

**CHARACTERISING FOREST FIRE PATTERN OVER INDIA
IN LAST TWO DECADES
(2001-2020)**

Dissertation submitted in the partial fulfilment of the requirements for the award of
the degree of

MASTER OF SCIENCE

Submitted by
Utsav Biswas

Supervisor
Prof. P.K. Joshi



Spatial Analysis and Informatics Lab
School of Environmental Sciences
Jawaharlal Nehru University
New Delhi-110067

2023

ACKNOWLEDGEMENT

“I slept and dreamt that life was joy. I awoke and saw that life was service. I acted and behold, service was joy” – Rabindranath Tagore

I would like to express my sincere gratitude to all those who have contributed to the completion of this MSc thesis.

First and foremost, I would like to thank my supervisor Prof. P.K. Joshi, for providing me the opportunity to learn under his guidance, for his invaluable guidance, support, and expertise throughout the entire research process. His insightful and timely feedback and constructive criticism have been instrumental in shaping this thesis.

I would also like to thank Prof. Paulraj Rajamani, Dean of School of Environmental Sciences (SES) who valuable resources and of the school during my course work.

I am also deeply thankful to the faculty members of the School of Environmental Sciences (SES) at Jawaharlal Nehru University (JNU) for their knowledge, inspiration, and encouragement during my academic journey. Their dedication to excellence has motivated me to strive for the highest standards in my work.

I am thankful to the National Aeronautics and Space Administration (NASA), USA and Google for providing the necessary datasets and platforms to conduct this study.

I am very grateful to Dr.Susanta Mahato, post-doctoral scholar for his invaluable inputs at all stages of my study and for being a guide, mentor and friend. I would also like to thank the other lab members - PhD scholars Sonali Sharma, Akshita Choudhary and Jayshree Das for their timely inputs and guidance. I also thank Mr. Ishwar Chand for his constant efforts in keeping the laboratory functioning.

I am incredibly fortunate to have such an amazing network of family and friends who have stood by me throughout my MSc journey. Their unwavering encouragement, understanding, and patience have been the cornerstone of my success. To my family, I am deeply grateful for their unconditional love and support. They have been my rock, providing a sense of stability and belief in my abilities even during the most challenging times. Their unwavering faith in me has fuelled my determination to overcome

obstacles and pursue my academic goals. Their presence at every step of this journey has meant the world to me.

I am also indebted to my friends, whose love and support have been invaluable. Their belief in my capabilities and their constant words of encouragement have lifted my spirits and inspired me to push beyond my limits. Whether it was through late-night study sessions, brainstorming ideas, or simply lending an empathetic ear, their unwavering support has been a constant source of strength and motivation. Some of the special ones are Jayita, Ruthi, Sakshi, Rani, Suraj, Amar, Kajal, Bhawana, Neha, Shibam, Sudip, Neel and Utathya.

Their understanding of the demands and sacrifices required to pursue higher education has been truly remarkable. They have patiently listened to my concerns, celebrated my achievements, and provided the much-needed emotional support during times of stress and uncertainty. Their belief in my abilities has served as a constant reminder of my potential and has propelled me forward even when self-doubt crept in.

I am profoundly grateful to my family and friends for their unwavering presence in my life. Their support has gone beyond mere words; it has been demonstrated through their actions and unwavering commitment to my personal and academic growth. Their belief in me has instilled a sense of confidence and resilience that I will carry with me throughout my future endeavours.

The equipment from the Sustainable Natural Resource Use in Arctic and High Mountains Areas (SUNRAISE) and Urban Resilience and Adaptation for India and Mongolia (URGENT) projects, co-funded by Erasmus+ Programme of the European Union are duly acknowledged.

Finally, I would like to acknowledge the contributions of all the researchers, authors, and institutions whose works I have referenced in this thesis. Their groundbreaking research has provided a solid foundation for my study.

