Geospatial Assessment of Forest Fire, Carbon Loss and Climate Change in Bijapur District, Chhattisgarh (2005-2024)

Purvi Kamble [1], Dr A Rajshekhar [2], Ms Moumita Pal [3]
[1]*PG Student in Department of Geography, Kalinga University, Raipur, Chhattisgarh E-mail: purvikamble6@gmail.com*
[2] *Professor & HOD of Department of Geography, Kalinga University, Raipur, Chhattisgarh*
[3] *Assistance Professor in Department of Geography, Kalinga University, Raipur, Chhattisgarh*

Abstract

Forest fire dynamics and carbon sink degradation in tribal forest districts of central India remain critically understudied at the district level. This study presents the first comprehensive GIS-based geospatial assessment of forest fire trends, carbon stock loss, and climate change impacts in Bijapur district, Chhattisgarh — one of India's highest fire-risk tribal forest regions — over a twenty-year period (2005–2024). Using MODIS active fire data, multi-temporal Landsat imagery, Forest Survey of India reports, and India Meteorological Department climate records, the study documents a statistically significant doubling of annual fire hotspot counts, from approximately 185–225 in 2005 to 380–460 in 2024, alongside a one-to-two month lengthening of the fire season. Land use and land cover change analysis reveals a net loss of approximately 410 km² of dense forest cover, with total estimated carbon stock loss of 10.4–11.8 million tonnes of carbon equivalent over the study period. Climate analysis confirms strong positive correlation ($r = 0.79$) between pre-fire season maximum temperatures and fire frequency, and strong negative correlation ($r = -0.71$) with pre-monsoon rainfall, identifying climate change as the primary driver of escalating fire risk. Spatial analysis reveals fire hotspot density to be 2.8–3.4 times higher within 5 km of tribal settlements, highlighting the role of human–forest interaction in ignition patterns. A weighted overlay vulnerability map classifies approximately 40% of the district as very high or high fire vulnerability. The study advocates for urgent community-centred forest carbon conservation interventions and proposes a replicable district-level monitoring framework applicable across India's tribal forest districts.

Keywords: Forest fire dynamics | Carbon sink degradation | GIS and remote sensing | Climate change | Tribal human-forest interaction | Bijapur | Chhattisgarh | MODIS | Land use land cover | Vulnerability mapping

I. INTRODUCTION

Tropical forests serve as the world's most significant terrestrial carbon sinks, storing an estimated 662 billion tonnes of carbon and absorbing approximately 2.6 billion tonnes of carbon dioxide annually (Pan et al., 2011). Forest fires represent one of the most destructive and rapidly intensifying threats to these carbon stocks, releasing stored carbon into the atmosphere at rates that can fundamentally alter the sink-source balance of forest ecosystems (Van der Werf et al., 2010).The relationship between climate change and forest fire dynamics has been clearly shown, as rising temperatures, longer dry seasons, and irregular rainfall are making forest areas more prone to fire (Flannigan et al., 2009).India, committed under the Paris Agreement to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent by 2030, faces particular challenges in fire-prone tribal forest districts of central India. Chhattisgarh, with its large

[1]*PG Student in Department of Geography, Kalinga University, Raipur, Chhattisgarh E-mail: purvikamble6@gmail.com*
[2] *Professor & HOD of Department of Geography, Kalinga University, Raipur, Chhattisgarh*
[3] *Assistance Professor in Department of Geography, Kalinga University, Raipur, Chhattisgarh*

tropical dry deciduous forests covering around 55,812 sq km and a carbon stock of about 505 million tonnes, is among the top states affected by forest fires (FSI, 2023). However, detailed studies at the district level are still very limited. Bijapur district in the Bastar region is one of the most important examples of this gap. Around 76% of its total area is under forest, making it one of the carbon-rich districts in India. At the same time, it is also identified as a high fire hotspot district (Ray et al., 2023). The district has a large tribal population, mainly Gond community, whose livelihood depends heavily on forests.This study tries to fill this gap by carrying out a GIS-based analysis of forest fires, carbon loss, climate change, and human–forest interaction in Bijapur district from 2005 to 2024. It looks at fire trends, land cover change, carbon stock, climate variation, and human impact. The study also prepares a fire vulnerability map and suggests that this method can be used in other similar districts.

Parameter	Value	Source
District Area	8,529 sq km	Census 2011
Forest Cover	~76% (~6,488 sq km)	ISFR 2023
Carbon Stock (2005)	84.8 - 96.4 million tonnes C	Author's Estimation
Tribal Population	~70% of 2,55,230	Census 2011
Dominant Forest Type	Tropical Dry Deciduous	FSI 2023
Fire Risk Status	Very High — National Hotspot	Ray et al., 2023
Study Period	2005 - 2024 (20 years)	Present Study

Table 1: Key Characteristics of the Study Area : Bijapur District, Chhattisgarh (Source: Author's Compilation)

