Project Report

Forest Fire Assessment in Northeast India

Under North Eastern Regional Node for Disaster Risk Reduction program (NER-DRR)

NORTH EASTERN SPACE APPLICATIONS CENTRE
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9.	Abstract	The study has been carried out under NER-DRR (North Eastern Regional Node for Disaster Risk Reduction) program to assess the status of forest fire occurrence in Northeastern region of India. The report contains detailed description of objectives, materials and methodology and results. The report presents the forest fire prone zone map north east region, fire alerts during fire season and post fire analysis. The study has fire data source from MODIS/Firms data, FSI and NRSC Bhuvan which were analysed with respect to fuel characteristics, topographic data, proximity to roads/settlements and meteorological data. It is found that large areas of north east region are affected by forest fire every season thereby damaging the good forests. The findings of this study can help State forest department to manage forest fire spread and intensity across the region.			
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PREFACE

Forest fires are a major environmental problem in North East Region (NER) with large tracts of forest areas being affected in every season. Forest fires have become a major threat to the forest ecosystems in the region, leading to loss of timber, biodiversity, wildlife habitat and other natural resources. When vegetation burns, the resulting release of stored carbon increases global warming. As per assessment of scientific research burning of such carbon storing vegetation is contributing about 20% of green house gas emissions. Studies on forest fire have reported that about 50% of forest fire in the country takes place in NE region. Fire data analysis shows record of approx. 10,084 number of fire incidents in 2014. Out of the seven sister states, Mizoram and Assam suffered maximum fire events which may be attributed to the widespread practice of Jhum cultivation in these states. Forest fire study at NESAC has been taken under the North Eastern Regional node for Disaster Risk Reduction (NER-DRR) at North Eastern Space Applications Centre (NESAC), initiative by Chairman ISRO to address various disasters in North East Region. The very purpose of setting up of NER-DRR is using geospatial technology to reduce the risk of disasters from natural hazards and to reduce the physical and social vulnerability of the people in the region. The present report is an approach towards that goal. This study is unique, from similar kind of work going on elsewhere, that it not only simply reports the fire locations but also prioritise fire pixels that could spread based on landuse pattern, wind speed, humidity, slope/aspect etc. While acknowledging the contribution of NESAC project team, I would like to thank all my staffs for their support and timely cooperation, MODIS-FIRMS (NASA), NRSC DSC (Bhuvan) and Forest Survey of India for providing with fire location data and officials of state forest departments of North Eastern states for their time to time feedback and suggestions. While this report is a small step, I hope that it will contribute meaningfully towards reducing disaster risk and providing greater physical security for the people of this vulnerable region.

(S.Sudhakar)

ACKNOWLEDGEMENT

We are extremely grateful to ISRO/Department of Space for entrusting this work on forest fire under NER-DRR program. The project team wishes to express gratitude to Dr. S. Sudhakar, Director, North-Eastern Space Applications Centre (NESAC) for his valuable guidance and constant encouragement during the course of the study. Sincere thanks is extended to Principal Chief Conservator of Forests, Chief Conservator of Forests and other forest officials of state forest departments of North Eastern states for their time to time feedback and suggestions. This work would not have been possible without the MODIS-FIRMS near real time fire data made available on the internet by NASA, which were downloaded everyday during fire season and helped to successfully provide the alerts to all the northeastern states. The project team also expresses its deep sense of gratitude to NRSC DSC (Bhuvan) and Forest Survey of India for historical fire data available in the website. The project team acknowledges the support provided by the Satellite and Communication department, Atmospheric Science division and all Scientists/Engineers/Research Scientists/JRF/computer support staffs of NESAC for their support and timely cooperation.

Project Team

SUMMARY

The present study focuses three aspects of forest fire in the region viz., the pre-fire analysis, during fire analysis and the post fire burnt area mapping. At present the data on forest fire locations can be obtained from various sources like MODIS/FIRMS data, ISRO/Bhuvan and Forest Survey of India (FSI). The fire location data or the co-ordinates are often more useful for the fire management authorities if they are translated into descriptions of associated land use and other related information. Therefore, various data on fuel characteristics (land use/ land cover, forest type map, forest density map), topography (DEM, slope, aspect) proximity to settlement, road, waterbodies, meteorological data from AWS on wind speed, wind direction, dew point have been used for each fire point.

To take up the work on forest fire in North East Region (NER), the first important task has been to assess the forest fire scenario in the region. For this purpose the historical forest fire locations in NER were downloaded from FSI website. Interestingly the data from the year 2001 shows a decreasing trend in the forest fire occurrence. Further,it is also important to know the distribution of fire prone zones of NER for fire mitigation. So far studies have been conducted considering NER as a single unit. In this study, considering the uniqueness of each of the North Eastern state the analysis of fire proneness of each state has been assessed independently. Based on the historical fire data the nature of fire occurrence with respect to fuel characteristics, topography and proximity to road and settlement appropriate weightages for each theme in each North East state was decided. With the help of given themes and weightages Fire Hazard Zonation map has been generated by Multi Criteria Decision Analysis (MCDA) in GIS environment. The fire hazard zonation map contain five risk zones categories classified as very high, high, moderate, low and very low for NER.

During fire season NESAC has provided value added fire locations to the respective State Forest Department. For this purpose near real time fire location data obtained from MODIS/FIRMS have been used in absence of the fire location data in GIS format from any other sources. The downloaded fire location data were masked with a forest boundary layer in order to extract out only the fire points falling inside forested area and exclude any other fire incidence like agricultural burning. They are further filtered using the confidence level quality flag included with the data to minimize the occurrence of false detection. The fire danger rating denoted as severe, high, moderate and low classes for each location is produced with the help of the above thematic layer and meteorological data within a buffer of 3 km for each fire location. Overall turn-around time for processing of raw shapefile to generate individual point-wise detailed report is 1-2 hrs, after downloading data from MODIS website depending on the number of fire points. During fire season such information is disseminated in the form of maps and tables containing information of latitude and longitude of fire location, fire occurrence date, state and district name, LULC, road connectivity, slope and aspect, settlements/water bodies and meteorological data and the corresponding rating of possibility of fire spread.

An attempt has also been made to map the burnt area using Normalized Burned Ratio with the help of Landsat data for the state of Nagaland and Mizoram. A case study in Mizoram shows the close relationship between forest fire and jhum cultivation.

From time to time NESAC has received appreciation and valuable feedback from the users for the service provided during fire season. The present report addresses the issue of forest fire hazard from the perspective of associated geographical and physical parameters & would be useful in understanding the underlying process and hence facilitating in disaster risk reduction.

Project Team

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ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AWiFS	Advanced Wide Field Sensor
AWS	Automatic Weather Station
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
DSC	Disaster Support Centre
FIRMS	Fire Information for Resource Management System
FSI	Forest Survey of India
GIS	Geographical Information System
IMD	Indian Meteorological Department
IRS	Indian Remote Sensing
ISRO	Indian Space research Organization
LISS	Linear Imaging Self Scanning
LULC	Land Use and Land Cover
MODIS	Moderate-Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NBR	Normalized Burn Ratio
NER	North Eastern Region
NESAC	North Eastern Space Applications Centre
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NRSC	National Remote Sensing Centre
SPOT-VGT	Système Pour l'Observation de la Terre-Vegetation
SWIR	Short Wave Infrared
µm	Micrometers

Chapter-1: Introduction

1.1 Background

Forests are a major natural resource and they play an important role in maintaining ecological balance. At present, with increasing population and urbanization, forests are threatened by both anthropogenic and wild forest fires. Basically causes of forest fire have been classified into three main categories: (a) Natural (b) Intentional/ Deliberate (c) Unintentional/ Accidental. In India, annual forest fire ranges from 33% in some states to over 90% in others (Jaiswal et al. 2002). About 90% of the forest fires in India are caused by human factors, such as slash and burn agricultural practices, deforestation, controlled burning, firewood burning etc. Thus, monitoring and management of forest fires is very important in countries like India. Fire monitoring has become easier with the availability of satellite data's such as Terra and Aqua, IRS P4 (OCEANSAT), IRS P6-AWiFS (Indian Remote Sensing - Advanced Wide Field Sensor), ATSR-2, SPOT-VGT (Système Pour l'Observation de la Terre-Vegetation), NOAA-AVHRR (National Oceanic and Atmospheric Administration -Advanced Very High Resolution Radiometer), EOS-MODIS (Moderate resolution Imaging Spectroradiometer) etc obtained with high temporal repeatability, spectral variability and wide spatial coverage (Giriraj et al. 2010). To understand and quantify the fire regime in India and relationship of fire distribution pattern to bio-geographic zones and protected areas of India, (A)ATSR (Advanced Along Track Scanning Radiometer was used (Giriraj et al. 2010). The study revealed that vegetation type in Central India was most severely affected with maximum fire incidences and the bio-geographic zone comprising Deccan peninsula, that includes Central Highlands, Eastern Highlands, Central Plateau and Chhota Nagpur accounted for approximately 36% of the total fire occurrences during the period 1997–2005.

Basically forest fires have been categorized in to three categories viz., ground fire, surface fire and crown fire. Ground fires spread within rather than top of organic matter and it consumes organic matter like duff, musk or peat present beneath the surface litter of the forest floor. It is difficult to detect fire burning in tree roots unless it follows a root near the soil surface. It can smolder for days or weeks with no flame and little smoke. So, ground fires are most hard to handle and there should be proper policy and practices for control agencies. Surface fire is characterized by a fast moving fire that produce flaming fronts, which consumes needles, moss, lichen, herbaceous vegetation, shrubs, small trees, and saplings. Surface fires can ignite large woody debris and decomposing duff, which can burn (glowing combustion) long after sur¬face flames have moved past and high-severity surface fires kill most trees. Crown fires advances from top to top of trees or shrubs and is fastest to spread and most destructive for trees and wildlife. Crown fires are strongly influenced by wind, topography, and tree (crown) density.

Studies on the impacts of forest fire (both anthropogenic and wild) on the environment and ecosystem indicated high carbon emissions (Hao et al., 1996; Fearnside, 2000), loss of biodiversity (Brown and Davis 1959; Meijaard et al. 2001), change in atmospheric chemistry, emissions of large amounts of trace gases and aerosol particles and black carbon (Crutzen and Andreae 1990; Dwyer et al., 1998), release of almost hundred million tons of smoke aerosols into the atmosphere (Hao and Liu 1994) and increase in surface albedo and water runoff (Darmawan and Mulyanto 2001) as a result of biomass burning. Fires not only consume or deeply char the vegetation but also affect the properties of soils, including the structure, porosity and hydraulic conductivity (Neary et al., 1999).

Forest fire occurrence and the factors affecting where fires occur are a major focus in studies determining forest fire risk zones (Chuvieco and Salas, 1996; Sunar and Ozkan, 2001; Jaiswal et al. 2002; Hernandez-Leal et al. 2006). Factors listed in earlier fire risk analyses include land cover (fuel), slope, aspect, socioeconomic variables (nearby population, roads, etc.), temperature, and relative humidity (Chuvieco and Congalton, 1989; Carrão et al. 2003;

Bonazountas et al. 2005). The forecast of forest fire risks can be achieved with the use of fire risk zone maps. Forest fire risk zones are locations where a fire is likely to start, and from where it can easily spread to other areas (Jaiswal et al. 2002).

The north-east region (NER) of India, comprising of eight states namely, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim, is physiographically categorized as Eastern Himalayas, Northeast hills and the Brahmaputra and Barak Valley plains. The north-eastern region (NER) is unique in providing a profusion of habitats, which features rich biodiversity with a high level of endemism and is regarded as one of the global biodiversity centers and a hotspot (Myers et al. 2000). Approximately a quarter of forest cover is found in northeast India with 637,293 km2 within reserved, protected and unclassified forests (Ningthoujam & Mutum, 2010). The region has some of the largest reserves of tropical and sub-tropical forests of wet evergreen, semi- evergreen, moist deciduous, coniferous forests, mixed forest and shrubland (Roy and Joshi, 2002). However, extensive agricultural practice through shifting cultivation locally called Jhum over the past decades and increasing human population have led the massive deforestation in the region (Lele and Joshi, 2009).

High aerosol loading from biomass burning associated with shifting cultivation is reported in NER of India (Badarinath et al., 2004) and a significant correlation was observed between forest fire occurences and variations in the aerosol concentrations in the in NER of India (Kharol et al, 2008). SO2 concentrations found to be ~3 times and BC concentrations ~6 times high during burning day compared normal day in Arunachal Pradesh, India (Badarinath et al. 2008). Columnar content of aerosols observed to be high during burning period in addition to the drastic reduction of visibility. Columnar content of aerosols in Mizoram (Northeast), India observed to be 3.16 × 108 cm2 during burning period and during pre- and post-burning periods it varies from 1.47 16 × 108 cm2 to 2.85 16 × 108 cm2 (Badarinath et al., 2004). A precise evaluation of forest fire problems and decision on solutions can only be satisfactory when a fire risk zone mapping is available (Jaiswal, 2002). Further, near real time forest fire alert may help to take precautionary measures by the concerned forest departments to minimize socio-economic and ecological damage.

1.2 Scope

In NER, there has been close link between forestry and fire since time immemorial due to wide practices of shifting cultivation and it is a seasonal phenomenon in the region that occurs mostly in between February to May every year. Close to 50 % of all forest fires in India occurs in north-east region of India (Bahuguna and Upadhyay 2002) and 95% forest fires occur during the process of burning of jhum or shifting cultivation. Around 14, 3761 forest fire incidences occurred in between January 2001 to April 2014. Looking at the severity of forest fire incidences and its associated vulnerability, it is very important to do detailed analysis of forest fire occurrence and fire vulnerability assessment of the region. The study is limited NER states during forest fire season. No comprehensive report is still available on forest fire and its associated vulnerability in NER. This study is first of its kind in the region. Although forest fire alerts in the form of fire pixels are given to different parts of the country by different agencies, in this study, efforts were made to provide value added information such as topographic factors, meteorological parameters, presence of roads, built-ups, water bodies associated with each fire pixels is not given. Present effort may thus help in taking serious steps to control forest fire and manage it effectively in the region.

1.3 Objective

The main objectives of this study are:

I. **Previous or historical forest fire location data analysis:** Analysis of historical fire location data collected from NRSC & FSI to understand the various parameters which are most likely to influence forest fire.

II. **Forest fire hazard alerts:** (a) to give forest fire hazard alerts to the state departments in NER India based on satellite data; (b) to do value addition to the fire alerts, obtained from MODIS-FIRMS/Bhuvan website, in terms of contextual LULC, connectivity, topographic and meteorological information associated with locations and in-turn judging their hazard level (high/medium/low).

III. **Vulnerability zonation:** to identify forest fire vulnerability zones based on multi-criteria decision analysis technique.

IV. **Support in forest fire mitigation activities:** Dissemination of information from NESAC to the state forest departments during forest fire season may help the fire controlling agencies to take up mitigation measures. Value addition considering various fire influencing parameters such as vegetation types, slopes, aspects, proximity to roads, built-ups, water bodies, meteorological parameters, thus integrating hazard level in the fire alerts may help to take immediate measures in high level hazard location.

V. **Burnt area assessment:** estimation of the total area burned during the fire season in the year 2014.

Chapter-2: Materials and Methods

2.1 Study Area

Forest fire study has been taken up for the entire eight northeastern states under the NER-DRR program (North Eastern Regional Node-Disaster Risk Reduction). Northeast India is the eastern-most region of India connected to East India via a narrow corridor squeezed between Nepal and Bangladesh. It comprises the contiguous Seven Sister States—Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura—and the Himalayan state of Sikkim. The NER (North Eastern Region) can be physiographically categorized into the Eastern Himalayas, Northeast Hills (Patkai-Naga Hills and Lushai Hills) and the Brahmaputra and the Barak Valley Plains.

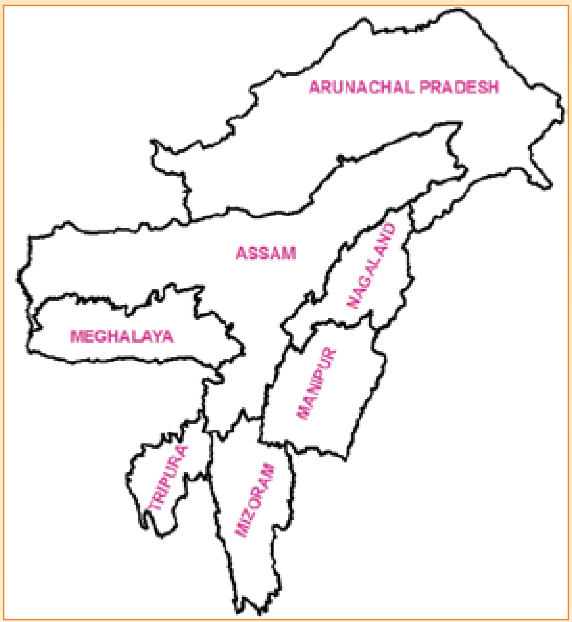


Figure 2.0. Study area

Among these seven sister states, the states of Arunachal Pradesh, located between 26.28° N and 29.30° N latitude and 91.20° E and 97.30° E longitude experience humid, sub-tropical climate with hot summers and mild winters. The state has 10 forest type groups, viz. Tropical Wet Evergreen (1.48%), Tropical Semi- Evergreen (68.75%), Tropical Moist Deciduous (5.35%), Subtropical Broadleaved Hill (3.35%), Subtropical Pine (0.84%), Himalayan Moist Temperate (7.43%), Himalayan Dry Temperate (1.51%), Sub Alpine Forests (10.3%), Moist Alpine Scrub (0.92%) and Dry Alpine Scrub (0.02%).

Assam located between 24°07′N – 28°00′N latitude and 89°42′E – 96°02′E longitude experiences temperate climate (summer max. at 35–38 °C and winter min. at 6–8 °C) with heavy rainfall and high humidity. The recorded forest area of Assam is 26,832 km2 accounting for 34.21% of its geographical area and the state have five forest type groups, viz. Tropical Wet Evergreen (12.04%), Tropical Semi Evergreen (51.71%), Tropical Moist Deciduous (25.64%), Tropical Dry Deciduous (0.09%) and Subtropical Pine Forests (0.45%) of the total forest type.

Manipur lies at a latitude of 23°83′N – 25°68′N and a longitude of 93°03′E – 94°78′E. Manipur enjoys a generally amiable climate, though the winters can be a little chilly. The recorded forest area of the state is 17,418 km2 which is 78.01% of its geographical area and forest group include: Tropical Semi-evergreen (24.82%), Tropical Moist Deciduous (3.05%), Subtropical Broadleaved Hill (52.94%), Subtropical Pine (8.47 %) and Montane Wet Temperate forests (10.46%).

Meghalaya located between the latitudes of 24°58′ N to 26°07′ N and the longitudes of 89°48′ E to 92°51′ E is the wettest place on earth with average annual rainfall as high as 1200 cm in some areas. The state has five forest type groups, viz. Tropical Wet Evergreen (10.45%), Tropical Semi Evergreen (1.93%), Tropical Moist Deciduous (61.62%), Subtropical Broadleaved Hill (17.71%) and Subtropical Pine Forests (8.29%) with a recorded forest area of the state is 9,496 km2 which is 42.34% of its geographical area.

Mizoram has a mild climate, comfortable in summer 20 to 29 °C and never freezing during winter, with temperatures from 7 to 21 °C and major forest type include: Tropical Semi Evergreen (71.94%), Tropical Moist Deciduous (27.4%), Subtropical Broadleaved Hill (0.04%) and Subtropical Pine Forests (0.62%) and the recorded forest area in the state is 16,717 km2 which is 79.30% of its geographical area.

Nagaland has a largely monsoon climate with high humidity levels. The recorded forest area of the state is 9,222 km2 which is 55.62% of its geographical area and the forest type includes: Tropical Wet Evergreen (0.49%), Tropical Semi-evergreen (16.34%), Tropical Moist Deciduous (47.43%), Subtropical Broadleaved Hill (15.56%), Subtropical Pine (7.49%) and Montane Wet Temperate Forest (12.69%).

Tripura is the third-smallest state in the country, it covers 10,491 km2. During winter, temperatures range from 13 to 27 °C, while in the summer they fall between 24 and 36 °C. The recorded forest area of the state is 6,294 km2 which is 60.02% of its geographical area and dominant forest group include: Tropical Semi Evergreen (11.06%) and Tropical Moist Deciduous Forests (88.94%). NER is influenced by monsoons, raining heavily from May to September/October with little rain in the dry (cold) season.

2.2 Materials/Data Used For Forest Fire Study

Different data used for forest fire assessment are shown in Table 2.1

Table 2.1 Analysis type and data used

Sl. No	Analysis done	Data Used
1	Forest Fire Scenario Assessment In NER	• Fire location data: from FSI
2	Historical Forest Fire Data Analysis	• Fire location data: from FSI • Spatial data: Administrative boundary; Land Use and Land Cover (LULC) map from Natural Resources Database (NRDB); aspect, slope and elevation from ASTER 30m DEM
3	Forest Fire Vulnerability Zonation And Mapping	• Weightages based on historical forest fire data analysis
4	Daily Fire Alerts	• Fire location data: from MODIS FIRMS • Spatial data: Administrative boundary; Land Use and Land Cover (LULC) map from Natural Resources Database (NRDB); aspect, slope and elevation from ASTER 30m DEM • Non-spatial data: meteorological data from IMD-AWS
5	Analysis of Forest Fire Incidences in NER in 2014	• Fire location data: from FSI • Spatial data: Administrative boundary; Land Use and Land Cover (LULC) map from Natural Resources Database (NRDB); aspect, slope and elevation from ASTER 30m DEM
6	Burnt Area Assessment	Landsat imagery from OLI (Operational Line scanner) sensors
7	Relationship Between Forest fire incidences and Shifting Cultivation	• Fire location data: from FSI • Spatial data: Administrative boundary from Natural Resources Database (NRDB) • Shifting cultivation data: from AWiFS (56M)

2.2.1 Forest Fire Scenario Assessment in NER

Forest fire data for the year 2001-2014 were collected from FSI (Forest Survey of India) to assess the forest fire incidence scenario of NER.

2.2.2 Historical Forest Fire Data Analysis

The input data required for historical forest fire data analysis fall into following categories:

Fire location data: Historical fire location data (year 2001 to 2013) of the fire points were collected/compiled from FSI (Forest Survey of India) for analysis.

Spatial data: Spatial data used for the study are:

(a) Administrative boundary of each of the NER states (state and district boundary)

(b) Land Use and Land Cover (LULC) map at 1:50,000 scale prepared using satellite data (LISS III) under the Natural Resources Database (NRDB). Information derived from LULC map include water bodies/drainage, built-ups, agriculture and forest area.

(b) Road networks

(c) Slope, Aspect and Elevation: Elevation, aspect and slope were generated from ASTER 30m DEM with the help of ArcGIS 10.1. A subset of the ASTER 30 m DEM of study area was clipped with the help of boundary vector layer.

Information on the road network, drainage pattern, forest type and cover/density, elevation, slope and aspect were extracted for each fire location to analyze relation of these factors in generation and spreading of the forest fire.

2.2.3 Forest Fire Vulnerability Zonation and Mapping

Weightages for fire vulnerability mapping: In the present study, weightages of factors that influence forest fires are based on historical fire data analysis (2001-2013). Historical analysis was done to understand the relationship between forest fire and various factors such as vegetation types, topographical factors (aspect, slope, elevation), roads, settlements, waterbodies in each state of NER. Such analysis showed how each of these factors are associated with number of forest fire incidences in different states. Due to uniqueness in the NER states, weight has been assigned separately for each state. Accordingly, weightages for each factor are given based on historical data analysis and is used for fire vulnerability mapping. All factors were rated on a scale of 1–5 and the vulnerability levels are ranked in five classes: very low, low, moderate, high and very high. In general, for fire vulnerability studies, weights are usually knowledge-based and are pre-assigned based on the importance of variables participating in fire environment. For instance, vegetation type such as dry deciduous or dry deciduous with bamboo was given more weight (4) as compared to riverine forest (1; Singh and Kumar, 2013). Pine and Chirpine were given more weightages (9, 6) than deodar (3) by Chavan et al. 2012 and Kanga et al. 2011, respectively. In our study, historical data shows that evergreen/Semi-evergreen are most burnt vegetation in Arunachal Pradesh, Assam and Manipur while deciduous in Meghalaya, Nagaland and Tripura, and Bamboo in Mizoram. So, the highest weight (5) is assigned accordingly to these vegetation types in these states. Similarly, weights have been assigned for other factors such as aspects, slope, elevation etc. Such variation of vegetation type in different states and from literature data may be because in NER, forest fires are mostly human-induced for shifting cultivation. Weightages assigned for each factor and each of the seven states of NER is given in Table 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, and 2.8.