This thesis would not have been possible without the collective efforts and support of all these individuals and organizations. I am truly grateful for their contributions.

Date: 12 June 2023

New Delhi

(Utsav Biswas)

TABLE OF CONTENTS

CERTIFICATE.....	1
ACKNOWLEDGEMENT.....	2
LIST OF FIGURES.....	7
LIST OF TABLES.....	9
LIST OF ABBREVIATIONS.....	11
CHAPTER 1.....	12
INTRODUCTION.....	12
1.1 Forest Fires – Global context.....	12
1.2 Forest types and Fires – Indian context.....	13
1.3 Contribution of Remote Sensing to the study of Forest Fires.....	13
1.4 Drivers of Forest Fires.....	14
1.5 Objectives of the study.....	15
CHAPTER 2.....	16
STUDY AREA.....	16
CHAPTER 3.....	18
MATERIALS AND METHODOLOGY.....	18
3.1 Materials.....	18
3.1.1 Forest Fire data.....	18
3.1.2 Land use data.....	18
3.1.3 Climatic, Biophysical, Topographic & other parameters’ data for variables that can influence Forest Fires.....	18
3.2 Methodology.....	20
3.2.1 Methodological Framework (Objective 1).....	20
3.2.2 Methodological Framework (Objective 2).....	21
3.2.3 Extraction of Forest Fire Points.....	22
3.2.4 Forest types.....	23
3.2.5 Spatial Distribution Pattern.....	23
3.2.6 Forest Fire Point Density Maps.....	23
3.2.7 Hotspot analysis.....	23
3.2.8 Linear Trend Analysis.....	24
3.2.9 Burned area.....	25

3.2.10 Multicollinearity Assessment.....	25
3.2.11 Forest Fire Occurrence Conditioning Factors.....	25
3.2.12 Forest Fire Occurrence Probability.....	27
3.2.13 Forest Fires and Sustainable Development Goals (SDGs).....	29
CHAPTER 4.....	30
RESULTS.....	30
4.1 Spatial Distribution of Forest fires.....	30
4.2 State and Union Territory wise distribution of Forest Fire.....	31
4.3 Annual Forest Burned Area and Forest Fire Occurrences.....	34
4.4 Decadal Cumulative Hotspot.....	34
4.4.1 Two decadal analysis (2001-2020).....	34
4.4.2 First decade (2001-2010).....	38
4.4.3 Second decade (2011-2020).....	38
4.5 Burned area.....	41
4.5.1 Overall trend in burned area.....	41
4.5.2 First Decade (2001-2010).....	41
4.5.3 Second Decade (2011-2020).....	43
4.6 Selecting months for trend analysis.....	43
4.7 Trend analysis.....	44
4.7.1 Two decadal trend analysis.....	44
4.7.2 First decade (2001-2010).....	46
4.7.3 Second decade (2011-2020).....	49
4.8 Area covered under different forest types.....	50
4.9 Spatial distribution of forest-type wise burned area.....	51
4.10 Burned area distribution in different states and union territories.....	52
4.11 Analysis of variable contributions.....	55
4.12 Jackknife Test of Training and Testing variables	55
4.13 Forest Fire Occurrence Probability.....	57
4.14 Validation - Analysis of omission/commission.....	57
4.15 Receiver Operating Characteristic (ROC) Curve.....	58
CHAPTER 5.....	59
DISCUSSION.....	59
5.1 Yearly Forest fire occurrences.....	59
5.2 Monthly Forest fire occurrences.....	59

5.3 Hotspot Analysis.....	60
5.4 Forest Fire Drivers.....	61
5.5 Occurrence Conditioning Factors and Forest Fire Occurrence Probability	61
5.6 Impacts of Forest fires on SDGs.....	62
5.7 Forest Fire Prevention Policies.....	64
CHAPTER 6.....	66
CONCLUSION.....	66
REFERENCES.....	69
SUPPLEMENTARY TABLES.....	77