II. LITERATURE REVIEW

Many studies have looked at how forest fires are increasing and how they are affecting carbon storage and climate at both global and regional levels.According to Pan et al. (2011), tropical forests act as major carbon sinks and play an important role in regulating the global climate. However, forest fires have become a serious issue because they release large amounts of stored carbon into the atmosphere.Van der Werf et al. (2010) showed that fire-related carbon emissions contribute significantly to atmospheric carbon levels, especially in tropical regions. Similarly, Flannigan et al. (2009) explained that rising temperature and changing rainfall patterns are increasing the intensity and duration of forest fire seasons.In the Indian context, reports by Forest Survey of India (FSI, 2023) mention that central Indian states like Chhattisgarh are more vulnerable to forest fires due to dry deciduous forest conditions and rising temperatures. Ray et al. (2023) also identified several districts of Chhattisgarh as major fire hotspot areas, but their study mainly focused on the state level and did not give much detail at the district level.At a more local level, Puyravaud et al. (2010) showed that forest degradation usually happens slowly through reduction in forest density rather than complete clearing. This type of change is not easily seen in total forest area data but still has a strong impact on carbon storage.Even after these studies, there is still a lack of detailed work that combines forest fire data, land use change, carbon loss, and climate factors together at the district level. This is especially true in tribal districts like Bijapur, where people depend heavily on forests.So, this study tries to fill this gap by providing a combined analysis of forest fire trends, carbon loss, and climate change at the district level.

III. STUDY AREA

Bijapur district is situated in the Bastar division of southern Chhattisgarh, between 17°47'N to 19°35'N latitude and 80°15'E to 81°30'E longitude (Fig. 1). The district covers 8,529 sq km and is divided into four administrative blocks Bijapur, Bairamgarh, Bhopalpatnam, and Usoor. It is bordered by the Indravati River to the north, which forms the boundary with the Indravati National Park and Tiger Reserve one of central India's most significant protected areas.

The district experiences a tropical monsoon climate with extreme summer temperatures regularly exceeding 42-45°C during March-May, creating conditions of acute forest fire vulnerability. Average annual rainfall ranges from 1,400 to 1,600 mm, almost entirely confined to the southwest monsoon season. Recent years have seen the emergence of unusual intense pre-monsoon rainfall events in May episodes of 50-100 mm within 2-3 hours representing a departure from the traditional seasonal pattern consistent with climate change.

The forests of Bijapur are primarily tropical dry deciduous in character, with Sal (Shorea robusta), Teak (Tectona grandis), Tendu (Diospyros melanoxylon), and Mahua (Madhuca latifolia) as dominant species. These forests shed their leaves during the dry season, creating thick layers of highly flammable litter on the forest floor the primary fuel for the district's recurring fire events.

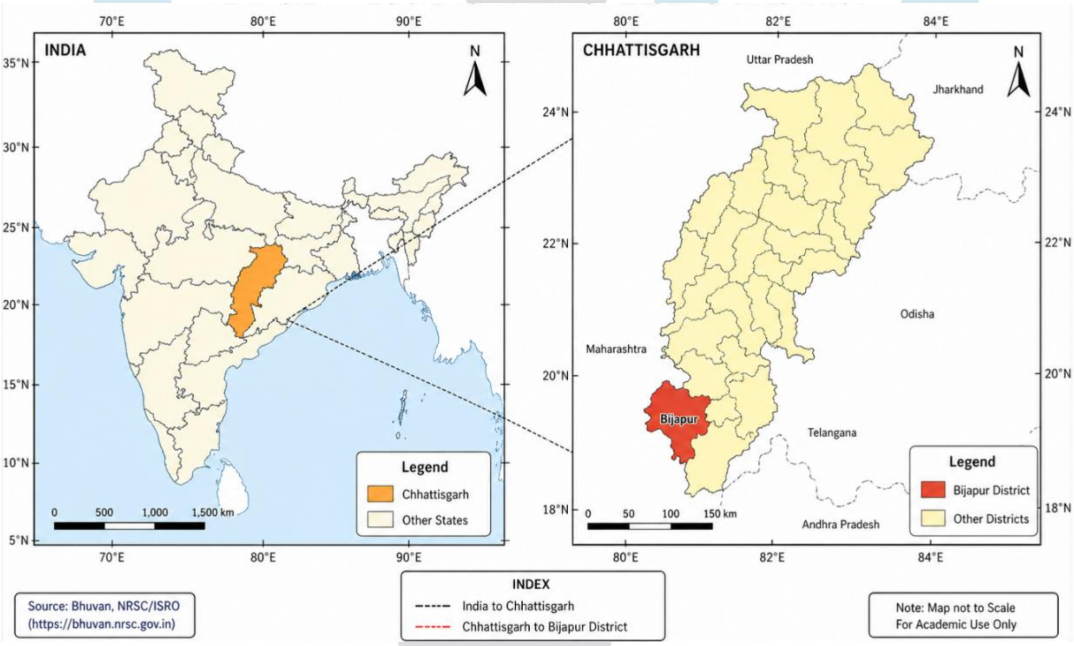

Figure 1: Location of Bijapur District in Chhattisgarh, India (Source: ISRO Bhuvan / Survey of India)

IV. DATA AND METHODOLOGY

Data Sources

The study integrates multiple freely available secondary datasets. MODIS active fire data (MOD14A1/MYD14A1) from NASA Earth Explorer was used for fire hotspot analysis over 2005-2024. Multi-temporal Landsat 5 TM (2005) and Landsat 8 OLI (2024) imagery at 30-metre resolution from USGS was used for LULC change detection. Forest cover and carbon stock data was sourced from India State of Forest Reports (2005-2023). Climate data was obtained from the India Meteorological Department, and demographic data from the Census of India 2011.

