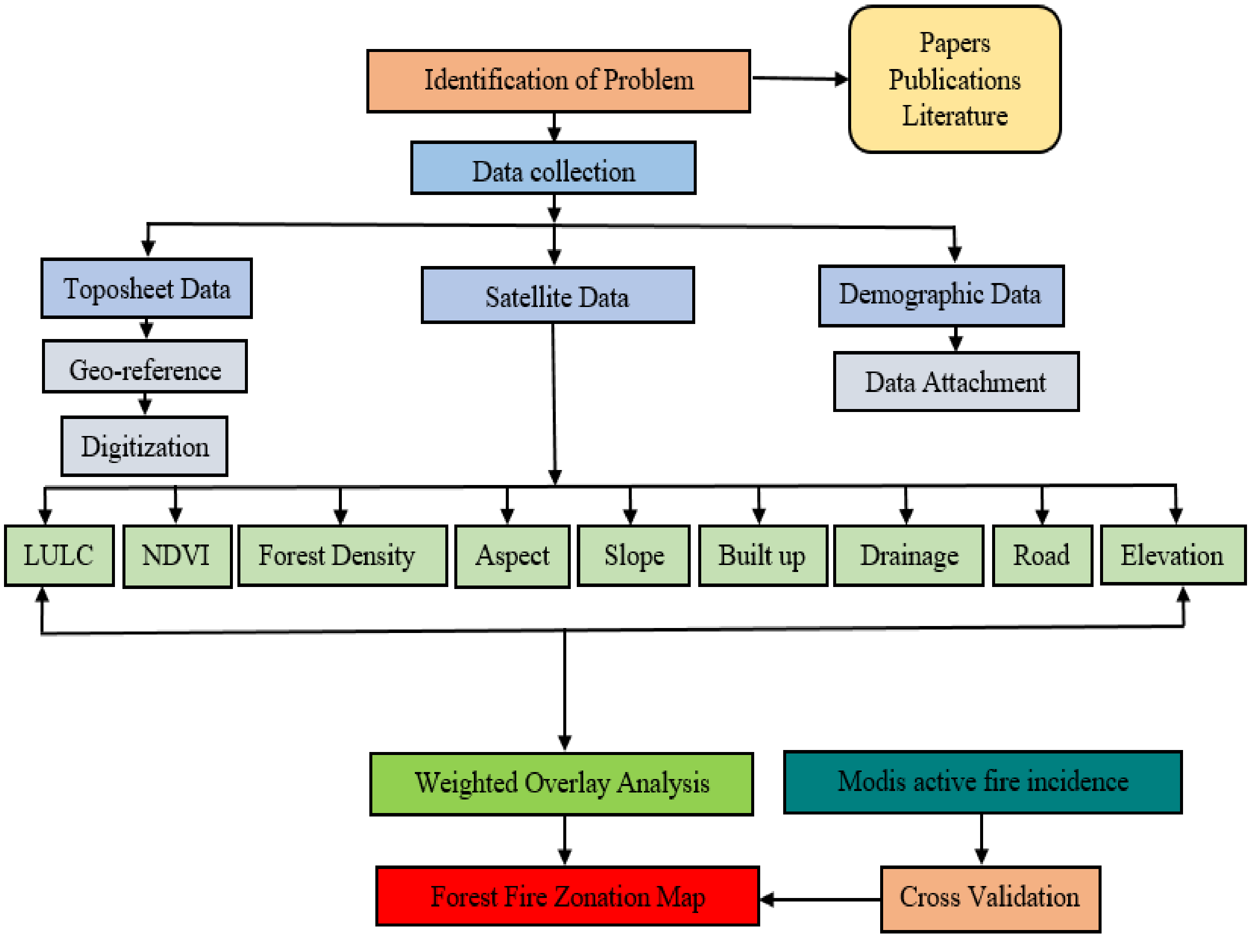

Figure 2: Flowchart of Methodology

Results and Discussion

LULC: Fires are more common in places with dense, dry vegetation. The Junnar Land Use Land Cover map displays human habitation, agriculture, water body, barren land and forest areas. There is a greater risk of forest fires in barren land and forest areas. In figure 3, the LULC map is displayed.