LIST OF FIGURES

Figure 1: The location of study area, (a) study area and nearby region with the different land cover types, (b) the forest type map of India in the year 2001 and (c) the forest type map of India in the year 2020. [Reclassified from LULC ESA-CCI v 0.007cds and v 2.1.1 300m yearly data based on the modified LULC codes for the world.....	17
Figure 2: Methodological framework of the study used to achieve Objective 1.....	20
Figure 3: Methodological framework of the study used to achieve Objective 2.....	21
Figure 4: Spatial distribution of forest fire incidences (a) in last two decades (b) in 2001 and (c) in 2020	22
Figure 5: Spatial distribution of temperature, human interferences and topographical factors as drivers of forest fire occurrence.....	26
Figure 6: Spatial distribution of atmospheric and biophysical factors as drivers of forest fire occurrence.....	27
Figure 7: Spatial distribution of forest fire count per pixel (625 sqkm) for (a) 2001 to 2020, (b) 2001 to 2010 and (c) 2011 to 2020.....	30
Figure 8: Frequency of forests fires in India between the years (a) 2001 and 2020, (b) Decade - I (2001-2010) and (c) Decade - II (2011-2020); (d) shows the yearly burned area (sqkm) and corresponding number of forest fire occurrences.....	33
Figure 9: Decadal Cumulative Hotspot map of India month-wise from 2001 to 2020 using z-scores and 25 km × 25 km grids. (<11.37=low, 11.37 to 24.72 = moderate, 24.72 to 38.08 = high, >38.08 = very high).....	35
Figure 10: Monthly variation in location and intensity of hotspots in India from January to June.....	36
Figure 11: Monthly variation in location and intensity of hotspots in India from July to December.....	37
Figure 12: Decadal Cumulative Hotspot map of India month-wise from 2001 to 2010 using z-scores and 25 km × 25 km grids. (<11.37=low, 11.37 to 24.72 = moderate, 24.72 to 38.08 = high, >38.08 = very high).....	39
Figure 13: Decadal Cumulative Hotspot map of India month-wise from 2011 to 2020 using z-scores and 25 km × 25 km grids. (<11.37=low, 11.37 to 24.72 = moderate, 24.72 to 38.08 = high, >38.08 = very high).....	40

Figure 14: (a) Yearly burned area (sqkm) from 2001 to 2020 and an overall increasing trend; spatial distribution of yearly forest burned area from (b) 2001 to 2010 and (c) 2011 to 2020; The year-wise forest burned area (sqkm) and overall trend is shown from (d) 2001 to 2010 and (e) 2011 to 2020.....42

Figure 15: Number of forest fire occurrences in each month over the years from 2001 to 2020. A horizontal line representing the threshold is shown at the level of 1500.....44

Figure 16: Two decadal trend in Regression slope (β), Coefficient of Determination (R^2), Coefficient of Variation (CV) and P value of forest fire density over India in the months of February, March, April and May in the years 2001 to 2020.....45

Figure 17: Decadal trend in Regression slope (β), Coefficient of Determination (R^2), Coefficient of Variation (CV) and P value of forest fire density over India in the months of February, March, April and May in the years 2001 to 2010.....48

Figure 18: Decadal trend in Regression slope (β), Coefficient of Determination (R^2), Coefficient of Variation (CV) and P value of forest fire density over India in the months of February, March, April and May in the years 2011 to 2020.....50

Figure 19: Decadal spatial distribution of forest-type wise burned area from (a) 2001 to 2010 and (b) 2011 to 2020; (c) shows the comparison of two decadal amount of burned area in each forest type.....52

Figure 20: Jackknife for training data.....55

Figure 21: Jackknife test for testing data.....55

Figure 22: Spatial distribution of the probability of occurrence of Forest Fires.....57

Figure 23: Omission rate and predicted area as a function of the cumulative threshold.....58