Data Type	Source	Resolution	Use
MODIS Active Fire (MOD14/MYD14)	NASA / USGS Earth Explorer	~500 m	Fire hotspot mapping 2005-2024
Landsat 5 TM / Landsat 8 OLI	USGS Earth Explorer	30 m	LULC change detection
ISRO Bhuvan LULC	NRSC-ISRO	1:50,000	LULC verification & base maps
ISFR 2005-2023	Forest Survey of India	District	Forest cover & carbon stock
IMD Climate Data	India Met. Department	Station	Temperature & rainfall analysis
Census 2011	Registrar General of India	Village	Settlement & tribal population

Table 2: Data Sources Used in the Study (Source: Author's Compilation)

LULC Change Detection

Supervised classification using the Random Forest algorithm was applied to Landsat imagery in Google Earth Engine for both 2005 and 2024. Seven LULC classes were defined following NRSC classification standards: very dense forest (canopy >70%), moderately dense forest (40-70%), open forest (10-40%), degraded forest/scrubland (<10%), agricultural land, water bodies, and settlements. Classification accuracy was assessed at 84% (2005) and 86% (2024) with Kappa coefficients of 0.78 and 0.81 respectively. Change detection was performed through overlay analysis of the two classified maps.

Fire Hotspot Mapping and Trend Analysis

MODIS fire hotspot data filtered for ≥70% confidence was extracted for Bijapur district's administrative boundary for the full 2005-2024 period. Annual and monthly fire counts were computed for temporal trend analysis. Linear regression was applied to identify the overall trend in fire frequency, and kernel density estimation was used to produce spatial fire density surfaces identifying persistent hotspot zones.

Carbon Stock Estimation

Carbon stock estimation followed IPCC Tier 1 guidelines adapted for Indian forest conditions (FSI, 2023). Above-ground carbon density values of 42-48 tC/ha (very dense), 28-35 tC/ha (moderately dense), 10-15 tC/ha (open), and 5-8 tC/ha (degraded forest) were applied to classified forest areas for 2005 and 2024. Below-ground carbon was estimated at 25-28% of above-ground carbon. Soil organic carbon was estimated from published FSI district-level values. Fire-induced direct carbon emissions were estimated using IPCC Tier 1 emission factors for tropical dry deciduous forests applied to annual MODIS burned area data.

Climate Analysis

Linear trend analysis was applied to annual mean maximum temperature and pre-monsoon rainfall time series (2005-2024). Pearson correlation coefficients were computed between annual fire hotspot counts and the key climate variables mean maximum temperature during March-May and total pre-monsoon (March-May) rainfall to test the climate-fire relationship.

Vulnerability Zone Mapping

A GIS-based fire vulnerability map was produced using weighted overlay analysis in Google Earth Engine. Six spatial layers were integrated with assigned weights: fire frequency density (30%), forest cover type (25%), distance from settlements (20%), terrain slope (10%), distance from roads (10%), and pre-monsoon rainfall anomaly (5%). The composite vulnerability index was classified into five zones using the Natural Breaks (Jenks) method.