Forest Density: Forest density refers to the number of trees and vegetation present in a given area. Higher forest density means more fuel available for a fire. In dense forests, there is typically more vegetation to burn, providing ample fuel for fires to spread quickly and intensify. In figure 4, the aspect map is displayed.

NDVI: The Normalized difference vegetation index (NDVI) is a remote sensing method that evaluates the density and overall health of vegetation. Normalised difference vegetation index (NDVI) is thus obtained by using the formula:

NDVI = (NIR – Red) / (NIR+Red).

The range of the NDVI value is -1 to 1. A higher NDVI score indicates more near infrared (NIR) light which indicates dense vegetation. NDVI = -1 to 0 represents water bodies, -0.1 to 0.1 represents barren rocks, sand, or snow, 0.2 to 0.5 represents shrubs and grasslands or senescing crops and 0.6 to 1.0 represents dense vegetation or tropical rainforest. Sentinel data was used. In figure 5, the NDVI map is displayed.

Slope: The slope describes the type of landscape. This parameter pertains to geomorphology. Slopes play a crucial role in accelerating the spread of forest fires[22]. The steeper is the slope, the faster forest fires spread. The slope and the rate of fire advancement are positively correlated. The areas slope has been divided into five classes. Areas with higher slope values (28-84.8) are ranked highest. In figure 6, the slope map is displayed.

Aspect: An area's aspect is defined as the direction of its slope, or how exposed it is to the sun's rays. It has to do with how quickly the fuel dries and how the fire moves. This area's aspects have been divided into nine classes. In figure 7, the aspect map is displayed.

Elevation: Higher is the elevation, the topography becomes steeper. In comparison to the plains region, wind speed, lighting and other activities are higher at higher elevations. For forest fires, these practices are more beneficial. In figure 8, the elevation map is displayed.

Closeness to road: Accidental forest fires can occur on motorable highways and forest paths used by tourists, travellers and forest dwellers. On the basis of closeness to roads, the area has been divided into five classes. Figure 9 displays the closeness to road map.

Proximity to settlements: Forest fires are more likely to occur due to human settlement close to the forest. Grazing, smoking and collecting firewood are some examples of forest fires. On the basis of proximity to settlements, the area has been grouped into five class. Figure 10 displays the proximity to settlements map.

Proximity to water body: The distance between a forest area and water resources is significant because in the event of the forest areas near water resources, firefighting team will have quick access to water. Figure 11 displays the proximity to water body map.