Table 2.2: The weight of parameters in determination of fire vulnerability areas in Arunachal Pradesh

Weights / Parameters	1	2	3	4	5
Vegetation	Pine/Scrub	-	Alpine forest	Bamboo/conifer	Evergreen/Semi-evergreen
Vegetation Density	-	-	Dense	-	Open/Moderate
Slope	0-3°	3-8°	8-15°	25-35°	15-25°
Aspect	N	NE/NW	SW/W	E	S/SE
Elevation	0-200/>2000		200-500	1000-2000	500-1000
Distance to settlement	-	2500-3000	2000-2500	0-500/1500-2000	500-1000/1000-1500
Distance to road	150-200	200-250/250-300	0-50	50-100	100-150
Distance to water bodies	0-100/100-200/200-300	300-500	500-1000	-	>1000

Table 2.3: The weight of parameters in determination of fire vulnerability areas in Assam

Weights / Parameters	1	2	3	4	5
Vegetation	Pine/ Scrub/ Conifer/Plantation	-	Bamboo	Deciduous	Evergreen/Semi-evergreen
Vegetation Density	Dense	-	Moderate	-	Open
Slope	0-3°	25-35°	3-8°	15-25°	8-15°
Aspect	SW	NE/W	N/S	E/NW	SE
Elevation	1000-2000	-	500-1000	0-200	200-500
Distance to settlement		2500-3000	2000-2500	0-500/1500-2000	500-1000/1000-1500
Distance to road	-	-	-	0-50/150-200	50-100/100-150/250-300/200-250
Distance to water bodies	0-100/100-200/200-300	300-500	-	500-1000	>1000

Table 2.4: The weight of parameters in determination of fire vulnerability areas in Manipur

Weights / **Parameters**	**1**	**2**	**3**	**4**	**5**
Vegetation	Scrub	Deciduous	Pine/Temperate	Bamboo	Evergreen/Semi-evergreen
Vegetation Density	Dense		Moderate		Open
Slope	0-3°	3-8°	8-15°	25-35°	15-25°
Aspect	N	NE/S	SW/W/NW	E	SE
Elevation	>2000	<200	200-500	1000-2000	500-1000
Distance to settlement	<500	2500-3000	2000-2500	500-1000	1000-1500/1500-2000
Distance to road	-	<50	150-200	100-150/200-250/250-300	50-100
Distance to water bodies	0-100/100-200/200-300	300-500	500-1000	-	>1000

Table 2.5: The weight of parameters in determination of fire vulnerability areas in Meghalaya

Weights / **Parameters**	**1**	**2**	**3**	**4**	**5**
Vegetation	Scrub	Pine/Bamboo	-	Evergreen/Semi-evergreen	Deciduous
Vegetation Density	Dense	-	Moderate	-	Open
Slope	0-3°	25-35°	3-8°	15-25°	8-15°
Aspect	-	-	NE/E/SW	W	N/SE/NW/S
Elevation		1000-2000	0-200	500-1000	200-500
Distance to settlement	2500-3000	2000-2500	1500-2000	0-500/1000-1500	500-1000
Distance to road	-	150-200/250-300	0-50/200-250	100-150	50-100
Distance to water bodies	0-100/100-200/200-300	300-500	500-1000	-	>1000

Table 2.6: The weight of parameters in determination of fire vulnerability areas in Mizoram

Weights / **Parameters**	**1**	**2**	**3**	**4**	**5**
Vegetation	Pine/Scrub	-	Deciduous	Evergreen/Semi-evergreen	Bamboo
Vegetation Density	Dense	-	Moderate	-	Open
Slope	0-3°	-	3-8°	8-15°/25-35°	15-25°
Aspect	-	N/S	NW	NE/SE/SW	E/W
Elevation		1000-2000	0-200	500-1000	200-500
Distance to settlement	0-500	-	500-1000	1000-1500/2500-3000	1500-2000/2000-2500
Distance to road	-	-	0-50/150-200	200-250/250-300	50-100/100-150
Distance to water bodies	0-100/100-200/200-300	300-500	500-1000	-	>1000

2.7: The weight of parameters in determination of fire vulnerability areas in Nagaland

Weights / **Parameters**	**1**	**2**	**3**	**4**	**5**
Vegetation Density	Dense	-	Moderate	-	Open
Slope	0-3°	3-8°	8-15°	25-35°	15-25°
Aspect	-	-	S	N/NE/E/SE/SW/W	NW
Elevation	-	0-200/>2000	200-500	1000-2000	500-1000
Distance to settlement	2500-3000		0-500/2000-2500	500-1000/1500-2000	1000-1500
Distance to road	-	150-200	0-50/250-300	200-250	50-100/100-150
Distance to water bodies	0-100/100-200/200-300	300-500	500-1000	-	>1000
Distance to water bodies	0-100/100-200/200-300	300-500	-	500-1000	>1000

Table 2.8: The weight of parameters in determination of fire vulnerability areas in Tripura

Weights / **Parameters**	**1**	**2**	**3**	**4**	**5**
Vegetation	Evergreen/Semi-evergreen /Scrub	-	Bamboo	-	Deciduous
Vegetation Density	Dense	-	Open	-	Moderate
Slope	25-35°	0-3°	15-25°	3-8°	8-15°
Aspect			N/NE/S	SE/SW/NW	E/W
Elevation	500-1000		200-500		0-200
Distance to settlement	-	0-500	500-1000	1000-1500/2000-2500/2500-3000	1000-2000
Distance to road	-	0-50	150-200/200-250	50-100	100-150/250-300
Distance to water bodies	0-100/100-200/200-300	300-500	500-1000	-	>1000

The forest fire vulnerability zonation methodology followed in the present study is shown in Figure 2.1. Finally, fire vulnerability map is generated for each states of NER India. Month wise data of forest fire incidences since 2001 to 2014 have been overlooked to obtain the peak fire month and peak fire season.

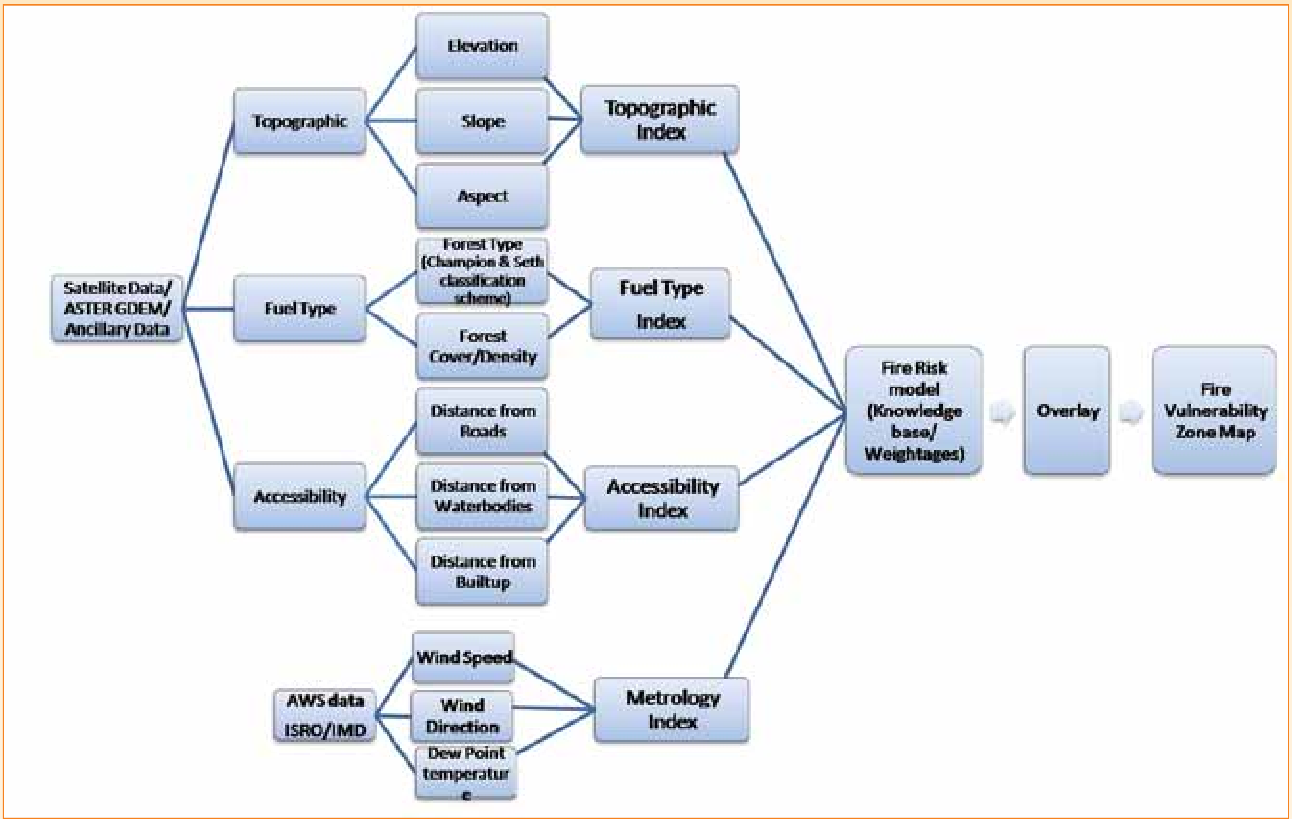


Figure 2.1: Methodology for forest fire vulnerability zonation

2.2.4 Daily Fire Hazard Alerts

During forest fire season (February to April, 2014), daily forest fire hazard alerts in the form of a map and corresponding table containing details pertaining to each point is given to the respective state forest departments based on the occurrence of forest fire. The input data required for daily forest fire hazard alerts fall into three categories:

- fire location data
- spatial data, and
- non-spatial data

Fire location data from MODIS FIRMS: The need for better tools in assessing biomass burning from remote sensing led to the inclusion of two fire channels in the MODIS instrument (Salomonson, 1989). The Moderate-Resolution Imaging Spectroradiometer (MODIS) from the National Aeronautic and Space Administration (NASA) is the first sensor that included fire monitoring capabilities in its design. And to date MODIS is one of the most important data sources for global mapping of both fire locations and burned areas. MODIS sensors are mounted aboard two satellites, the Terra and the Aqua. Terra crosses the equator at approximately 10:30am and 10:30pm local time in ascending and descending node respectively each day while Aqua passes over the equator at approximately 1:30pm and 1:30am local time in ascending and descending node respectively.

MODIS active-fire detection mechanism: There are two fire stages, flaming and smoldering, characterized by different fire intensity, temperature, combustion efficiency and emission ratios. The availability of oxygen to the fire is a function of the fire intensity and structure and the fire intensity and structure affect the fire temperature and the spatial extent of the hot zone (Justice et al. 2006). Smoldering and flaming can be distinguished using infrared remotely-sensed measurements if the fire temperatures vary significantly between these two stages. Flaming temperature can be anywhere between 800 K and 1200 K, and as hot as 1800 K while smoldering should be under 850 K and above 450 K. A given fire pixel may have areas that are not burned, areas that are smoldering and areas that are in flames. The 1.65 μm channel is very sensitive to fflame and the flaming energy but not very sensitive to fsmold and its energy. The 2.13 μm channel is very sensitive to fflame and somewhat sensitive to fsmold. Since the thermal energy is more concentrated in the flaming fire, the sensitivity to thermal energy is independent of smoldering or flaming. The limitation of 2.13 μm channel is that it saturates at a reflectance of 0.8, which for the low solar brightness corresponds to less than 1% of the 500 m pixel being in flames. The 4 μm channel is sensitive to both fflame and fsmold, and is five times more sensitive to the thermal energy emitted from flaming than from smoldering. The 4 μm channel response in daytime may be strongly enhanced by surface reflection where the satellite-surface-solar geometry results in sunglint. This effect has been documented over oceans (Nath et al., 1993; Cracknell, 1993) and can lead to false fire detections over land. Therefore, the MODIS fire algorithm test for sun glint and excludes those pixels from the fire products (Justice et al. 2006).

Fire detection is performed using a contextual algorithm (Giglio et al., 2003) that exploits the strong emission of mid-infrared radiation from fires (Dozier, 1981; Matson and Dozier, 1981). The algorithm examines each pixel of the MODIS swath, and ultimately assigns to each one of the following classes: missing data, cloud, water, non-fire, fire, or unknown. Seven MODIS channels are used for active fire detection and characterization are:

(a) Channel 1 (0.65 μm): For sun glint and coastal false alarm rejection; cloud masking
(b) Channel 2 (0.86 μm): Bright surface, sun glint, and coastal false alarm rejection; cloud masking
(c) Channel 7 (2.1 μm): Sun glint and coastal false alarm rejection
(d) Channel 21 (3.96 μm): High-range channel for fire detection and characterization
(e) Channel 22 (3.96 μm): Low-range channel for fire detection and characterization
(f) Channel 31 (11 μm): Fire detection, cloud masking
(g) Channel 32 (12 μm): Cloud masking

The fire detection algorithm uses brightness temperatures derived from the MODIS 4 μm and 11 μm channels, denoted by T4 and T11, respectively. The MODIS instrument has two 4 μm channels, numbered 21 and 22, both of which are used by the detection algorithm. Channel 21 saturates at nearly 500 K; channel 22 saturates at 331 K. Since the low-saturation channel (22) is less noisy and has a smaller quantization error, T4 is derived from this channel whenever possible. However, when channel 22 saturates or has missing data, it is replaced with the high saturation channel to derive T4. T11 is computed from the 11 μm channel (channel 31), which saturates at approximately 400 K. The 12 μm channel (channel 32) is used for cloud masking; brightness temperatures for this channel are denoted by T12. The 250~m resolution red and near-infrared channels, aggregated to 1 km, are used to reject false alarms and mask clouds. The 500-m 2.1 μm band, also aggregated to 1 km, is used to reject water-induced false alarms. For each fire pixel detected, the fire radiative power (FRP) within the pixel is estimated using the empirical relationship of Kaufman et al. (1998):

FRP = (4.34 ×10–19 MWK–8 km–2)(T84 –□4)Apix ,

where T4 is the 4-μm brightness temperature of the fire pixel, T4 is the mean 4-μm brightness temperature of the non-fire background, and Apix is the total area (in km2) of the pixel in which the fire was detected. The resulting value of the FRP is expressed in MW.

Each hotspot/active fire detection represents the center of a 1km (approx.) pixel flagged as containing one or more fires, or other thermal anomalies (such as volcanoes). The "location" is the center point of the pixel (not necessarily the coordinates of the actual fire). The actual pixel size varies with the scan and track. The fire is often less than 1km in size and although it is not able to determine the exact fire size, at least one fire is located within that 1km pixel. MODIS routinely detects both flaming and smoldering fires 1000 m2 in size. Under very good observing conditions (e.g. near nadir, little or no smoke, relatively homogeneous land surface, etc.) flaming fires one tenth this size can be detected. Under pristine (and extremely rare) observing conditions even smaller flaming fires 50 m2 can be detected. However, due to undulating topography in NER, there may be limitation in MODIS fire detection process. Further, for those fire that may have started and ended between satellite overpasses, MODIS may not detect such fire. Cloud cover may also add limitation to fire detection. The likelihood of detecting a fire beneath the tree canopy is unknown, but likely to be very low. Understory fires are typically small, and with the tree canopy obstructing the view of the fire, detection will be very unlikely. In NER, two types of anthropogenic forest fire are common: ground fire for regeneration of vegetation for feeding cattle's and slash and burn fire for cultivation. Thus, most of the fire pixels detected may indicate slash and burn fire or shifting cultivation fire as thermal radiation from these fires is expected to be high.

Spatial data: Spatial data such as administrative boundary, LULC, aspect, slope and elevation, road networks etc used in historical data analysis were used for daily fire hazard alerts

Non-Spatial data: Non-spatial data used is:

(a) Meteorological data: Daily wind speed, wind direction and dew point temperature data was downloaded from IMD-AWS (Indian Meteorological Department-Automatic Weather Station) website. An automatic weather station (AWS) is an automated version of the traditional weather station, which enable measurements of meteorological parameters from remote areas. It consists of a weather-proof system containing the data logger, solar panel, rechargeable battery, satellite telecommunication system and the meteorological sensors. The system sends data in near real time at every one hourly using satellite based telecommunications system and the same is archived at MOSDAC (Meteorological & Oceanographic Satellite Data Archival Centre) server located in Space Applications Centre, Ahmadabad. AWSs typically consist of rainfall, humidity, temperature, pressure, sunshine, wind speed and wind direction sensors. Data from two different networks is used viz. ISRO-AWS (www.mosdac.gov.in) and IMD-AWS (www.imdaws.com). Presently data from 118 AWSs are available in MOSDAC web domain which includes 82 ISRO AWSs and 36 from different network while IMD have own web-link and archival facility of their own 64 AWSs. AWSs distributions over NE sector of India installed by different agency are shown Figure 2.2.

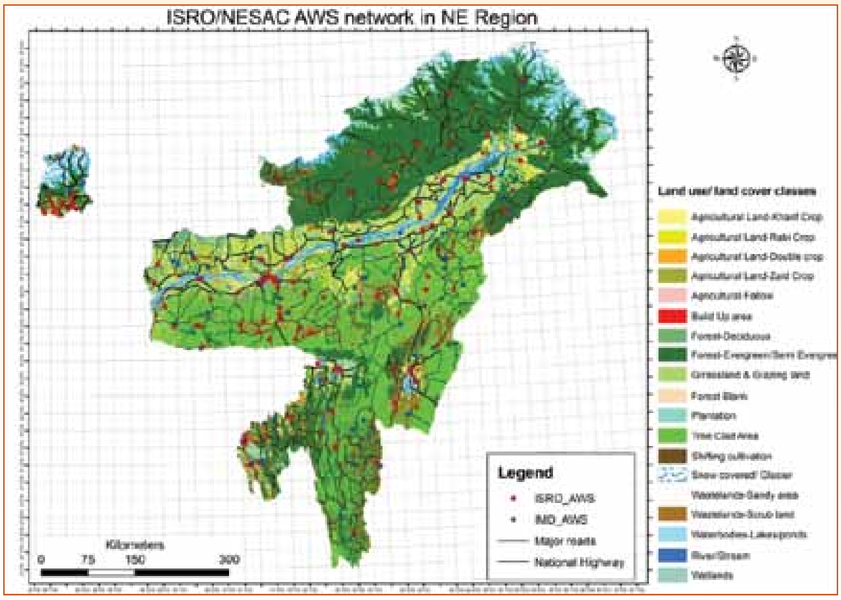


Figure 2.2 Locations of ISRO/NESAC AWS network in NE region

Development of toolbox for MODIS FIRMS data processing at NESAC

A comprehensive toolbox has been developed in ArcGIS platform to facilitate and automate the whole processing chain of MODIS FIRMS data. Fire location data in the form of shapefile (point) is downloaded from the NASA's website. The file includes the following fields: latitude and longitude (center location of a pixel), brightness (brightness temperature measured in Kelvin), scan and track (spatial resolution of the scanned pixel, Acquisition date, time (time of the overpass of the satellite), satellite (Terra or Aqua), and confidence (quality flag of the individual hotspot). Fire location data from the 1st satellite pass (Terra-10:30am equator crossing time) is downloaded by 1.00-1.30 pm. The downloaded fire location data are masked with a forest boundary layer in order to extract out only the fire points falling inside forested area and exclude any other fire incidence outside it (like agricultural burning). They are further filtered using the confidence level quality flag included with the data to minimize the occurrence of false detection. MODIS fire product confidence ranges from 0% to 100%. In our study, only fire pixel with ≥ 60% confidence level is considered for giving fire hazard alerts to reduce the number of false alarms. Processing of each individual fire point require around 20 seconds run time. The processed shapefile is overlaid on to the road network, LULC map, forest map, elevation, slope and aspect to analyze relation of these factors in generation and spreading of the forest fire within 3 km buffer of each fire location. Further, meteorological data for each location is interpolated and the weather information is integrated with each fire location. The processed report needs to be slightly rearranged to fit the prescribed format.

Turn-around time for MODIS raw data processing

Overall turn-around time for processing of raw shapefile to generate individual point-wise detailed report is 1-2 hrs, after downloading data from MODIS website depending on the number of fire points. The processed hazard alerts in the prescribed format to be sent to respective forest departments/administrative offices via emails is ready by around 3.00 pm. Fire location data from the 2nd satellite pass (Aqua-1:30 pm) is ready for download by around 3.00-3.30 pm.

It is appreciable that NRSC uploads the fire alert location data for the 1st satellite pass in their Bhuvan portal by 11.00 am and for the 2nd satellite pass by 1.30-2.00 pm. At present, fire pixel data is not given in downloadable format (shapefile) to be used effectively. Information of fire pixel location can be accessed by clicking on each pixel that needs to be noted down separately. During peak fire season (March and April), number of fire pixels are too many to be noted down manually and there is also chance of error due to shifting of fire pixel location by manual clicking process. So, at present, the study is wholly dependent on MODIS-FIRMS data for fire location that has an extra time-lag of around 2 hours between satellite overpass and actual dissemination of shapefiles. Thus, if there is a provision of availability of fire pixel data in shapefile format from NRSC Bhuvan/FSI, the turnaround time for fire hazard alert dissemination may be reduced.

Dissemination of forest fire information

Daily fire hazard alerts is presented in terms of a map and table (Figure 2.3 and Table 2.9) containing information of latitude and longitude of fire location, fire occurrence date, state and district name, type of LULC, type of road connectivity, slope and aspect, presence of settlements/water bodies, and meteorological data. Based on these associated parameters each fire location is classified into one of the four vulnerability categories viz. severe, high, moderate and low fire and the same is reported in the hazard alert table. Fire hazard alerts in the mentioned format is sent via emails to different forest fire controlling authorities in respective forest departments of 8 NER states and is also uploaded in the public domain in NESAC-NERDRR website (www.nesac.gov.in/nerdrr).

***2.2.5 Analysis of Forest Fire Incidences in NER in 2014*:** Source of fire location data and spatial data for analysis of forest fire incidences in NER in 2014 is same as historical data analysis.