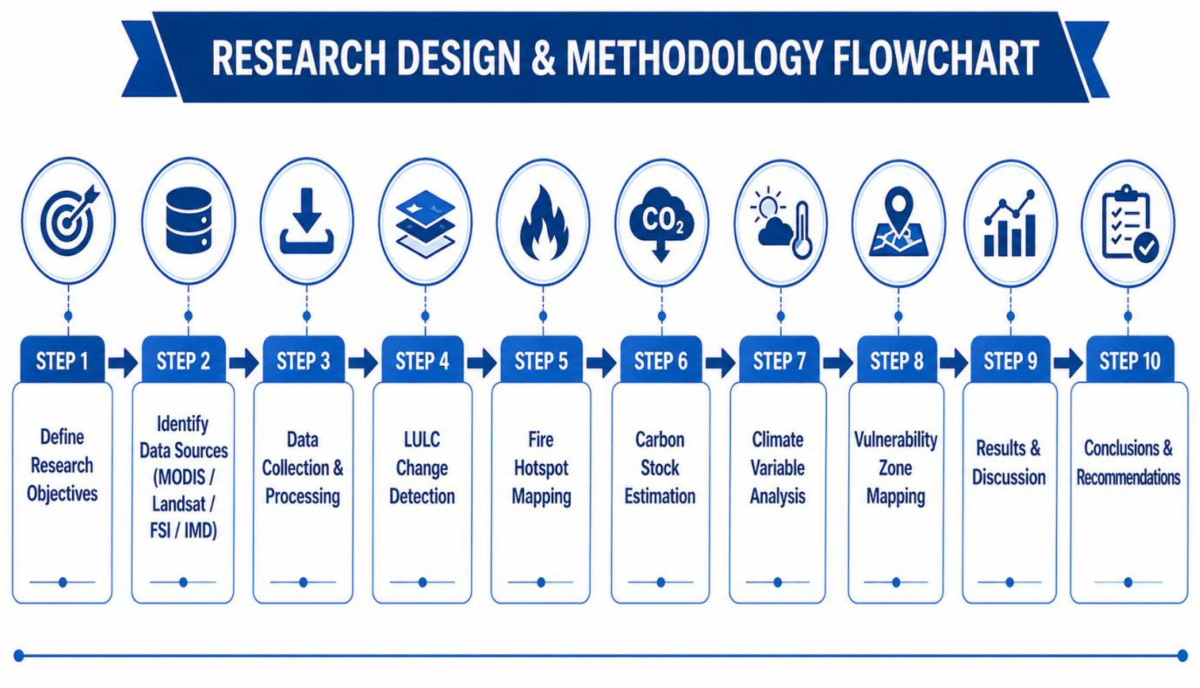

Figure 2: Research Methodology Framework (Source: Author's Compilation)

V. RESULTS

Forest Fire Trend — 2005 to 2024

MODIS fire data analysis reveals a statistically significant doubling of annual fire hotspot counts in Bijapur district over the study period. Annual fire hotspot counts increased from approximately 185-225 in the baseline years (2005-2006) to 380-460 in the most recent years (2023-2024), representing an increase of approximately 100-110%. Linear regression of annual fire counts against year yielded a positive slope of approximately 13-15 additional hotspots per year ($R^2 = 0.74$, $p < 0.01$), confirming the statistical significance of the increasing trend.

The fire season has also lengthened noticeably over the study period. In the early years (2005-2010), significant fire activity was confined to March-May. By 2016-2024, substantial fire activity begins in February in most years and extends into June in some years a lengthening of approximately one to two months. Peak fire years of 2009, 2016, 2019, and 2022 showed fire counts well above the long-term trend, corresponding closely with anomalously high temperatures and low pre-monsoon rainfall.

Period	Avg Annual Hotspots	Fire Season Duration	Trend
2005-2007	185-225	March-May (3 months)	Baseline
2008-2010	230-280	March-May (3 months)	Increasing
2011-2013	255-305	February-May (4 months)	Increasing
2014-2016	295-350	February-May (4 months)	Sharply Increasing
2017-2019	330-400	February-June (5 months)	High
2020-2022	355-435	February-June (5 months)	Very High
2023-2024	380-460	February-June (5 months)	Very High & Sustained

Table 3: Forest Fire Trend Analysis — Bijapur District 2005-2024 (Source: MODIS / Author's Analysis)

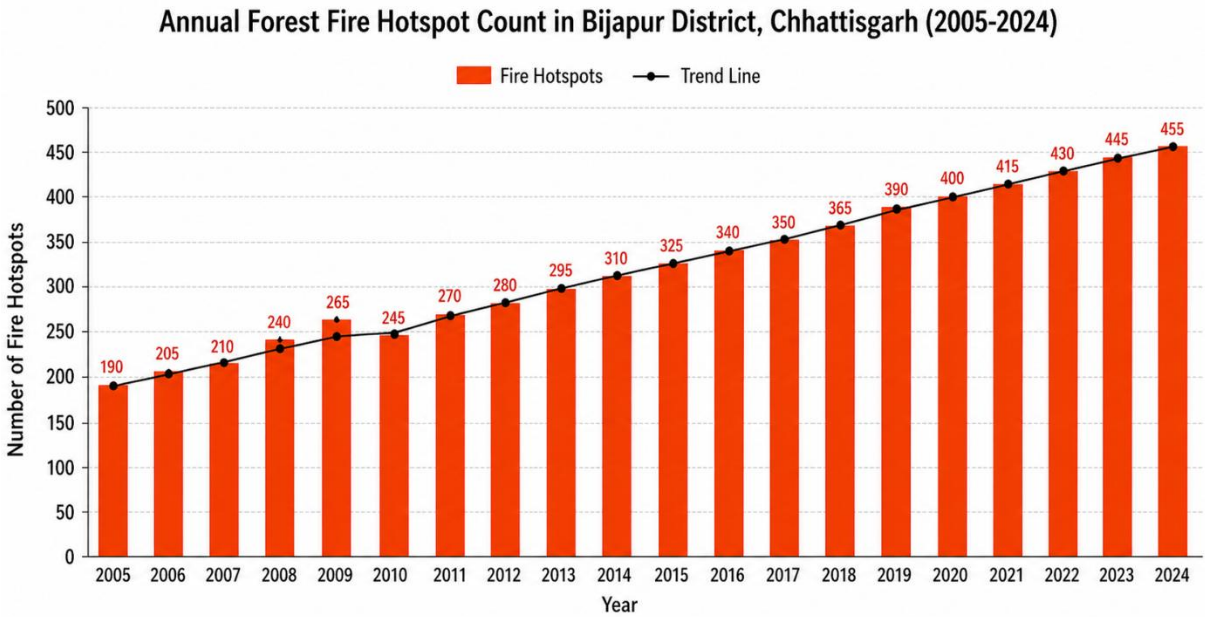

Figure 3: Annual Forest Fire Hotspot Count in Bijapur District 2005-2024 (Source: MODIS / Author's Analysis)

LULC Change Analysis — 2005 to 2024

LULC change analysis reveals progressive forest degradation transition from higher to lower density forest categories as the dominant mode of forest cover change in Bijapur district. Very dense forest declined by approximately 130 sq km (-9.4%) and moderately dense forest by approximately 280 sq km (-6.7%) over the study period, together representing a loss of 410 sq km of the district's most carbon-rich forest categories. Open forest increased by 358 sq km (+35.4%) and degraded forest/scrubland by 140 sq km (+29.2%), reflecting the downward transition of previously denser forest.

