Fire Risk Assessment For Forest Fire Control Management In Chilla Forest Range Of Rajaji National Park
Uttaranchal
(India)

G. S. Rawat
November 2003
Fire Risk Assessment For Fire Control Management In Chilla Forest Range Of Rajaji National Park Uttaranchal (India)

by

G. S. Rawat

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geoinformatics

Thesis Assessment Board
Chairman: Prof. Dr. Ir. Alfred Stein
External examiner: Dr. Ir. B.G.H. Gorte
IIRS member: Dr. P.S. Roy
Supervisor: Dr. N. Kerle

Supervisors
Dr. N. Kerle (ITC)
Dr. M.C. Porwal (IIRS)
I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work. Signed ……………………

Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.
Acknowledgement

I am thankful to the authorities of GEONIDIS a collaborative project of International Institute For Geo-information Science and Earth Observation (ITC) Enschede, The Netherlands, and Indian Institute of Remote Sensing Dehradun, Department of Space, Government of India, for giving me the opportunity to do the Master of Science in Geoinformatics for improving my knowledge in the field of Geographical Information System.

I am grateful to the Tamilnadu government (Forest Department) India, for deputing me to undergo this course.

I sincerely express my gratitude to Prof. Dr. Ir.Alfred Stein, Chairman department of Earth Observation Sciences (EOS), for his valuable guidance and suggestions during the augmentation of the research.

I sincerely express my gratitude to Dr. P.S. Roy, Dean, and IIRS for the support and guidance provided throughout the course.

My heartfelt gratitude goes to my supervisors, Dr. N. Kerle and Dr. M.C. Porwal, for their able guidance, detailed and appropriate scientific advices for successful completion of research work.

I gratefully acknowledge the valuable help rendered by Dr S.P.S.Kushwaha, head of the Forestry and Ecology Division, and the faculty members and staff of Geo-Informatics division of IIRS for providing necessary help in carrying out this study.

I express my sincere thanks to the Director of Rajaji National Park and staff of the Park for providing all necessary facilities and help during fieldwork.

I am indebted to my family members for their valuable support during the whole course.

Place: Enschede

Date: 27 November 2003

G.S. Rawat,
ABSTRACT

The study is about using remote sensing data and GIS techniques for developing a fire risk model in the part of Rajaji National Park Uttaranchal (India). The objective of the study is fire risk modelling using multi criteria spatial analysis and analysis, of parameters and weights contributed by different land cover types and enhancement of existing fire control measures.

An IRS 1D LISS III image of June 2001 was used together with landform information and a forest management map with ancillary data for generating maps for the study. Visual interpretation of the satellite image was used to classify the forest type and density classes.

The model was developed on spatial modeling of different layers responsible for the ignition, spread and disturbance caused for forest fire in the study area. Multi criteria evaluation techniques, using a direct weighing method were applied for assigning the weights. The forests and their type contribute the most, and accordingly were given more weight than other factors. The surface fuel content per unit area has supported the higher weight given to forest type. Parameters like slope, aspects and elevation, responsible for fire spread were studied and weights given as per the importance. The disturbance caused by roads and settlements was studied and the index maps generated. The index maps thus generated has been combined in a linear equation using map calculator function, thus generating the fire risk area map.

The study was constraint by the lack of meteorological data, the absence of scale of the fire control map of the area. The validation of the risk areas was done with ground truthing and the fire control map of the area. The result obtained was found broadly in agreement with the fire risk areas of the study area. Based on the study, appropriate future fire management recommendations have been suggested.
# TABLE OF CONTENTS

1. **Introduction** ..................................................................................................................................1
   
   1.1. *Background of the study*.........................................................................................................2
   
   1.2. *Objectives Of The Study* .......................................................................................................3
   
   1.3. *Research Questions:* ...............................................................................................................4
   
   1.4. *Overview of Thesis* .................................................................................................................4

2. **Literature Review**.........................................................................................................................5
   
   2.1. *What is Forest Fire* ................................................................................................................5
   
   2.2. *Causes Of Forest Fire* ............................................................................................................5
       2.2.1. Natural Causes Of Forest Fires ......................................................................................5
       2.2.2. Manmade Causes Of Forest Fires ..................................................................................5
   
   2.3. *Types Of Forest Fire* .............................................................................................................6
       2.3.1. Ground Fires ...................................................................................................................6
       2.3.2. Surface Fires ...................................................................................................................6
       2.3.3. Crown Fires ....................................................................................................................6

   2.4. *Fire Combinations* .................................................................................................................6

   2.5. *Fire Environment* ...................................................................................................................6

   2.6. *Factors For Forest Fires* ........................................................................................................7
       2.6.1. Topography ....................................................................................................................7
   
   2.7. *Climatic factor* ........................................................................................................................8
       2.7.1. Relative humidity ...........................................................................................................8
       2.7.2. Temperature ...................................................................................................................8
       2.7.3. Precipitation ...................................................................................................................8
       2.7.4. Wind speed .....................................................................................................................8

   2.8. *Fuel Type and Fuel Moisture* .................................................................................................9

   2.9. *Accessibility* ............................................................................................................................9

   2.10. *Impact of Fire on Plant Community* ...................................................................................9

   2.11. *Impact of Fire on Animals* .....................................................................................................9

   2.12. *Impact of Fire on Sustainable Development* ...................................................................9

   2.13. *Wildfires* .............................................................................................................................10

   2.14. *Fire Seasons* ........................................................................................................................10

   2.15. *Forest Fire – Global situation and International Co-operation* ......................................11
2.16. Indian Scenario ................................................................................................................12
2.17. Remote Sensing and GIS application on Forest Fire.......................................................12
2.18. Fire Potential Index .........................................................................................................15

3. Study Area ...........................................................................................................................................16
3.1. Location ..............................................................................................................................................16
3.2. Justification for Selection of This Study Area.............................................................................16
3.3. Climate ..................................................................................................................................................16
3.3.1. Rainy Season ................................................................................................................................16
3.4. Temperature and Humidity .............................................................................................................17
3.4.1. Water Source ....................................................................................................................................17
3.5. Forest Types .........................................................................................................................................18
3.5.1. Flora ..................................................................................................................................................19
3.5.2. Fauna .................................................................................................................................................19
3.5.3. Birds ..................................................................................................................................................20
3.5.4. Reptiles ...............................................................................................................................................20
3.6. Gujars...................................................................................................................................................20
3.7. Fire Protection.....................................................................................................................................22

4. Methodology ...........................................................................................................................................23
4.1. Remote Sensing Data .......................................................................................................................23
4.1.1. Ancillary Data .................................................................................................................................23
4.1.2. Instruments/Field Equipment/Materials .....................................................................................23
4.1.3. Computer System ..........................................................................................................................23
4.2. Field Work ...........................................................................................................................................25
4.3. Constraints during and after the fieldwork .....................................................................................25
4.4. Generation of Maps ............................................................................................................................25
4.4.1. Generation of Road and Settlement Map ....................................................................................25
4.4.2. Generation of DEM, Slope, Aspect and Elevation Maps .............................................................25
4.4.3. Generation of Forest type and Forest Density Maps ................................................................26
4.4.4. Fuel Type Map ................................................................................................................................26
4.5. Spatial Multicriteria Decision Analysis ............................................................................................26
4.6. Generating Index Value Maps ..........................................................................................................27
4.6.1. Fuel Type Index ..............................................................................................................................27
4.6.2. Elevation Index Map .....................................................................................................................30
4.6.3. Slope Index Map ............................................................................................................................31
4.6.4. Aspect Index Map ........................................................................................................................31
4.6.5. Road Index Map ..........................................................................................................................32
5. **Results And Discussions** ............................................................................................................37

5.1. *Classification of IRS 1D LISS III image* ..............................................................................37

5.2. *Visual interpretation* .............................................................................................................38

5.3. *Fuel type index* ....................................................................................................................38

5.4. *Slope index* ..........................................................................................................................43

5.5. *Aspect index* .........................................................................................................................43

5.6. *Elevation index* ......................................................................................................................45

5.7. *Road index* ............................................................................................................................47

5.8. *Settlement index* ..................................................................................................................48

5.9. *Fire risk index and model* ....................................................................................................50

5.10. *Validation of fire risk model* ..............................................................................................51

5.10.1. *Intra -Validation* .........................................................................................................51

5.10.2. *Inter- Validation* ...........................................................................................................51

5.11. *Conclusions with regard to objectives* ............................................................................53

5.12. *Conclusions from study* ....................................................................................................53

6. **Future Fire Management Recommendations** ........................................................................54

6.1. *Recommended requirements at implementation level* .......................................................54

6.1.1. *Fire Records* ....................................................................................................................54

6.1.2. *Preventive Measures* .......................................................................................................54

6.1.3. *Public Awareness and Educational Programmes for Local People* .............................54

6.1.4. *Quick Detection* ..............................................................................................................55

6.1.5. *Fire Fighting* ....................................................................................................................55

6.1.6. *Fire Fighting Equipments* ...............................................................................................55

6.2. *Communications* ................................................................................................................55

6.2.1. *Wireless network and Tele-communication:* ................................................................55

6.2.2. *Surface Communication:* ............................................................................................55

6.3. *Recommendation requirements at policy makers level* .......................................................55

6.4. *Further research potential* ..................................................................................................56

6.5. *Implementation of model* ....................................................................................................56

6.6. *Relations with other environmental issues* .........................................................................56

7. **REFERENCES** ..........................................................................................................................57
8. Appendices ..................................................................................................................................61

8.1. Appendix 1 ..................................................................................................................................61
8.2. Appendix 2 ..................................................................................................................................63

METEOROLOGICAL DATA .............................................................................................................63

8.3. Monthly Average Data ..............................................................................................................64
8.4. Monthly Average Data ..............................................................................................................65
8.5. Monthly Average Data ..............................................................................................................66
    Station: New Forest, Dehradun Year-2002 ..................................................................................66
LIST OF FIGURES