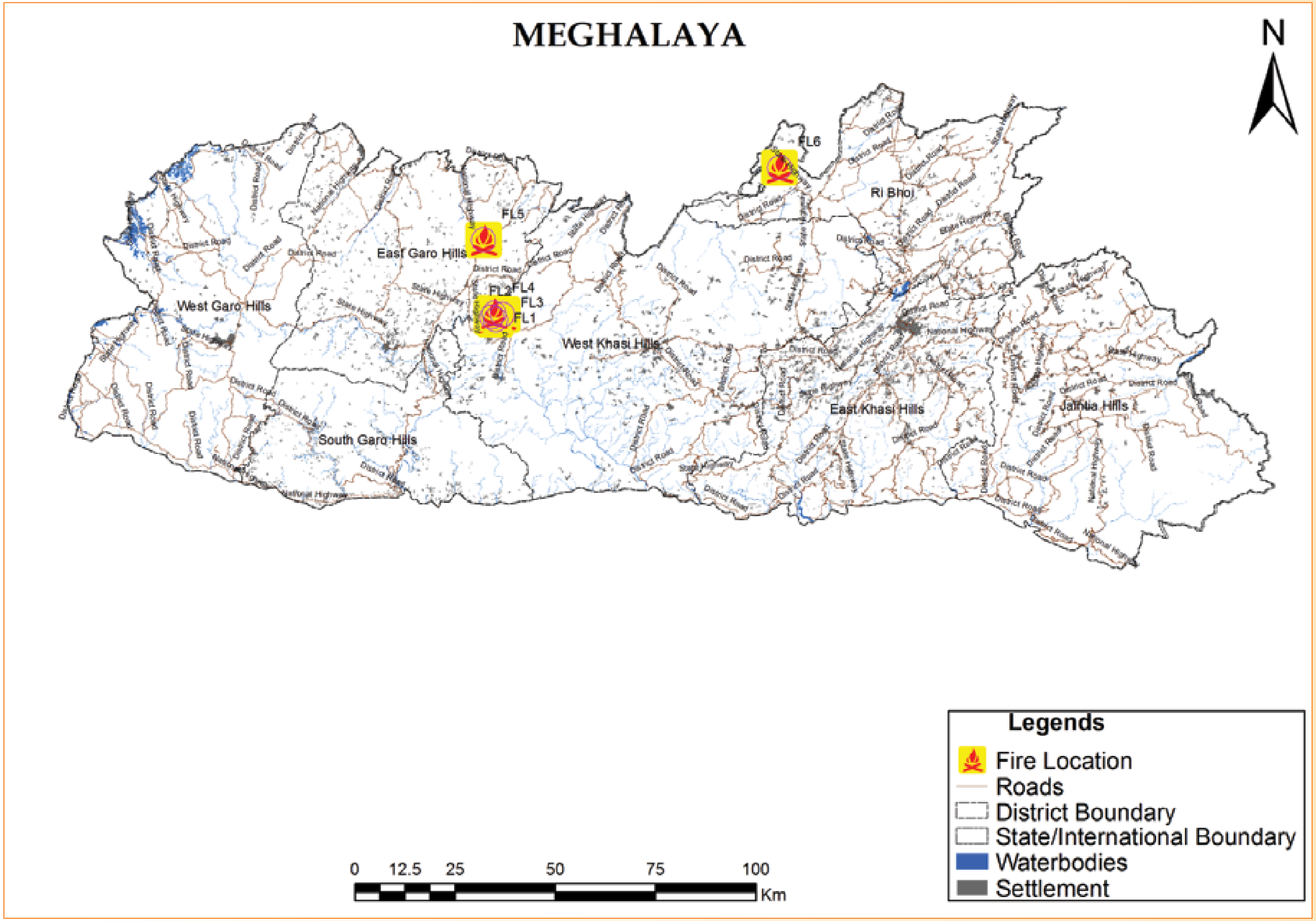


Figure 2.3: Sample map format of daily forest fire hazard alerts

Table 2.9 Sample table format of daily forest fire hazard alerts

Fire Location (FL)	Long	Lat	Date	State Name	District	Vegetation type/Land use Land cover category (buffer of 3 km centered at FL)	Road connectivity to fire location	Aspect	Slope(deg)	Settlement (if present)	Nearby water body (if any)	WS(km/hr)	WD	Dew point (C)	Vulnerability
FL1	90.873	25.577	3/9/2014	Meghalaya	West Khasi Hills	Agricultural Land; Dense Evergreen; Open Evergreen; Scrub	Village Road - Kutchha	S	3-8	Yes	Yes	3.6	S	4.2	
FL2	90.864	25.583	3/9/2014	Meghalaya	West Khasi Hills	Agricultural Land; Dense Evergreen; Jhum; Open Evergreen; Scrub	Village Road - Kutchha	NW	3-8	Yes	Yes	3.6	S	4.2	
FL3	90.890	25.589	3/9/2014	Meghalaya	West Khasi Hills	Agricultural Land; Dense Evergreen; Open Evergreen; Scrub	Village Road - Kutchha	W	25-35	Yes	Yes	3.6	S	4.2	
FL4	90.869	25.591	3/9/2014	Meghalaya	West Khasi Hills	Agricultural Land; Bamboo; Dense Evergreen; Jhum; Open Evergreen; Scrub	Village Road - Kutchha	NW	8-15	Yes	Yes	3.6	S	4.2	
FL5	90.840	25.756	3/9/2014	Meghalaya	East Garo Hills	Agricultural Land; Bamboo; Dense Evergreen; Jhum; Open Evergreen; Scrub	National Highway;Village Road - Kutchha	NW	15-25	Yes	No	NA	N	6.4	
FL6	91.574	25.928	3/9/2014	Meghalaya	Ri Bhoi	Agricultural Land; Dense Deciduous; Dense Evergreen; Jhum; Open Deciduous; Open Evergreen;Scrub	State Highway;Village Road - Kutchha	SW	8-15	Yes	No	7.4	SE	NA	

Data source: MODIS, Bhuvan, ISRO & IMD-AWS, * NA: Not Available

Severe High Moderate Low

Note: The fire locations reported are with confidence level ≥ 60%

Disclaimer: This report is only for planning tool not for any legal purposes; NESAC Team

2.2.6 Burnt Area Assessment

Landsat imagery was used for burnt area assessment of two states (Nagaland and Mizoram) of northeast India. Since, peak fire occurred in March 2014, pre-fire imagery was collected on 15th & 24th November, 17th December, 2013 and 11th January & 27th January, 2014 whereas post-fire imagery was collected on 1st and 24th April, 2014. Landsat imagery has desirable temporal, spatial and spectral characteristics, so is preferred for burn area mapping (Hudak et al. 2002). All images used in this project were acquired by Landsat OLI (Operational Line scanner) sensors and geometrically registered using terrain correction algorithms (Level 1T) by the EROS Data Center and then converted to at sensor reflectance (NASA, 1998; Chander & Markham, 2003).

The Normalized Burn Ratio (NBR) computed from Landsat NIR and SWIR bands has gained considerable attention in recent years for mapping burned areas (Miller & Yool, 2002; Brewer et al., 2005; Epting et al., 2005; Key & Benson, 2005). In the present study, NBR is calculated as follows:

NBR = NIR-SWIR/NIR+SWIR (1)

Landsat OLI band-5 (NIR) and band-7 (SWIR) was used for calculation of NBR. NBR typically responds to the substantial decrease in near-infrared reflectance (NIR) due to plant canopy damage (Chuvieco et al. 2006) and consumption by fire, and a substantial increase in shortwave infrared reflectance (SWIR) (White et al. 1996).

Most fire severity mapping applications to date have subtracted a post-fire NBR image from a pre-fire NBR image in an absolute change detection methodology to derive the "differenced NBR" (dNBR) as follows:

dNBR = (prefireNBR–postfireNBR)×1000 (2)

2.2.7 Relationship between Forest fire incidences and Shifting Cultivation:

To see the relationship between forest fire incidences and shifting cultivation, a case study was done for Mizoram. Data used include fire location data from FSI, spatial data (administrative boundary) and AWiFS.

Chapter-3: Results and Discussion

3.1 Forest fire incidence scenario in NER India (2001-2014)

Of the total fire incidences between the years 2001-2014, year wise fire incidences in NER indicates that forest fire increased from 1.5% in 2001 to 9% in 2004 and again decreased to 7.2% in 2005. Interestingly, it increased to 11.7% and 9.8% in the year 2006 and 2007, respectively (Figure 3.1). However, similar trend in fire incidences was observed in 2011 (4.9%), 2012 (6.4%) and 2013 (5.4%). In 2014 (February to April), the fire incidences was reduced to 2.6%. State-wise fire incidences showed similar trend in between 2001-2014 (Figure 3.2).

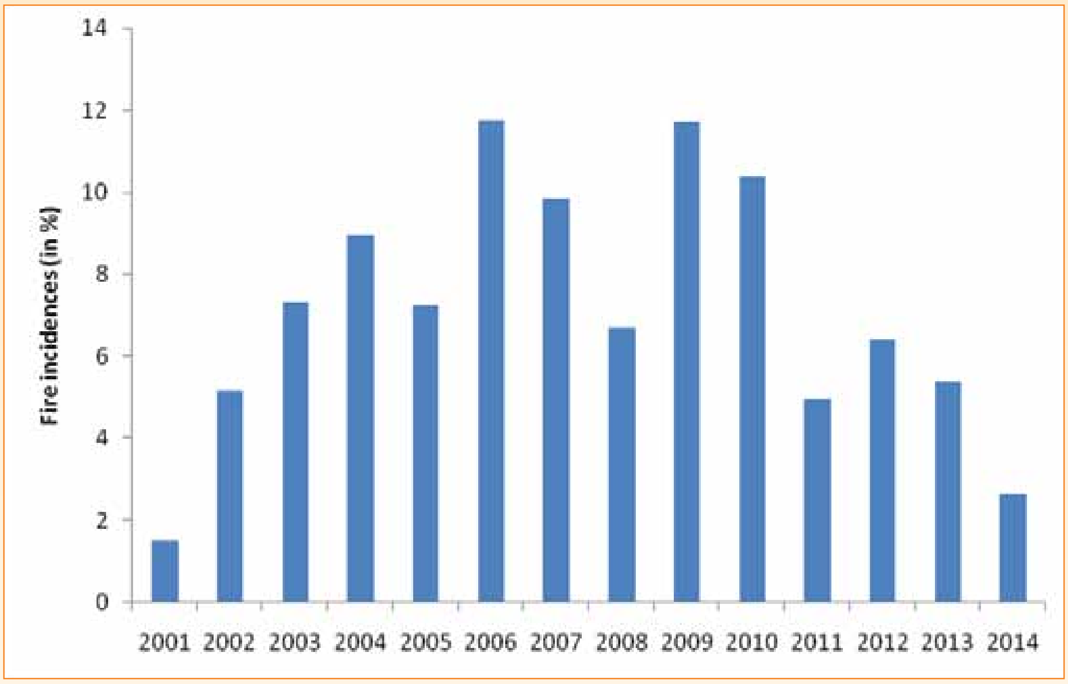


Figure 3.1: Overall year-wise fire incidences (in %) in NER

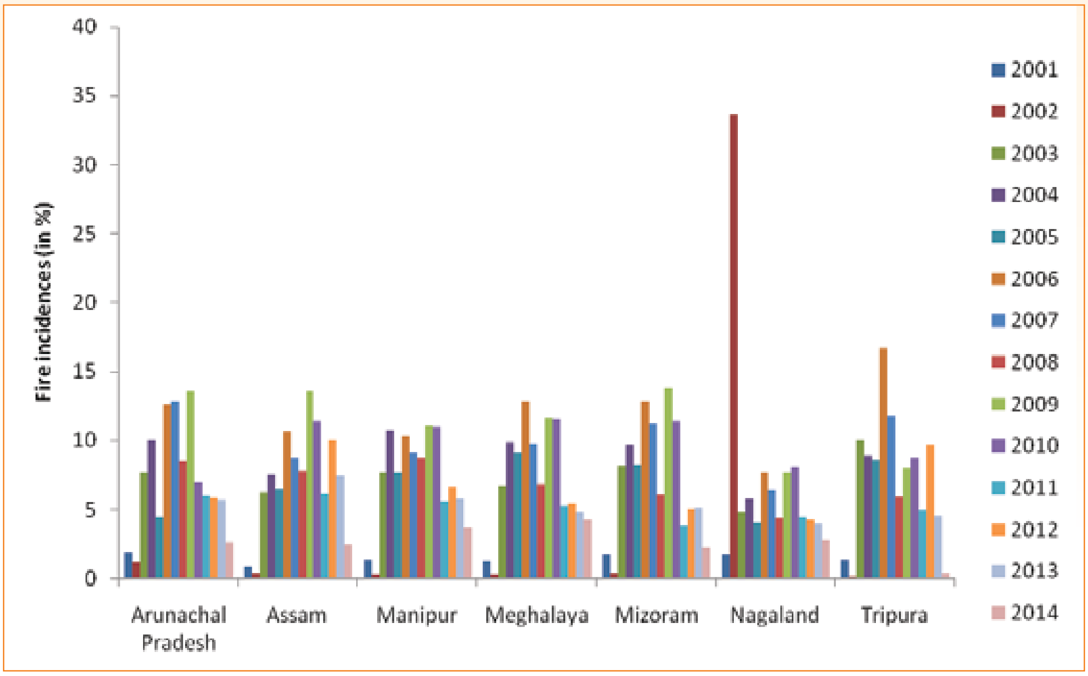


Figure 3.2: State-wise and year-wise fire incidences (in %) in NER

3.2 Forest fire incidence scenario in NER India in 2014

During forest fire season in the year 2014 in NER India, a total of 10,084 fire incidences have been reported (FSI, 2014). Among seven states, Assam showed the maximum (25%) number of fire incidences followed by Mizoram (22%), Manipur (18%), Tripura (12%), Meghalaya (11%), Nagaland (8%) and Arunachal Pradesh (6%) as shown in Figure 3.3.

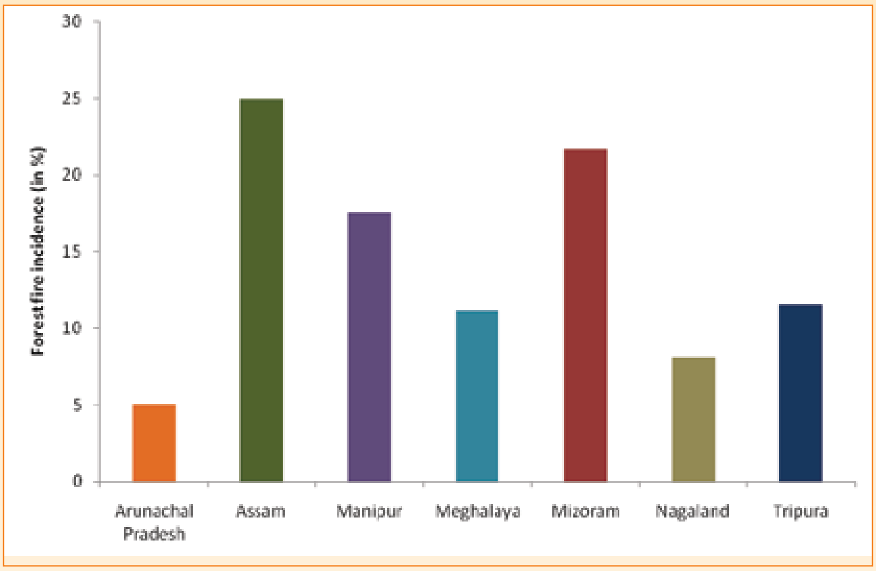


Figure 3.3: Fire incidences (%) in NER states in India (February -April 2014)
Source: FSI

Forest fire location in NER in 2014 is shown in Figure 3.4.

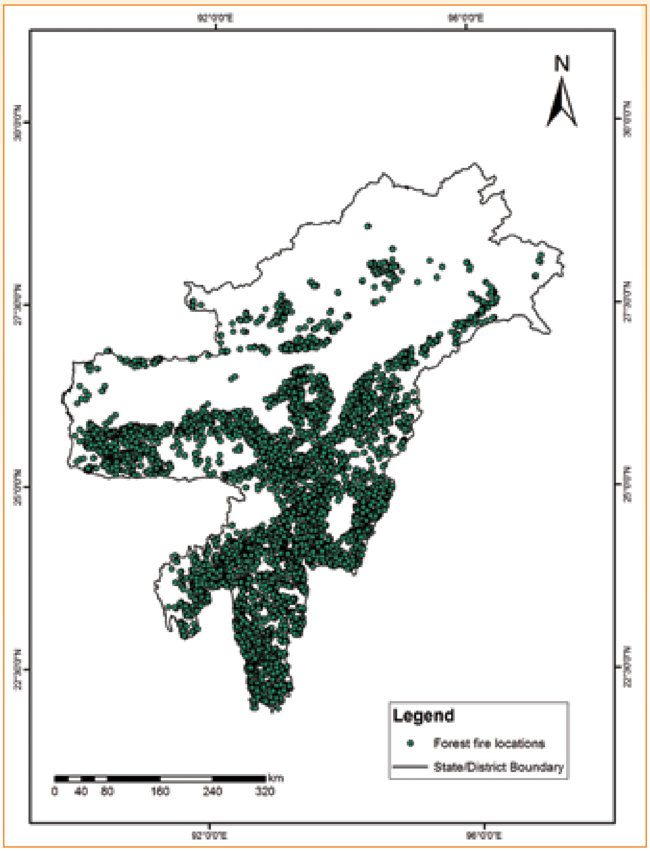


Figure 3.4: Forest fire locations in NER states in February to April 2014
Source: FSI

Number of fire incidences in the year 2014 for each NER state is shown in Figure 3.5.

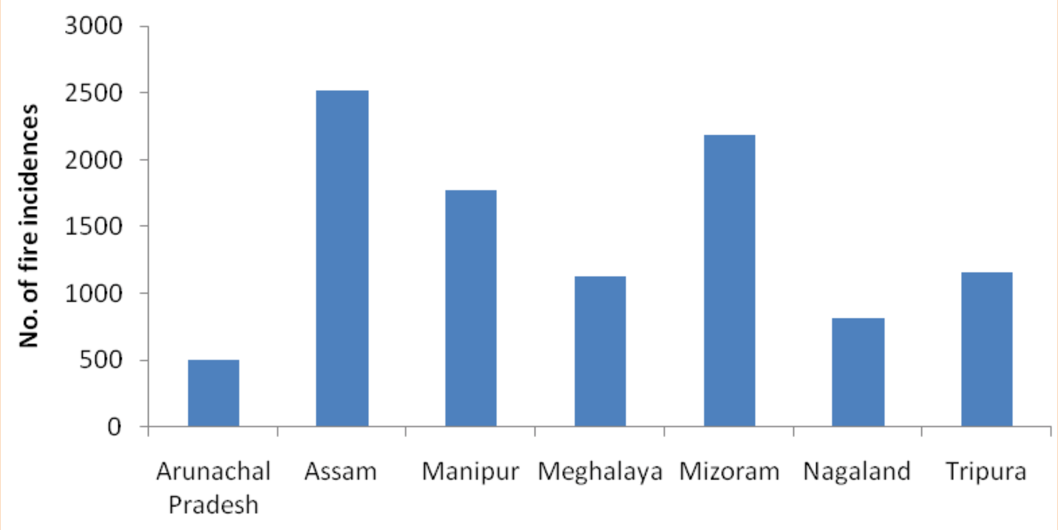


Figure 3.5: Fire incidences (%) in NER states in India (February -April 2014)
Source: FSI

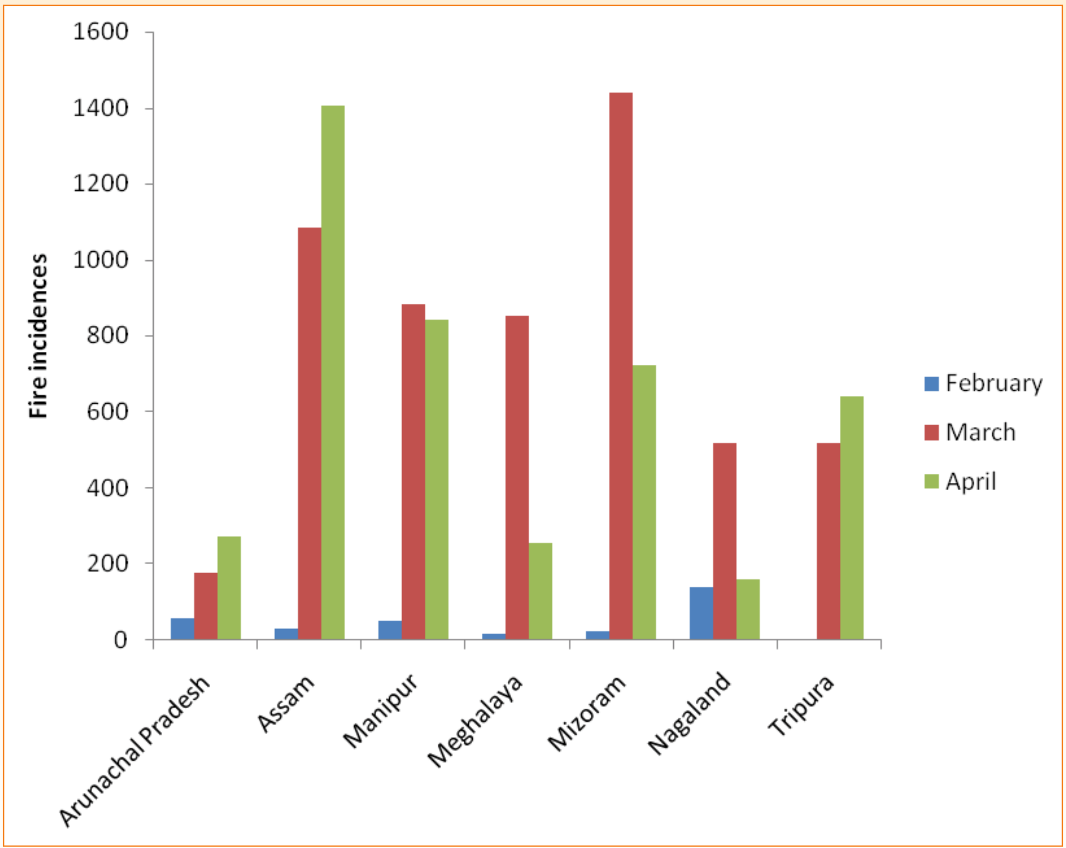


Figure 3.6: Month-wise fire incidences in NER in 2014 (FSI)

Month-wise fire incidences in NER India indicates that forest fire incidence is the maximum in the month of April in the states of Arunachal Pradesh, Assam and Tripura and the minimum in February in all other states except for Tripura where no fire is observed in the month of February (Figure 3.6). On the other hand, in Manipur, Meghalaya, Mizoram and Nagaland, the maximum fire occurred in the month of March (Figure 3.6). Overall, the order of fire incidences observed is: March (54%) > April (43%) > February (3%) in 2014 (Figure 3.7).

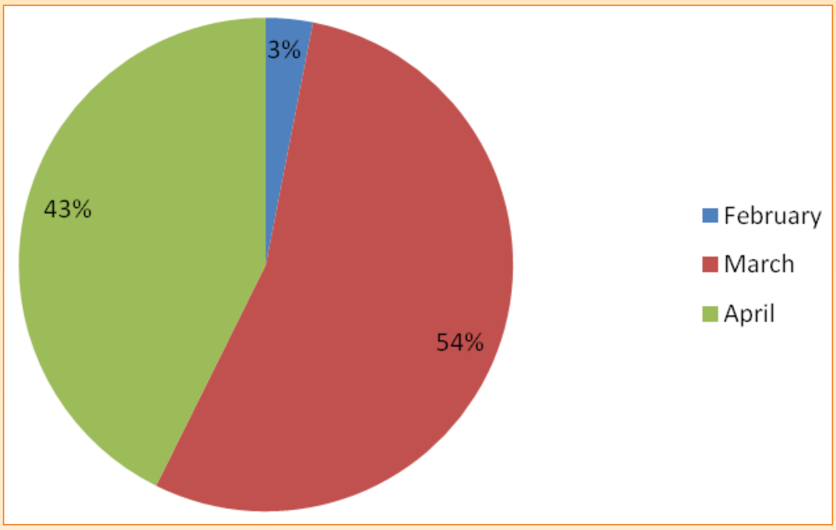


Figure 3.7: Overall month-wise fire incidences in 2014 (FSI)

3.3 Historical fire data analysis:

Historical analysis was done to understand the relationship between forest fire and various factors such as vegetation types, topographical factors (aspect, slope, elevation), roads, settlements, waterbodies in each state of NER. Based on historical occurrence of forest fire incidence state-wise forest fire scenario with respect to above mentioned factors is assessed.

Fuel characteristics analysis: The fuel (in our case vegetation or forests) plays a significant role in the occurrence of fire. Incidence of historical forest fires were analyzed with respect to forest type and density.

Forest type and density: In Arunachal Pradesh and Manipur, results indicated high incidence of forest fire in evergreen/semi-evergreen forest followed by bamboo and conifers (Figure 3.8).