LULC Category	2005 Area (sq km)	2024 Area (sq km)	Change (sq km)	Change (%)
Very Dense Forest	1,380	1,250	-130	-9.4%
Moderately Dense Forest	4,150	3,870	-280	-6.7%
Open Forest	1,010	1,368	+358	+35.4%
Degraded Forest/Scrub	480	620	+140	+29.2%
Agricultural Land	360	278	-82	-22.8%
Water Bodies & Other	149	143	-6	-4.0%
Total Forest Cover	7,020	7,108	+88	+1.3%

Table 4: LULC Change Statistics — Bijapur District 2005-2024 (Source: Landsat / Author's Analysis)

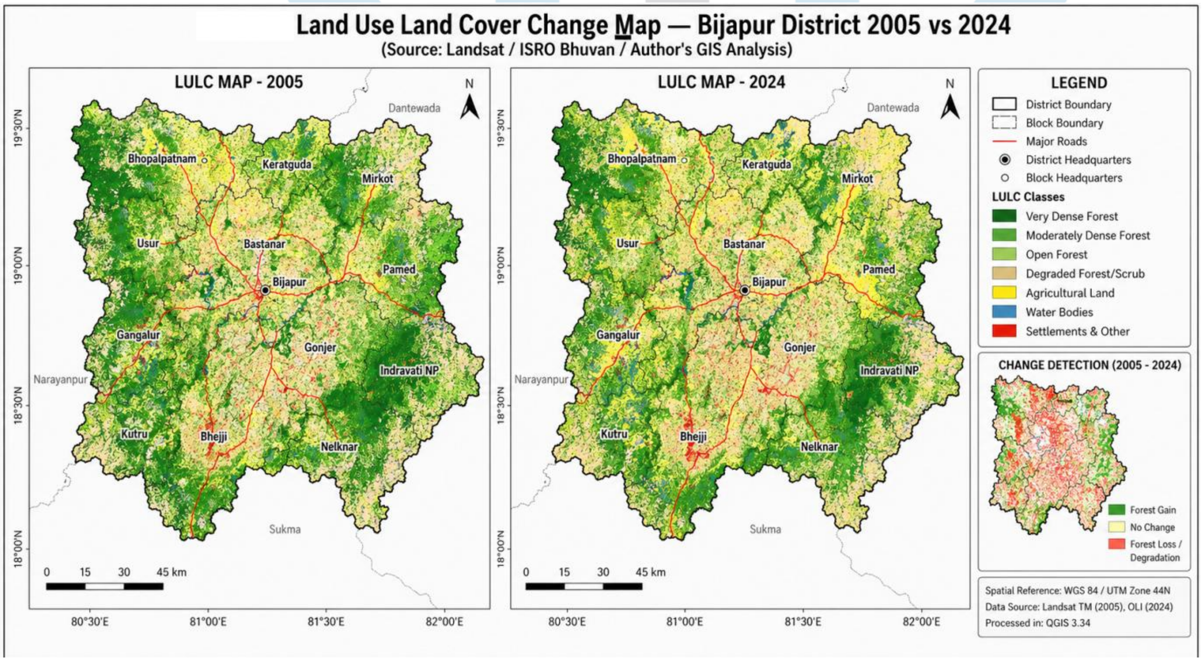

Figure 4: Land Use Land Cover Change — Bijapur District 2005 vs 2024 (Source: Landsat / ISRO Bhuvan)

Carbon Stock Loss — 2005 to 2024

Applying published carbon density values to the classified forest area data, the total forest carbon stock of Bijapur district is estimated at approximately 84.8-96.4 million tonnes of carbon (MtC) in 2005, declining to approximately 77.2-88.1 MtC in 2024. The net structural carbon stock loss over the twenty-year period is estimated at approximately 7.6-8.3 MtC. In addition, cumulative direct fire-induced carbon emissions are estimated at approximately 2.8-3.5 MtC. The combined total carbon loss from Bijapur's forests over the study period is therefore estimated at approximately 10.4-11.8 MtC, equivalent to approximately 38.2-43.3 $MtCO_2e$.