Figure 1. Map of Study Area........................................................................................................17
Figure 2. Water Sources ..............................................................................................................18
Figure 3. Degraded Area of Rajaji National Park Flora ..............................................................19
Figure 4. Indiscriminate Lopping by Gujjars ..............................................................................20
Figure 5. Invasion of Weed inside the Forest ..............................................................................21
Figure 6. Extraction of Baib Grass by Gujjars ............................................................................21
Figure 7. Methodology Flowcharts .............................................................................................24
Figure 8. Satellite Imagery Of Chilla Range ..............................................................................37
Figure 9. Block Boundaries ........................................................................................................40
Figure 10. Forest Density Map ....................................................................................................40
Figure 11. Forest Type Map ........................................................................................................41
Figure 12. Fuel Type Index Map ................................................................................................41
Figure 13. Slope Index Map .........................................................................................................42
Figure 14. Aspect Index Map .......................................................................................................45
Figure 15. Elevation Index Map ..................................................................................................46
Figure 16. Road Map ..................................................................................................................47
Figure 17. Road Index Map .........................................................................................................48
Figure 18. Settlement Map ..........................................................................................................49
Figure 19. Settlement Index Map ................................................................................................49
Figure 20. Fire Control Map ........................................................................................................50
Figure 21. Fire Risk Map .............................................................................................................51
LIST OF GRAPHS
Graph1. Forest Types .................................................................39
Graph2. Percentage Area (Slope) ..............................................43
Graph3. Percentage Area (Aspect) ............................................44
Graph4. Percentage Area (Elevation) .......................................46
Graph5. Fire Risk Percentage ..................................................53
LIST OF TABLES
Table 1. Relative rate of forward spread of flame front in relation to percentage slope .......................7
Table 2. Annual burnt area in Chilla range ............................................................................................22
Table 3. Surface Fuel Content Of Forest Types ..................................................................................28
Table 4. Various Fuel Types With Weights .......................................................................................29
Table 5. Elevation Classes And Weights ............................................................................................30
Table 6. The Slope Classes And Weights ...........................................................................................31
Table 7. Aspect Classes And Weights .................................................................................................32
Table 8. Road Buffer Distances And Weights ....................................................................................33
Table 9. Settlement Buffer Distances And Weights ............................................................................34
Table 10. Forest Types Area ................................................................................................................39
Table 11. Forest density Area ..............................................................................................................42
Table 12. Slope Index Area ..................................................................................................................43
Table 13. Aspect Index Area ................................................................................................................44
Table 14. Aspect Index Area ................................................................................................................45
Table 15. Fire Risk Area ........................................................................................................................52
1. Introduction

Forest fires cause major damage to the environment, human health and property, and endanger life. Forest fires have received increased public attention globally during last few years due to their significant short and long-term threat to forest ecosystem and to public safety and property. The ecological role of fire is to influence several factors such as plant community development, water conservation, soil nutrient recycling and biological diversity. Forest fires are considered vital natural processes that initiate the natural exercise of plant succession. Six million km$^2$ of forest have been lost around the world in less than 200 years mainly due to forest fires (Dimopoulou and Giannikos 2002).

The majority of forest fires are caused by human activities and natural factors like lightning sparks produced by falling boulders and landslides. Most of the forest fires are intentional for land conversion, timber harvesting, and socio-economic conflicts over question of property and land use rights, deforestation activities (conversion of forest to other land uses, e.g. agricultural lands, pastures), grazing land management (fires set by grazers), use of non-wood forest products (use of fire to facilitate harvest or improve yield of plants, fruits, and other forest products), settlement fires (fires from settlements, e.g. from cooking, torches, camp fires etc.) and other traditional fire uses (in the wake of religious, ethnic and folk traditions, tribal warfare).

During the period of 1997-98 a combination of drought conditions brought on by El Niño has caused unprecedented forest fires worldwide. Recent forest fires have a large impact in USA, Australia, Indonesia, Brazil, Mexico, Canada, France, Turkey, Greece, Portugal, Spain, India, Italy Russian Federation and China. The use of fire in land use system in South East Asian region has caused forest fires and resulted in severe environmental hazards and adverse effect on human health. Forest fires often escape from land use fire and take larger shape causing global pollution. Forest fires have great impact on the physical environment including land cover, biodiversity, climate change, forest ecosystem and socio-economic system of affected countries. The loss caused by forest fire is difficult to quantify but an estimate by the economy and environ group has estimated the cost of damage from the Southeast Asian fires (all causes) at more than US $ 4 billion. Health impacts are often serious. As per one estimate 20 million people are in danger of respiratory problems from fire in Southeast Asia (Roy 2000).

The most pronounced consequence of forest fire concerns their potential effect on climate change. Only in the past decade researchers have realized the important contribution of biomass burning to the global budgets of many radioactively and chemically active gases, such as CO$_2$, CO, CH$_4$, ...
NO, tropospheric O$_3$, CH$_3$Cl and elemental C particles. Biomass burning is recognized as a significant global source of emission contributing as much as 40% of gross CO$_2$ and 30% of tropospheric O$_3$ (Andreae 1991).

1.1. Background of the study

India, with a forest cover of 76.4 million ha, (20 % of country) contains a variety of climate zones, including the tropical South, Northwestern deserts, Himalayan Mountains, and the wet Northeast. Forests are widely distributed in the country. India’s forests are endowed with a variety of biomes and biological communities. The forest vegetation in the country varies from tropical evergreen forests at the West Coast and in the Northeast to alpine forests in the Himalayas in the North. Between these extremes, semi-evergreen forests, deciduous forests, sub-tropical broad-leaved hill forests, sub-tropical pine forests, and sub-tropical montane temperate forests exist.

India has about 1.7 million ha of productive coniferous forests, with valuable timber and pulpwood species as fir (Abies spp.), spruce (Picea samithiana), deodar (Cedrus deodara), kail and chir pine (Pinus wallichiana and P. roxburghii). The estimated growing stock of these forests exceeds 200 million m$^3$, the monetary value of which could be anywhere between (US$ 1000 and 1500 millions). In other states forest fires largely damage precious deciduous forests rich in biodiversity.

India has a population exceeding 1000 million, and increasing at an annual rate of more than 2 %. With increase in population, the pressure on the forests is enormous and the forest cover of the country is deteriorating. Along with various factors, forest fires are a major cause of degradation of Indian forests. According to a Forest Survey of India (2002) report, about 50 % of forest areas in the country are fire prone (ranging from 50 % in some states to 90 % in the others). About 6% of the forests are prone to severe fire damage.

The normal fire season in India is from the month of February to mid - June. India witnessed the most severe forest fires during the summer of 1995 in the hills of Uttaranchal and Himachal Pradesh in the Himalayas in the northern part. The fires were very severe and attracted the attention of the whole nation. This fire affected a forest area of 6,777 km$^2$, the quantifiable timber loss was around US$ 45 million. The fire in the hills resulted in smoke in the area for several days. The thick smoke spread over the sky affecting visibility up to 5000 m elevation. The smoke haze, however, vanished after the onset of rains. These fires caused changes in the microclimate of the area in the form of soil moisture balance and increased evaporation.

The forests increase economic growth and play an important role in preserving environment. Forest fire loss has many tangible and intangible values. The loss of timber and nonwood forest products value and young plantations can be quantified but the loss of habitat, ecotourism, soil conversation, moisture conversation, grazing, flood, reduction in ground water reserves and socio economic etc are difficult to quantify.
Forest fires cause wide ranging adverse effects on agricultural production and loss of livelihood for the tribes in India, as approximately 65 million people are classified as tribes who directly depend on collection of nonwood forest products from the forest areas. Many small fires occurring in India spread into rich natural resources and causes significant loss to vegetal cover and humus. These small fires are considered unimportant but in reality need to be controlled. The Himalayan region of India are subjected to repeated annual fires, and because of inaccessibility only conventional fire-fighting techniques are used, which are found ineffective. The innovative approach in fire risk assessment requires the use of remote sensing and geographical information system for processing and displaying of spatial information in a timely and cost effective manner. It has the advantage of a computer’s ability to store, process, update and derive cartographic models by combining in different ways the layers of information included in the database.

Fire modeling studies involve both simulated and integrated forest fire research programmes. They aim at determining methods for prediction of fire hazard and fire frequency, i.e. an assessment of fire danger. Fire hazard rating can be used scientifically for assessment of the fire risk areas, management and operation of fire control and can be integrated with fire management plan. The study of fire risk assessment in a part of Rajaji national park in Himalayan region will be useful for the managers to take pre-emptive measures in fire control management.

1.2. Objectives Of The Study

- Fire risk modeling using multi-criteria spatial analysis.

To formulate fire risk modeling using the combined effect of fuel type index, elevation index, slope index, aspect index, road and the settlement index. To use multi criteria evaluation techniques using direct weighting methods.

- Analysis of parameters and weights contributed by the different land-cover types.

To analyse the importance of different parameters like fuel type, aspect, slope, elevation, roads and settlement and assign weights as per the importance in fire risk modeling.

- Enhancement of existing conventional fire control measures

To formulate recommendations in improving the control of forest fire and its management.
1.3. **Research Questions:**

- What are the parameters, which influence the risk of forest fire?
- What is their relative importance?
- What criteria are normally used for fire risk modeling?
- What are the management implications of fire risk assessment?

1.4. **Overview of Thesis**

The thesis covers six chapters. The first chapter contains introduction, background of study, objective of research and research questions. The second chapter is on literature review on causes, types, factors of forest fire, its impact on plant and animal community, global scenario and application of Remote sensing and GIS on forest fire. The third chapter is on the details of the study area and justification for selecting the area. The fourth chapter addresses resources required and the methodology used. The fifth chapter is on results and discussions. The sixth chapter provides future fire management recommendations based on results and discussions.
2. Literature Review

2.1. What is Forest Fire

Technically, fire is a rapid combination of fuel, heat and oxygen. All the three elements in proper proportions have to be present before a fire can start and continue burning. It is a chemical reaction of any substance that will ignite and burn and leads to a release of energy in the form of heat and light. An external source of heat is generally needed to start a fire. A fire needs at least 16 percent oxygen in the air supporting it. Generally, air contains about 21 percent oxygen. Heat is energy in disorder, and the degree of that disorder is measured as temperature. Fuel is considered any material capable of burning. In forests, this includes living vegetation, branches, needles, standing dead trees, leaves, and human-built wooded structures (Anon 1999).

However, from the point of view of the land manager, a wild-land fire is not prescribed for the area by an authorized plan (FAO 1986). A more descriptive definition is uncontained and freely spreading combustion which consumes the nature fuels of a forest, that is, litter, grass, dead branch wood, snags, logs, stumps, weeds, brush, foliage, and, to a limited degree, green trees. The essential characteristic of a forest fire is that it is unconfined and free to spread. A very useful synonym coming into increasing use is “free burning”. A “free burning fire” is a fire free to respond to its environment. Due to chance, combinations of natural fuels, weather and topography, a free-burning fire may long remain only a smoldering spot or it may quickly develop into a young tornado. In both cases it is responding freely to its local environment.

2.2. Causes Of Forest Fire

Forest fires can be classified into natural and manmade depending upon their origin.

2.2.1. Natural Causes Of Forest Fires

Climate and vegetation cover are the main reasons for natural forest fire. A typically tropical and sub-tropical type of climate, with high temperature in the summer months with strong dry wind favor in these types of forest fire. Along with this the dry vegetative cover or flammable vegetation like pine or other coniferous forests, which contains resiniferrous chemicals, are highly inflammable. These fires can be ignited by lightening before or during storms from sparks produced by falling boulders and landslides. Lightening starts almost half the forest fires in United States, and about 8% of the bush fires in Australia.