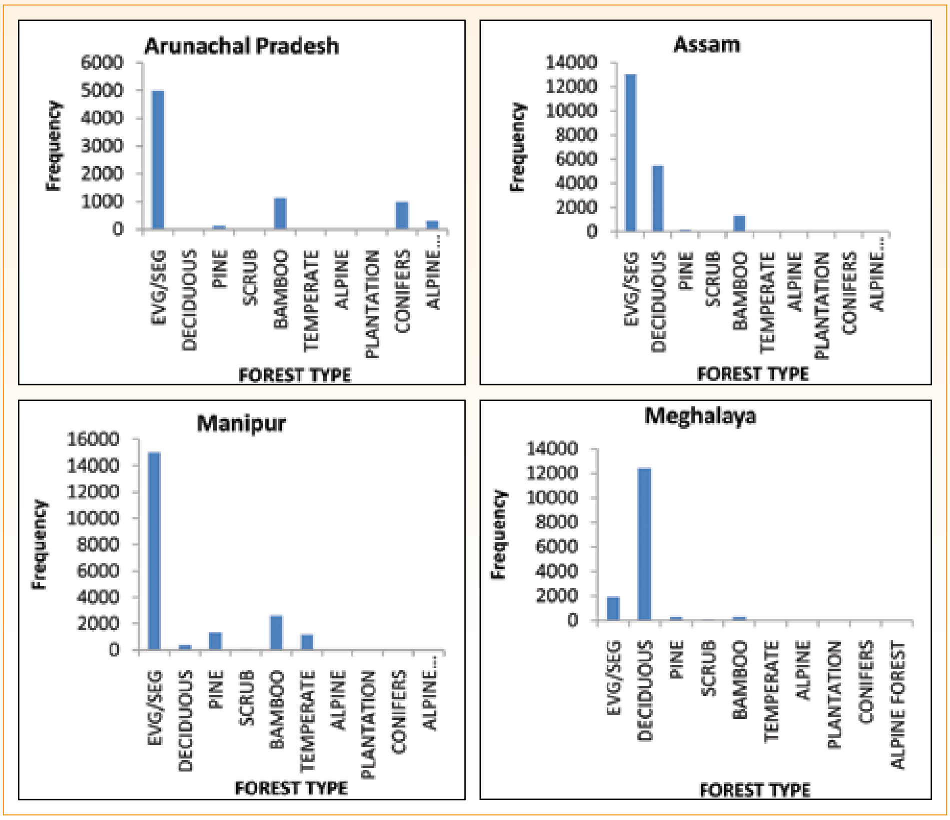


Figure 3.8: Fire frequency based on forest type in the year 2001-2013

In Assam, high incidence of forest fire is indicated in evergreen/semi-evergreen forest followed by deciduous forest and bamboo while in Meghalaya and Nagaland higher forest fire incidence is observed in deciduous forest followed by evergreen/semi-evergreen forest and bamboo. In Mizoram, highest incidence is observed in bamboo followed by evergreen/semi-evergreen and deciduous forest while in Tripura deciduous forest is followed by bamboo (Figure 3.8).

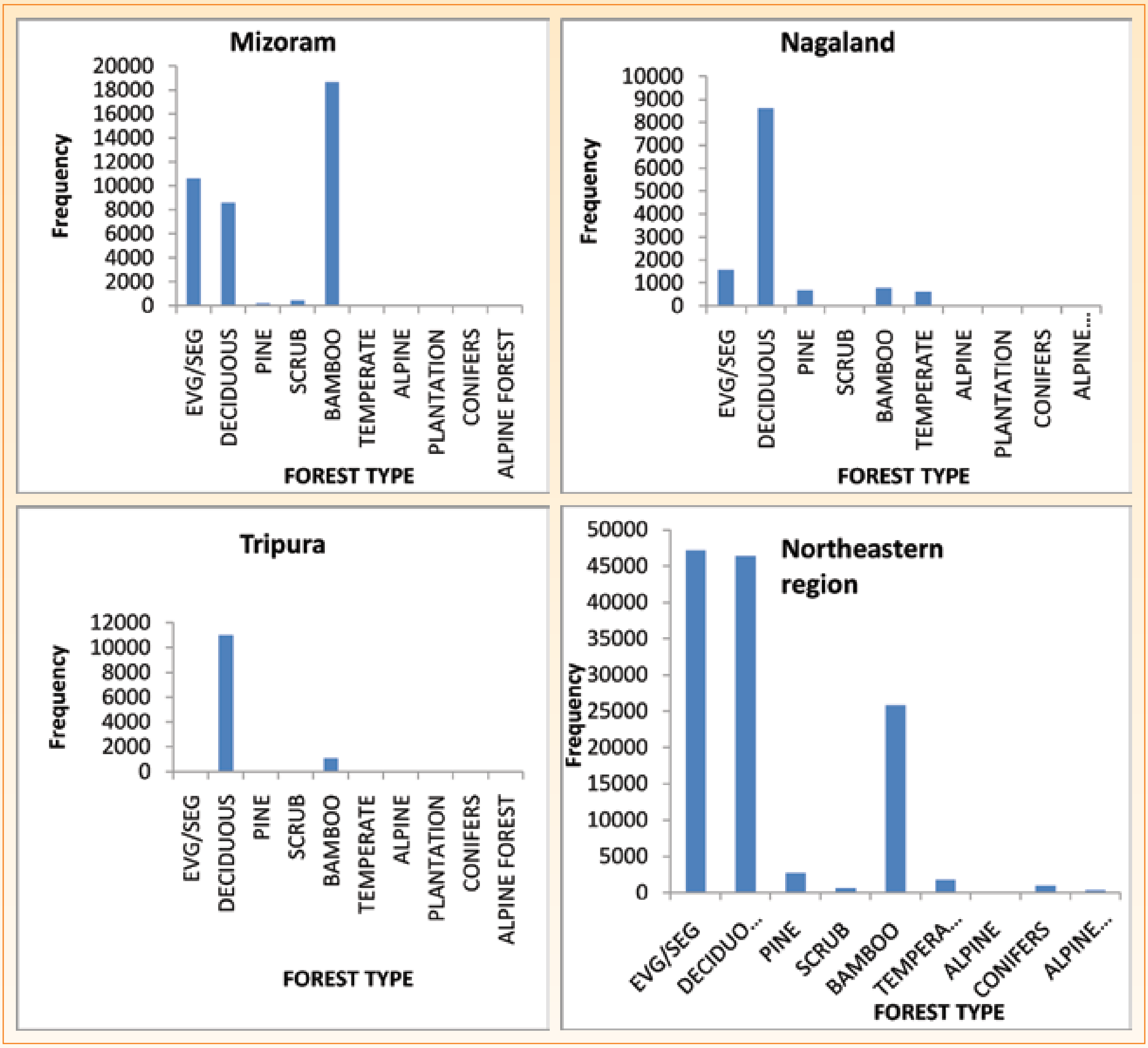


Figure 3.8: Fire frequency based on forest type in the year 2001-2013

Overall order of forest type showing forest fire incidence in NER is: Evergreen/Semi-evergreen > Deciduous > Bamboo > Pine > Temperate > Conifers > Scrub > Alpine forest > Alpine.

In terms of forest density, except for Tripura, highest incidence of forest fire is indicated in open forest followed by moderately open forest (Figure 3.9). Open and Medium dense forest have high wind velocity that caused the flames into the un-burnt material ahead of the fire front resulting in more efficient preheating of the fuel and greater rates of spread in surface head fires (Luke & McArthur, 1978; Cheney, 1981, Trollope et al., 2002).

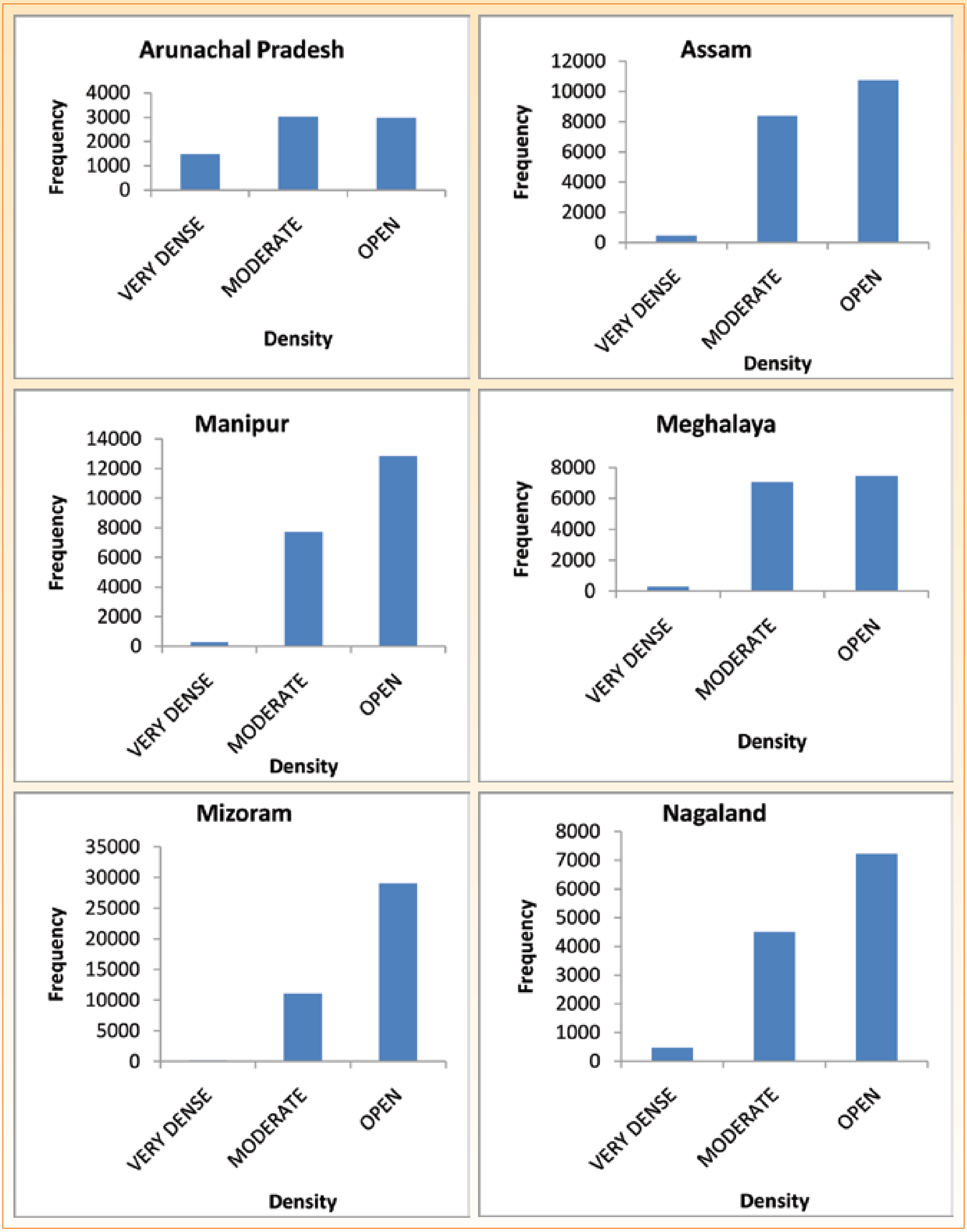


Figure 3.9: Fire frequency based on forest density in the year 2001-2013

Order of forest density in terms of forest fire incidence in NER is: Open forest > Moderate forest > Very dense forest.

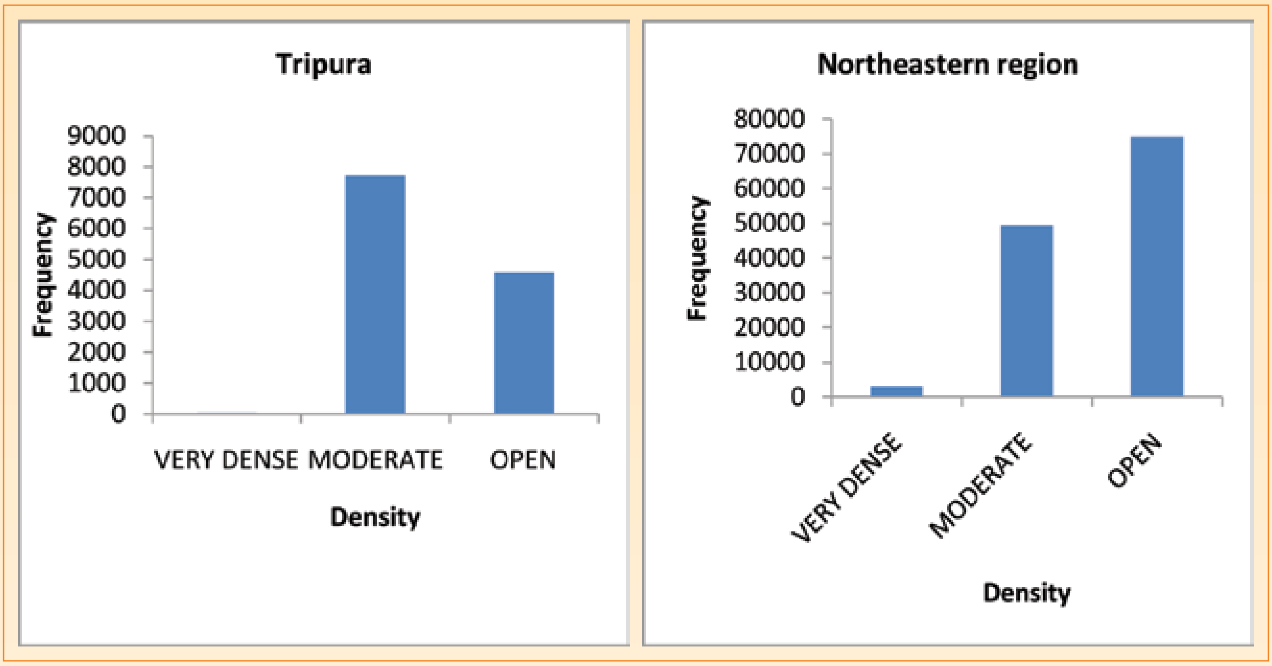


Figure 3.9: Fire frequency based on forest density in the year 2001-2013

Topographical factors analysis: Various topographical factors such as slope, aspect and elevation may influence forest fire behavior.

Aspect: South and west slopes are considered to receive the most sunlight, and so they are much warmer and drier than northern slope, which get the least amount of sunlight. The results indicated that the maximum fire points are observed in south slope and the minimum in north, in Arunachal Pradesh (Figure 3.10).

Figure 3.10: Fire frequency based on aspect in the year 2001-2013

In Assam, the maximum fire points are observed in southeast and the minimum in southwest. In Manipur, the maximum fire points are observed in southeast and the minimum in north while in Meghalaya, the maximum fire points are observed in northwest and the minimum in northeast.

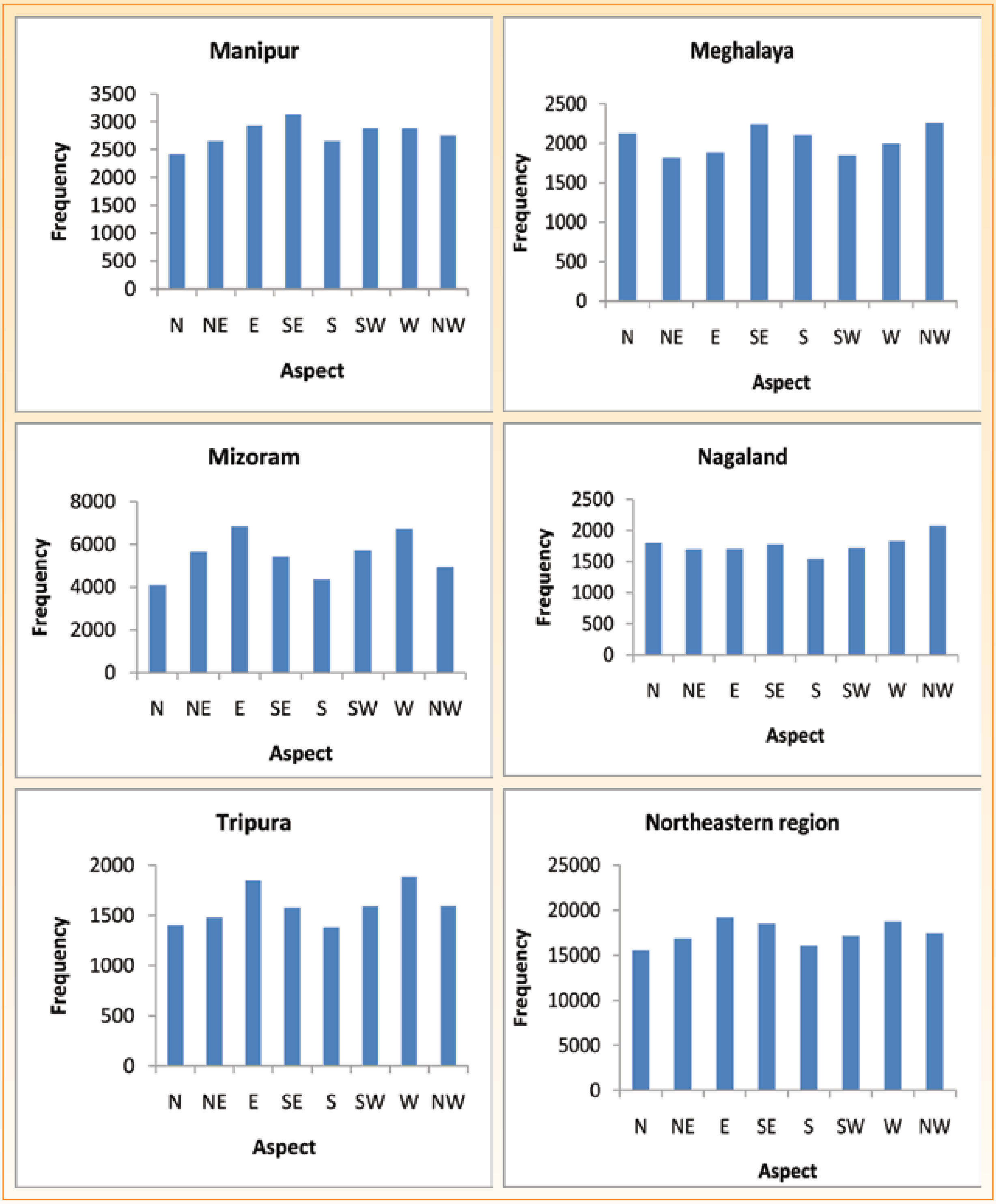


Figure 3.10: Fire frequency based on aspect in the year 2001-2013

East aspect showed the maximum fire points and north showed the minimum in Mizoram while in Nagaland, northwest showed the maximum and south showed the minimum number of fire points (Figure 3.10). In Tripura, west showed the maximum and south showed the minimum number of fire points.

Overall, in northeast India, east showed the maximum and north showed the minimum number of fire points (Figure 3.10).

Slope: Slope is one the parameters that influences fire behavior. Fire moves most quickly up slope and least quickly down slope (Adab et al. 2011). Also, in steeper slopes, rate of fire spread might rise, since flames are angled closer to the surface of ground and wind effects can supply the process of heat convection for the fire produced (Zhong 2003).

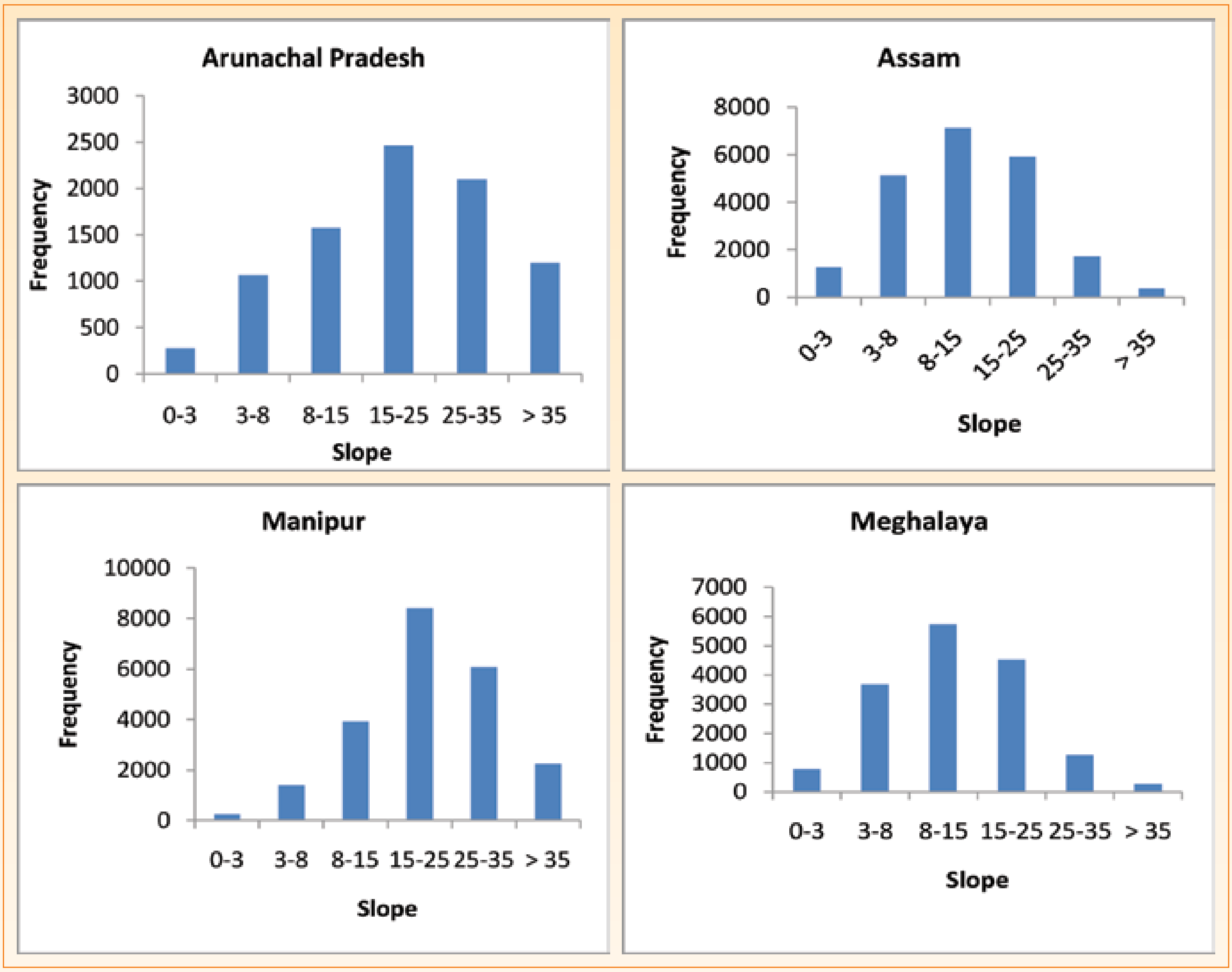


Figure 3.11: Fire frequency based on slope in the year 2001-2013

Present study showed that maximum fire incidences occurred in slope that range from 15-25° & the minimum in 0-3° in the states of Arunachal Pradesh, Manipur, Mizoram and Nagaland while in Assam, Meghalaya and Tripura, the maximum fire occurs in slope range from 8-15° and the minimum in > 35° (Figure 3.11).

In NER, considering all states the maximum fire point is observed in slope range from15-25° and the minimum in 0-3° slope.

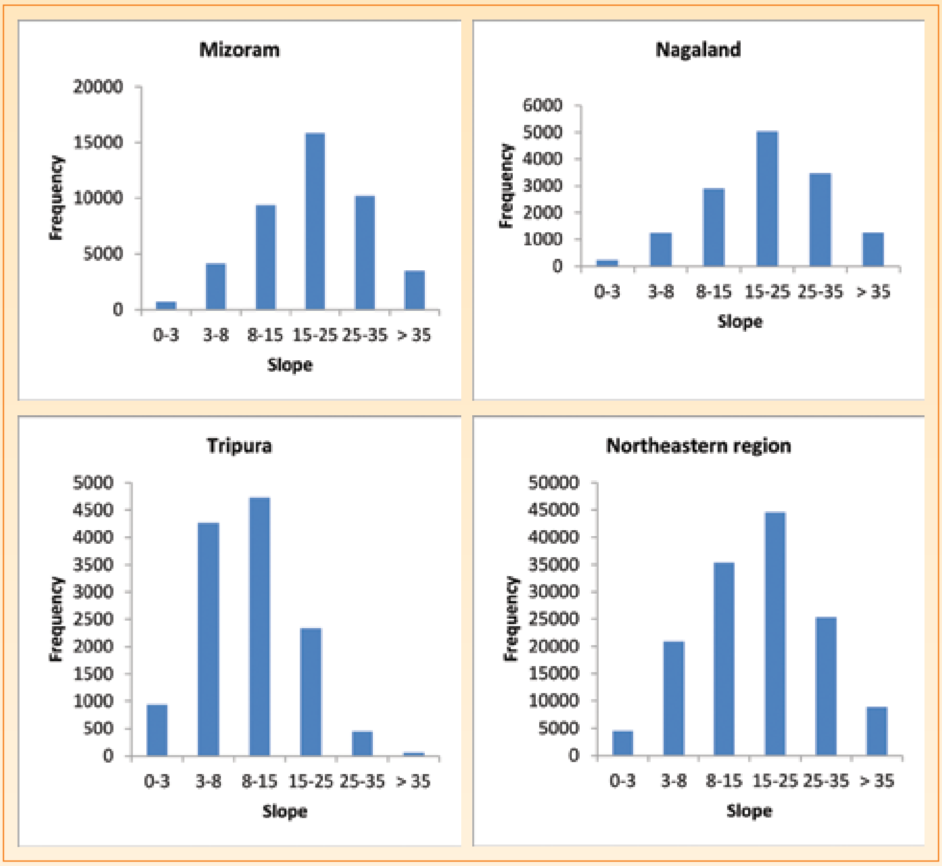


Figure 3.11: Fire frequency based on slope in the year 2001-2013

Elevation: As can be seen in Figure 3.12, the maximum numbers of fire points are observed in the elevation range of 500-1000m in the states of Arunachal Pradesh, Manipur and Nagaland and in the range of 200-500m in Meghalaya and Mizoram and 0-200m in Tripura.