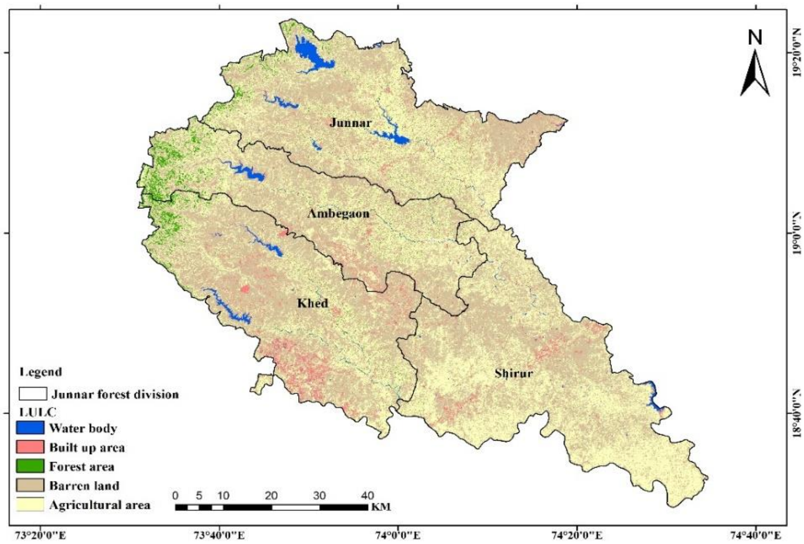

Figure 3: LULC

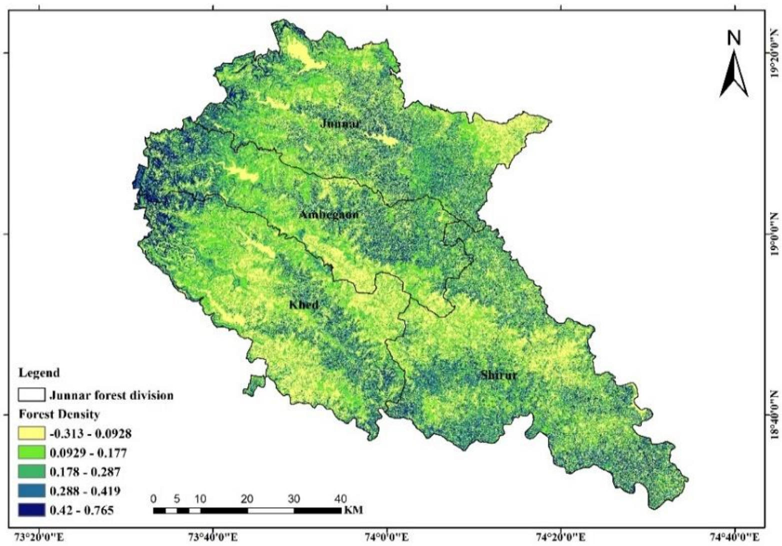

Figure 4: Forest Density

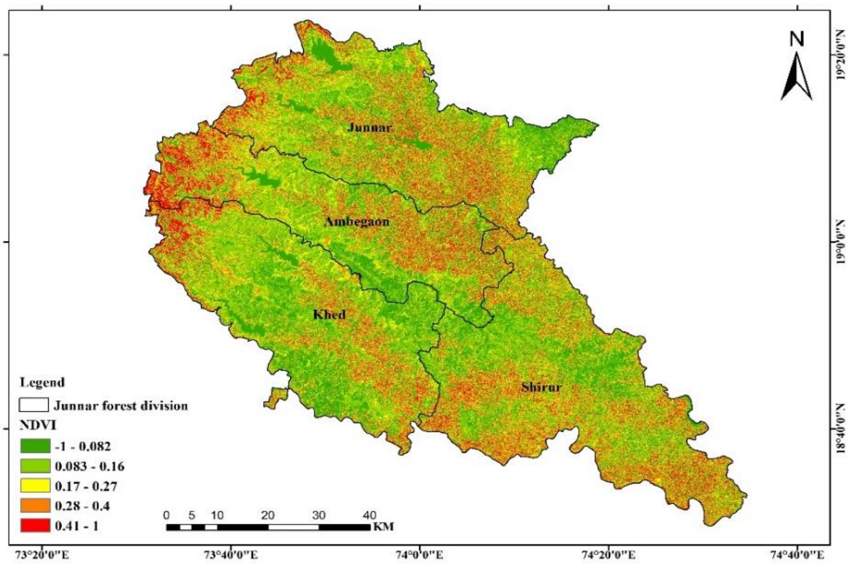

Figure 5: NDVI

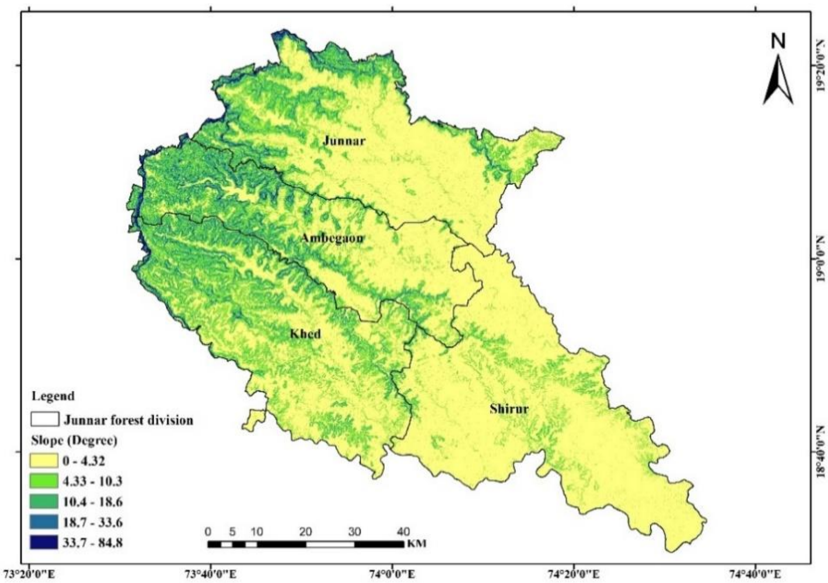

Figure 6: Slope

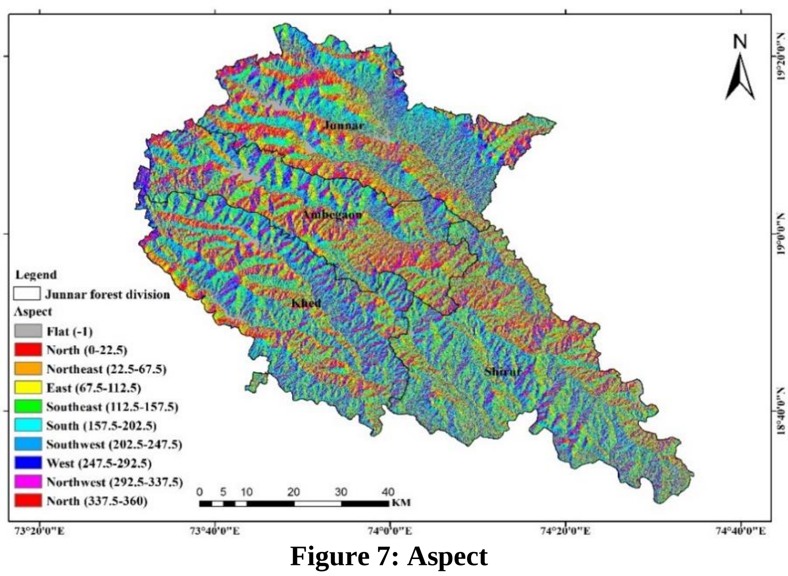

Figure 7: Aspect

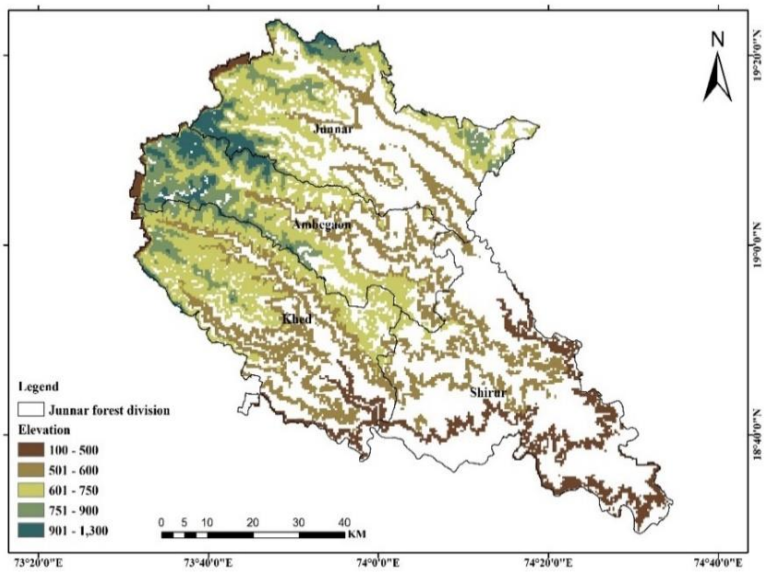

Figure 8: Elevation

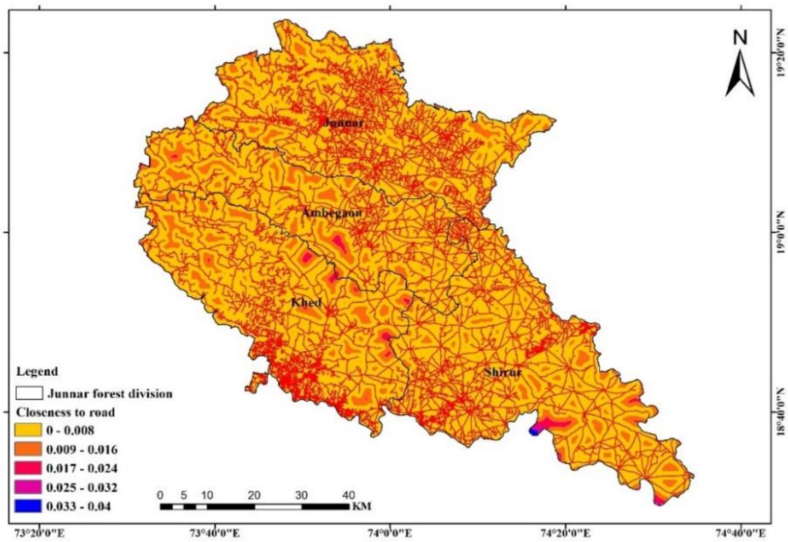

Figure 9: Closeness to road

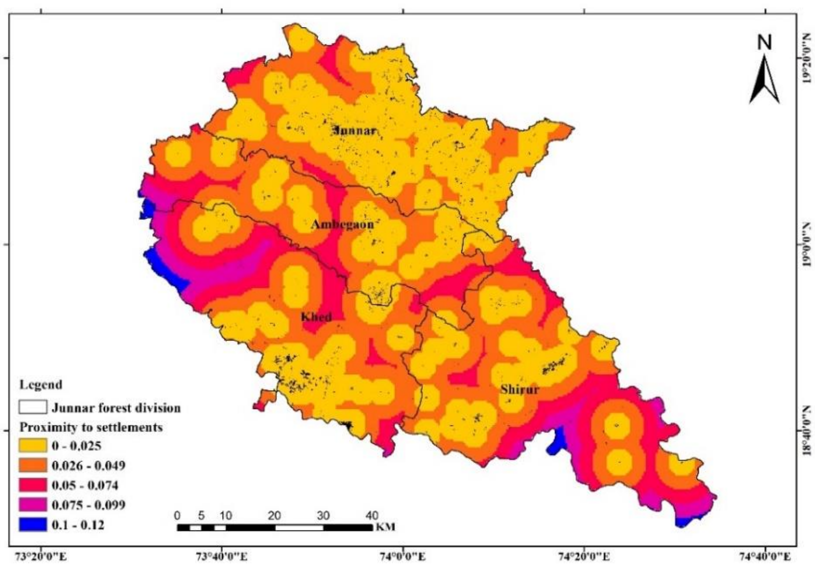

Figure 10: Proximity to settlements

Table 2