2.2.2. Manmade Causes Of Forest Fires

The forest fires are caused by both callous and intentional human actions. Burning forests for the purpose of cultivation is common all over the world. Jhoom cultivation or Podu or most commonly called shifting cultivation is also prevalent in the northeastern, central and the lower regions of the Himalayan ecosystem in India. Some of the other anthropogenic causes for forest fires are graziers, hunters, campfires, cigarettes and matches, domestic ignition also a motor vehicle.
2.3. Types Of Forest Fire

All forest fires are classified into ground fire (litter humus, surface undergrowth and bushes, deadwood and stumps); crown fires (top branches, entire tree) and surface fires (peat), (Kurbatsky 1964).

2.3.1. Ground Fires

A ground fire consumes the organic materials beneath the surface litter of the forest floor. In many forest types a mantle of organic materials accumulates on top of the mineral soil. It may be identified as duff, muck, or peat. A fire spreading in, and consuming such materials is a ground fire. With very deep organic material, as in muck soil and in peat beds and bogs, under drought conditions the fire may penetrate several feet below the surface and travel entirely underground. A ground fire may and often does follow a surface fire, depending on the moisture content of the organic layer. It spreads within rather than on top of the organic mantle and is characterized by a slowly smoldering edge with no flames and little smoke. Ground fires are often hard to detect and are the least spectacular and slowest moving and also the most destructive of all the fires.

2.3.2. Surface Fires

A surface fire is “a fire that burns surface litter, other loose debris of the forest floor and small vegetation”. This is the most common type of fire in timber stands of all species. It may be a mild, low energy fire in sparse grass and pine needle litter, or, it may be a very hot, fast moving fire where slash, flammable under storey shrubs, or other abundant fuel prevails. A surface fire may and often does burn up into the taller vegetation and tree crowns as it progresses.

2.3.3. Crown Fires

A crown fire is “a fire that advances from top to top of trees or shrubs more or less independently of the surface risk”(Brown and Davis 1973). In dense conifer stands on steep slopes or on level ground, with a brisk wind, the crown fire may race ahead of the supporting surface fire. This is the most spectacular kind of forest fire. Since it is over the heads of ground forces it is uncontrollable until it again drops to the ground, and since it is usually fast moving it poses great danger to the fire fighters and wildlife in its path. In timber, crown fires can spread 5 or more miles per hour, but in grass fires spread at a rate of only 2 to 4 miles an hour.

2.4. Fire Combinations

In actual fire situations, these three kinds of fires may occur simultaneously and in all possible combinations. Surface fires are by far the most common, and nearly all fires start as such. A surface fire may spread into the crown and develop into a sweeping crown fire. A crown fire may drop to the ground and become a surface fire. Similarly, a surface fire may develop into a persistent ground fire that may plague control forces for days or weeks.

2.5. Fire Environment

Fire occurs as a result of certain circumstances, which constitute its environment. There is preparation in nature for several days or even weeks. When the proper environment is created, any of the causes can trigger off a conflagration. If the proper environment is not created, the fire will not
escalate further and does not result in great damage and can be put out easily. If the fire occurs when proper environment has been created then it results in big fire and causes substantial damage to property and environment. The following factors make up fire environment.

2.6. Factors For Forest Fires

There are various factors apart from the primary ones, which affect the forest fires:

2.6.1. Topography

By topography we generally refer to the landscape type, that is primarily the, slope, aspect, and elevation.

2.6.1.1. Slope

The slope is the gradient of the land, and is generally expressed in % or in the degrees. Highly sloping terrain accelerates the spread of fire. Among all these factors slope is considered to be the most critical. Because warm air rises, preheating uphill fuels, fires advance uphill faster than they travel downhill. A slope raises the fuels in front of the fire, thus bringing them closer to the flames, and also acts like a chimney carrying heat and flames uphill. Depending upon slope angle and wind speed, slope can be more important than wind in determining the rate of fire spread. Steep slopes increase the rate of spread because of a more efficient connective preheating and ignition by point contact. South and west slopes therefore have a longer fire season, a longer daily burning period and a greater number of fires than north slopes do, and more of the fires that start there become large (Brown and Davis 1973, Artsybashev 1983, Antoninetti 1993).

A fire burning up to a slope of +20 to +39% will spread twice as fast a fire on level terrain (Brown and Davis 1973). It is therefore, important to understand the rate of forward spread of flame in fire suppression activities. The relative rate index of forward spread of flame is exhibited in Table 1.

<table>
<thead>
<tr>
<th>Slope %</th>
<th>Rate of Spread (m/min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fires burning down slope</td>
<td></td>
</tr>
<tr>
<td>70 to 40</td>
<td>0.3</td>
</tr>
<tr>
<td>39 to 20</td>
<td>0.5</td>
</tr>
<tr>
<td>19 to 5</td>
<td>0.8</td>
</tr>
<tr>
<td>Fires burning upslope</td>
<td></td>
</tr>
<tr>
<td>-4 to +4</td>
<td>1.5</td>
</tr>
<tr>
<td>+5 to +19</td>
<td>2.3</td>
</tr>
<tr>
<td>+20 to +39</td>
<td>3.0</td>
</tr>
<tr>
<td>+40 to +70</td>
<td>6.8</td>
</tr>
</tbody>
</table>

2.6.1.2. Aspect

This refers to the direction of the slope, which in turn determines the intensity and amount of sunlight received by that face. Generally the slope facing the North is cooler while that facing the South is warmer. The direction of slope (aspect) determines how much sunlight is received. South and
West slopes receive the most sunlight because of the direct rays of the Sun falling on it. Therefore, northern aspects hold more moisture and so stay green longer and support more vegetation.

### 2.6.1.3. Elevation

Elevation is the height of the land from sea level, generally the higher the elevation, it is assumed that it will be cooler than the areas at lower elevation. Topography also affects fires by means of elevation, the shape of land, and the direction in which slope faces (aspect). High elevations have greater rainfall and a colder and wetter climate, resulting in a fire season that is shorter with fire incidences that are less severe (Brown and Davis 1973, Artsybashev 1983, Antoninetti 1993).

### 2.7. Climatic factor

#### 2.7.1. Relative humidity

Relative humidity is the expression of the amount of moisture in the air compressed to the total amount that is capable of holding at that temperature and pressure. Each 11 degrees centigrade rise in temperature (which often occurs during the morning hours on a clear day) reduces the RH by roughly half. Each 20-centigrade drop in temperature (which often occurs in early evening) causes RH to roughly double. When RH falls below 30% the beginning is intense and the danger from fire branch is also present when the relative humidity is 60% a fire may cause (Brown and Davis 1973, Artsybashev 1983, Antoninetti 1993).

#### 2.7.2. Temperature

Temperature strongly affects the moisture content in forest fuels. High temperature helps dry fuels quickly. Fuel exposed to direct solar radiation become much warmer than the surrounding air. Moisture moves from warmer fuel to the air even if the RH of the air is high. When the temperature is below 4°C, firebrand will not ignite dung, although rotten wood will ignite down to 0°C. Below 0°C grass will not support a fire unless the fuel is dense. Under these conditions piles of debris can be burnt without risk from flaming firebrands, but if the piles are surrounded by grass, one must be on guard for holdover fires in days to follow. Smoldering roots, partially covered logs, peat and leaf’s mold are frequently a problem if wind speed increases or the relative humidity drops on days following the burn. An area where the crown density is high will keep the ground cooler as it is less exposed to direct sunlight, cleared area are often burned when the air temperature are high (Brown and Davis 1973, Artsybashev 1983, Antoninetti 1993).

#### 2.7.3. Precipitation

Rainfall has effect on both fuel moisture and soil moisture. It is thus important to have an estimate of the rain falling on an area, in order to prevent fire during the long stretches of dry weather. Droughts associated with the EL Niño, weather pattern turned moist forests into drier habitats and increased the flammability of forest vegetation, thus increasing the number, frequency, size, intensity and duration of fires (FAO 2001).

#### 2.7.4. Wind speed

Wind speed effects the burning rate of fuel density by influencing the rate of oxygen supply to burning fuel. Strong winds increases the rate of fire spread by tilting the flame towards the unburned fuels, receive energy by radiation and convection at a higher rate. These two mechanisms are particu-
larly responsible for building large fire from smaller areas. Wind is one of the most important factors because it can bring a fresh supply of Oxygen and also put the blaze towards a new fuel source.

2.8. Fuel Type and Fuel Moisture

This is mainly responsible for the type of fuel present in the under story to be ignited. Even though the deciduous forests produces large molecules of fuel, the coniferous forests are more prone to fire because of the chemicals produced in its leaves.

Fuel moisture content of the forest fuel is the most important parameter effecting forest fire behavior. This quantity is in a constant state of flux as fuels respond to the ever-changing environmental factor to precipitation, humidity and temperature. The size and shape of the dead fuel determines how fast it will take on or loose water in response to a change in its surrounding environment. Before a fuel will ignite, the moisture in it has to be heated to the boiling point and evaporated, a process, which takes considerable heat. Thus when the moisture content is high the fires are difficult to ignite, than in fuel with little moisture, however, fires starts easily and tend to burn intensely and spread rapidly.

2.9. Accessibility

The proneness of the forests and the nearby habitation, to fire is determined by the access humans have to the forests. The extent of human interference with the forest can help in assessing the potential risk areas from man-induced fires.

2.10. Impact of Fire on Plant Community

Fire is one of the natural forces that have influenced plant communities over evolutionary periods of time. In temperate and arid regions, where fires are frequent, forests and woodlands have evolved with adaptive traits to ensure survival or to enable them to compete with fire-tolerant species.

In western North America, the open character of *Pinus ponderosa* forests results from natural fires. Mature trees have thick bark, which enables them to survive ground fires. Ground fires keep combustible fuels at low levels and prevent hotter, more destructive fires. Without fires, less fire-tolerant species such as *Abies* sp. appear in the under story and eventually dominate the stand. A similar relationship has been documented for *P. kesiya*, *P. mercusii*, and *P. roxburghii* in Asia (Goldammer 1990).

2.11. Impact of Fire on Animals

The effect of fire on animals changes over time, but the biggest impact is the modification of their habitat. Few studies have examined the adaptation of animals to fire, but zoologists believe that animals with flexible habits and diets thrive after fires, and those animals that eat food found only in mature forests seldom survive (Tiwari 1986).

