Forest Fire Vulnerability and Risk assessment in Forest of Chikmagaluru Using AHP/MCDA Methods, Chikmagaluru District, Karnataka, India : A Geospatial approach

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ABSTRACT

Every year, natural crisis such as fires wreak havoc on forests, which constitute a vital component of the ecosystem. The losses occurred due to this disaster created an alarming situation in the state of Karnataka, which amidst the backdrop of climate change. One crucial step in mitigating forest fire risk (FFR)is conducting a risk assessment, which pinpointing of high-risk areas and offers decision-making support to firefighting agencies. The aim of this study was to monitoring forest fires in the Chikmagalur district of Karnataka utilizing RS and GIS technologies. Climatic, vegetation, topographic and anthropogenic parameters which influence fires and input parameters used are Forest type and density, Proximity from roads and settlements, Elevation, Aspect, Slope, Maximum temperature, Maximum relative humidity, and Wind speed for FFR assessment. MCDA methods such as Weighted Overlay Analysis (WOA) and Analytical Hierarchical Process (AHP) models in a GIS framework were used to delineate forest fire vulnerability. The Comparison of the two methods done and results from AHP and WOA models shown quite similar. Zones of FFRZ were classified into 3 classes viz., low risk, medium and high-risk zone. According to the generated FFR maps, the results showed that pivotal role of tree species as a primary risk factor for forest fire prevention, and assessing the sensitivity of forest areas and implementing appropriate management strategies for fire prevention. This study highlighted that the combination of GIS techniques with the AHP method proved a highly advantageous approach to rapid mapping of forest areas prone to fire risk in short time.

KEYWORDS: Remote Sensing (RS), Geographical Information System (GIS), Forest Fire Risk Zone (FFRZ), Multi-Criteria Decision analysis (MCDA), Analytical Hierarchical Process (AHP).

1. INTRODUCTION

Forest fires, whether natural or anthropogenic, occur worldwide, causing adverse environmental, economic, and ecological impacts. Natural hazards such as earthquakes, floods, droughts, and forest fires are increasingly affecting life on Earth. Three major natural factors contribute to forest fires. Firstly, thunderstorms and lightning strikes on trees have been recorded in regions including India, southeastern and central USA, Australia, and southern Africa. Secondly, during dry seasons, a small spark can ignite fires, whether from friction generated by rolling stones (landslides) or due to the high rate of dry winds in mountainous areas covered with large quantities of dry leaves. Notable instances include the Rudraprayag district of Uttaranchal in 2001 and annual occurrences in Germany and the USA. Thirdly, volcanic eruptions can also lead to forest fires. Two major anthropogenic factors contribute to forest fires, deliberate and accidental. Deliberate actions manifest in forms such as shifting cultivation and slash-and-burn practices.

Accidental factors include careless behaviour, such as the improper disposal of cigarettes or sparks from transformers or vehicles, which can lead to forest fires. These disturbances influence various aspects of the Earth, including physical, ecological, and humanistic. The physical aspect is strongly correlated with relief, climate, drainage patterns, and soil composition. The ecological aspect refers to the components of ecosystems that sustain life on Earth through processes such as air purification, soil conservation, biomass creation, biodiversity support, rainfall effectiveness, and groundwater replenishment. The humanistic aspect pertains to human requirements for health, habitat, food, and behavioural conditions. Forest fires lead to biomass destruction, resulting in biodiversity loss, habitat destruction, and the endangerment of specific species. Additionally, forest fires alter water properties, leading to changes in water chemistry such as acid rain, shifts in runoff patterns, groundwater level fluctuations, and issues with water recharge. These problems create socio-economic disturbances due to forest degradation. RS and GIS technologies plays an important role in monitoring and analysing forest fires, providing valuable insights for forest management and mitigation efforts. By leveraging these tools, stakeholders can better understand the extent of forest degradation and implement effective strategies for prevention and recovery.

OBJECTIVES: To prepare a forest fire risk map of Chikmagalur district using Multi Criteria DecisionAnalysis (MCDA) techniques and to suggest measures to mitigate forest fire.