Rank and weight assigned for different factors

Factor	Class	Rank	Weight
Land cover type	Water body	1	18.7
	Built up area	3	
	forest	5	
	barren land	2	
	Agriculture	4	
Forest Density	-0.313 – 0.0928	1	19.7
	0.0929 – 0.177	2	
	0.178 – 0.287	3	
	0.288- 0.419	4	
	0.42 – 0.765	5	
NDVI	-1 - 0.082	1	10
	0.083 - 0.16	1	
	0.17 - 0.27	3	
	0.28 - 0.4	4	
	0.41 - 1	7	
Slope(º)	0 - 4.32	1	13.4
	4.33 - 10.3	2	
	10.4 - 18.6	3	
	18.7 - 33.6	4	
	33.7 - 84.8	5	
Aspect	Flat (-1)	1	8.9
	North (0-22.5)	2	
	Northeast (22.5-67.5)	3	
	East (67.5-112.5)	3	
	Southeast (112.5-157.5)	4	
	South (157.5-202.5)	5	
	Southwest (202.5-247.5)	5	
	West (247.5-292.5)	3	
	Northwest (292.5-337.5)	3	
	North (337.5-360)	2	
Elevation	100 - 500	1	8.9
	501 - 600	2	
	601 - 750	3	
	751 - 900	4	
	901 – 1,300	5	
Closeness to road (m)	0 - 0.008	5	8.6
	0.009 - 0.016	4	
	0.017 - 0.024	3	
	0.025 - 0.032	2	
	0.033 - 0.04	1	
Proximity to settlements(m)	0 - 0.025	5	5
	0.026 - 0.049	4	
	0.05 - 0.074	3	
	0.075 - 0.099	2	
	0.1 - 0.12	1	
Proximity to water body (m)	0 - 0.011	1	6.8
	0.012 - 0.022	2	
	0.023 - 0.033	3	
	0.034 - 0.044	4	
	0.045 - 0.055	5	