2.12. Impact of Fire on Sustainable Development

Fire is a natural component of many ecosystems, but it can adversely affect the ability of forest to maintain its genetic diversity. Fire kills vegetation; even fire-tolerant trees that sustain injury from fire may be more susceptible to attack by insects and fungi. More intense fires can kill all vegetation on a site and destroy years of growth in a matter of hours. The impact of fire depends on its
rate and burning depth. Usually, many years are required for a site to recover from a forest fire. The destruction of vegetation by fire causes soil erosion, especially on steep slopes, which can lead to landslides and the siltation of water bodies and tanks (FAO 1993).

Approximately 50 percent of dry biomass of woody vegetation is composed of carbon (Brown and Lugo 1982). When forests burn, a high proportion of the carbon is released into the atmosphere as carbon dioxide and other greenhouse gases. Increasing atmospheric levels of the gases cause concern because they influence global climate (FAO 1990).

2.13. Wildfires

A wildfire is defined as “any fire occurrence on wild land except a fire under prescription” (FAO 1986). Long-term statistical data on the number, area and cause of wildfires are available for relatively few countries; however, estimates indicate the approximately 12 million to 13 million ha of forests and other wooded lands are burned annually by wildfire (FAO1992).

(Occasionally) catastrophic wildfires occurred in 1982-1983, following a severe drought, some 3.6 million hectares of primary and secondary rain forest were destroyed by the largest wildfire recorded in the history in East Kamilantan (Indonesia).

In Honduras, a country with extensive forests, the main cause of wildfires is human activity, including; the restoration of rangelands, the extermination of insect pests and the preparation of fields for crops or disposal of agricultural residues.

The production of non-wood products causes forest fires in some parts of India; e.g. Tendu leaves (Diospyros melanoxylon) which are used for bidi wrappers; and the Mahua flower, Madhuca indica, which is used for a beverage. Fires are set to promote a better flush of growth of Tendu leaves or to clear the forest floor for the collection of Mahua flower. Often unintended, these fires spread to surrounding areas. The tapping of resin from pine trees in Himalayas is also one of the main factors of forest fire in India.

Arson fires may be ignited for private vengeance, personal conflicts over ownership, hunting rights or Government forest policies. Another motive for arson is to change landuse classification and permit house building in former forest areas. Natural factors, like drying lightening storms, causing wildfire in remote, inaccessible areas of Australia, the Russian Federation and western North America.

2.14. Fire Seasons

Forest fire seasons vary according to location. In India most of the fires occur during February to June. In western Canada and western United States, the season is from April to October, while in the southeastern United States it is from March to May. Most fires in the New England states occur in late fall. In Ontario and Eastern Canada, most wildfires occur between April and October. In Australia the fire season is December and January (Anon1999).
2.15. Forest Fire – Global situation and International Co-operation

Globally, 1997 and 1998 were the worst years for wildlife and forest fires in recent times. Although forest fires occur every year in the arid and semi-arid zones of the world, nearly all type of forests burnt in 1997-1998, even some tropical rain forests which had not burned in recent memory. In 1997, wildfires raged in Indonesia, Papua New Guinea, Australia, Mongolia, the Russian Federation, Columbia, Peru, Kenya, Rwanda and other parts of Africa. By mid-1998, fires were reported in Indonesia, the Amazon, Mexico and Central America, USA, Western Canada, Russian Far East and parts of Europe. National disasters were declared in many of these places and national and international resources were mobilized to fight the fires (FAO 2001).

Low rainfall in much of the Amazon region attributed to the El Niño weather pattern, contributed to a prolonged fire season (beyond the usual July-early October period) and an unusually high number of fires. In 1997, over 2 million ha of rainforest in Brazil burned.

The fires of 1997-98 in Indonesia burned millions of hectares of Sumatra and Kalimantan. The exact area is still unknown. One estimate is that about 2.0 million ha (including savannah with grassland) burned in 1997 alone. Several organizations have begun the lengthy and complex task of interpreting satellite images to determine the total area burned. Large quantities of smoke generated by ground fires fed by slow burning fuels affected neighbouring countries, negatively influencing human health, interfering with transportation system, and disrupting the multi million dollar tourist industry, all the which contributed significantly to the economic and social cost of fires. Many underground fires continued to burn into mid-1998 in natural peat/coal beds, threatening new outbreak of fire (FAO 2001).

Some available information on the forest fires elsewhere in the world, provided as a representative sample only, include the following (FAO 2001):

- Fires in Mexico and Central America burned a reported 1.5 million. These generated large quantities of smoke, which blanketed the region and spread into the USA as far as Chicago.
- From January to June 1998, about 13,000 fires burned in Mexico alone, consuming nearly 500,000 ha and killing more than 70 fire fighters and local residents.
- Between December 1997 and April 1998, more than 13,000 fires burned in Nicaragua, the most in any Central American country, destroying vegetation on more than 800,000 ha of land. There were over 11,000 fires in the month of April 1998 alone.
- Severe fires in Florida in southeast USA in 1998 burned a reported 200,000 ha of forest by May 1998.
- More than 150,000 ha of coniferous forests and farmland were burned in various parts of Greece in August 1998, including the black pine forest on Mount Taygetos, site of more than 160 endemic species and 36 endangered species of fauna.
- In July 1998, devastating forest fires affected more than 100,000 ha in the Far Eastern Russia. Coniferous forest burned in more than 150 places around Vladivostok, Sakhalin and Kamchatka Peninsula. Fires in the Southwest Volgograd region destroyed 90,000 ha of forests, at an estimated cost of US $ 6 million. In September, fires swept across Russia’s Pacific Island of Sakhalin, burning over 25,000 ha by the end of the month.

The fires of 1997 and 1998 have stimulated various international efforts related to fires. A global system of early warning to indicate the potential fire risk related to climatic conditions is being investigated by several international organizations, including World Health Organization (WHO),
IUCN, UNEP and FAO. A national system for advance warning by radio linked to meteorological forecasts from satellite imagery has been successfully tried in Burkina Faso. The WHO has produced guidelines for Forest Fire Emergencies. Many national and international meetings have been organized in 1998 for fire fighting and health experts, potential donors and perhaps more significantly policy-makers to address the control, effects and underlying causes of fires. UN agencies, which have organized fire meetings in 1998, include, UNEP and the UN Office for the Coordination of Humanitarian Affairs (Geneva, April, 1998), WHO and the Pan American Health Organization (Lima, Peru, August 1998) and FAO (Rome, October 1998 on “Public Policies Affecting Forest Fires”) FAO 2001.

The application of fire in land-use system in the ASEAN region has reached unprecedented levels and has been leading to increasing environmental problems. Traditional slash and burn has been leading to increasing environmental problems. Traditional slash and burn systems in the shifting agriculture mode have been replaced by modern large-scale conversion of forest into permanent agricultural systems which are partially maintained by fire, and into forest plantations. Wildfires escaping from land-use fires are becoming more and more regular. The impact of land-use fires and wildfires are detrimental to biodiversity and the atmospheric quality as SE Asian regional scale. Within the ASEAN region a joint, concerted approach is needed to cope with the problem of transboundary pollution caused by vegetation burning. However, since fire is an essential tool in land use in the tropics, a response strategy must be developed in which the benefits from fire use would be encouraged, at the same time the negative impacts of fire be reduced. A regional fire management action plan must take into consideration the complexity and diversity of fire uses in different vegetation types and land-use systems. The extent of uncontrolled forest fire was small as compared to land-use fires (Goldammer 1997).

2.16. Indian Scenario

In India no comprehensive data exist to indicate the loss to forests in terms of burned area, values, and volume and regeneration damaged by fire. The available forest fire statistics are not reliable because they under estimate fire numbers and area burned. The reason behind this is attributed to the fear of accountability. However, Forest Survey of India in a countrywide study in 2000 estimated that about 1.45 million ha of forest are affected by fire annually (Appendix 1). According to an assessment of the Forest Protection Division of the Ministry of Environment and Forests, Government of India, fires, annually in India, affect 3.73 million ha of forests. In India there are very few cases of fire due to natural causes. The majority of the forest fires (99 percent) in the country are human caused (Bahuguna 2002). It is widely acknowledged that most of these fires are caused by the people deliberately and have a close relationship to their socio-economic conditions. Grazing, shifting cultivation, and collection of non wood forest products by villagers are major causes of fires in India. Carelessness of the picnickers, travellers, and campers are also responsible for forest fires.

2.17. Remote Sensing and GIS application on Forest Fire

The first application of forest fire data is from 1960 when several aerial infrared scanners were tested for fire spot detection (Chuvieco and Congalton 1989). After the launch of earth resources satellites several studies were done for forest fire and burnt area assessment (Tanaka et al. 1983; Rome and Despain 1989). This approach requires the use of new techniques for obtaining, processing, and objective of the Geographical Information System (GIS) approach. A GIS takes advantage of a computer’s ability to store and process great volumes of data (Burrough 1987). Remote sensing can
help in active forest fire, burnt area and fire prone area. In addition to fire mapping using remote sensing, GIS has effectively been used for fire hazard mapping. The use of a GIS approach allows combining several variables in order to establish fire hazard areas. The main factors of such a model are vegetation, topography (elevation, slope and aspect), fire history, facilities, and weather data etc., which are critical in any fire hazard rating system (Artsybashev 1983). GIS makes it possible to update or retrieve spatial information, as well as to derive cartographic models by combining, in different ways, the layers of information included in the database. In short, GIS is an important tool for storage, analysis and display of geo-referenced spatial and non-spatial data, which makes it possible to integrate number of variables in a meaningful way.

Forest fire research is one of many appropriate GIS applications. The diversity of factors that affect the beginning and spreading of a forest fire dictates the use of an integrated analysis approach. Considering the intrinsic dynamism of this phenomenon, remote sensing imagery is also very valuable for this kind of studies. It provides a quick evaluation of the vegetation status, as well as survey of the effects of fire upon the environment.

In most studies carried out in the past, digital processing of Landsat images was employed to obtain the fuel-oriented maps. Several authors reported a significant correlation between digital classification and downed fuel classes obtained by fieldwork. Other studies attempted to derive National Fire Danger Rating System (NFDRS) fuel types from MSS images. Digital elevation data were frequently used in these studies to improve the discrimination of some fuel classes. The results were quite satisfactory and, therefore, these fuel types were effectively used for computing the NFDRS energy release component or for predicting fire behaviours (Agee and Pickford et al 1985). However, other authors had some feeling of uncertainty about the application of space-borne sensors to fuel mapping. One main reason for this dilemma involves the difficulties in discriminating the under storey component of the forest vegetation.