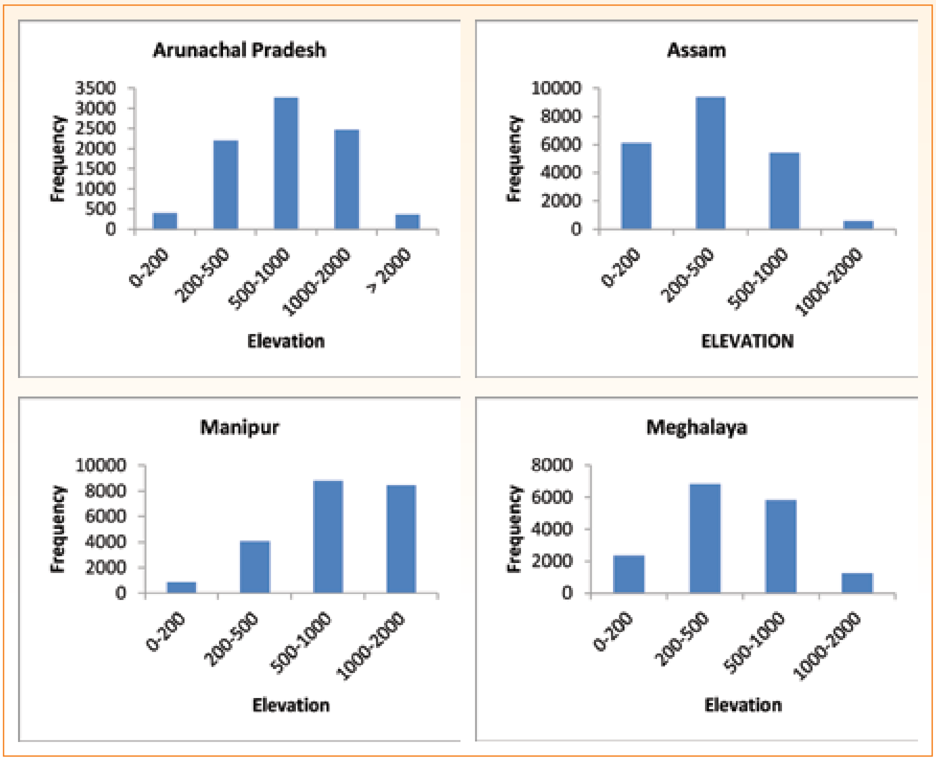


Figure 3.12: Fire frequency based on elevation in the year 2001-2013

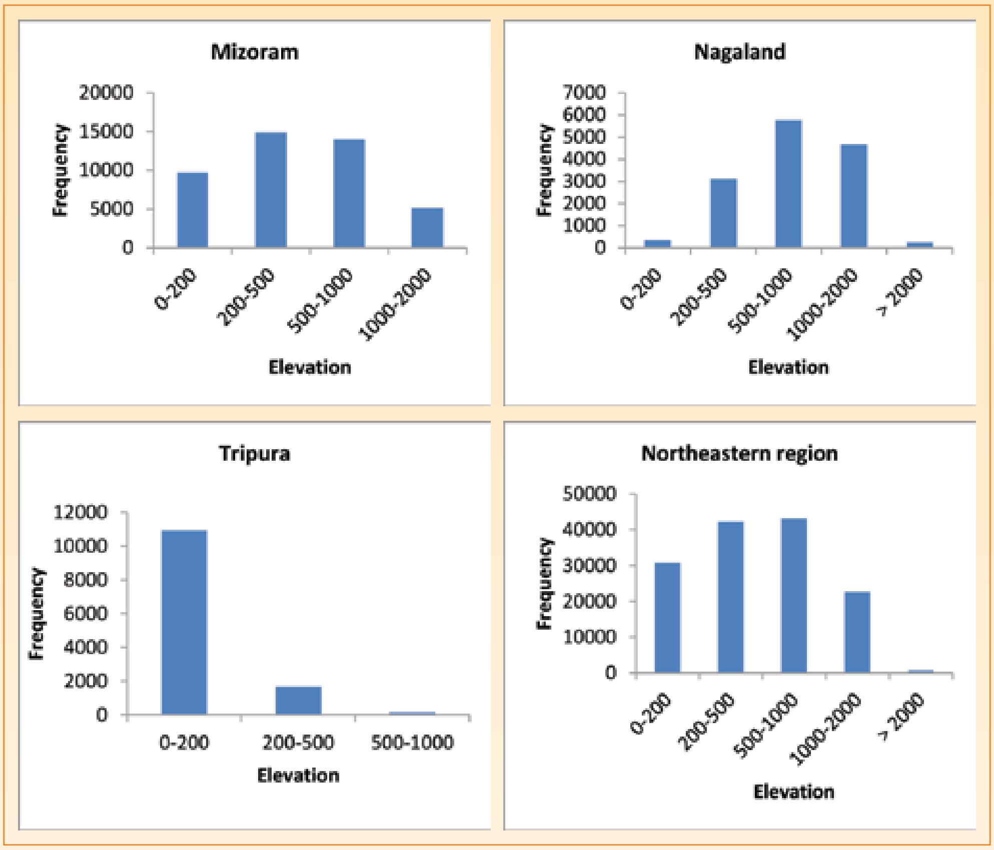


Figure 3.12: Fire frequency based on elevation in the year 2001-2013

The minimum fire incidence is observed in the elevation range of 0-200m in Manipur, 1000-2000m in Assam, Meghalaya and Mizoram, 500-1000m in Tripura and more than 2000m in Arunachal Pradesh, Nagaland and NER.

In NER, the maximum fire points showed similar trend in elevation in the range of 200-500m and 500-1000m (Figure 3.12).

Proximity analysis: Proximity to roads, settlements and water bodies may play important role in forest fire, though it does not influence the behavior of a fire.

Roads and built ups: The presence of roads may influence forest fire vulnerability in two ways: (a) as source of fire through activities such as hiking and camping ground/areas and (b) they can serve as firebreaks or pathways for suppression of the fire. The presence of built ups with human settlements inside or near the forest could be the source of human induced forest fire either for agricultural/shifting cultivation or other forest related activities.

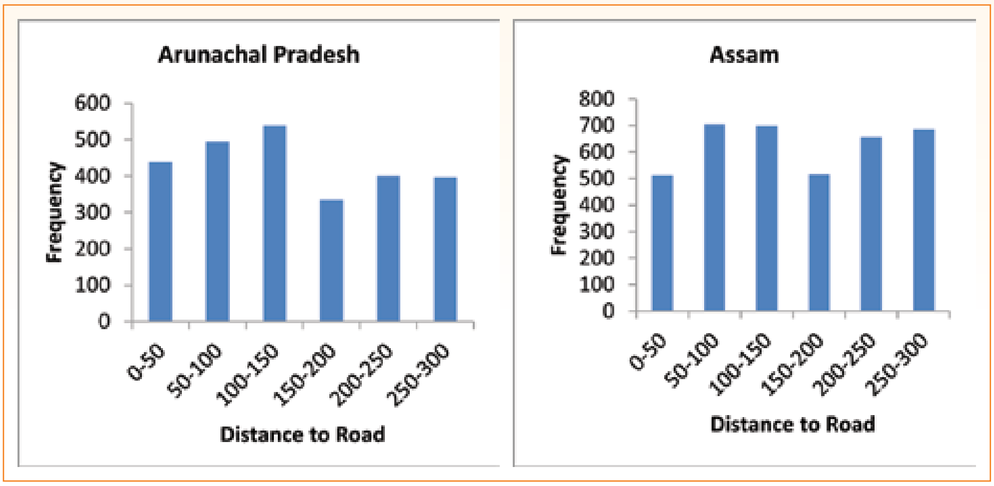


Figure 3.13: Fire frequency based on distance to road in the year 2001-2013

In the present study, except for Arunachal Pradesh and Tripura, higher fire frequency is observed in forest lying at a distance of 50-100m from roads in Assam, Manipur, Meghalaya, Mizoram, Nagaland (Figure 3.13). On the other hand, the minimum fire frequency is observed at a distance of 150-200m from roads in Arunachal Pradesh, Assam, Meghalaya, Nagaland and Tripura.

In NER, higher fire frequency is observed in forest lying at a distance of 50-100m from roads and the minimum fire frequency is observed at a distance of 150-200m from roads.

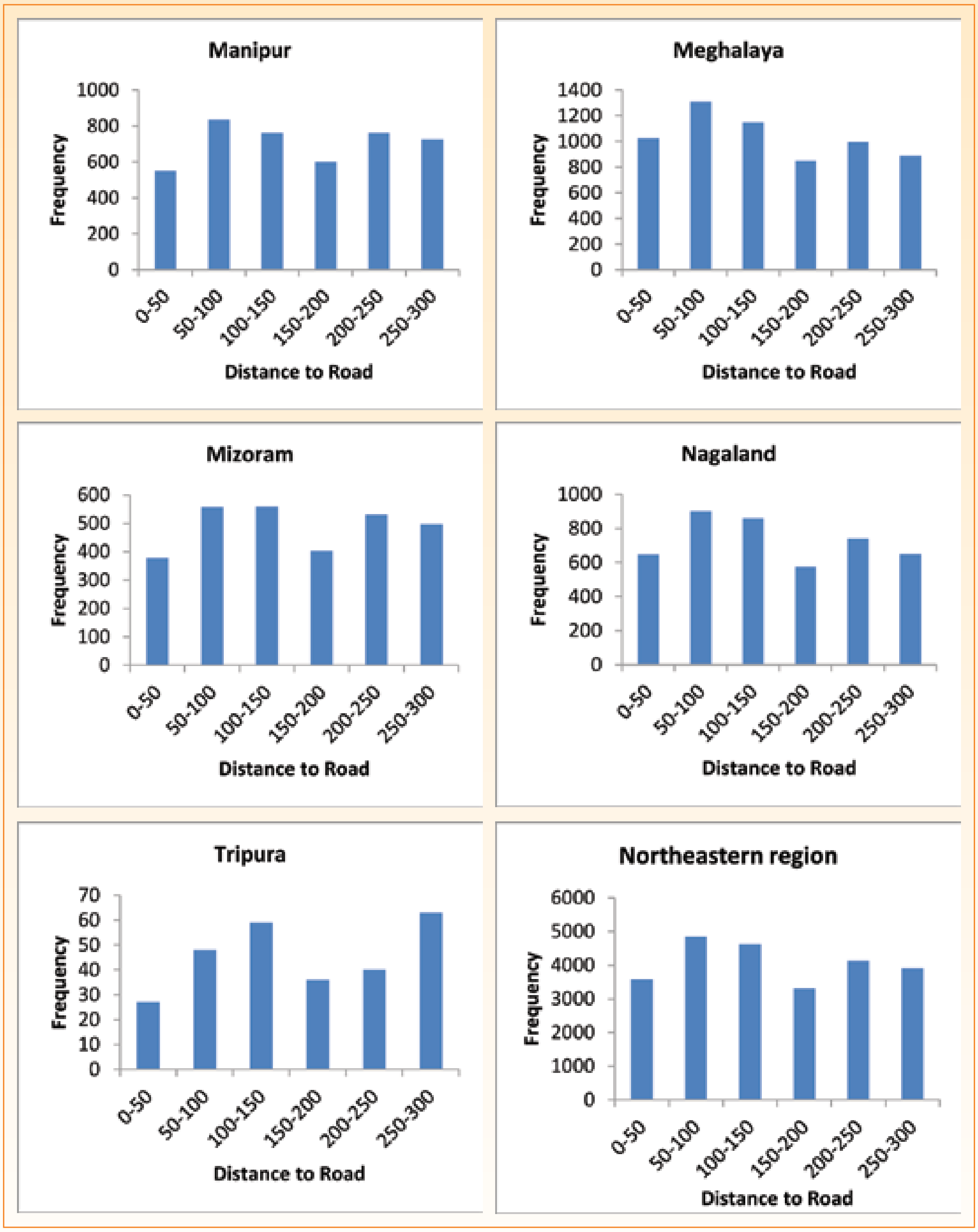


Figure 3.13: Fire frequency based on distance to road in the year 2001-2013

As far as distance to built-ups is concerned, the maximum fire incidences occurred at a distance of 500-1000m in Arunachal Pradesh, Assam and Meghalaya, 1000-1500m in Manipur, Nagaland, 1500-2000m in Mizoram and Tripura (Figure 3.14). The minimum fire incidences occurred at a distance of 2500-3000m in Arunachal Pradesh, Assam, Meghalaya and Nagaland, 0-500m in Manipur, Mizoram and Tripura (Figure 3.14).

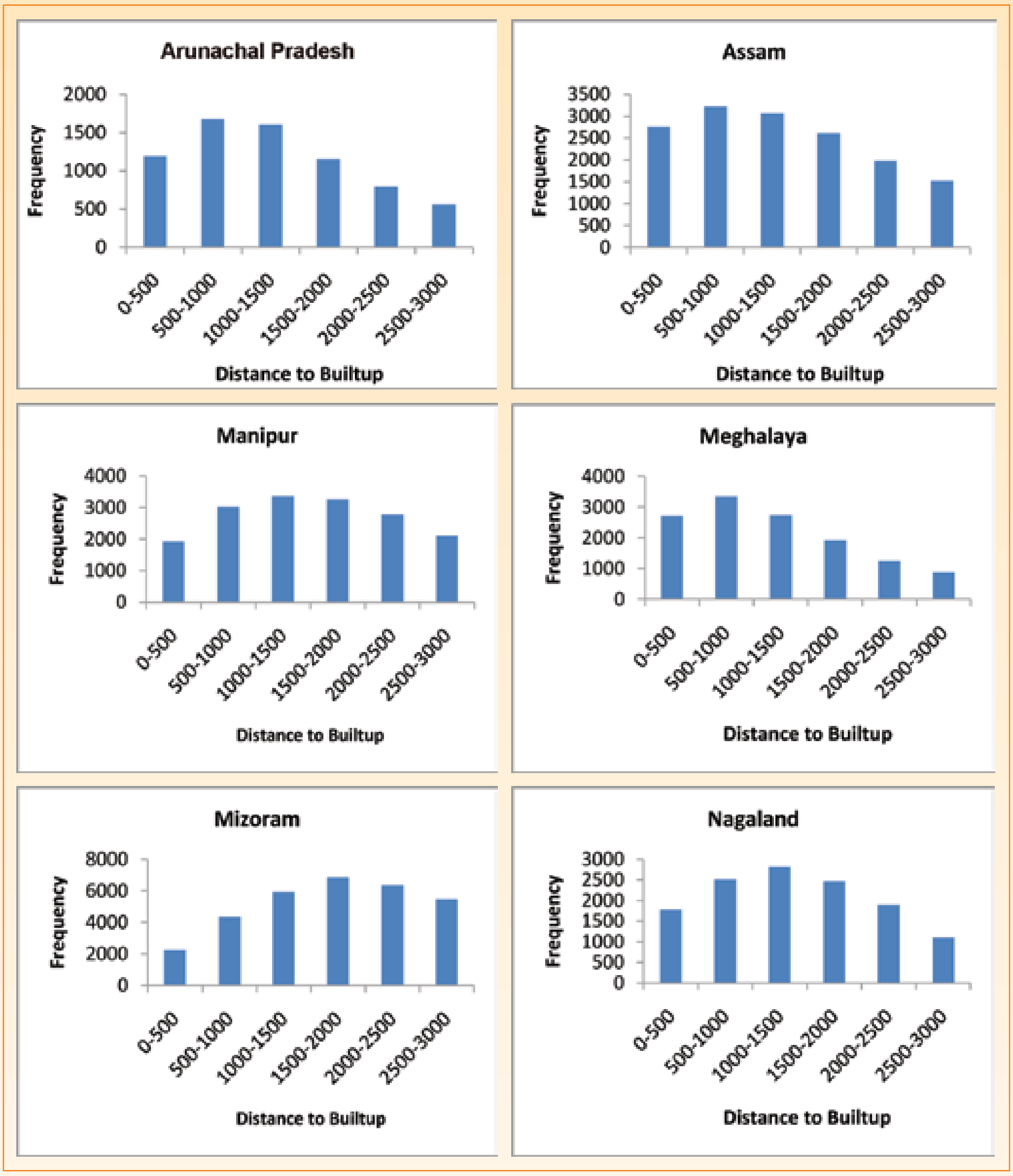


Figure 3.14: Fire frequency based on distance to built-up in the year 2001-2013

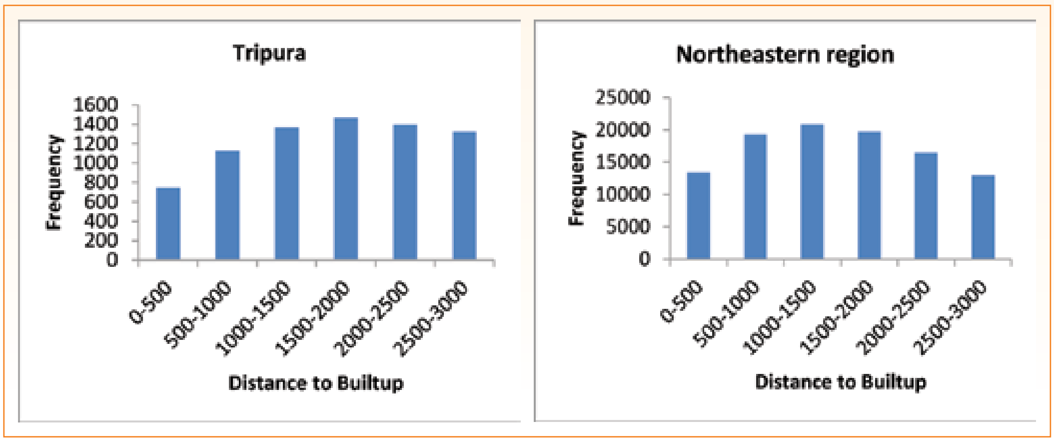


Figure 3.14: Fire frequency based on distance to built-up in the year 2001-2013

In NER, the maximum fire incidences occurred at a distance 1000-1500m and the minimum at 2500-3000m from built-ups or settlement area.

Drainage or water bodies: Drainage pattern or water-bodies helps in controlling the forest fire incidences as natural fire lines or fire barrier. In this study, as expected, higher fire frequency is observed at longer distance from water body. Interestingly, maximum fire frequency was observed at a distance of more than 1000m in all states (except for Mizoram: 500-1000m) and the minimum at a range of 0-100m (Figure 3.15).

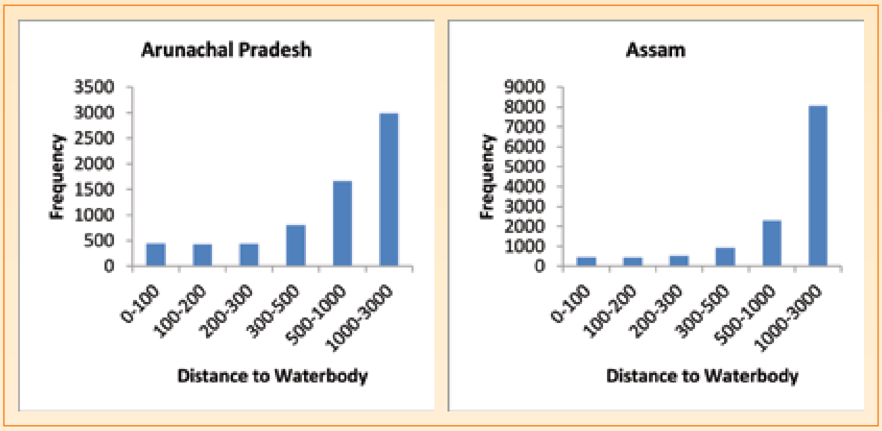


Figure 3.15: Fire frequency based on distance to water-body in the year 2001-2013

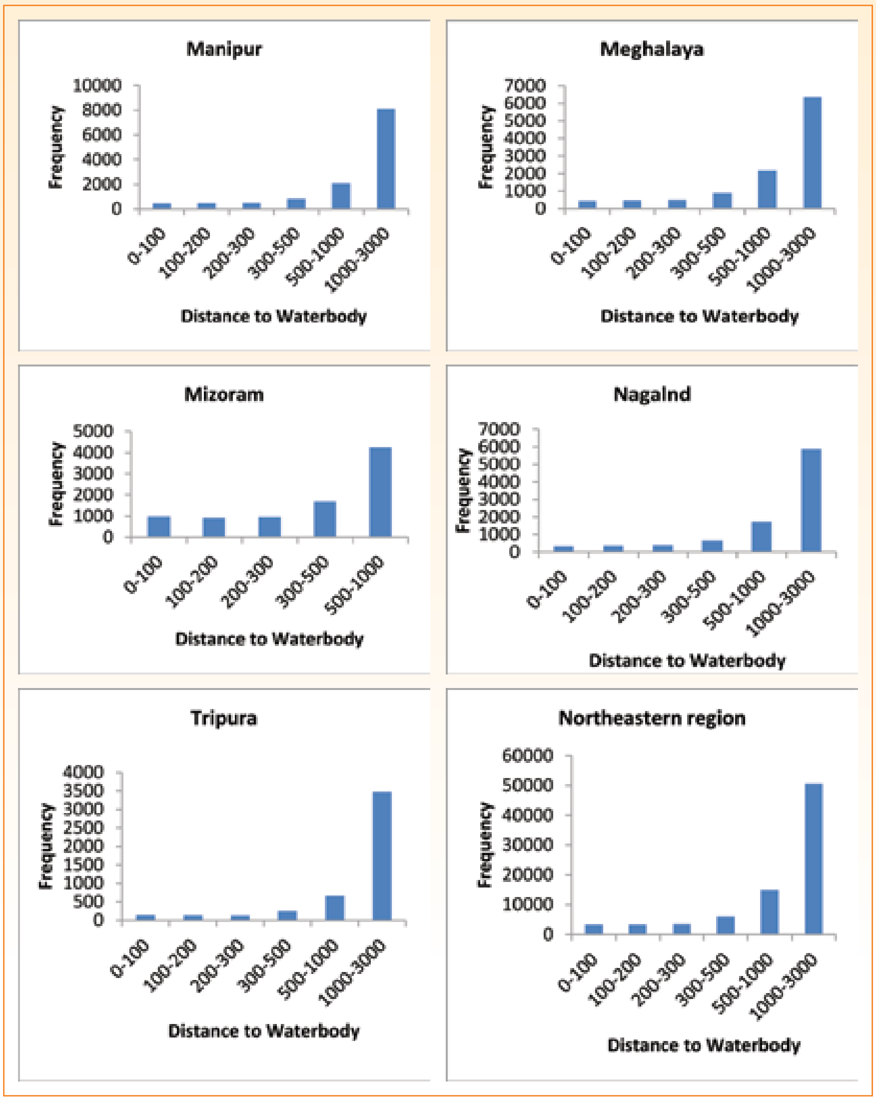


Figure 3.15: Fire frequency based on distance to water-body in the year 2001-2013

3.4 Forest fire vulnerability zone mapping

Fire vulnerability zones were classified into five categories, viz., very high, high, moderate, and low and very low vulnerability zone. State-wise fire vulnerability zone maps are shown in Figure 3.16-3.22. Table 3.1, 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7 shows the state-wise different fire vulnerability zones and their corresponding areas. In Arunachal Pradesh, the study shows that of the total area about 51% (the highest) of the area is under moderate vulnerable zone. 0.4% and 17% is under very high and high vulnerability zones, whereas almost 9% and 23% of the area has very low and low fire potentials (Table 3.1), and about 51% of the area has moderate fire vulnerability. Thus of the total area of the forest, more than 70% is prone to acute fire.