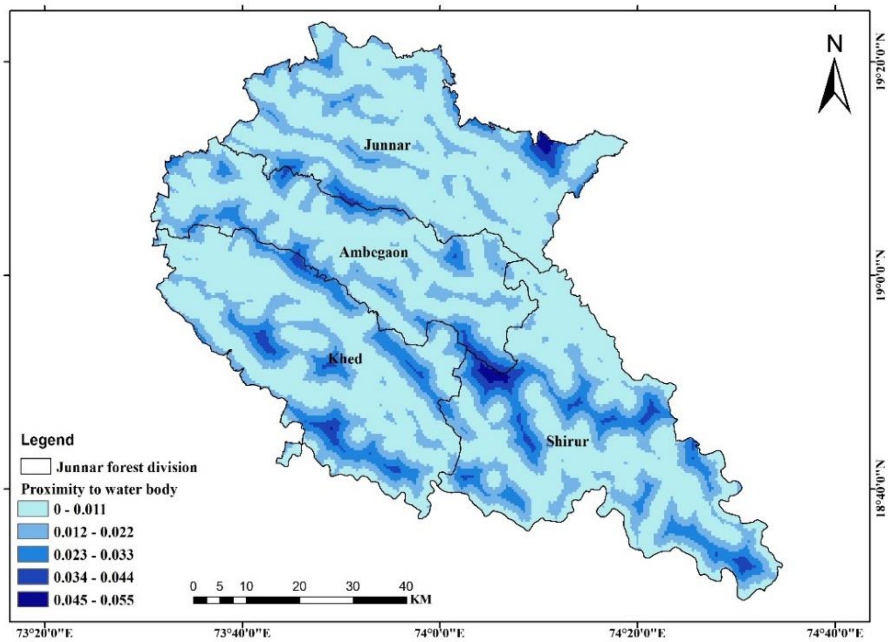

Figure 11: Proximity to water

Table 3
Table of the parameters used for forest fire zonation in various studies.

Authors	LU	FD	NDVI	S	A	E	CR	PS	PW
Adab et al[1]				*	*		*	*	
Ajin et al[3]	*			*		*	*	*	
Ajin et al[4]	*			*		*	*	*	
Ajin et al[5]	*			*	*	*	*	*	
Benguerai et al[6]	*			*	*		*	*	
Chavan et al[7]		*		*	*		*	*	*
Chuvieco et al[9]		*		*	*	*	*		
Gulcin et al[12]		*		*	*	*	*	*	
Jaiswal et al[13]		*		*			*	*	
Kanga et al[16]		*		*	*	*	*		
Matin et al[20]	*			*		*	*	*	
Mohajane et al[21]	*		*	*	*	*	*	*	
Kayet et al[19]			*	*	*	*	*	*	
Pradhan et al[24]			*	*	*				
Rasooli et al[25]		*		*	*		*	*	*
Kanga et al[17]	*	*		*	*	*	*	*	
Tiwari et al[30]		*	*	*	*	*	*	*	*
Tomar et al[31]	*	*		*	*	*	*	*	*
Zhang et al[32]	*	*	*	*	*	*	*	*	

LU land use land cover, FD forest density, NDVI normalized difference vegetation index, S slope, A aspect, E elevation, CR closeness to road, PS proximity to settlements, PW proximity to water body.

Forest fire zones: The forest fire risk map of the Junnar Forest Division is prepared based on parameters such as land use, land cover map, normalized difference vegetation index, slope, aspect, elevation, distance from water bodies, distance from roads and distance from human settlements. Combine these layers and prepare a forest fire zone map. Ranks and weights are assigned to the significance of each thematic layer. There are five risk zones shown on the forest fire zonation map: very low, low, moderate, high and very high. Figure 11 shows the map of the forest fire risk zone.