Figure 24: Receiver Operating Characteristic (ROC) curve for the above data.....59

Figure 25: Impact of forest fires on Sustainable Development Goals (SDGs).....63

LIST OF TABLES

Table 1: Descriptions of datasets used in this study.....	19
Table 2: The different factors, their spatial resolution and range.....	25
Table 3: Number of forest fire occurrences, forest fire occurrences/area of state, rank, count difference and rank difference of every state and union territory that witnessed at least one forest fire occurrence in between 2001 and 2020.....	31
Table 4: Area covered (sqkm) under different forest types in India in the years 2001 and 2020, along with the difference in area. The positive and negative values in area difference indicate an increase and decrease respectively in forest area in the year 2020 compared to the year 2001.....	51
Table 5: State-wise Forest burned area (sqkm) and burned area/state area, rank, % share, difference in burned area and difference in rank for two decades.....	54
Table 6: Estimates of relative contributions and importance of environmental variables.....	55
Supplementary Table 1: Forest Burned Area (sqkm) in Top Five States and States with Least (Non-zero) Burned Area in India between 2001 and 2010. (First decade).....	77
Supplementary Table 2: Forest Burned Area (sqkm) in Top Five States and States with Least (Non-zero) Burned Area in India between 2011 and 2020. (Second decade).....	78
Supplementary Table 3: Regression slope (β) of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2001 to 2020.....	79
Supplementary Table 4: Coefficient of Determination (R^2) values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2001 to 2020.....	80
Supplementary Table 5: Coefficient of Variation (CV) values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2001 to 2020.....	81
Supplementary Table 6: P values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2001 to 2020.....	82

Supplementary Table 7: Regression slope (β) values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2001 to 2010.....	83
Supplementary Table 8: Coefficient of Determination (R^2) values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2001 to 2010.....	84
Supplementary Table 9: Coefficient of Variation (CV) values of India over four months (having the highest number of forest fires) from the year 2001 to 2010.....	85
Supplementary Table 10: P values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2001 to 2010.....	86
Supplementary Table 11: Regression slope (β) values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2011 to 2020.....	87
Supplementary Table 12: Coefficient of Determination (R^2) values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2011 to 2020.....	88
Supplementary Table 13: Coefficient of Variation (CV) values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2011 to 2020.....	89
Supplementary Table 14: P values of forest fire density maps of India over four months (having the highest number of forest fires) from the year 2011 to 2020.....	90

LIST OF ABBREVIATIONS

AMO	- Atlantic Multidecadal Oscillation
CCI	- Climate Change Initiative
CV	- Coefficient of Variation
ENSO	- El Nino Southern Oscillation
ESA	- European Space Agency
FAO	- Food and Agriculture Organization
FIRMS	- Fire Information for Resource Management System
FSI	- Forest Survey of India
GIS	- Geographic Information System
IMD	- Indian Meteorological Department
LCCS	- Land Cover Classification System
LULC	- Land Use and Land Cover
MODIS	- Moderate Resolution Imaging Spectroradiometer
NAO	- North Atlantic Oscillation
NFFPMS	- National Forest Fire Prevention and Management Scheme
NRSC	- National Remote Sensing Centre
SDG	- Sustainable Development Goal
UNEP	- United Nations Environment Programme



Co-funded by the
Erasmus+ Programme
of the European Union



Last Page

The appended material is based on research carried out at the partner institution of URGENT Project, and has potentially utilised the equipment support, inputs based on course revised/developed and training programs (*lecture series, research seminar and webinars*) through the URGENT Project.

The document is part of thesis part of PhD/MSc/MA research work carried out at the Jawaharlal Nehru University. Purposefully limited pages are shared to avoid copyright and other issues. However, the full thesis can be shared on request.

The complete thesis can be obtained from Prof P K Joshi (pkjoshi27@hotmail.com or pkjoshi@mail.jnu.ac.in).