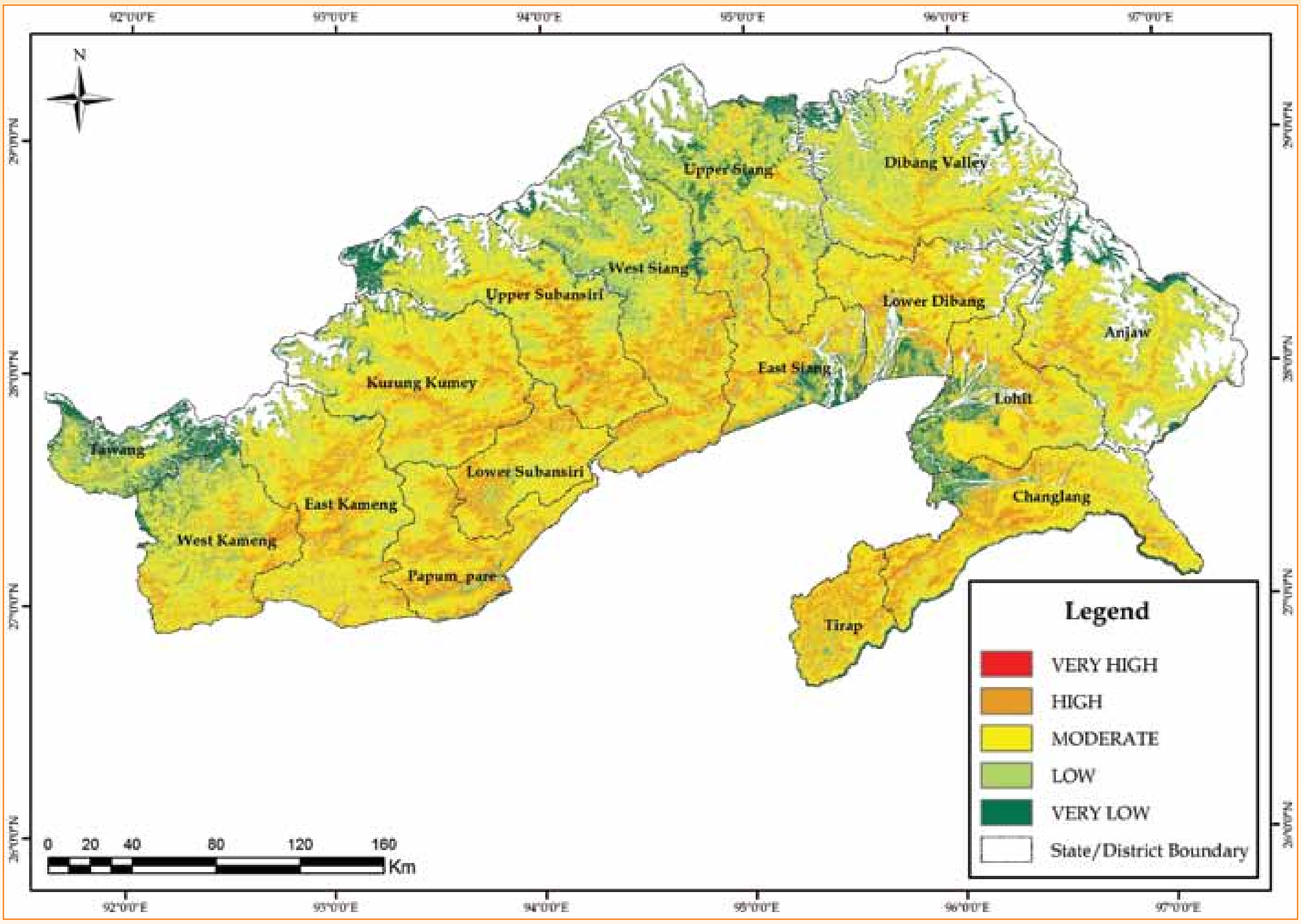


Figure 3.16: Fire vulnerability zone map of Arunachal Pradesh

Table 3.1: Forest fire vulnerability zones in Arunachal Pradesh with corresponding areas

Fire vulnerability class	Area (Sq. km)	% Area
Very Low	6597.6	9.0
Low	16900.3	23.0
Moderate	37442.1	51.0
High	12229.8	16.7
Very High	263.5	0.4

In Assam, about 0.03% and 10% is under very high and high vulnerability zones, whereas almost 12% and 56% of the area has very low and low fire potentials (Table 3.2), and about 21% of the area has moderate fire vulnerability.

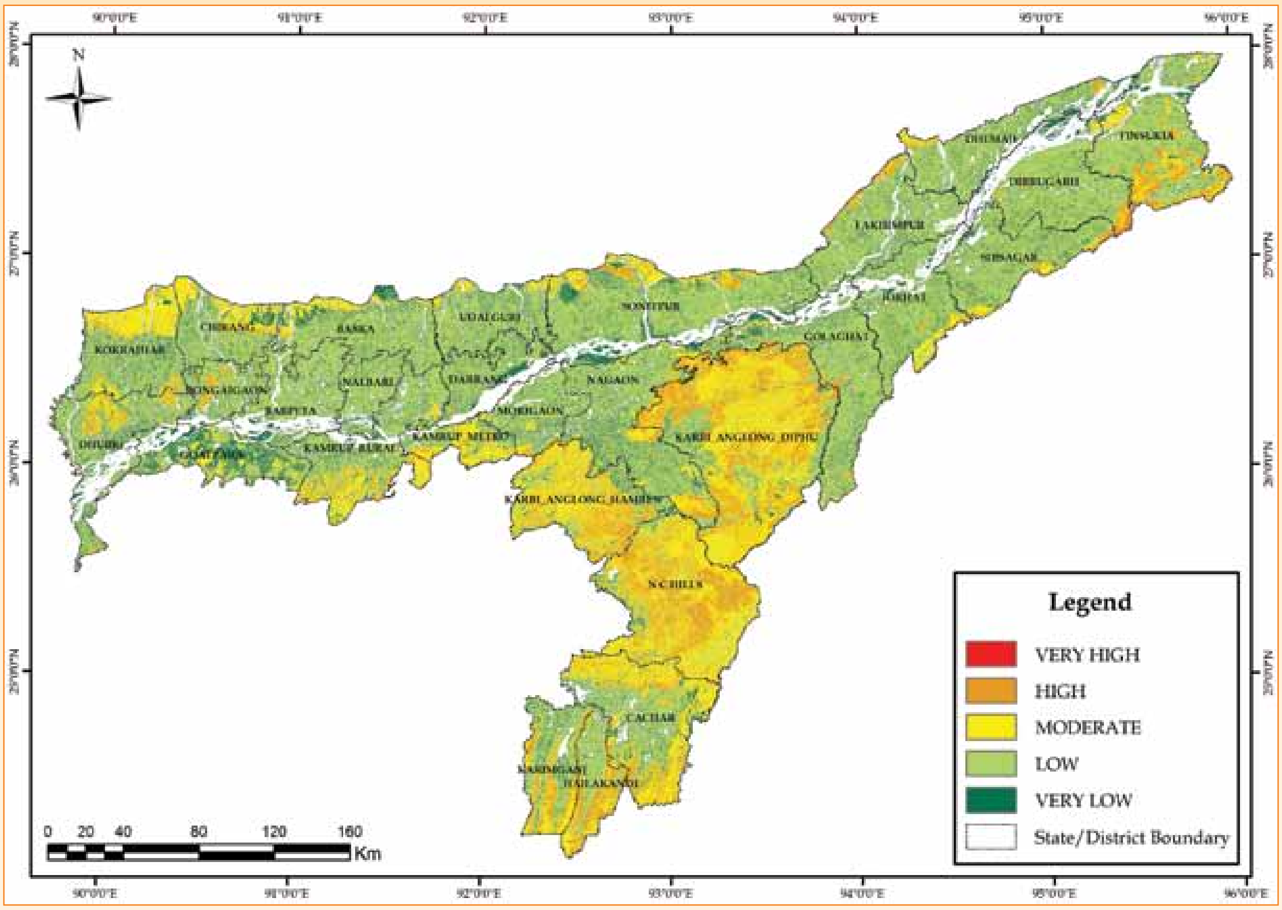


Figure 3.17: Fire vulnerability zone map of Assam

Table 3.2: Forest fire vulnerability zones in Assam with corresponding areas

Fire vulnerability class	Area (Sq. km)	% Area
Very Low	8670.6	12.4
Low	39323.5	56.4
Moderate	14604.0	21.0
High	7038.9	10.1
Very High	24.0	0.03

In Manipur, 0.8% of the forest area is under very high vulnerability, 33% in high vulnerability zones, 39 % in moderate vulnerability and 20% in low vulnerability zone (Table 3.3).

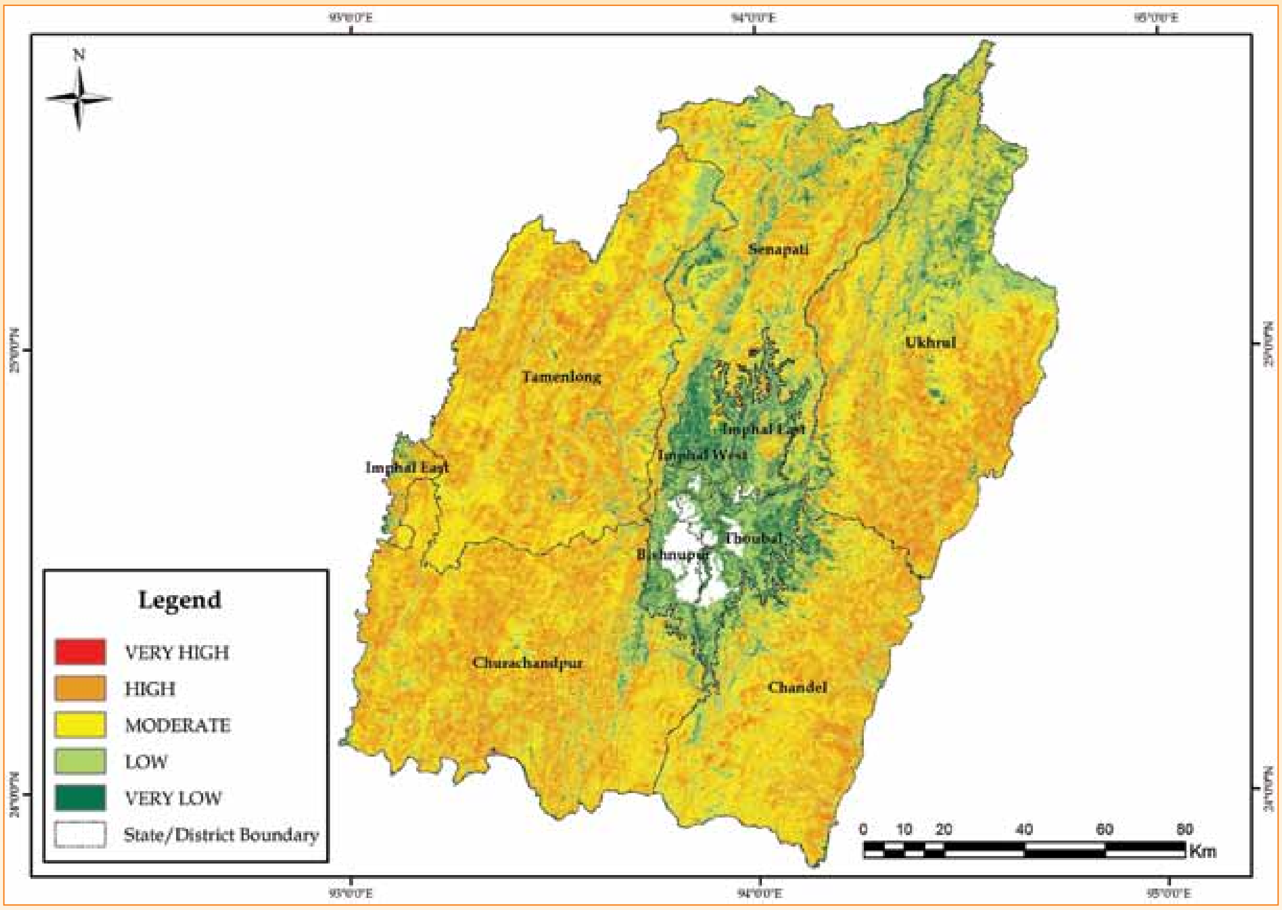


Figure 3.18: Fire vulnerability zone map of Manipur

Table 3.3: Forest fire vulnerability zones in Manipur with corresponding areas

Fire vulnerability class	Area (Sq. km)	% Area
Very Low	1508.6	6.9
Low	4366.8	20.0
Moderate	8529.4	39.0
High	7291.2	33.4
Very High	164.5	0.8

36% of the area is under high vulnerability in Meghalaya while 40% lie in moderate vulnerability zones (Table 3.4).

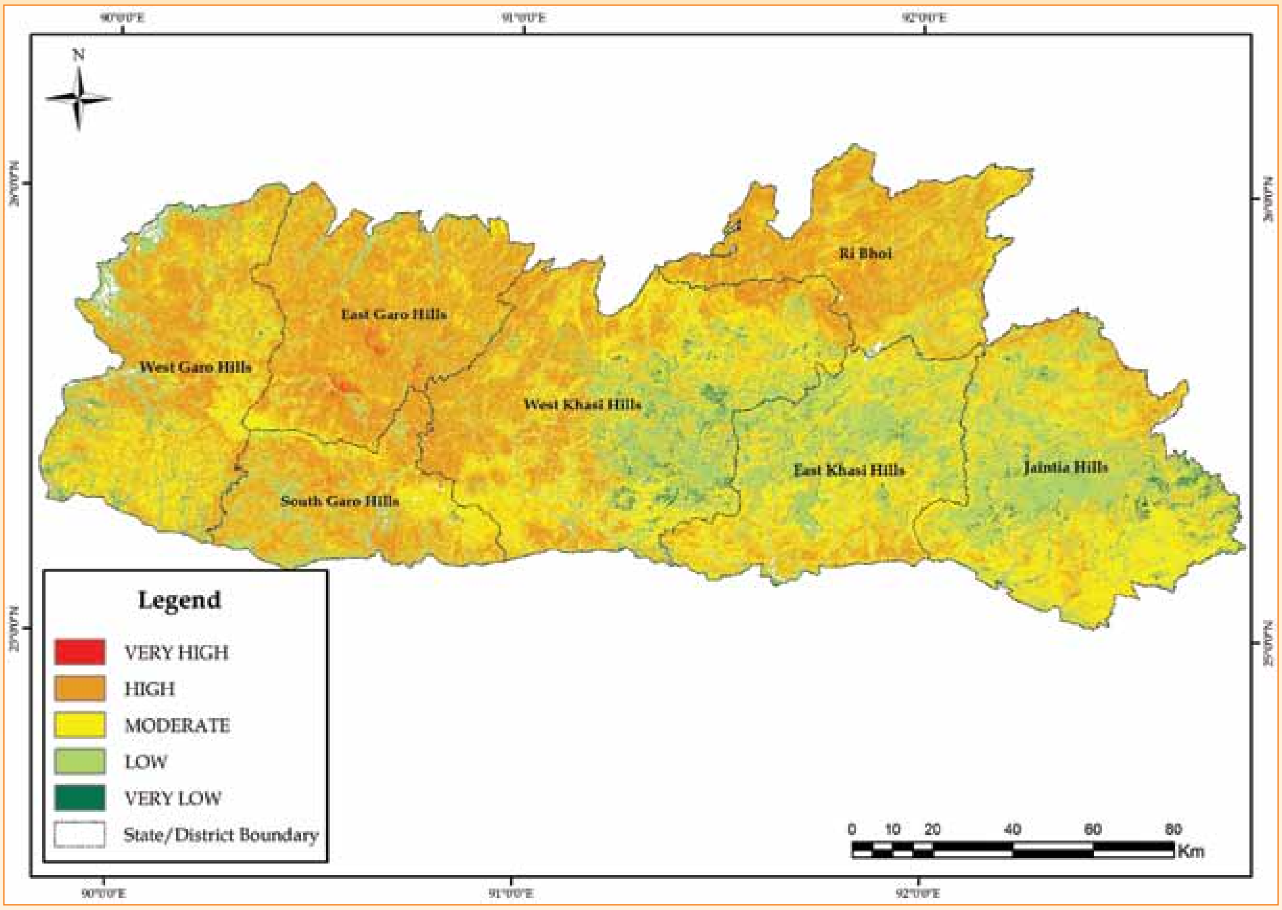


Figure 3.19: Fire vulnerability zone map of Meghalaya

Table 3.4: Forest fire vulnerability zones in Meghalaya with corresponding areas

Fire vulnerability class	Area (Sq. km)	% Area
Very Low	396.2	1.8
Low	4836.6	21.9
Moderate	8761.4	39.6
High	8038.8	36.4
Very High	71.6	0.3

In Mizoram, as high as 37% lie in high vulnerability zone, 48% in moderate and 12.5% in low vulnerability zones (Table 3.5).

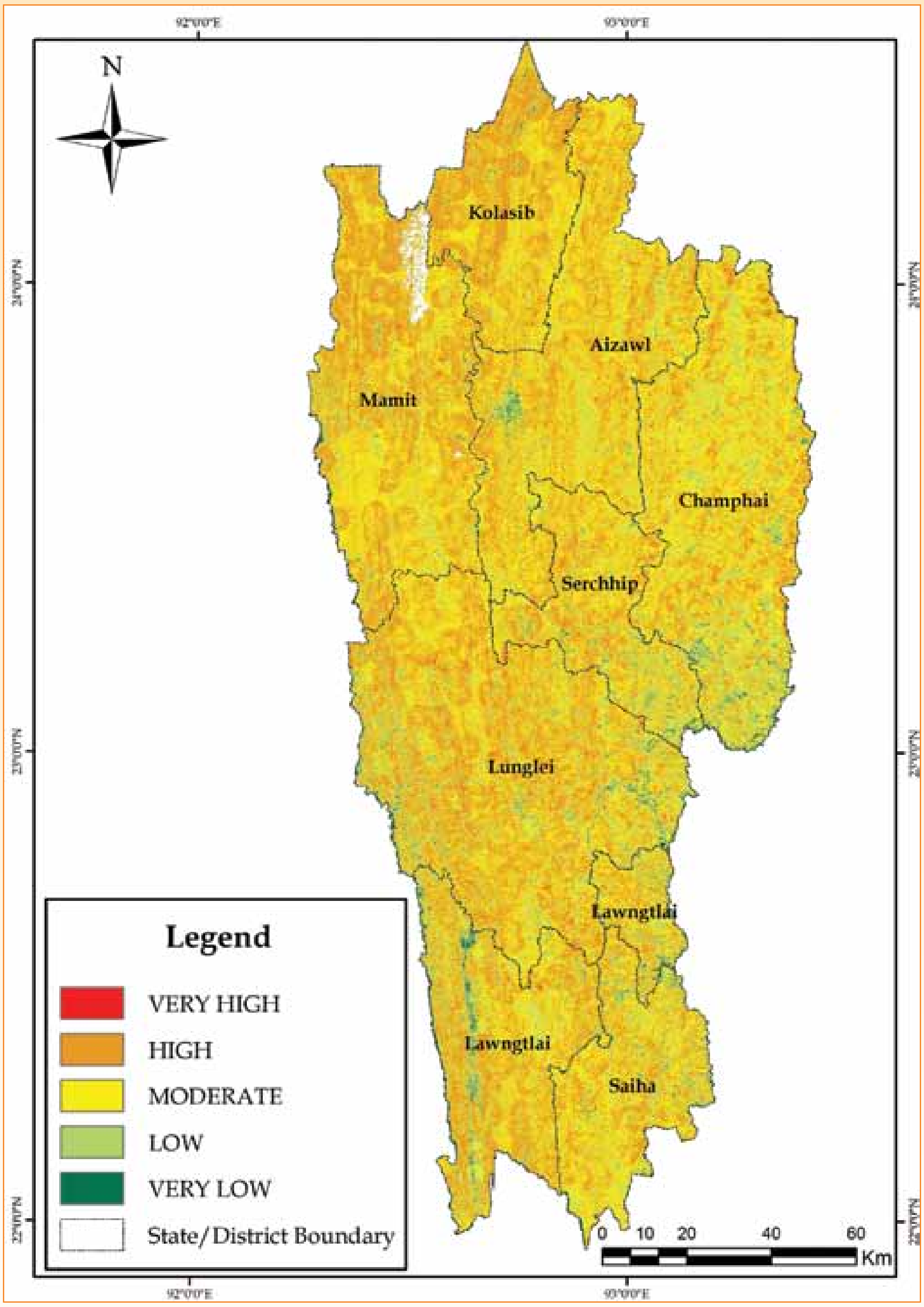


Figure 3.20: Fire vulnerability zone map of Mizoram

Table 3.5: Forest fire vulnerability zones in Mizoram with corresponding areas

Fire vulnerability class	Area (Sq. km)	% Area
Very Low	322.7	1.5
Low	2599.3	12.5
Moderate	10068.4	48.4
High	7735.4	37.2
Very High	93.2	0.4

Similarly, 43% of the forest area is under high vulnerability zone in Nagaland, 36% under moderate vulnerability while 18% is under low vulnerability zone (Table 3.6).

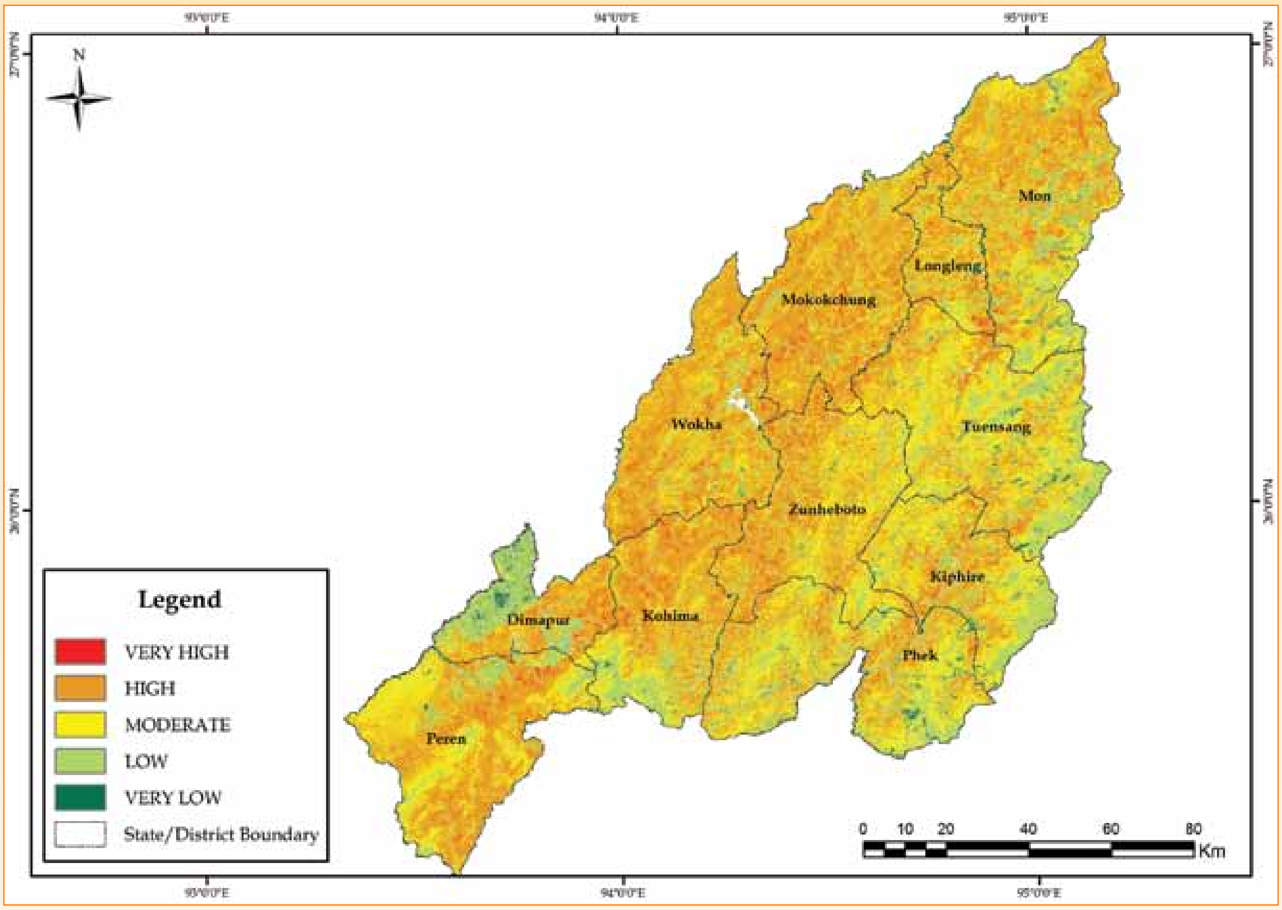


Figure 3.21: Fire vulnerability zone map of Nagaland

Table 3.6: Forest fire vulnerability zones in Nagaland with corresponding areas

Fire vulnerability class	Area (Sq. km)	% Area
Very Low	268.4	1.6
Low	2905.8	17.8
Moderate	5820.6	35.7
High	7004.9	43.0
Very High	284.8	1.7

In Tripura, 53% is under high vulnerability zone, 23% in moderate and 22% in low vulnerability zone (Table 3.7).