There is a significant risk of forest fire in the western regions of Ambegaon, Khed, Junnar and Shirur Talukas. The tribal settlements of Ingaloon, Bhiwade, Hatavij, Nimgiri, Taleran, Bagadwadi, Sitewadi, Malin, Kondhare, Kushire Kh. Tale Ghar, Niphad, Pabhe, Pimpale Khalsa and Apti are primarily located inside a high-risk area for forest fires.

Validation: ROC and AUC are valuable methods for model validation, offering important insights into the model's performance[23,27]. For quantifying forest fire activity, MODIS active fire data is very useful[11]. The MODIS active fire (hotspot) data is used to validate the outcome. To verify the outcome, forest fire risk zones have been overlayed with MODIS hotspots. This year, 88 hotspots have been identified. ROC curve was used to verify its accuracy. The percentage is 78%.

Table 4
Area and percentage of the fire risk zones

Risk zones	Area (km2)	Percentage of the area of fire risk zones
Very low	227	4.313
Low	1283	24.377
Moderate	1905	36.196
High	1339	25.441
Very high	509	9.673
Total	5263	100

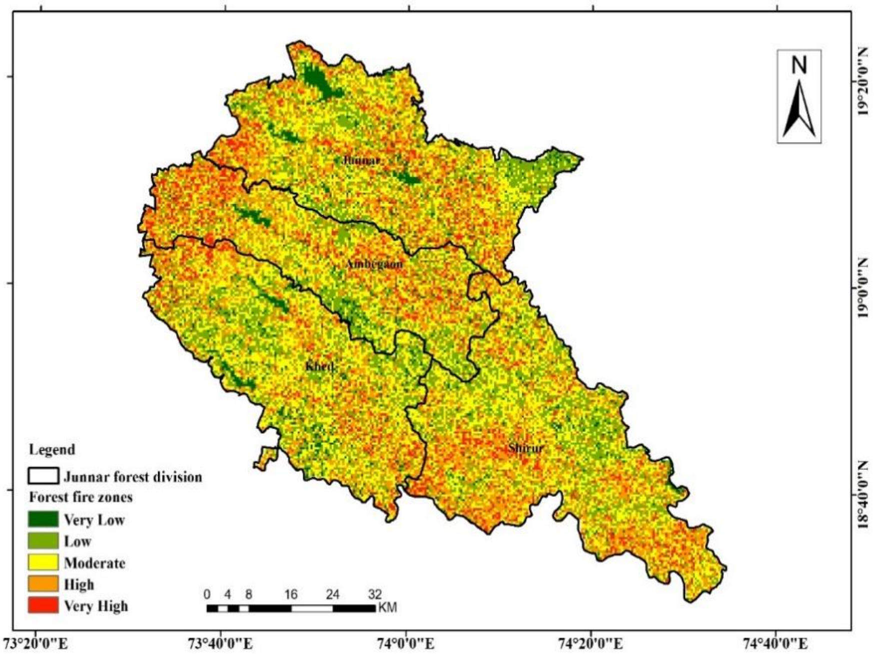

Figure 12: Forest Fire Zone Map of Junnar Forest Division

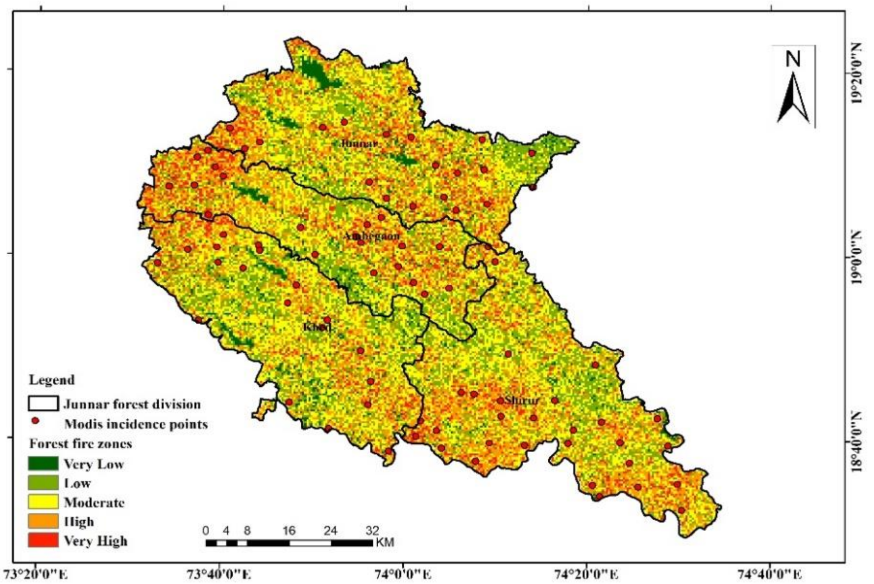

Figure 13: Forest fire zone validated with modis active fire data.

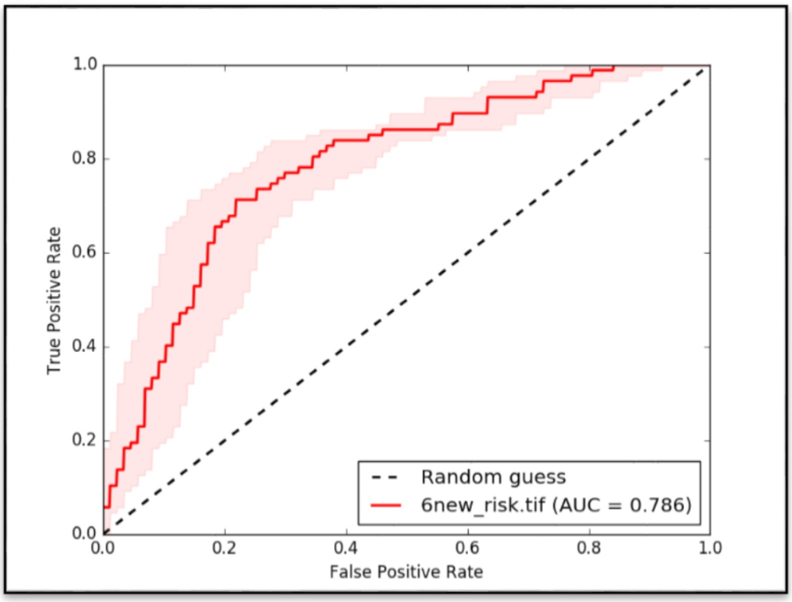

Figure 14: Active forest fire data validated with Receiver operating characteristic curve (ROC Curve).

Preventive measures: Based on the forest ire risk zone mapping, some preventive measures are suggested as follows:

- Construct watch towers on high and very high risk zones and appoint adequate number of trained and well equipped fire watchers during the fire season.
- Conduct training programs for the forest planners and officials.