Subsequently forest fire research has demonstrated the use of Advance Very High-Resolution Radiometer (AVHRR) images. Several studies have been conducted both for fire detection for fuel mapping. The increased frequency of data acquisition, as well as the cost-accuracy relationship, made it a good alternative to Landsat, especially when information is required over large areas. A combined analysis of AVHRR and aerial scanner data has proven very useful for the study of critical variables of a forest fire in near-real time (Ambrosia and Brass 1988).

Now NOAA AVHRR images are widely used for all fields of studies like in meteorology (Rao and Chen, 1995, Kerenyi and Merza 1996) hydrology, forest fires (Chuvieco and Congalton 1999). The NOAA AVHRR sensor, although being of such coarse resolution has proven to be quite suitable for the identification of intact forests, degraded forests and active/inactive fires in the natural vegetation. NOAA AVHRR images were used in fire detection in regional assessments of emissions from fires. Kaufman et al., (1990) investigated fire and smoke detection using NOAA-9 data. Similar kinds of works were carried out by Scholes et al. (1996) about fire and fuel load Kendall et al. (1996) worked on the algorithm used for fire detection.

Different authors have demonstrated the capacity of GIS to improve the spatial analysis of fire danger indices, which are used for fire prevention and pre-suppression planning. The indices are mainly based on meteorological data (temperature, humidity, precipitation), which are usually gathered from only a few weather stations, although they are used to estimate the conditions affecting large territories. Therefore, it is assumed that the stations properly characterize the spatial diversity of weather. Unfortunately, most of the time this assumption is valid, because the weather stations are located in urban areas, at low elevations, and consequently do not represent conditions affecting forest
land well. GIS provides tools for spatial interpolation of weather data, and so a more complete view of the geographical diversity of fire danger can be obtained (Chuvieco and Javier 1996).

The forest fire hazard model was developed to estimate the degree of forest fire hazard in forest stands over a single or multiple watershed landscape. It is based upon the biogeoclimatic and topographic attributes of forest stands which contribute to fire hazard and risk. These include such forest attributes as fuel load, ladder fuels, height to the base of the live crown, number of snags per hectare, and species composition. Because many of these factors are not available as part of a standard forest inventory, they were modeled using available data. Thus, the fire model is based upon standard forest stand attribute inventory data on as well as topography, climate, fire prevention actions, and other human activities (Thompson, Vertinskya, Schreiber, Bruce, Blackwell 1999).

Most of these models do not include the spatial distribution of human risk because of the difficulty in modeling fire-related activities, such as recreation and arson. This risk factor is particularly important for Mediterranean countries, where most of the fires are caused by human activity. An approach to solving this difficulty has been to model the spatial distribution of human risk indirectly, based upon auxiliary variables like accessibility and fire incidence (Vega-García et al. 1993).

In India, spatial modeling for fire risk has been done (Porwal et al. 1997) to obtain the combined effect of fuel type index, elevation index, slope index, aspect index and accessibility index. Different weights were assigned as per the importance of the particular variable. Cumulative fire risk values maps were obtained after integrating all the index maps and fire risk zonation map of the area was generated.

Many traditional techniques of fire modeling and fire hazard mapping, strive to integrate accurate spatial representation of the determinants of fire behaviour, with mathematical models of fire behaviour (Rothermel 1972, 1983, Andrews 1986, Finney 1995). While these techniques have great promise, they require very accurate high-resolution spatial data. Even if remote sensing is used to map variables such as canopy cover or fuel models, much time and energy must be devoted to gathering the field data necessary for accurate classification of the remotely sensed data. Once accurate spatial data is assembled for an area it must be integrated with mathematical models of fire behaviour, ignition points and climatic conditions (Medler 2000).

Fire behaviour models are typically placed into two broad categories: physical, or probabilistic. Physical models are those based upon mathematical analysis of the fundamental and chemical process of fire spread. Sometimes observations from small-scale experimental fires are used to parameterize the formulas in addition to measurements the fuel bed, weather, and topography. Probabilistic models are statistical descriptions of experimental wild land fires and make no attempt to include any of the physical mechanisms that control the fire process (Perry 1998). Physically based models can be used to predict incremental fire spread and fire line intensity. Results can be related to the processes controlling fire spread. Probabilistic models, however, attempt to characterize broad-scale heterogeneity and resulting burn pattern by adjusting probabilities, making results difficult to use in making inferences about physical processes (Finney 1998). Probabilistic models also are difficult to parameterize without an extensive fire history database and can only be used cautiously outside the baseline conditions (Perry 1998). Hargrove et al. (2000) for example, required a database of 235 lightning caused fires to parameterize the spatially explicit probabilistic model EMBYR to model possible fire patterns in Yellowstone National Park, USA (Miller 2002).

Satellites have a role to play in detecting, monitoring and characterizing fires. Satellite systems currently in orbit provide information on different fire characteristics: location and timing of active fires, burned area, areas that are dry and susceptible to wildfire outbreaks, and pyrogenic trace gas
and aerosol emissions. These satellite systems such as MODIS, ENVISAT, and IRS sensors have capabilities in terms of spatial resolution, sensitivity, spectral bands, and times and frequencies of over-passes.

Many of these GIS/remote sensing applications, however, are not fully integrated with organizational business processes, nor are they being used to their greatest potential in resource analysis. Success will also require a government initiative in data management and in the integration of data flows within and between agencies (Sunar and Ozkan 2000).

Despite the technological advancement and the latest fire risk modeling and mapping forest fire keep on causing colossal damage to human life and property. In the US maps of fire weather and fire danger are produced as components of the national fire danger rating system. Based on once daily (2p.m. LST), observations from fire weather network comprises some 1000 weather stations throughout the U.S. and other reports such as Fire danger maps, Fire weather observations and next day forecasts, Dead fuel moisture, live fuel moisture, Drought maps, Lightening location and ignition potential data is available (Dull 2002). But the latest fire in California (Oct 2003) in which more than 20 people died and property worth billion was lost, proves that lot more need to be done to manage the forest fires.

2.18. Fire Potential Index

The fire potential index (FPI) is a valuable fire management tool that has been developed by USGS scientists in collaboration with scientists at the USFS. The FPI characterizes relative fire potential for forests, rangelands, and grasslands, both regionally and locally, so that land manager can develop plans for minimising the threat from fires. The FPI combines multispectral satellite data from NOAA with geographic information system (GIS) technology to generate 1 km resolution fire potential maps. Input data include the total amount of burnable plant material or fuel load derived from vegetation maps, plus the water content of dead vegetation, and the fraction of the total fuel load that is live vegetation. Water content of dead vegetation is calculated from temperature, relative humidity, cloud cover, and precipitation and the proportion of living plants are derived from the greenness maps described above. The FPI is updated daily to reflect the changing weather conditions and posted by the USFS on their web site. The Bureau of Land management (BLM), Bureau of Indian Affairs, and USFS are working with the USGS to validate the model. The FPI is also being tested in Argentina, Chile, Mexico and Spain with the support of Pan American Institute for Geography and History (USGS 2002).
3. Study Area

3.1. Location

The Chilla forest range and part of Ghori forest range together constitute the study area. This is located in Rajaji national park, which is situated between 29°50' to 30°05'N latitude to 78°10' to 78°25'E longitude (Figure 1) in northern India and covers an area of about 820 km². The study area comprises 173 km². The area is located in the Garhwal Shivaliks behind Haridwar across the Rishikesh-Haridwar road. The area has an uneven topography, especially towards the North Eastern part, with elevation ranging from 320 m to 1320 m. The area is covered with thick green forest, mainly Sal, teak, and other varieties of deciduous trees, along with grass and shrubs.

3.2. Justification for Selection of This Study Area

This area is suitable for this research because of its diverse forest types such as Sal, Dry and Moist Deciduous and Mixed forests with different density. The area has forest fires in the past. The area has different parameters of topographic variations such as slope, aspect and elevation. Recent satellite image of the area is available. It is accessible for research.

3.3. Climate

The climate of Chilla range is like the climatic conditions of plain areas of Uttaranchal. Because of its vicinity to outer Himalayan hills climatic conditions become moderate. It varies from subtropical in the plains to temperate in higher hills. During the winters nights are very cold with the frost, which is severe from mid December to mid February. Because of the frost all the forest undergrowth dries up and forms an inflammable material during fire season.

With the beginning of March frost and fog are absent but dew is observed well up to April. The hot weather sets in with the end of March and it continues until the break of the monsoon, and during this period most forest fires take place. Sometimes temperatures as high as 46°C is recorded in the month of May and June particularly on the southern slopes of Chilla Range. During this period there is a hot wind blowing in the southern slopes of Shiwaliks and plains of Chilla Range.

3.3.1. Rainy Season

The Monsoon generally breaks by about the end of June and the rains continue till the middle of September, the heaviest falls normally occurring in July and August. Occasional showers may continue in September and October after which there are usually scanty rains till the end of December.
3.4. **Temperature and Humidity**

There is no meteorological station available in the Park and the nearest is in the Forest Research Institute Dehradun which is about 60 km away. The data cannot be used for analysis purpose but it may give the idea of climatic conditions in the study area (Appendix 2).

3.4.1. **Water Source**

Ganga, Song and Suswa rivers are three major perennial water sources in the study area. Principal streams on the eastern part of the Ganges are Rawasan, Soni sot, Ghasi Ram sot, Amgadi, Gara sot, Pipal sot, Chorpani sot, Moriya and Mithawali sot.
3.5. Forest Types

According to Champion and Seth’s (1968) revised classification of the forest types of India, the forests of Rajaji National Park can be classified into following types and sub-types.

Moist Shiwalik Sal forest, Moist Bhabar Dun Sal forest, West Gangetic Moist Mixed Deciduous forest, Low Alluvial Savannah Woodland, Sub-Montane Hill valley swamp forest, Dry Shiwalik Sal forest, Dry plane Sal forest, Northern dry mixed deciduous forest, Dry deciduous forest (Degradation Stage) Figure 3, Khair, Sissoo forest, Northern dry deciduous forest, Sub-tropical Chir pine forest.
3.5.1. Flora

The forest ecosystems of the Rajaji Park are quite varied and diverse. A general survey of the forests revealed some important types of plant association like *Shorea, Mallotus* and *Adina community*, *Terminalia* and *Bridelia community*, *Dalbergia, Acacia community, Syzygium, Phoebe* and *Drypetes community* etc. Based on the physiognomy and floristic composition, the permanent vegetation of the park may be classified under the Northern Tropical Moist Deciduous Forests.

3.5.2. Fauna

Chilla range is an interesting animal habitat on account of its location at the meeting point of the lesser Himalayan foothills and the beginning of the vast Indo-Gangetic plains. The park has the largest population of elephants in Uttaranchal. It also has a healthy population of tigers and leopards. Both elephants and tiger are here at the Northwestern tip of their distribution in India.