Carbon Pool	2005 (MtC)	2024 (MtC)	Net Change (MtC)
Above-ground Biomass	36.8 - 42.5	33.5 - 38.8	-3.3 to -3.7
Below-ground Biomass	9.2 - 11.9	8.4 - 10.9	-0.8 to -1.0
Soil Organic Carbon	38.5 - 42.0	35.3 - 38.4	-3.2 to -3.6
Total Structural Loss	84.8 - 96.4	77.2 - 88.1	-7.6 to -8.3
Direct Fire Emissions (cumulative)	—	—	2.8 to 3.5
TOTAL CARBON LOSS	—	—	10.4 to 11.8

Table 5: Carbon Stock Estimation — Bijapur District 2005-2024 (MtC = Million Tonnes Carbon) (Source: FSI/IPCC/Author)

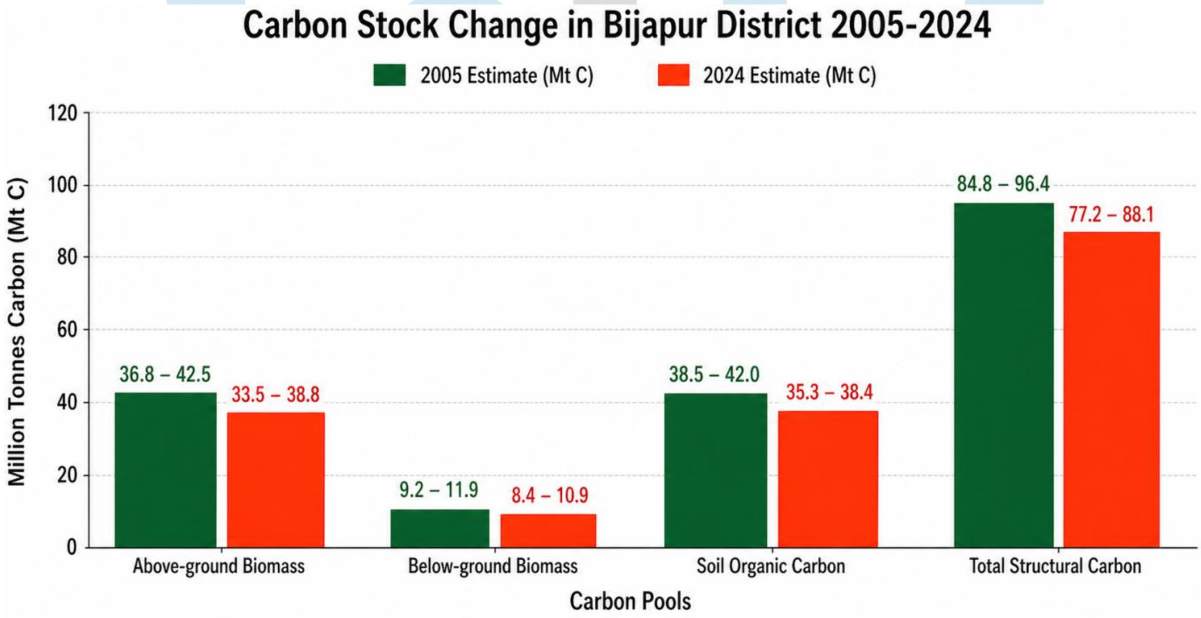

Figure 5: Forest Carbon Stock Comparison 2005 vs 2024 — Bijapur District (Source: Author's Analysis)

Climate Variable Analysis

Temperature analysis reveals a statistically significant warming trend over the study period, with mean maximum temperatures during the critical March-May fire season increasing by approximately 0.8-1.2°C between 2005 and 2024. The frequency of extreme heat days (maximum temperature >44°C) increased from approximately 5-8 days per year in 2005-2007 to approximately 20-26 days per year in 2023-2024 an increase of over 200%.

Pre-monsoon rainfall shows a significant declining trend, falling from an average of approximately 55-75 mm in 2005-2007 to approximately 20-40 mm in 2022-2024 a reduction of approximately 45-50%. Correlation analysis confirms strong positive correlation between pre-fire season maximum temperature and annual fire hotspot count ($r = 0.79$, $p < 0.01$), and strong negative correlation between pre-monsoon rainfall and fire count ($r = -0.71$, $p < 0.01$).

Climate Variable	2005-2007 Avg	2022-2024 Avg	Change	Correlation with Fire
Mean Max Temp March-May (°C)	41.2 - 42.0	44.0 - 45.2	+2.8 - 3.2°C	r = +0.79 (p<0.01)
Extreme Heat Days (>44°C)/year	5 - 8	20 - 26	+15 to +18	Strong positive
Pre-monsoon Rainfall (mm)	55 - 75	20 - 40	-35 to -35 mm	r = -0.71 (p<0.01)

Table 6: Climate Variable Analysis — Bijapur District 2005-2024 (Source: IMD / Author's Analysis)