2. LITERATURE REVIEW

Fire plays an important role in ecological processes, including altering the composition of plant populations, conserving water, enhancing soil quality, and promoting biodiversity. Because of their role in natural plant succession, forest fires are an important mechanism for initiating new growth in the ecosystem. A total of 5.5 million hectares of forest land along the coasts of the Mediterranean Sea and the Marmara Region are considered fire areas of special concern (Akay et al., 2017). Integrated multi-criteria decision analysis i.e. offers quick and efficient answers to complex spatial problems by using GIS techniques (Jaiswal et al., 2002; Carmel et al., 2009). One of the multi-criteria approaches used in forestry is the analytical hierarchy process (Analytical Hierarchy Process; Coulter et al., 2006; Gulci, 2014). The model in Espirito Santo was designed to represent the probability of fires, applying statistical weights to the different factors that lead to them (Eugenio and dos Santos, 2016). Ahmed and Goparaju (2018) have attempted to correlate climatic parameters with forest fire. Various climatic parameters like Maximum Temperature, Precipitation, Solar radiation, Wind velocity, wet-days frequency and evapotranspiration of Himachal Pradesh and Uttarakhand are considered to show the impact of climate change on forest fires. Ajin R.S et al. (2016) formulated a risk index for forest fires in Western Ghats.

Weighted Overlay Analysis was carried out for Land Cover Type, Distance from road and settlements, Slope and Aspect. Weights for each parameter are based on forest fire risk index. Akay and Erdagon et al. (2017) worked on MCDA for FFR mapping in Mediterranean region of Turkey. Tree classes, Tree stage, Slope and Aspect parameters were considered for mapping risk zones. AHP is the MCDA used to bring out the weighted values for each parameter. Arvind C.P. and Binita K et al. (2019) worked on Geo-informatics based FFR mapping using Analytical Hierarchal Process (AHP) in Palamau Tiger Reserve, Jharkhand. The inputs considered to map risk zone were Fuel Type, Distance from road and settlement, Bare Soil Index, Aspect, Elevation and Slope. Pair-wise comparison was done and a Forest Fire Risk Index(FFRI) was made use. Motlagh M.G. et.al (2022) worked on models like Dong model and CFRISK model to map FFRZ in the region of southwest Iran. Along with the FFR parameters, distance from streams and distance from farmlands were considered with higher weights. Ridalin Lamat et.al (2021) mapped FFRZ using AHP for Northeast India. Satellite Data, Meteorological Data, Ancillary Data and MODIS data were considered as inputs. Thanh Van Hoang et.al. (2020) developed an early warning system for Vietnam city using Multi-Criteria Analysis and GIS methods. Landsat 7 images were considered for Land Use Land Cover mapping. Weights of each parameter were done using AHP. Regression Analysis was done to validate previous fire incidents with Forest Fire Risk Map generated.

3. MATERIALS AND METHODOLOGY

3.1 Study Area

The study area encompasses Chikmagaluru Circle within the bounds of Chikmagaluru district, situated between latitudes 12.9°N to 13.5°N and longitudes 75.5°E to 76.3°E. It boasts a diverse array of natural landscapes, including the Bhadra Tiger Reserve, Chikmagaluru, and Koppa Forest Divisions, all within the administrative jurisdiction of Chikmagaluru district. Covering an approximate total area of 6000 square kilometers, the circle spans elevations ranging from 600 to 1972 meters above sea level. Notably, the highest peak of Karnataka, Mullayanagiri hill, resides within the Chikmagaluru Circle. The area exhibits a rich variety of forest types, including evergreen, semi-evergreen, shola, dry deciduous, moist deciduous, and thorn forests.