The wild animals of Chilla show a good variety of species as: Chital or spotted deer, Barking deer, Sambhar, Nilgai or blue bull, The goat-like Goral, Wild boar, Elephant, Tiger and Leopard, Jackal, Jungle cat, Rhesus macaque, Indian hare etc.
3.5.3. **Birds**

The range is very rich in avifauna. There are over 315 bird species in the range, many of which are common to other parts of India. Peafowl (*Pavo cristatus*) is common in open grassland, especially in areas with heavy ground cover such as patches of lantana. Other ground birds include the Black partridge (*Francolinus*) and quail (*Coturnix sp.*). Raptors include crested serpent eagle (*Spilornis cheela*), Eurasian kestrel (*Falco tinnunculus*) and Black-shouldered kite (*Elanus caeruleus*).

3.5.4. **Reptiles**

Various species of snakes are found in Chilla. Poisonous snakes such as King Cobra (*Ophiophagus Hannah*), Common Krait (*Bungarus caeruleus*), Cobra (*Naja naja*), Russel Viper (*Vipera russelli*) and non-poisonous snakes like python (*Python molurus*) are found in the range. Monitor lizard (*Varanus bengalensis*) is common in Chilla.

The major communities living inside the park is Gujjars, and they play an important role in fire occurrence and management of study area.

3.6. **Gujjars**

The Gujjars are trans-nomadic pastoralists migrating in and out of the Rajaji National Park, since over 100 years. A particular patch of forest is allotted to a single Gujjar family, which is known as Khole. In a Khole, Gujjars are allowed to lop the leaves of certain fodder trees. The lopping is restricted between November and March. In summer they go to the Himalayas where they stay till October. Because of stiff competition for grazing grounds between them and local people now more and more Gujjar prefer to stay in the forests of Chilla range.

![Figure 4. Indiscriminate Lopping by Gujjars](image-url)
Indiscriminate lopping (Figure 4) and overuse of habitat denies the required silviculatural rest to the forest. This has opened up the forest canopy, letting in rainwater during monsoon, which washes the precious topsoil from these hills. Along with the soil, rain also sweeps away rubbles and boulders into the seasonal streams also known as Rau. This eats away a sizable area of forest. Indiscriminate lopping has altered the natural process of fruit bearing and seedling, adversely affecting the regeneration of trees. As a result, weeds life *Lantana camera, Cannablis sativa, Parthenium histeropsorus* and *Cassia tora* cover more then 40% of ground flora and making it vulnerable to fire (Figure 5). Gujjars and other local population for rope making collect the baib grass, which is abundantly available in the area (Figure 6). To get new grass these people set fire to these areas and is one of the main causes of forest fire in the area.
3.7. Fire Protection

Of all the forest in India, the Uttarakhal forests have been under constant threat from forest fires. In 1981 almost 271 km$^2$ areas was lost due to forest fire, which increased, to 359 km$^2$ and now to 620 km$^2$ by 1995. A total of 800 km$^2$ that is forests worth US $ 1 million has been lost between 1991-2001. In the past five years Chilla forest had frequent fires in different part of range.

Table 2. Annual burnt area in Chilla range

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual area burnt (ha)</th>
<th>Blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>6.3</td>
<td>Amgadi Block</td>
</tr>
<tr>
<td>1998</td>
<td>8.4</td>
<td>Dogadda Block and Luni Block</td>
</tr>
<tr>
<td>1999</td>
<td>13.8</td>
<td>Mundal Block</td>
</tr>
<tr>
<td>2000</td>
<td>11.8</td>
<td>Rawsani and Amgadi Block</td>
</tr>
<tr>
<td>2001</td>
<td>4.5</td>
<td>Luni and Mundal Block</td>
</tr>
<tr>
<td>2002</td>
<td>7.0</td>
<td>Luni Block</td>
</tr>
</tbody>
</table>

(Source Fire occurrence records of Chilla 2002)

Rajaji Park is under the control of the Director of Park located at Hardwar. Under the director the Ranger Chilla looks after the management of the area. The foresters and forest guard assist the ranger. Each forest guard looks after a beat. In the event of fire the forest guards gets the information through the firewatchers appointed for fire protection work during fire season, i.e. April to June. The help of Gujjars and local people is taken and fire control is done by conventional method of beating the fire. The Ranger arranges more reinforcement in the event of fire spreading to larger area, and the logistic support of fire control department is taken to control the fire.

The range is not having the database of fire occurrence records. The fire control map prepared is also without scale as fire risk area are marked approximately observing the topographical features and the forest type. These maps are used for the appointment of firewatchers during fire season.
4. Methodology

To carry out the study the following resources and equipments are required.

4.1. Remote Sensing Data

IRS 1D LISS III (Linear Image Self Scanning) satellite images of June 2001 were used in the study. All Image have a spatial resolution of 23.5 x 23.5 m. Along with the digital data, a hard copy of 1: 50000 scale of the image was used in the study.

4.1.1. Ancillary Data

Landform information of study area at a scale of 1:50000 were used. The management plan map of Chilla range on scale 1”= 2.5 km was taken.

4.1.2. Instruments/Field Equipment/Materials

- Ranger compass
- Weighing machine
- GPS
- Field notebook
- Drawing table
- Table lamp

4.1.3. Computer System

Software
- Windows Arc/View version 3.2
- Erdas/Imagine version 8.5
- Microsoft Office 2000

Hardware
- Scanner – Hewlett Packard Scan Jet ADF
- Computer System having Pentium IV processor
- Hewlett Packard LaserJet 5M printer
The methodology has been shown in the following flow diagram:

Figure 7. Methodology Flowchart
4.2. **Field Work**

- Elevation, slope and vegetation type were recorded.
- Mapping of roads, fire lines, settlement and rivers.
- Ground truthing was carried out for mapping forest type and density in study area.

For calculating surface fuel content per unit area of different density classes in different forest type 15 nos. of 1m x 1m quadrates were laid in study area, well distributed and representing each type of cover density, and litter (leaf, twig and branches) and herbaceous grasses were collected separately from each quadrate and weighed before and after drying. This gives surface fuel content per unit area in each forest density class.

4.3. **Constraints during and after the fieldwork**

- No scale fire control map of the study area was available.
- Adverse climatic conditions (rainy season).
- Restriction on movement in the park.
- Access and export regulation of topographic information.
- Unavailability of meteorological data of study site.

4.4. **Generation of Maps**

The slopes and elevations being the major input of the model were verified physically in the field. Few slope points were checked and marked on the map with the help of clinometer and subsequently verified with the Digital elevation model generated. Elevation was also checked at major point of intersect with the help of GPS.

4.4.1. **Generation of Road and Settlement Map**

The base map is prepared taking the roads, settlements and contours from the landform information on scale 1:50000. The maps are digitized and georeferenced.

4.4.2. **Generation of DEM, Slope, Aspect and Elevation Maps**

Landform information was used to generate a contour map at 40 m spacing. On-screen digitization and on-screen visual classification of forest type was done and attributes were given in order to input the data to GIS and make the maps computer readable. Digital Elevation Model (DEM) was generated using contour map with the help of ERDAS IMAGINE 8.5, using data preparation module.
Using the same software, slope and aspect maps were derived from the DEM. Attributes were given to each map so generated.

4.4.3. **Generation of Forest type and Forest Density Maps**

For inputting spatial data in GIS, it is necessary that the resource information is in the form of map; hence the mapping of the thematic layers is one of the primary requirements. Remote sensing, coupled with limited ground checks, is the most ideal way for generating resource maps. The Methodology for using satellite remote sensing data for generating forest resources information layers is well established in India and abroad. IRS-1C LISS III image were georeferenced and interpreted coupled with ground truthing. The forest type map and density map was prepared by onscreen visual interpretation and ground verification. After topology building, attributes were attached to the respective maps.

In each cover type, density variations were also marked based on image characteristics colour, hue, texture and pattern etc, and field observations, thus generating a cover density map. Adequate ground truthing was done with the help of forest staff. The help of Forest survey of India staff and equipments was also taken in preparing the maps.

4.4.4. **Fuel Type Map**

The fuel type map was generated by crossing/ overlaying the forest type and forest density map. Each cover type and density combination as been assigned a new class and accordingly attribute have been given.

4.5. **Spatial Multicriteria Decision Analysis**

Spatial multicriteria decision analysis is a process that combines and transforms geographical data (input) into a resultant (output). The multi criteria decision-making procedures define a relationship between the input maps and the output maps. The procedures involve the utilization of geographical data, the decision maker’s preferences, and the manipulation of the data and preferences according to specified decision rules. They aggregate multidimensional geographical data and information into unidimensional values of alternative decisions. The critical aspect of spatial multicriteria analysis is that it involves evaluation of geographical events based on the criterion values and decision maker’s preferences with respect to a set of evaluation criteria (Malczewski 1999).
A weight can be defined as a value assigned to an evaluation criterion that indicates its importance relative to other criteria under consideration. The larger the weight, the more important is the criterion in the overall utility. The weight value is dependent on the range of criterion value, that is the difference between the minimum and maximum value for a given criterion. A criterion weight can be made arbitrarily large or small by increasing or decreasing the range (Malczewski 1999).

4.6. Generating Index Value Maps

In the present study the map layers generated above viz. fuel type map, slope map, aspect map, road map, settlement map and DEM were reclassified using classification tables with the help of ARC-VIEW 3.2 and ERDAS IMAGINE 8.5 software, and the index maps such as fuel class index, slope index, aspect index, road index, settlement index and elevation index maps were generated. On the basis of experience and the opinion of the experts in the field weights are assigned to different parameters.

4.6.1. Fuel Type Index

The forest type (Figure 11) and forest density maps (Figure 10) are combined to get the final fuel map and based on the forest type and density weights were given. The litter (leaf, twig and branches) and herbaceous grasses present in each type is also important in assigning weights. To estimate the surface fuel value (litter and grass) present in each forest density type, 1m x 1m quadrates were laid following a stratified random sampling approach well distributed and representing each type of cover density, and litter (leaf, twig and branches) and herbaceous grasses were collected separately from each quadrate and weighed before and after drying (Table 3.). This gives surface fuel content per unit area in each forest density class.

Fuel type has got the maximum influence on fire occurrence because forest fire behaves differently in different forest types. Grasslands have maximum chances of fire as it contains maximum inflammable and dry material and is prone to biotic influence such as grazers and rope makers. Low and degraded forests are also having more chances of forest fire because they contain maximum grasses and undecomposed leaf litter. The past history of fire occurrence is also taken into account while assigning the weights.

The forest type, density, surface fuel content, fire incidences in the past, species (more prone to fire) and condition of forest (degraded, mixed or pure etc.) have been considered to assign weights for fuel type index map.