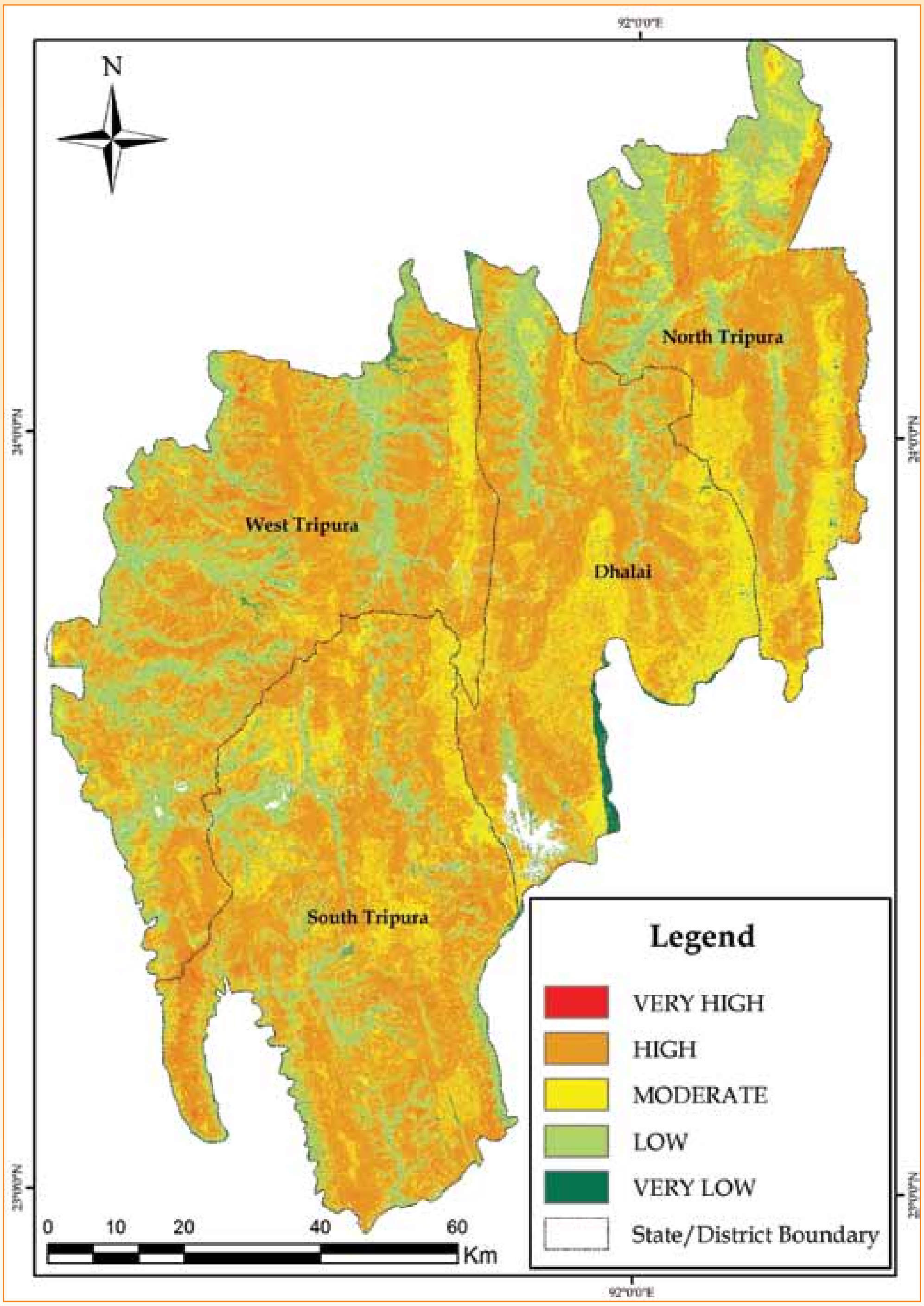


Figure 3.22: Fire vulnerability zone map of Tripura

Table 3.7: Forest fire vulnerability zones in Tripura with corresponding areas

Fire vulnerability class	Area (Sq. km)	% Area
Very Low	138.6	1.3
Low	2292.2	22.2
Moderate	2361.8	22.9
High	5444.2	52.7
Very High	92.1	0.9

3.5 Daily fire hazard alerts sent to the state forest departments

Fire hazard alerts based on fire occurrence for each state were given from the month of February to April, 2014. A total of 392 forest fire hazard alert emails were sent to different forest fire controlling authorities in respective forest departments of 8 NER states. Among these, 46, 66, 66, 54, 62, 60, 38 and 4 email alerts were sent to Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim, respectively. Except for Assam and Mizoram, other six states in NER showed more fire incidences with low level of hazard. For instance, in Arunachal Pradesh, Manipur, Meghalaya, Nagaland, Tripura and Sikkim, about 98%, 57%, 58%, 75%, 97% and 100% of fire incidences showed low level hazard, respectively (Figure 3.23) and only 2%, 43%, 42%, 20% and 3% showed moderate level of hazard, respectively (Figure 3.23). 5% of fire alerts showed high level of hazard in Nagaland and only 0.3% showed severe hazard level. In Assam and Mizoram, 68% and 92% of the fire hazard alerts showed moderate hazard while 26% and 7% showed low hazard level, respectively (Figure 3.23).

More fire incidences under moderate hazard in Assam and Mizoram is due to presence of bamboo plantations in the region while other states are dominated by evergreen/semi-evergreen forest followed by other forest types. However, other factors such as slope, aspect, meteorological conditions also play significant role in determining forest fire hazard level in a particular location.

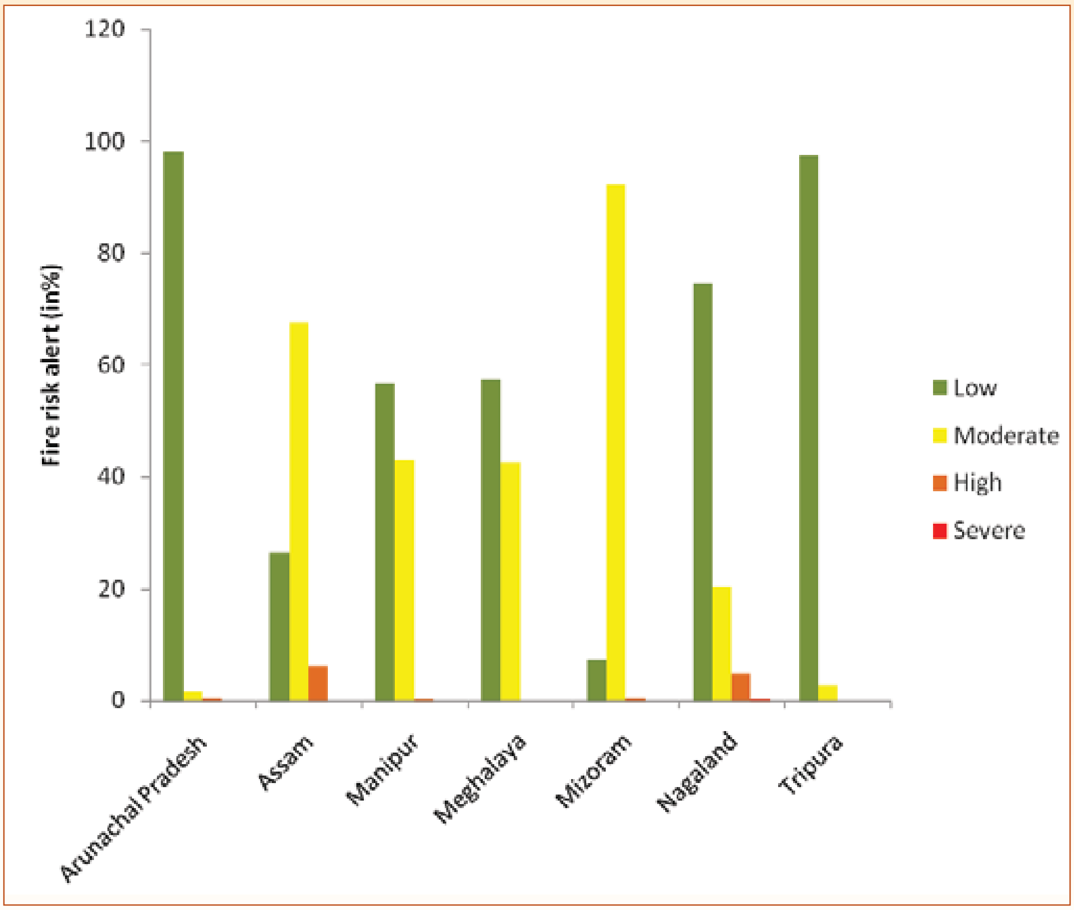


Figure 3.23: State-wise forest fire hazard level

3.6 Analysis of forest fire incidences in NER in 2014

Forest fire incidences in the year 2014 in NER was analyzed with respect to fuel characteristics (forest type and density), topographical factors (aspect, slope and elevation) and proximity to roads, builtups and water bodies. Results showed that overall order of forest type showing forest fire incidence in NER in 2014 is: Evergreen/Semi-evergreen > Deciduous > Bamboo > Pine > Temperate > Conifers > Scrub > Alpine forest > Alpine (Figure 3.24).

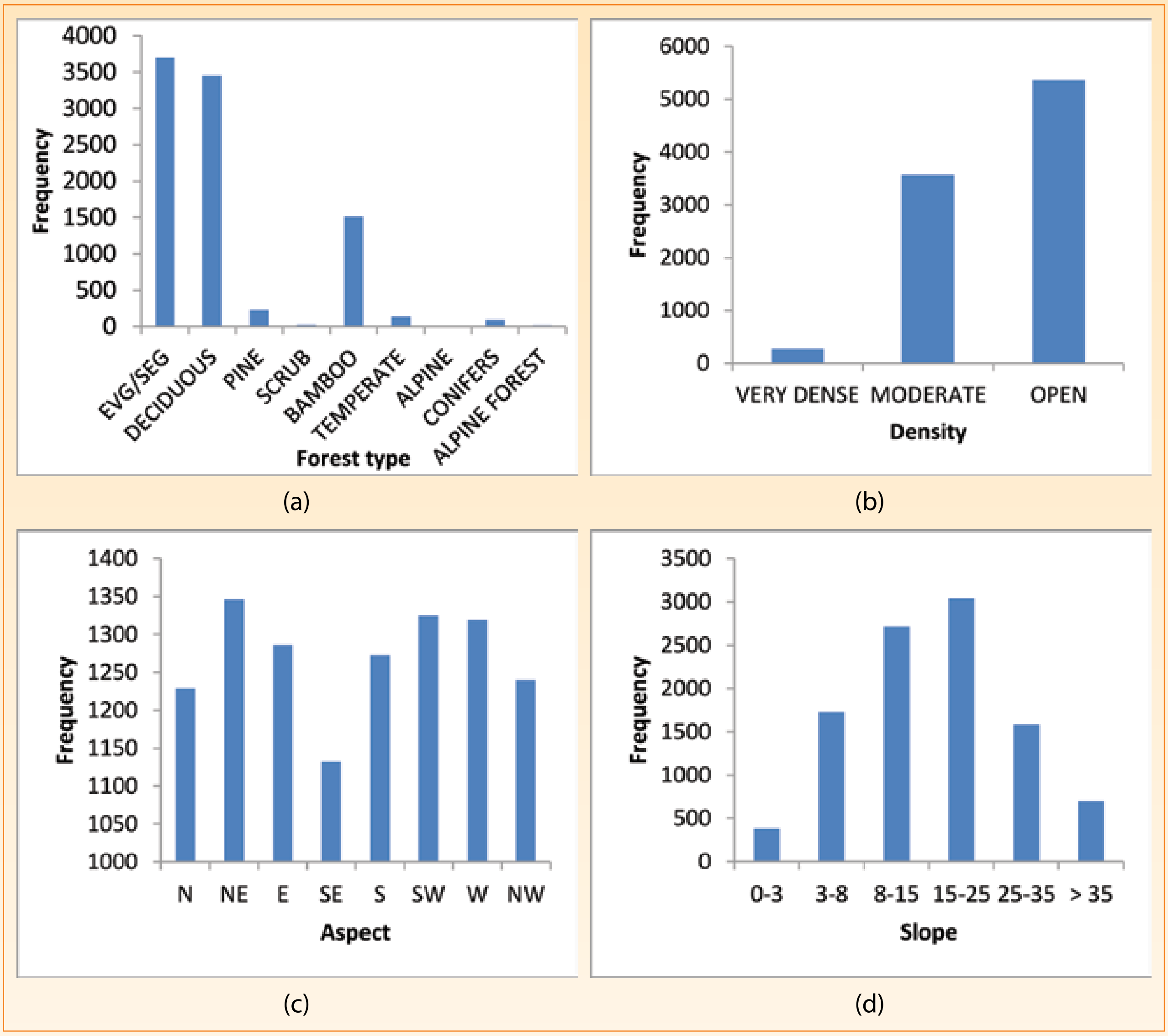


Figure 3.24: Fire frequency based on (a) forest type (b) forest density (c) aspect and (d) slope in the year 2014 in NER

Similar trend was seen for fire incidences between 2001 to 2013 in NER. Further, open forest showed the highest number of forest fire incidence followed by moderately open and dense forest. NE aspect showed the maximum fire incidences and the highest fire point is observed in slope range from 15-25° and the minimum in 0-3° slope. In terms of elevation, the maximum fire points is observed in the range of 200-500m (Figure 3.24). Higher fire frequency is observed in forest lying at a distance of 50-100m from roads and the minimum fire frequency is observed at a distance of 150-200m from roads. Similar pattern was observed for fire points in the year 2001-2013. The maximum fire incidences occurred at a distance 1000-1500m and the minimum at 2500-3000m from built-ups or settlement area and higher fire frequency was observed at a distance of 1000-3000m and the lower incidences at a distance of 10-100m from water bodies.

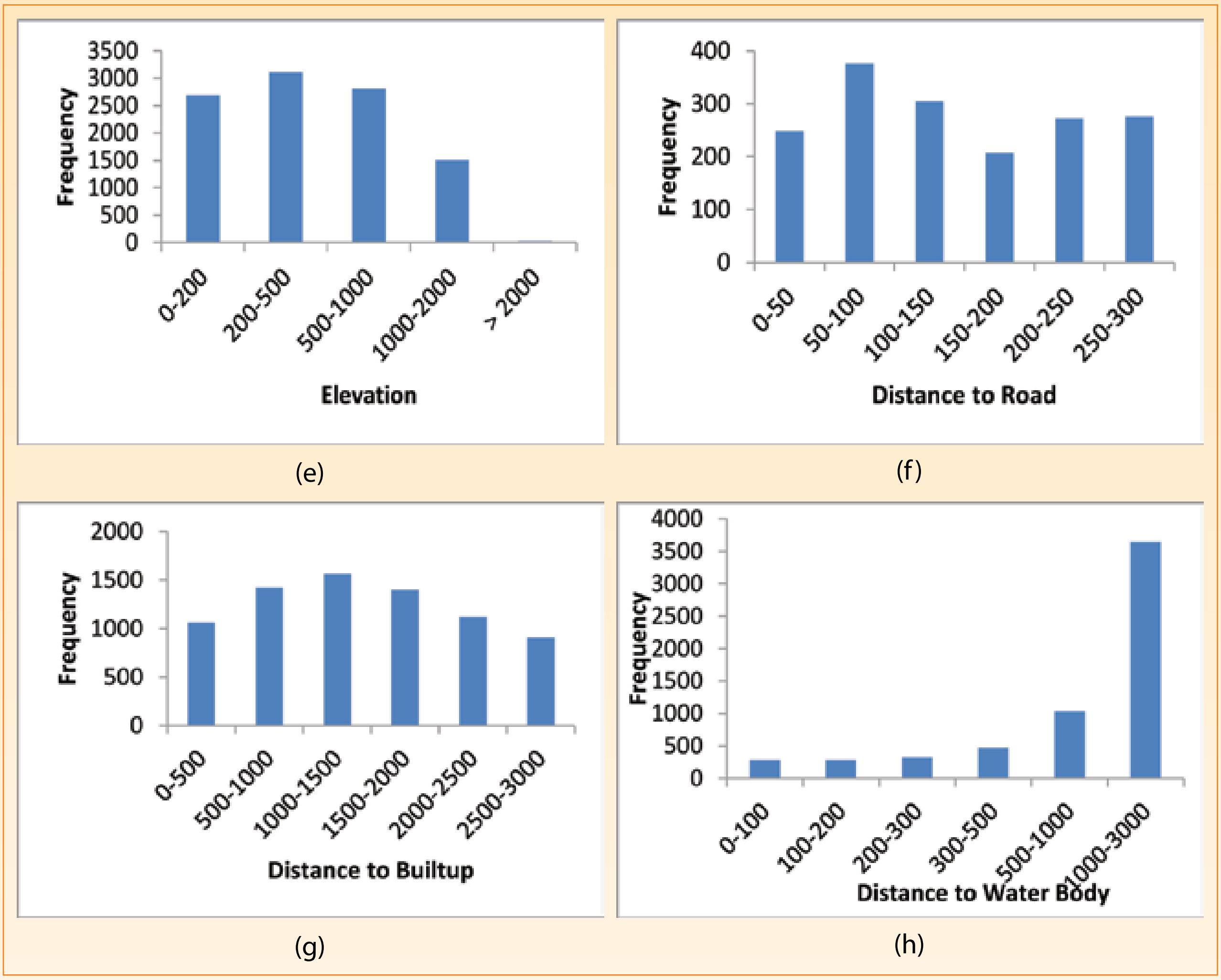


Figure 3.24: Fire frequency based on (e) elevation (f) distance to road (g) distance to builtup (h) distance to water-body in the year 2014 in NER

Forest fire incidence data of 2014 was analyzed with respect to vulnerability zonation. Results showed that the maximum (50%) forest fire occurred in moderate vulnerable zones in Arunachal Pradesh (Figure 3.25). This corresponds to the results of forest fire vulnerable area in Arunachal Pradesh. Most of the forest fires were observed in moderate and high vulnerability zones in Assam (53% and 35%), Manipur (45% and 43.7%) and Mizoram (43.3% and 42.2%). In Meghalaya, the maximum fire incidence occurred in high (52.1%) vulnerable zone followed by moderate zone (39.4%). In Nagaland and Tripura, the maximum fire (53.3%, 59.8%) occurred in high vulnerable zone and the minimum (1.5%, 0.3%) in very low vulnerable zone, respectively (Figure 3.25). Except for Assam, forest fire occurrences in all other NER states in the year 2014 corresponds with respect to vulnerable zonation area created for NER based on historical data analysis. Thus, it indirectly validates the vulnerability map created for NER.

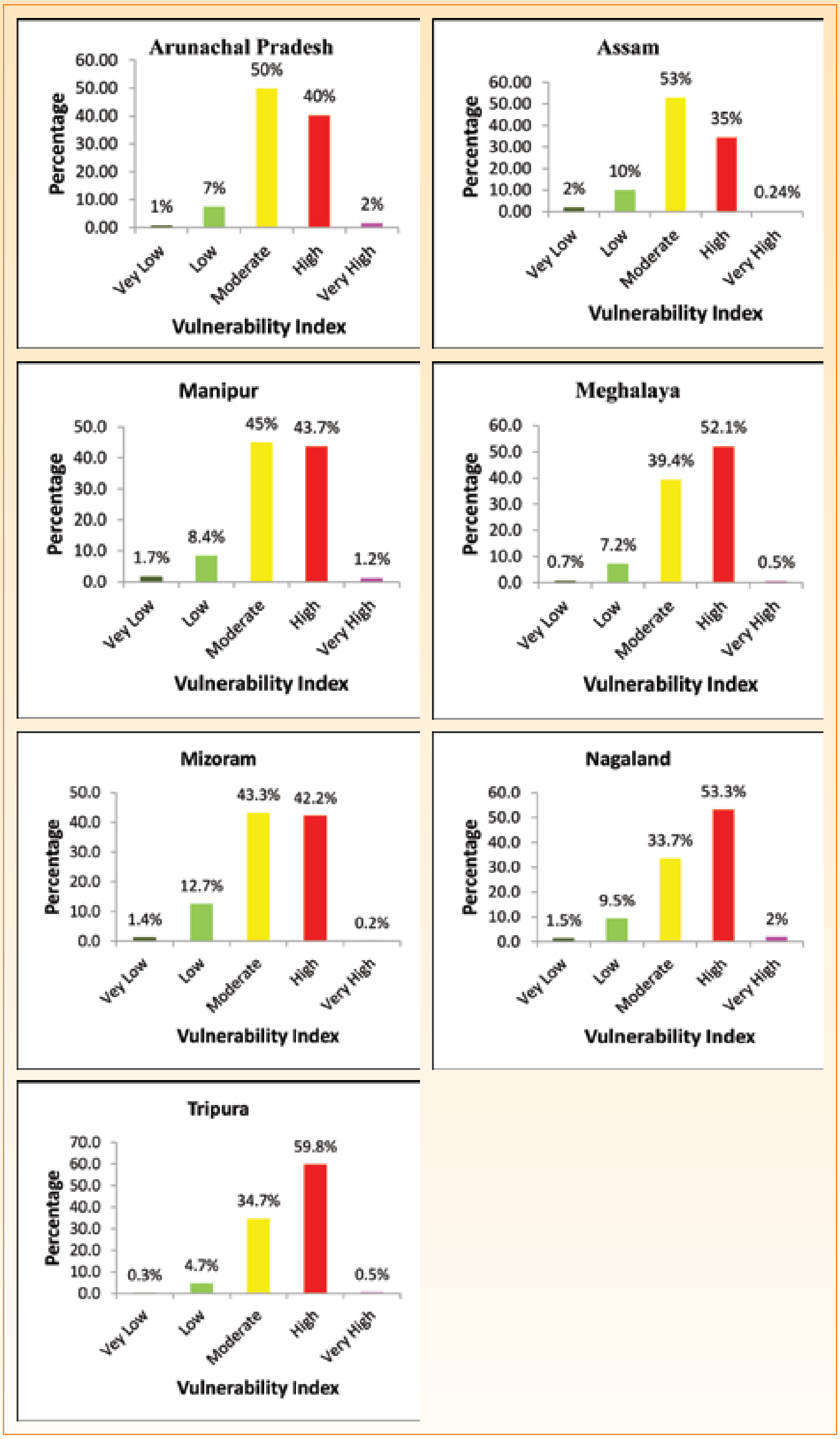


Figure 3.25 Forest fire incidences with respect to vulnerability index in NER

3.7 Burnt area assessment

Differenced NBR (dNBR) image was used to extract the burnt area pixels. Pre-fire imagery was collected on 15th & 24th November, 17th December, 2013 and 11th January & 27th January, 2014 whereas post-fire imagery was collected on 1st and 24th April, 2014. A threshold method was used to separate burned pixels from the surrounding unburned ones. Furthermore, a majority filter was used iteratively to remove very small patches with area less than about 1 hectare in order to reduce over-estimation of burnt area due to spurious pixels.

Results indicate that in Nagaland, about 200 sq. km of the area showed under burnt area while in Mizoram, about 263 sq. km of the area was burnt. Burnt area patches in Nagaland and Mizoram are shown in Figure 3.25 and 3.26, respectively.