Table 3.1: Chikmagaluru circle divisions and their area

Division	Area in Square Kilometers
Bhadra Wildlife	657.9
Chikmagaluru	3203.1
Koppa	1889.01

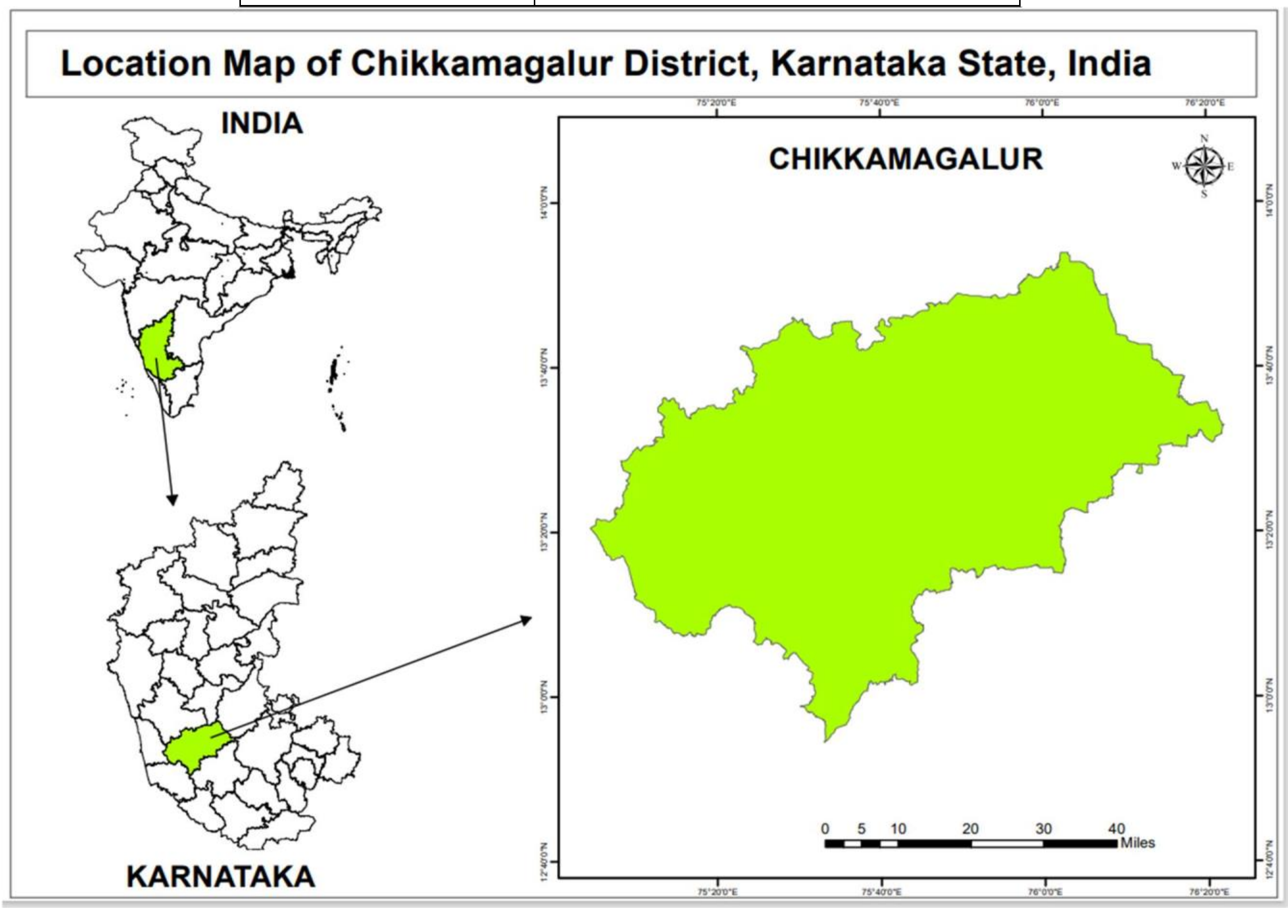


Figure 3.1: Representation of the study area in the form of maps

3.2 Data required and its sources

This section outlines the input parameters utilized in the study. The following data sources are used in the process of mapping Forest Fire Risk Zones (FFRZ) in Chikmagaluru Circle:

Table 3.2: The details of required data and its sources

Sl. No	Input data	Sources
1	Forest Type	KSRSAC
2	Forest Density	
3	Settlements Shapefile	
4	Roads Shapefile	
5	Elevation	Cartosat – DEM (Bhuvan portal)
6	Slope	
7	Aspect	
8	Maximum Temperature	KSNDMC
9	Maximum Relative Humidity	
10	Wind Speed	
11	Population Data	Projected Census Data
12	Past Fire Incidents	KFD

Software used: Quantum GIS, Arc GIS 10.8, Google Earth Engine, Microsoft Excel

WOA: Weighted Overlay Analysis: The Weighted Overlay Method in ArcGIS combines multiple raster datasets into a single output by assigning weights to each layer based on their importance. It is a powerful decision-making tool in spatial analysis, allowing users to prioritize criteria according to field knowledge and study area relevance.