- Conduct awareness campaign on the causes and consequences of forest fires for the tribal villagers and tourists.
- Promote controlled burning to remove the dry leaves (fuel) on the forest floor and make fire belts on either side of forest roads.
- Create fire lines (firebreaks) to slow down or prevent the advancement of forest fire.
- Develop and maintain effective communication system among the forest guards and forest administrative system.

Conclusion

The Junnar Forest Division forest fire danger zones have been identified by this study utilizing GIS and remote sensing methods. According to the study, forest fires typically occur in regions with steep topography and large forest densities. Forest cover map, NDVI, slope, aspect, elevation, closeness to road, proximity to settlement, land use and land cover are important layers. With the use of remote sensing and GIS, we can easily delineate the areas that are more prominent in high-risk forest fire-prone areas.

The final fire risk map created indicates that the very low forest fire risk area is 227 sq. km. and low forest fire risk area is 1283 sq. km. The moderate forest fire risk area is 1905 sq. km. The high forest fire risk area is 1339 sq. km. and the very high forest fire risk area is 509 sq. km. Therefore, there is a need for proper management of forest fires. The proposed work focuses on assessing detailed processes such as identified forest fire zones, using geospatial techniques. Also, it is helpful for a sustainable environment in the study area.

Acknowledgement

We acknowledge the open access DEM data provided by Bhuvan NRSC, Copernicus Open Access Hub sentinel 2 data, road and settlement layer data from Open Street Maps and active fire MODIS data from FRIMS.

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