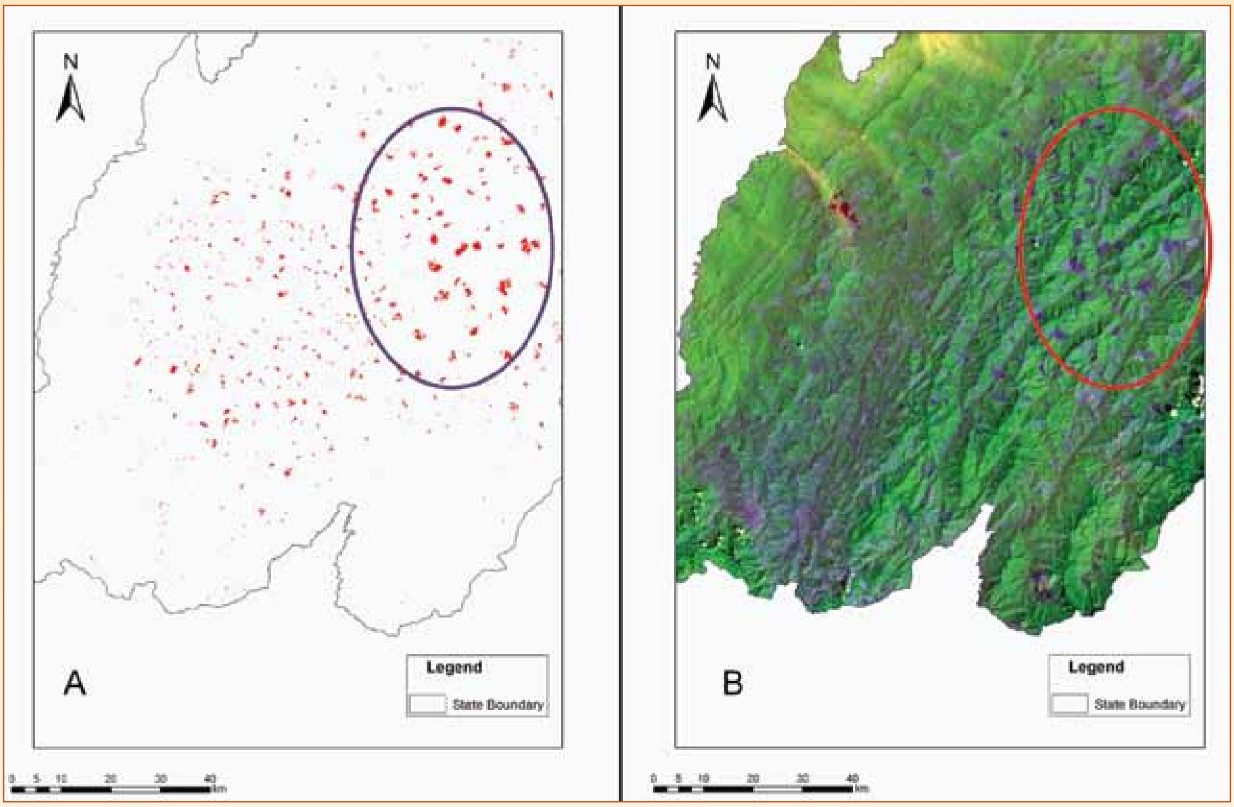


Figure 3.26: Burnt area scar (A) using dNBR (B) post fire image (24th April, 2014) in Nagaland in 2014

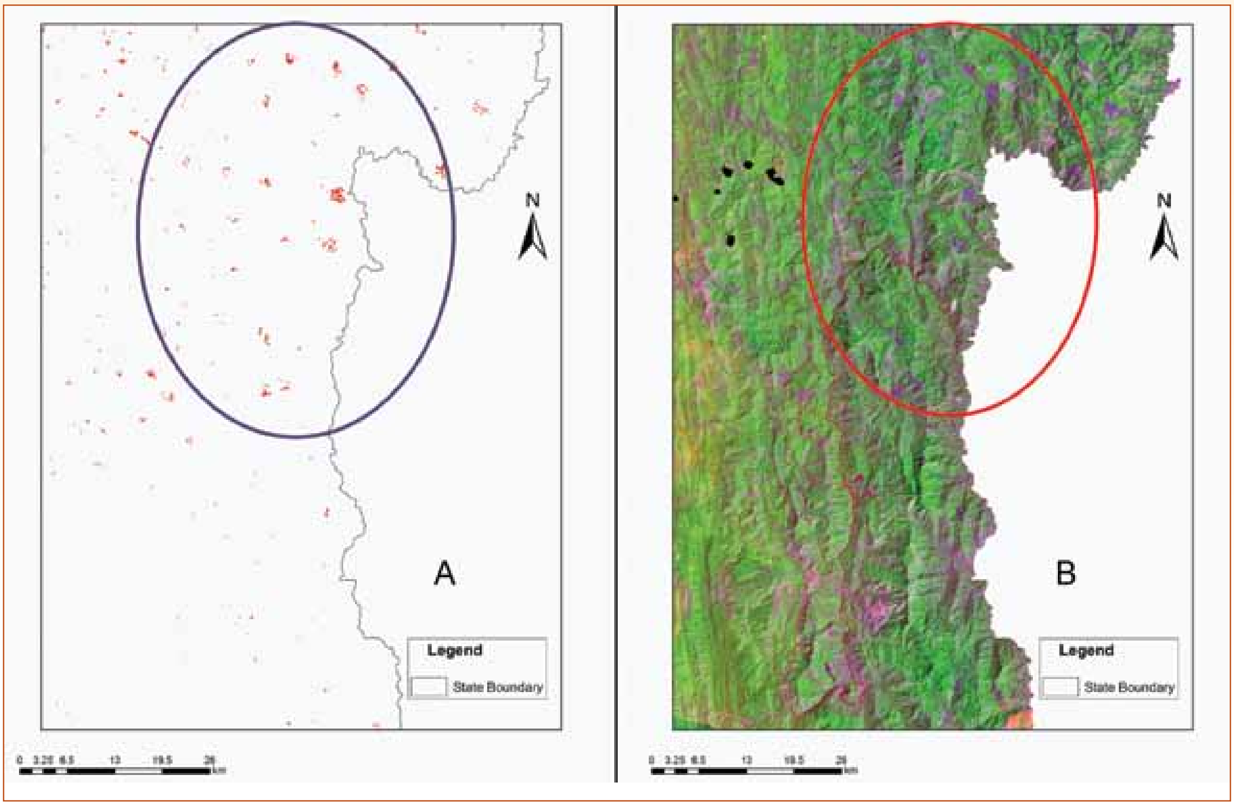


Figure 3.27: Burnt area scar (A) using dNBR (B) post fire image (1st April, 2014) in Mizoram in 2014

3.8 Shifting cultivation and forest fire: a case study of Mizoram

An effort has been in order to see the relationship between shifting cultivation and forest fire. Shape files containing information on areas under current shifting and abandoned shifting agriculture were collected for three years viz. 2005-06, 2008-09 and 2011-12. As illustrated in Figure 3.27 (a & b), number of forest fire points showed moderate relationship with current shifting cultivation (r = 0.5) but showed significant relationship with abandoned shifting cultivation (r = 0.99). The result indicates that abandoned shifting patches are preferred for repetition of shifting cultivation or shifting cultivation is one of the causes of forest fire. Further, it is found that south aspect and 15-25° slope is dominant topographic factors for shifting cultivation in Mizoram.

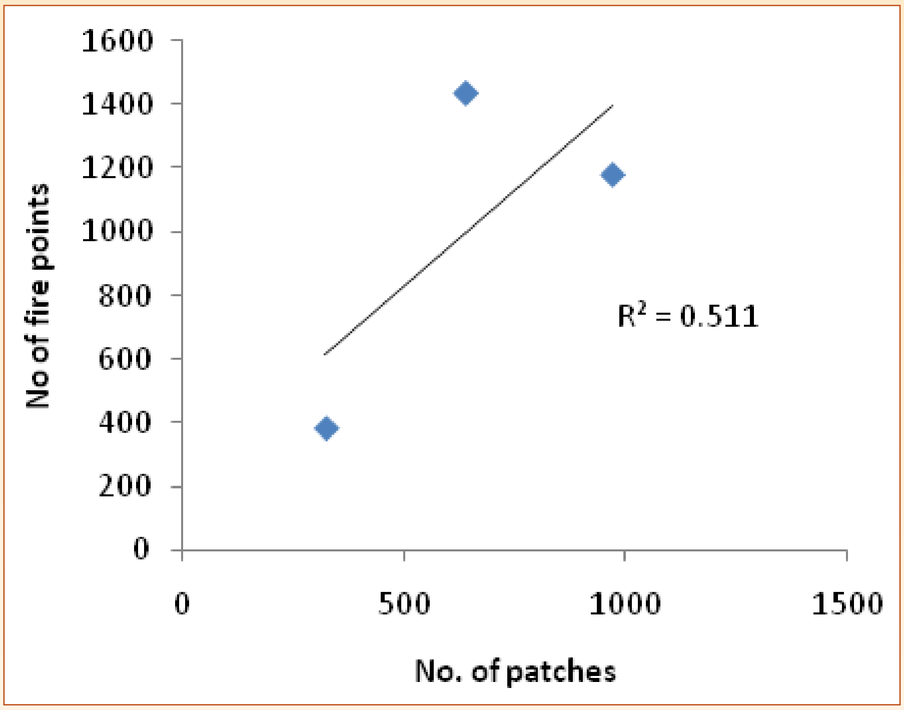


Figure 3.28 (a) Correlation between fire points and patches of current shifting cultivation

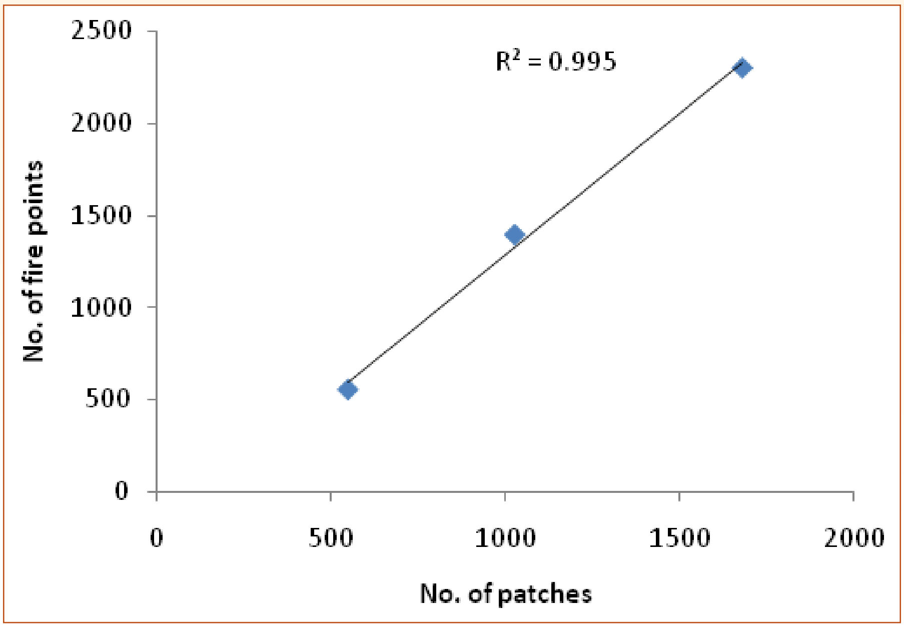
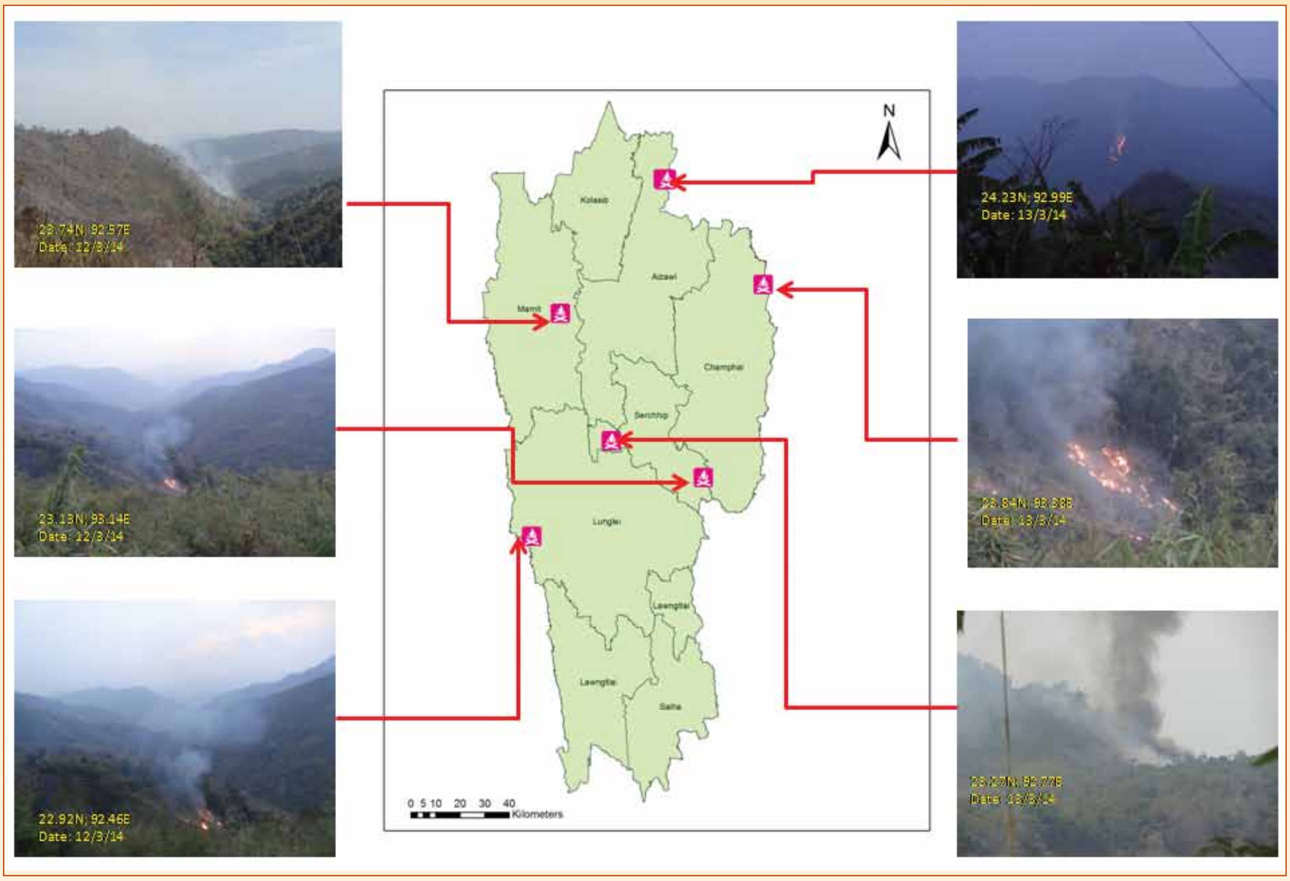


Figure 3.28 (b) Correlation between fire points and patches of abondoned shifting cultivation



Field photos showing forest fires during forest fire season (March, 2014) in Mizoram

Chapter-4: Conclusion

The study indicates that as NER is subjected to man-made forest fire, in particular, for shifting cultivation, evergreen/semi-evergreen forest is at highest vulnerability followed by deciduous forest and the least is for alpine forest. Overall order of forest type showing deceasing trend in forest fire hazard is: Evergreen/Semi-evergreen > Deciduous > Bamboo > Pine > Temperate > Conifers > Scrub > Alpine forest > Alpine. While in terms of forest density, open forest is at the highest vulnerability.

In addition, topographical factors (such as slope, aspect and elevation), roads, built-ups and drainage also play important role in forest fire vulnerability. Considering all states, the maximum fire point is observed in slope ranged from15-25° and the minimum in 0-3° slope. Overall, in northeast India, east facing showed the maximum and north facing showed the minimum number of fire points. In NER, the maximum fire points showed similar trend in elevation in the range of 200-500m and 500-1000m. It is observed that forest fire occurrences and its distribution in northeast India showed significant differences with slopes ($p < 0.05$ level) but showed no significant variations with respect to aspect, elevation, distance to road and built-ups ($p > 0.05$).

In the present study, overall, higher fire frequency is observed in forest lying at a distance of 50-100m from roads the minimum fire frequency is observed at a distance of 150-200m. Further, in NER, the maximum fire incidences occurred at a distance 1000-1500m and the minimum at 2500-3000m from built-ups or settlement area. Interestingly, the distance range of 1000-3000m from water bodies showed the maximum fire frequency in all states (except Mizoram: 500-1000m) and the minimum at a range of 0-100m.

In terms of forest fire vulnerability, among different NER states, the minimum values of area observed under very low, low, moderate, high and very high observed were 1.3%, 12.5%, 21%, 10.1%, 0.03%, respectively and the maximum values were 12.4%, 56.4%, 51%, 52.7%, 1.7%, respectively. Fire vulnerability zonation map would help in planning the main roads, subsidiary roads, inspection paths, etc. and may lead to a reliable communication and transport system to efficiently fight small and large forest fires.

Year wise fire incidences in NER India indicates that forest fire increased from 1.5% in 2001 to 9% in 2004 and again decreased to 7.2% in 2005. Interestingly, it increased to 11.7% and 9.8% in the year 2006 and 2007, respectively. However, similar trend in fire incidences was observed in 2011 (4.9%), 2012 (6.4%) and 2013 (5.4%). In 2014 (February to April), the fire incidences was reduced to 2.6%. Overall, the order of fire incidences observed is: March (54%) > April (43%) > February (3%) in 2014.

Out of 392 daily forest fire hazard email alerts, 46, 66, 66, 54, 62, 60, 38 and 4 email alerts were sent to Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim, respectively. Of the total fire hazard alerts, in Arunachal Pradesh, Manipur, Meghalaya, Nagaland, Tripura and Sikkim, about 98%, 57%, 58%, 75, 97% and 100% of fire hazard alerts showed low level of vulnerability, respectively and only 2%, 43%, 42%, 20% and 3% showed moderate level of vulnerability, respectively. 5% of fire alerts showed high level of vulnerability in Nagaland and only 0.3% showed severe vulnerability level. In Assam and Mizoram, 68 and 92% of the fire vulnerability alerts showed moderate vulnerability while 26 and 7% showed low vulnerability level, respectively.

Burnt area assessment indicated that in Nagaland, about 200 sq. km of the area showed under burnt area while in Mizoram, about 263 sq. km of the area was burnt.

Present study indicates that forest resources of NER India are threatened due to seasonal fire and evergreen/semi-evergreen forest is the most targeted forest type for fire. Effort should be made to reduce the anthropogenic fire incidences in the region and some alternative agricultural activities or economic activities need to be encouraged to save the forest resources and associated bio-diversity from further loss. Since, our attempt is to provide fire hazard alerts considering vegetation type, topographic factors influencing fire and meteorological parameters; it may help the state forest department to adopt mitigation measures to reduce the spread of fire during fire season. Further, fire vulnerability mapping based on historical data analysis may serve as a reference to identify vulnerable areas and take necessary measures to control fire. Post fire assessment may further help to identify the status of loss so that effort may be made to minimize loss in future.

Future scope of the study:

- Fire hazard alerts: During 2014, fire hazard alerts were generated at state level but it is being planned to provide alerts at district levels with details of accessibility etc. Efforts will also be made to reduce number of false fire hazard alerts by considering all aspects of fire analysis. The present confidence level considered as 60% of MODIS fire pixels may need to be further examined for understanding towards any missing fire alerts.
- Post fire analysis: Preliminary burnt area assessment has been carried out for two NER states viz. Nagaland and Mizoram. Detailed post fire assessment may be extended for other NER states based on the availability of pre and post fire images.
- Study on forest regeneration status may be taken up
- Need to have downloading facility in NESAC: Efforts may be taken up for providing fire locations directly from NRSC-INFRASS/FSI in GIS compatible format to reduce the turnaround time for data processing and sending alerts in time. NESAC may also be equipped with the provision to have direct MODIS data reception facility to reduce the turnaround time.
- DEM usage towards understanding fire spread: The use of improved DEM resolution for the whole NER may help in better understanding of the fire behavior with respect to fire spread
- Mobile application for disaster risk alert: A mobile application named FIDATRA (Field Data Transmission Application) has been developed at NESAC under SATCOM (satellite communication) division. The application need smart phone for its use. Details of information in the form of photo, GPS location, text, type of disaster can be sent from field to NER-DRR server by GSM network instantly. The data can be extracted for later use and provide further relevant field information. In the next fire season, effort will be made to use this apps to send forest fire risk alerts to the state forest department.

Recommendation and mitigation measures:

- Tree lines or fire break line may be a mandatory activity for slash and burn cultivation in the region to prevent the spread of fire. Number of fire break lines may be increased depending on the vulnerability of spread in bamboo areas or dry deciduous forest.
- Dried leaved, debris may be collected before set up of fire around the vulnerable forest areas particularly along the protected areas. In states, such as Meghalaya, pine needles may be collected before fire season. These needles may in turn be used as fuel source as they have high calorific value due to high resin content.

- Protected areas such as national parks, sanctuaries etc may be provided with sufficient fire watch towers and may well equipped with fire extinguishers and water storage tanks in case of emergency
- Creation of awareness among public regarding forest fire and its associated risk to human life, global warming, economic and biodiversity loss.
- Policy may be made to divert shifting cultivation to alternative agricultural activities or economic activities to reduce deforestation of forest

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APPENDIX






Field photos showing forest fires during forest fire season (March, 2014) in Mizoram

Figure: (A) Live burning fire seen from satellite and (B) Burned patches seen in satellite imagery in Mizoram (1st April, 2014)

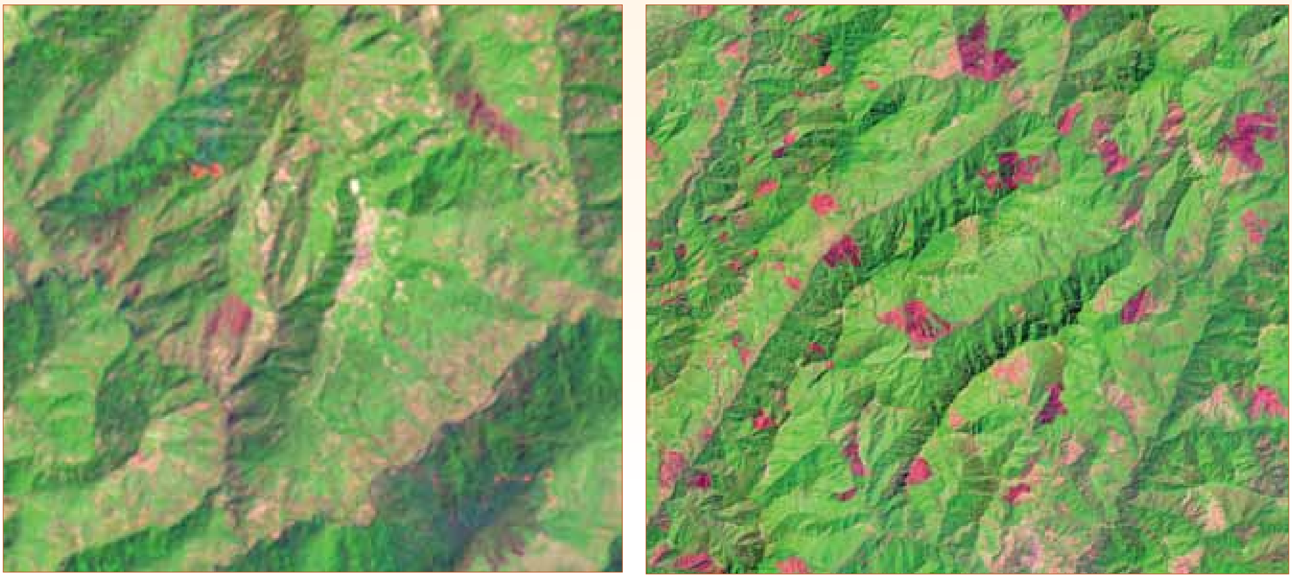

Figure: (C) Live burning fire seen from satellite and (D) Burned patches seen in satellite imagery in Nagaland (16th March, 2014)

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