AHP: Analytical Hierarchal Process: In Multi-Criteria Decision Analysis (MCDA), variables are weighted before pairwise comparisons. AHP, a type of MCDA, assigns values on a scale from 1 to 9, indicating relative importance. Saaty's scale sets diagonal values.

Table 3.3: Saaty's Scale of Importance

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Weak Importance one over another	Experience and Judgement slightly favour one activity over another
5	Essential or Strong Importance	Experience and Judgement strongly favour one activity over another
7	Demonstrated Importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute Importance	The Evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When Compromise is needed

Step1: **Pair wise comparison**

The criteria in the row and the criteria in the column are being contrasted.

Step2: Normalization

The matrix will be normalized in this stage by adding the values in each column. The column total is then divided by each entry's normalized score to produce the result. Each column's total should equal one.

Step 3: Analysis of Consistency

The consistency ratio is reached through three steps:

1. Determine the CF, 2. Determine the CI

5. Determine consistency ratio.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2.)$$

$$CR = \frac{CI}{RI} \quad (3.)$$

Table 3.4: Random Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

3.4 METHODOLOGY

The steps followed in the study to map risk zones are projected here

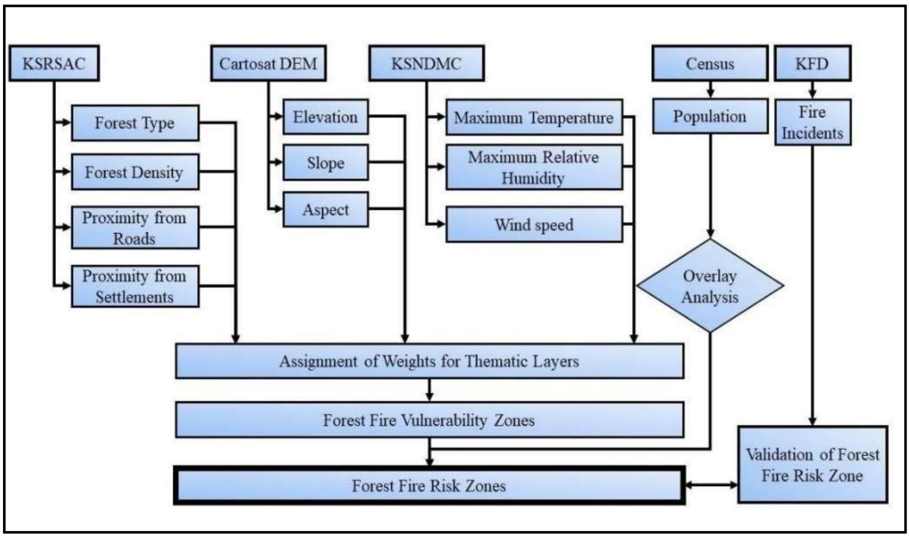
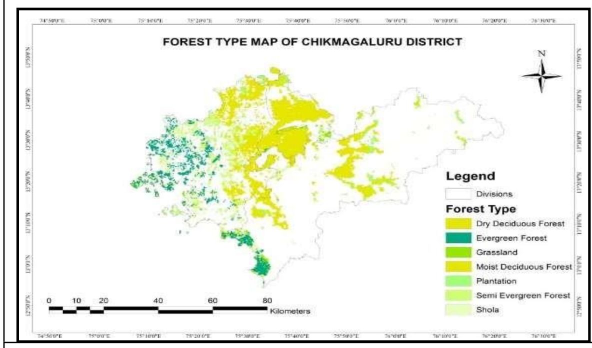