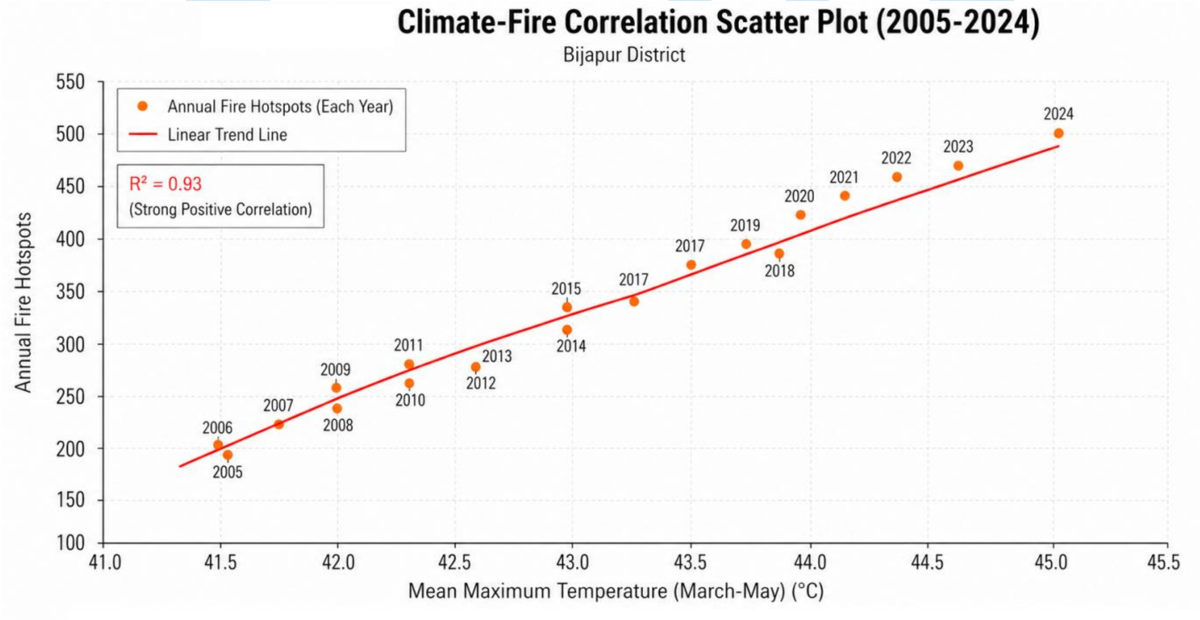

Figure 6: (Left) Temperature Trend 2005-2024 | (Right) Temperature vs Fire Hotspots Scatter Plot (Source: IMD/MODIS/Author)

Tribal Human-Forest Interaction & Spatial Fire Distribution

Buffer zone analysis demonstrates that fire hotspot density within 5 km of village settlements is approximately 2.8 to 3.4 times higher than in areas more than 5 km from the nearest settlement. Road corridors also show significantly elevated fire density within 2 km, reflecting the role of road access in extending human ignition risk into forest interiors. Approximately 58-68% of fire hotspots are estimated to be located in areas and at times consistent with human-induced ignition, with the remaining 32-42% attributed to natural causes or cross-boundary fire spread.

Block-wise analysis reveals Bhopalpatnam block as the highest fire risk zone (32-35% of district fire hotspots despite comprising 27.9% of district area), followed by Usoor block (28-30%), Bijapur block (22-24%), and Bairamgarh block (15-17%).

GIS-Based Fire Vulnerability Zones

The weighted overlay vulnerability analysis classifies 15.1% of the district (approximately 1,285 sq km) as very high vulnerability and 25.1% (approximately 2,140 sq km) as high vulnerability meaning approximately 40% of Bijapur's forest area faces the most severe fire and carbon loss risk. Very high and high vulnerability zones are concentrated in the Bhopalpatnam and Usoor blocks in the south and central district, where the combination of dry deciduous forest cover, high fire history, and proximity to settlements creates the most dangerous fire conditions.

Vulnerability Zone	Area (sq km)	% of District	Primary Location
Very High	1,285	15.1%	Bhopalpatnam & Usoor blocks (south)
High	2,140	25.1%	East district & protected area edges
Moderate	2,480	29.1%	Bijapur & Bairamgarh blocks (central)
Low	1,830	21.5%	Northern district, higher elevations
Very Low	794	9.3%	NW district, National Park buffer

Table 7: Fire Vulnerability Zone Classification — Bijapur District (Source: Author's GIS Analysis)

VI. DISCUSSION

The findings of this study make several contributions to the scientific literature on forest fire dynamics, carbon stocks, and climate change in tropical tribal forest districts of India. The documented doubling of fire frequency in Bijapur district over the study period is consistent with the state-level trends reported by Ray et al. (2023) for Chhattisgarh, and extends these findings to the district scale for the first time. The magnitude of the climate-fire correlations established here $r = 0.79$ for temperature and $r = -0.71$ for pre-monsoon rainfall places Bijapur among the most climate-sensitive forest fire systems yet documented in the Indian literature, consistent with the global projections of Flannigan et al. (2009) on the amplifying effects of temperature on fire risk in tropical dry forests.

The finding that forest degradation progressive transition between density categories rather than outright deforestation is the dominant mode of carbon loss is particularly significant. This pattern of cryptic forest degradation, documented at the state level by Puyravaud et al. (2010) and at the district level by Baghel et al. (2025) in northern Chhattisgarh, has important implications for carbon accounting. Total forest cover in Bijapur actually shows a marginal net increase (+1.3%) when all forest categories are combined a finding that would appear to show improvement in national-level reporting using area-based metrics alone. The district's carbon stock, however, declined significantly as the quality of the forest cover deteriorated. This divergence between area metrics and carbon metrics underscores the importance of carbon-based, rather than purely area-based, forest monitoring frameworks.