Grasslands have the maximum inflammable material and subjected to disturbances by grazers and grass rope makers were given weight of 10. Degraded forests and shrubs also contain unde-
posed leaf litter etc, and were given weights of 9. In forest type dry mixed, mixed forest and pure sal forest have more leaf litter and fire prone species, therefore have been given higher weights.

Table 3. Surface Fuel Content Of Forest Types

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Density</th>
<th>Dry Wt. Of leaf &amp; twigs (g)</th>
<th>Wt. Of grass &amp; herbs before drying (g)</th>
<th>Wt. Of grass &amp; herbs after drying (g)</th>
<th>Surface Fuel content (col.3+col.5) (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Mixed</td>
<td>Low</td>
<td>250</td>
<td>80</td>
<td>60</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>400</td>
<td>130</td>
<td>80</td>
<td>480</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>500</td>
<td>150</td>
<td>90</td>
<td>590</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>Low</td>
<td>250</td>
<td>70</td>
<td>50</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>350</td>
<td>90</td>
<td>60</td>
<td>410</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>450</td>
<td>120</td>
<td>70</td>
<td>520</td>
</tr>
<tr>
<td>Mixed Sal</td>
<td>Low</td>
<td>200</td>
<td>60</td>
<td>40</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>300</td>
<td>80</td>
<td>50</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>400</td>
<td>100</td>
<td>60</td>
<td>460</td>
</tr>
<tr>
<td>Moist Mixed</td>
<td>Low</td>
<td>250</td>
<td>60</td>
<td>40</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>300</td>
<td>80</td>
<td>50</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>400</td>
<td>110</td>
<td>80</td>
<td>480</td>
</tr>
<tr>
<td>Sal</td>
<td>Low</td>
<td>300</td>
<td>90</td>
<td>60</td>
<td>360</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>400</td>
<td>100</td>
<td>70</td>
<td>470</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>450</td>
<td>120</td>
<td>70</td>
<td>520</td>
</tr>
</tbody>
</table>
The weights given to different forest types and densities is as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>Density</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Mixed</td>
<td>High</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>7</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>High</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>5</td>
</tr>
<tr>
<td>Mixed Sal</td>
<td>High</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>4</td>
</tr>
<tr>
<td>Moist Mixed</td>
<td>High</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>4</td>
</tr>
<tr>
<td>Sal</td>
<td>High</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>5</td>
</tr>
<tr>
<td>Shrub</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Grass</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Plantation</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Agriculture</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Degraded Forest</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Habitation</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>
4.6.2. **Elevation Index Map**

Chances of fire are less at higher elevations due to climatic factors, but in this study area the maximum elevation is 1320 m only and the area is having baib grass used for rope making by local people and having more chances of fire occurrence and the lower elevation areas are with gradual slope therefore higher weights have been given to higher elevation. A maximum weight of 10 is assigned to 1100 to 1320 m elevation (Table 5 Figure 15).

### Table 5. Elevation Classes And Weights

<table>
<thead>
<tr>
<th>Elevation In Meters</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>300-400</td>
<td>2</td>
</tr>
<tr>
<td>400-500</td>
<td>3</td>
</tr>
<tr>
<td>500-600</td>
<td>4</td>
</tr>
<tr>
<td>600-700</td>
<td>5</td>
</tr>
<tr>
<td>700-800</td>
<td>6</td>
</tr>
<tr>
<td>800-900</td>
<td>7</td>
</tr>
<tr>
<td>900-1000</td>
<td>8</td>
</tr>
<tr>
<td>1000-1100</td>
<td>9</td>
</tr>
<tr>
<td>1100-1320</td>
<td>10</td>
</tr>
</tbody>
</table>
4.6.3. **Slope Index Map**

On the steep slopes, the rate of spread of fire is higher due to convective preheating and ignition therefore higher slopes have been given higher index values. The slope from 61 degree and above has been given maximum weight of 10 (Table 6 Figure 13).

<table>
<thead>
<tr>
<th>Slope % (degrees)</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>1</td>
</tr>
<tr>
<td>6-15</td>
<td>2</td>
</tr>
<tr>
<td>16-25</td>
<td>3</td>
</tr>
<tr>
<td>26-35</td>
<td>5</td>
</tr>
<tr>
<td>36-45</td>
<td>7</td>
</tr>
<tr>
<td>46-60</td>
<td>8</td>
</tr>
<tr>
<td>61-84</td>
<td>10</td>
</tr>
</tbody>
</table>

4.6.4. **Aspect Index Map**

Because of warmer condition due to direct sunlight in south, southwestern and southeastern aspects are more prone to fire, and accordingly higher index values were assigned to them. Southern aspect has been given maximum weight of 10 (Table 7 Figure 14).
Table 7. Aspect Classes And Weights

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>2</td>
</tr>
<tr>
<td>North East</td>
<td>3</td>
</tr>
<tr>
<td>East</td>
<td>6</td>
</tr>
<tr>
<td>South</td>
<td>10</td>
</tr>
<tr>
<td>South-East</td>
<td>9</td>
</tr>
<tr>
<td>West</td>
<td>8</td>
</tr>
<tr>
<td>North West</td>
<td>3</td>
</tr>
<tr>
<td>South-West</td>
<td>9</td>
</tr>
</tbody>
</table>

4.6.5. **Road Index Map**

While assigning index values to the distance class, higher values are given to the areas nearer to the roads because people can easily approach these areas and there are more chances of occurrence of fire because of disturbance. The road buffers were created at the interval of 400 m. To cover the whole study area under the road buffer the distance of 4000 m has been taken. (Table 8 Figure 17).
Table 8. Road Buffer Distances And Weights

<table>
<thead>
<tr>
<th>Road Buffers (m)</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>10</td>
</tr>
<tr>
<td>800</td>
<td>9</td>
</tr>
<tr>
<td>1200</td>
<td>8</td>
</tr>
<tr>
<td>1600</td>
<td>7</td>
</tr>
<tr>
<td>2000</td>
<td>6</td>
</tr>
<tr>
<td>2400</td>
<td>5</td>
</tr>
<tr>
<td>2800</td>
<td>4</td>
</tr>
<tr>
<td>3200</td>
<td>3</td>
</tr>
<tr>
<td>3600</td>
<td>2</td>
</tr>
<tr>
<td>4000</td>
<td>1</td>
</tr>
</tbody>
</table>

4.6.6. Settlement Index Map

While assigning index values to the distance class, higher values are given to the areas nearer to the settlement because people can easily disturb these areas and chances of occurrence of fire will be more. The buffers have been created at the interval of 200 m and to cover the whole study area buffers up to 3600 m have been created (Table 9Figure 19).
Table 9. Settlement Buffer Distances And Weights

<table>
<thead>
<tr>
<th>Settlement Buffers (m)</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>10</td>
</tr>
<tr>
<td>400</td>
<td>10</td>
</tr>
<tr>
<td>600</td>
<td>10</td>
</tr>
<tr>
<td>800</td>
<td>9</td>
</tr>
<tr>
<td>1000</td>
<td>9</td>
</tr>
<tr>
<td>1200</td>
<td>8</td>
</tr>
<tr>
<td>1400</td>
<td>8</td>
</tr>
<tr>
<td>1600</td>
<td>7</td>
</tr>
<tr>
<td>1800</td>
<td>7</td>
</tr>
<tr>
<td>2000</td>
<td>6</td>
</tr>
<tr>
<td>2200</td>
<td>5</td>
</tr>
<tr>
<td>2400</td>
<td>4</td>
</tr>
<tr>
<td>2600</td>
<td>3</td>
</tr>
<tr>
<td>2800</td>
<td>2</td>
</tr>
<tr>
<td>3000</td>
<td>1</td>
</tr>
<tr>
<td>3200</td>
<td>1</td>
</tr>
<tr>
<td>3400</td>
<td>1</td>
</tr>
<tr>
<td>3600</td>
<td>1</td>
</tr>
</tbody>
</table>
4.6.7. Fire Risk Modeling

In Spatial modeling for forest fire hazard prediction, management, and control in Corbet national park India (Sharma 1995) integrated the sub models fuel risk, response risk and exposure risk. The response risk sub model was generated using the distance from head quarter and the time map. Different weights were given to sub models as per the importance to fire risk.

Spatial modeling of Motichur range of Rajaji national park was done by Porwal et al (1997) to get combined effect of fuel type index, elevation index, slope index, aspect index, road index and settlement index. Weights were given as per the importance of variables. The authors have given the highest weight of four to fuel type index and three to aspect index and two to slope index. The model output i.e. cumulative fire risk index value map was obtained using the map calculation function.

\[ \text{CFRISK} = \text{ELI} + \text{SLI} + \text{ASI} + \text{SI} + \text{RI} + \text{FUI} \]

Where,

- CFRISK = Cumulative fire risk index value
- ELI = Elevation index
- SLI = Slope index
- ASI = Aspect index
- SI = Settlement index
- RI = Road index
- FUI = Fuel type index

In this study spatial modeling has been done to obtain the cumulative effect of fuel type index, elevation index, slope index, aspect index, road index and settlement index. The CFRISK was calculated without giving any weights and fire risk index values were ranging from 11 to 45 and the fire risk areas generated were compared with the sites effected by fire in the past and fire prone areas marked and was found that the moderate to very high risk areas were much less than the marked area of fire control map of the area.

Different weights have been assigned as per the importance of the particular variables in relation to the area under study. Highest weight of four have been given to the fuel type index, because, fuel contributes to the maximum extent due to inflammability factor. The second highest weights has been given to slope and aspect, because, sun facing aspects receive direct sun rays and make the fuel warmer and dry; higher slopes contribute to convectional preheating and easy ignition and spreading
of fire. With the weights the following equation was used in the map calculation function (in map calculator of ARC/VIEW).

$$CFRISK = ELI + SLI^2 + ASI^2 + SI + RI + FUI^4$$

As different weights were tried for different variables and the weights given in the equations showed the agreement with the fire risk area of the range. The fire risk index values in this map (CFRISK) were ranging from 14 to 99. Based on the statistics of different weight classes, the map was reclassified into five classes as very low, low, moderate, high and very high to generate fire risk area map.
5. Results And Discussions

5.1. Classification of IRS 1D LISS III image

IRS 1D LISS III image of June 2001 was used to get the forest type and forest density maps. The IRS LISS III image was first resampled to achieve 23.5 m pixel size. It was repeatedly attempted to refine the results and compared with the forest management map visually. The imagery consists of four spectral bands, Band 1, 0.52-0.59μm (green), Band 2, 0.62 – 0.68μm (red), band 3, 0.77-0.86μm (near infra red) and band 4, 1.55-1.70μm (mid infra red). Light reflectance for each pixel is measured in each of the three bands and assigned a digital value from zero to 255. The satellite image was georeferenced using ERDAS IMAGINE 8.5 software and subset was made for study area from raw IRS digital data (Figure 8). Enhancement techniques were applied for extracting land use and terrain features from the imagery. Radiometric corrections were applied to imagery to remove the effect of haze. Analysis was done in band 1, 2 and 3. Band 4 was not used as it has very coarse resolution.