Figure 3.4: Forest Fire Risk Zone mapping Methodology

4. RESULTS AND DISCUSSION

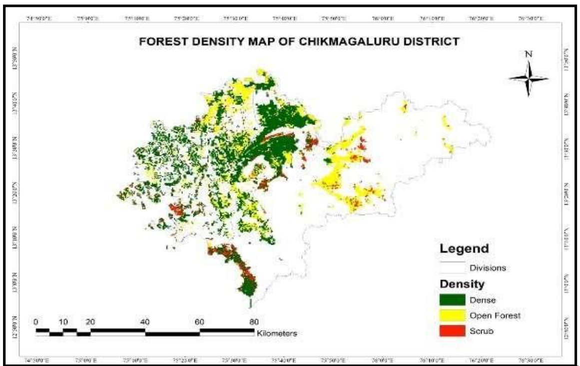
Vegetation, Topography, Anthropogenic, and Weather parameters are taken into consideration for FFRZ mapping.

4.1 Thematic layers:



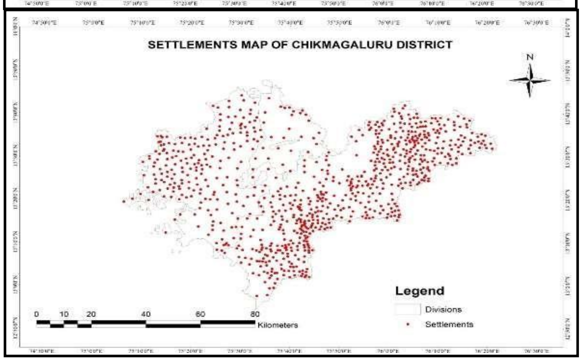
Forest Type	Ranking	Weightage
Dry Deciduous	7	15%
Moist Deciduous	6	
Shola	5	
Grassland	4	
Plantation	3	
Semi-Evergreen	2	
Evergreen	1	

Forest Type plays a prominent role in the severity and intensity of forest fire. The types of forests considered are Dry Deciduous, Evergreen, Grassland, Moist Deciduous, Plantation, Semi Evergreen and Shola forests. As deciduous forests shed their leaves more often, it is more prone to forest fire as compared to evergreen forests where it is green throughout the year. Hence dry deciduous forests ranking more.



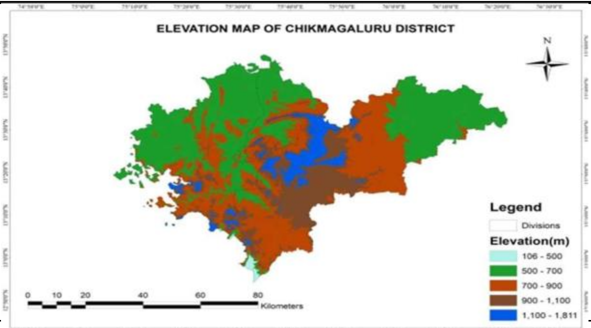
Forest Densities	Ranking	Weightage
Scrub	3	15%
Open	2	
Dense	1	

Density of the forests determines the spread of fires. Hence, making it key factor for fire risk assessment. Density refers to the fuel load that is available to burn. The close proximity of trees allows the flames to move from one tree to another easily, increasing the fire spread rate. It's tough to control these fires. Density is generally higher in core region of the forest where human intervention is less. Therefore, dense forest is given lower ranking compared to open and Scrub Forest.



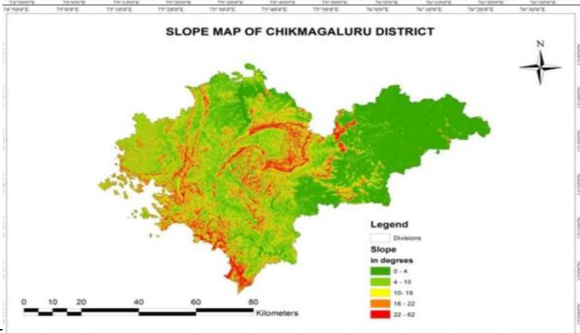
Proximity from Settlements(m)	Ranking	Weightage
0-200	5	16 %
200-400	4	
400-600	3	
600-800	2	
800-1000	1	

In Karnataka, 95% of forest fires stem from human activities, highlighting the urgency of addressing forest dweller negligence. Settlement data from KSRSAC was utilized to create buffer zones of varying distances in QGIS, prioritizing closer proximity to settlements due to their greater impact on fire incidence.