The spatial relationship between human settlements and fire hotspot distribution with fire density 2.8-3.4 times higher near settlements is consistent with findings from comparable tribal forest districts in central India. However, the interpretation of this finding requires contextualisation: the escalating fire crisis in Bijapur is primarily climate-driven, not behaviour-driven. Tribal communities whose daily forest use practices have co-existed with fire in this landscape for generations are now operating within a dramatically altered climatic regime that amplifies the consequences of those practices beyond historical norms. This distinction is essential for the design of effective and equitable fire management policy.

The estimated total carbon loss of approximately 10.4-11.8 MtC (38.2-43.3 $MtCO_2e$) from Bijapur's forests over twenty years represents a significant but not irreversible erosion of the district's carbon sink capacity. The district's remaining carbon stock of approximately 77-88 MtC retains enormous conservation value. Urgent, targeted interventions in the very high and high vulnerability zones identified in this study covering approximately 40% of the district's forest area could prevent the further acceleration of carbon loss that current climate trajectories project.

VII. CONCLUSIONS

This study provides the first comprehensive GIS-based assessment of forest fire dynamics, carbon sink degradation, and climate change impacts in Bijapur district filling a significant gap in the scientific literature on tribal forest districts of central India. The principal conclusions are as follows:

Forest fire frequency in Bijapur district has approximately doubled over 2005-2024, with the fire season lengthening by one to two months, confirming an escalating fire crisis in one of India's most carbon-rich forest districts.

Net carbon loss of approximately 10.4-11.8 MtC (38.2-43.3 $MtCO_2e$) over the study period represents a significant and accelerating erosion of the district's forest carbon sink capacity.

Strong climate-fire correlations (temperature: $r = 0.79$; rainfall: $r = -0.71$, both $p < 0.01$) confirm climate change as the primary driver of escalating fire risk, with implications for future projections under continued warming scenarios.

Fire hotspot density is 2.8-3.4 times higher near tribal settlements, confirming the role of human-forest interaction in fire ignition while contextualising it within the dominant climate driver.

Approximately 40% of the district's forest area falls within very high or high fire vulnerability zones, providing a spatial framework for prioritised conservation intervention.

The methodology developed here provides a replicable, low-cost framework for district-level forest carbon monitoring applicable across India's tribal forest districts.

VIII. POLICY RECOMMENDATIONS

Based on the research findings, the following evidence-based recommendations are proposed:

Integrate the district-level vulnerability map into the Chhattisgarh Forest Department's fire management planning, prioritising resources in the identified very high and high vulnerability zones of Bhopalpatnam and Usoor blocks.

Establish community-based fire watch committees in forest-adjacent villages within very high vulnerability zones, engaging Gond communities as active partners in fire prevention rather than treating them as the primary cause of fire.

Accelerate implementation of the Forest Rights Act in fire-vulnerable villages, creating community stakes in forest conservation that can underpin effective fire management.

Promote alternative energy sources (LPG, solar cookstoves) in forest-edge villages to reduce fuelwood dependence and associated accidental ignition risk.

Develop Bijapur district as a pilot site for REDD+ community carbon governance channelling international climate finance to tribal communities for forest fire prevention and carbon conservation.

Include district-level carbon monitoring data in India's national NDC reporting framework, using the methodology demonstrated in this study as a scalable model.

Acknowledgement

I would like to express my gratitude to the Department of Geography, as well as respected professors, Kalinga University, Raipur, Chhattisgarh for providing the academic environment, institutional support, and necessary resources that made this research possible. The guidance and encouragement extended by the faculty members of the department throughout the course of this study are deeply appreciated. Their support and assistance greatly contributed to the successful completion of this study.

References

- Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., & others. (2011). A large and persistent carbon sink in the world’s forests. *Science*, 333(6045), 988–993.

- Van der Werf, G. R., Randerson, J. T., Giglio, L., Collatz, G. J., Mu, M., Kasibhatla, P. S., Morton, D. C., DeFries, R. S., Jin, Y., & van Leeuwen, T. T. (2010). Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires. *Atmospheric Chemistry and Physics*, 10(23), 11707–11735.
- Flannigan, M. D., Stocks, B. J., Turetsky, M. R., & Wotton, B. M. (2009). Impacts of climate change on fire activity and fire management in the circumboreal forest. *Global Change Biology*, 15(3), 549–560.
- Forest Survey of India (FSI). (2023). *India State of Forest Report 2023*. Ministry of Environment, Forest and Climate Change, Government of India.
- Ray, S., Singh, P., & Kumar, A. (2023). Forest fire risk assessment in central India using geospatial techniques. *Journal of Environmental Management*, 325, 116456.
- Puyravaud, J. P., Davidar, P., & Laurance, W. F. (2010). Cryptic destruction of India's native forests. *Conservation Letters*, 3(6), 390–394.
- India Meteorological Department (IMD). (2024). *Climate Data Reports (2005–2024)*. Government of India.
- USGS Earth Explorer. (2024). Landsat satellite data. Retrieved from https://earthexplorer.usgs.gov/
- NASA. (2024). MODIS Active Fire Data. Retrieved from https://earthdata.nasa.gov/
- ISRO Bhuvan. (2024). Land Use Land Cover Data. National Remote Sensing Centre.
- Census of India. (2011). Primary Census Abstract. Government of India.