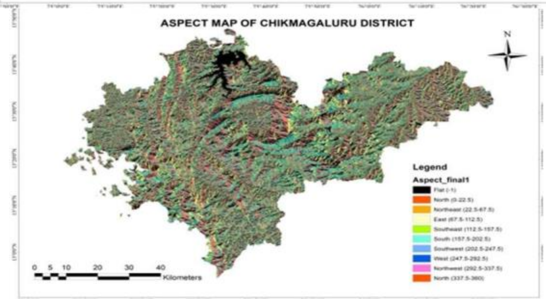
Elevation	Ranking	Weihtage
Below 500	5	10%
500-700	4	
700-900	3	
900-1100	2	
1100-1811	1	

In Karnataka, elevation influences fire spread, but less so than in steeper areas like the North East. Elevation is divided into five categories, with lower elevations prioritized due to higher human accessibility and fire risk.



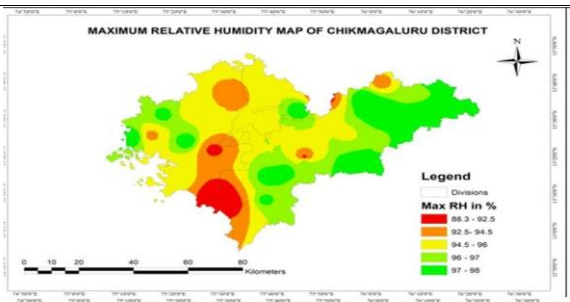
Slopes	Ranking	Weightage
0-4	1	9%
04-Oct	2	
Oct-16	3	
16-22	4	
22-62	5	

Though humans trigger forest fire, spread is generally due to the steep ness of forest. Higher the slope, faster is the spreading rate. Hence steeper slopes are given more ranking. Slopes are in degrees.
It is divided into 5 classes which are 0-4, 4-10, 10-16, 16-22 and 22-62.



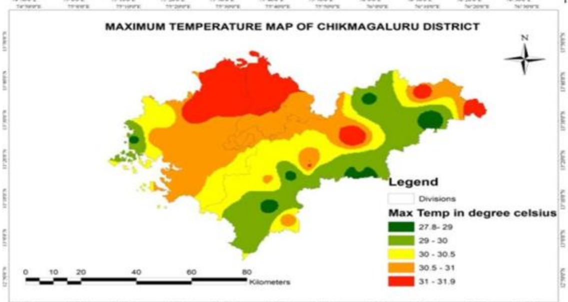
Slopes	Ranking	Weightage
Flat	1	9%
North	1	
North East	1	
East	3	
South East	4	
South	6	
South West	5	
West	2	
North West	2	

Aspect denotes the direction of the slope. Sun's exposure plays a prominent role in fire risk. Therefore, aspect should be considered. As Sun moves east to west along south, southern parts will be exposed more hence taking higher rankings.



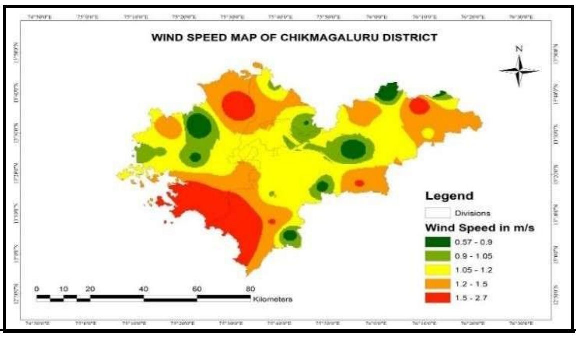
Max Temp	Ranking	Weightage
Below 92.5		2%
92.5-94.5	4	
94.5-96	3	
96-97	2	
97-99	1	

Relative humidity refers to the amount of moisture content present in the air with respect to maximum amount of moisture content that the air can hold. If the RH is low, it shows that the air is dryer. So, lower RH values are given lower ranking.



Max Temp (0C)	Ranking	Weightage
Below 29		5%
29-30	2	
30-30.5	3	
30.5-31	4	
31-32	5	

As the maximum temperature is more, more will be the evaporation, more will be the dryness. If the dryness is more, fire susceptibility is also high.
So, higher temperature values are given higher rankings. Inverse Distance Weightage is done from having 32 stations data using IDW tool in ArcGIS 10.8.
It was classified into 5 classes which are below 29, 29-30, 30-30.5, 30.5-31, 31-32.



Zones	Hectors	Weightage
Below 0.9	1	5
0.9-1.05	2	5
1.05-1.2	3	5
1.2-1.5	4	5

Wind speed will play a crucial role in the Spread of forest fire. The severity of the forest fire will depend on the speed of the wind. Higher wind speed values are given more ranking compared to lower values. Similar to the above steps, IDW is done To wind speed too. These are divided into 5 classes: below 0.9, 0.9-1.05, 1.05-1.2, 1.2-1.5, 1.5-2.7.

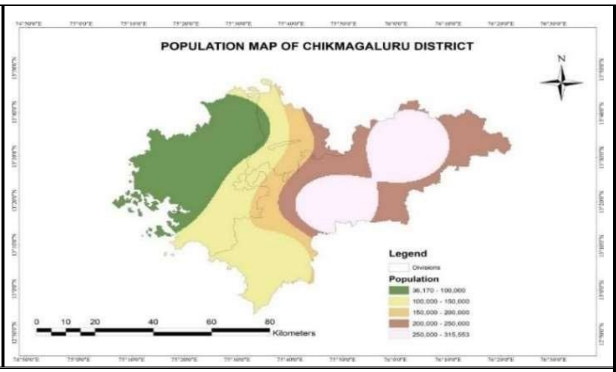


Figure 4.10: Map showing Population of Chikmagaluru District

Taluk-wise population data was obtained from District at a Glance report done by KSRSAC. Census data of 2011 is being projected to 2021 considering decadal changes. This data is considered after vulnerability mapping to map the risk zones. Thickly populated regions are more risk prone. Hence it is vital to consider population to map forest fire risk zones. The population data was mapped and IDW was done for the same.

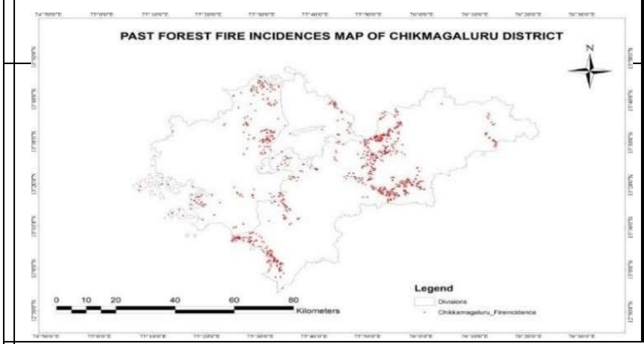


Figure 4.11: Map showing Past Forest Fire incidences of Chikmagaluru District

To validate the work done, past fire incidents shapefile was taken from KFD cell of KSRSAC. This is done after mapping FFRZ. Most of the points overlaid on risk zones showing high-risk zones.

Figure 4.12: Map showing Forest Risk

Raster Calculator tool in ArcGIS was used to overlay population data with vulnerability map to obtained FFR zones. A multiplicative function was performed to overlay both the layers.

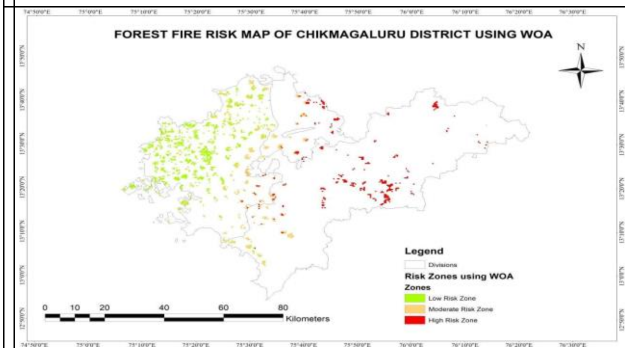


Figure 4.13: Map showing Forest Fire Risk Zones of Chikmagaluru District using WOA method Table 4.12: Area under different zones are shown in this table

ZONES	Area in hectares	Percentage
Low Risk zone	17343.62	52.64%
Moderate Risk	9263.49	28.11%
High Risk Zone	6342.07	19.25%

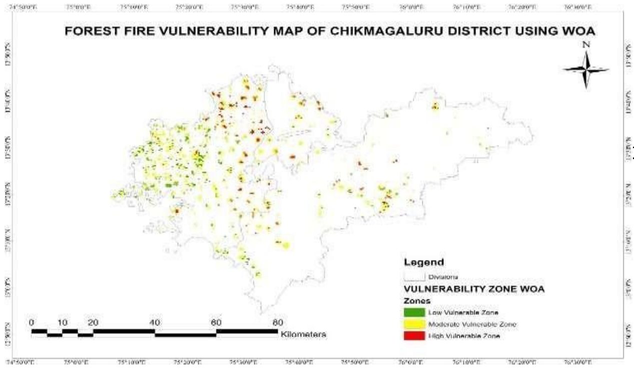


Figure 4.14: Map showing Forest Fire Vulnerability Zones of Zones of Chikmagaluru District using WOA method

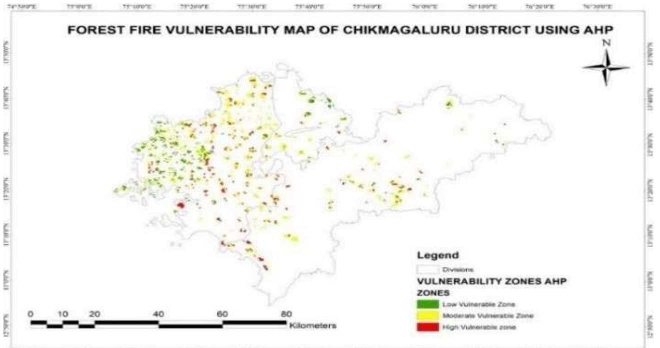


Figure 4.15: Map showing Forest Fire Vulnerability Zones of Zones of Chikmagaluru District using AHP method

5. CONCLUSION:

Forest Fire Risk Zonation mapping done here requires 12 thematic layers generation. All layers are rasterized using the reclassify tool, WOA and AHP methods were used. As a first step, vulnerable areas are mapped using thematic input layers. The demographic data is then overlaid to obtain the areas at risk of forest fire. Past fire incidences were used for validating risk zone map. Many points were in High-risk zone. Hence, proving the risk zone map is quite accurate. The two methods were compared in the study.

One of the biggest threats to the growth and preservation of forests today is forest fires. The findings in this study demonstrated that the creation of trust worthy fire risk maps is made possible by the integration of GIS technology and multi-criteria decision analysis tools (MCDA) with layers of data pertaining to the risk of forest fires, including wind speed, forest type, slope, density, distance to residence, main roads, etc. The accuracy and dependability of the system are validated by comparing the model findings with historical data. Karnataka is very susceptible to wildfires. 3000 hectares of forest land were affected by almost 865 significant fire occurrences that occurred between November 1, 2022, and June 12, 2023. A crucial part of identifying, evaluating, and reducing the disaster is played by RS and GIS. It has been demonstrated by using the semi-quantitative AHP approach in the evaluation is a useful addition, and this method beneficial when creating a real-time early warning system. Furthermore, the outcomes of project enhance comprehension of expert knowledge may be combined with scientific and technological uses of RS and GIS to enhance forest management. The use of GIS and remote sensing technology significantly increases the effectiveness of preventing and battling forest fires in terms of both money and time.

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ACKNOWLEDGEMENTS:

We gratefully acknowledge the contributions of all individuals who assisted in data collection and entry processing, without their contribution this study would not have been possible. Special thanks to the Director, Karnataka State Remote Sensing Applications Centre (KSRSAC), Bangalore, for their sponsorship and support.