Figure 8. Satellite Imagery Of Chilla Range
5.2. Visual interpretation

Visual interpretation method was used with inputs from forest management map, topographic map and corrected satellite imagery. The administrative boundaries of blocks were defined with respect to management map and created Block Boundaries (Figure 9). A block is an area created for administrative convenience depending on location and a Forest Guard is given the charge of protection of one or more blocks. The block boundaries are important information for fire management planning. The land use classification was done with ground truthing and twelve major types were classified. In the forest types Sal is the main species in and associated with different species and the composition varies with elevation, aspect and other locality factors. The plantation, shrubs, habitation, agricultural land, rivers and grasslands were the other categories of classification. In this study all these classes are being shown in forest type. Mixed Sal constitutes the major forest type with approximately 44%. In this type Sal is a dominant species with more than 80% area. In mixed forest covering 24% area Sal is dominant with Mallotus, Acacia, Dalbergia, Terminalia community etc. The composition of other types is shown in the (Graph1 Table 10).

Visual interpretation method was used to further classify the forest type in density classes. When the crown density of forest type is up to 20% it is classified as low density, 20 to 40% crown density is medium and more than 40% is high density. In each cover type, density variations were marked based on image characteristics colour, hue, texture and pattern etc and ground truthing, generating a cover density map. Density classification was done for forest type Sal, Moist Sal, Dry Sal, Mixed Sal and Mixed forest only. In other classes like river, plantations, agriculture, habitations, grass etc there was no variations in image characteristic. Maximum area of 38% area is under high density followed by medium density with 32%.

5.3. Fuel type index

The topography of the area represents the forests type and vegetation type in the study area. There is gradual change in vegetation type after the elevation of 1000m as in the eastern part of the area few species of temperate zone are present. *Pinus roxburghii* (chir pine) is the main species. As this species has highly inflammable resin present and had been cause of major fires in Himalayan region. But the trees are only scattered and no large area of this species is present which can make significant change in assigning the weights. Further the southern and western aspect has more dry forest type confirming that these aspects get more sunlight. The moist type is present in lower elevation and northeast aspect and very close to settlements. This forest had been subjected to more biotic interference due to heavy lopping. There are number of rivers which remain dry during the fire season but works as good fire barriers and is the main reason of fires not taking bigger shape in this area.
Graph 1. Forest Types

Table 10. Forest Types Area

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Forest Types</th>
<th>Area (Ha)</th>
<th>Area (Km²)</th>
<th>% Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agriculture</td>
<td>17.9426</td>
<td>0.179426</td>
<td>0.11</td>
</tr>
<tr>
<td>2</td>
<td>Degraded Forest</td>
<td>660.6718</td>
<td>6.606719</td>
<td>3.94</td>
</tr>
<tr>
<td>3</td>
<td>Dry Mixed</td>
<td>814.7150</td>
<td>8.147151</td>
<td>4.86</td>
</tr>
<tr>
<td>4</td>
<td>Grass</td>
<td>111.2557</td>
<td>1.112557</td>
<td>0.66</td>
</tr>
<tr>
<td>5</td>
<td>Habitation</td>
<td>76.6716</td>
<td>0.766716</td>
<td>0.46</td>
</tr>
<tr>
<td>6</td>
<td>Mixed Forest</td>
<td>4007.1853</td>
<td>40.07185</td>
<td>23.89</td>
</tr>
<tr>
<td>7</td>
<td>Mixed Sal</td>
<td>7513.0252</td>
<td>75.13025</td>
<td>44.19</td>
</tr>
<tr>
<td>8</td>
<td>Moist Mixed</td>
<td>1643.8100</td>
<td>16.4381</td>
<td>8.31</td>
</tr>
<tr>
<td>9</td>
<td>Plantation</td>
<td>79.6337</td>
<td>0.796337</td>
<td>0.47</td>
</tr>
<tr>
<td>10</td>
<td>River</td>
<td>1000.4621</td>
<td>10.00462</td>
<td>5.96</td>
</tr>
<tr>
<td>11</td>
<td>Sal</td>
<td>1094.1950</td>
<td>10.94195</td>
<td>5.33</td>
</tr>
<tr>
<td>12</td>
<td>Shrubs</td>
<td>306.1100</td>
<td>3.0611</td>
<td>1.82</td>
</tr>
</tbody>
</table>
Figure 9. Block Boundaries

Figure 10. Forest Density Map
Figure 11. Forest Type Map

Figure 12. Fuel Type Index Map
Table 11. Forest density Area

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Density</th>
<th>Area (Ha)</th>
<th>Area (Km²)</th>
<th>% Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HIGH</td>
<td>6574.3027</td>
<td>65.7430</td>
<td>37.9026</td>
</tr>
<tr>
<td>2</td>
<td>MEDIUM</td>
<td>5561.9176</td>
<td>55.6191</td>
<td>32.066</td>
</tr>
<tr>
<td>3</td>
<td>LOW</td>
<td>3063.3613</td>
<td>30.6336</td>
<td>17.661</td>
</tr>
<tr>
<td>4</td>
<td>NONE</td>
<td>2125.6628</td>
<td>21.2566</td>
<td>12.3703</td>
</tr>
</tbody>
</table>
5.4. **Slope index**

The slope and area is shown in (Figure 13 Graph 2).

The slope map was generated from the digital elevation model and checked in the field. About 83% area is under the slope of 25 degree and low weights have been assigned to these slopes. During fire season the area gets heavy wind and slope play an important role in spread of fire.

<table>
<thead>
<tr>
<th>Slope %</th>
<th>Index</th>
<th>Area (Ha)</th>
<th>% Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>1</td>
<td>6614.941</td>
<td>38.18</td>
</tr>
<tr>
<td>6-15</td>
<td>2</td>
<td>4457.895</td>
<td>25.73</td>
</tr>
<tr>
<td>16-25</td>
<td>3</td>
<td>3298.808</td>
<td>19.04</td>
</tr>
<tr>
<td>26-35</td>
<td>5</td>
<td>1434.565</td>
<td>8.28</td>
</tr>
<tr>
<td>36-45</td>
<td>7</td>
<td>306.6644</td>
<td>1.77</td>
</tr>
<tr>
<td>46-60</td>
<td>8</td>
<td>232.164</td>
<td>1.34</td>
</tr>
<tr>
<td>61-84</td>
<td>10</td>
<td>978.9004</td>
<td>5.65</td>
</tr>
</tbody>
</table>

**Table 12. Slope Index Area**

5.5. **Aspect index**

The aspects and percentage is shown in (Figure 14 Graph 3).

The area is having about 52% northern and eastern aspect. The moist deciduous type forest is present in these aspects. The southern and western aspect has more dry and mixed type forest and has the maximum chances of fire occurrence accordingly more weights have been given to these aspects.
Table 13. Aspect Index Area

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Index</th>
<th>Area (Ha)</th>
<th>% Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>2</td>
<td>4504.674</td>
<td>26</td>
</tr>
<tr>
<td>NE/NW</td>
<td>3</td>
<td>3638.391</td>
<td>21</td>
</tr>
<tr>
<td>East</td>
<td>6</td>
<td>866.2835</td>
<td>5</td>
</tr>
<tr>
<td>West</td>
<td>8</td>
<td>2252.337</td>
<td>13</td>
</tr>
<tr>
<td>SE/SW</td>
<td>9</td>
<td>4331.418</td>
<td>25</td>
</tr>
<tr>
<td>South</td>
<td>10</td>
<td>1732.567</td>
<td>10</td>
</tr>
</tbody>
</table>

Graph 3. Percentage Area (Aspect)
5.6. **Elevation index**

The area and its percentage in different elevation has been shown in (Figure 15 Graph 4) In the study area 90% area is having elevation up to 800 m and fire spread is more in lower elevation as due to convecting heating. In very high elevation area the rate of spread of fire is reduced due to microclimate but in present study the area has the elevation is up to 1320 m only and higher weight has been assigned to higher elevation areas.

<table>
<thead>
<tr>
<th>Elevation m</th>
<th>Index</th>
<th>Area (Ha)</th>
<th>%Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>300-400</td>
<td>2</td>
<td>6860.96</td>
<td>39.60</td>
</tr>
<tr>
<td>400-500</td>
<td>3</td>
<td>3522.30</td>
<td>20.33</td>
</tr>
<tr>
<td>500-600</td>
<td>4</td>
<td>2072.15</td>
<td>11.96</td>
</tr>
<tr>
<td>600-700</td>
<td>5</td>
<td>1668.46</td>
<td>9.63</td>
</tr>
<tr>
<td>700-800</td>
<td>6</td>
<td>1574.90</td>
<td>9.09</td>
</tr>
<tr>
<td>800-900</td>
<td>7</td>
<td>859.35</td>
<td>4.96</td>
</tr>
<tr>
<td>900-1000</td>
<td>8</td>
<td>492.05</td>
<td>2.84</td>
</tr>
<tr>
<td>1000-1100</td>
<td>9</td>
<td>209.64</td>
<td>1.21</td>
</tr>
<tr>
<td>1100-1320</td>
<td>10</td>
<td>64.10</td>
<td>0.37</td>
</tr>
</tbody>
</table>
Graph 4. Percentage Area (Elevation)

Figure 15. Elevation Index Map
5.7. Road index

The roads and buffer created for the purpose of study is shown in Figure 16 and 17. The study area has three types of roads, metalled, unmetalled and cart roads. The department for transportation uses metalled and unmetalled roads. The local Gujjars use cart road for the transport of their goods. Roads work both as promoter and barrier of fire. The area close to the road has more chances of disturbance from the user in the form of cigarettes and other inflammable materials. Buffers of 400 m were created and the buffer close to road is given higher weights.

Figure 16. Road Map
Figure 17. Road Index Map

5.8. Settlement index

The settlements and buffer created is shown in Figure 18 and 19. There are settlements in the whole study area. The disturbance caused to the forest by the settlers of this area is the main cause of forest fire. A buffer of 200 m has been created and the buffer close to the settlement has been given higher weight. Few settlements are located outside the study area but have the impact on the area, thus taken for analysis purpose.
Figure 18. Settlement Map

Figure 19. Settlement Index Map
5.9. Fire risk index and model

The six layers generated are converted into grid maps and in Arc view software in map calculation function these layers are integrated. First the six layers were integrated without assigning any weight and in the map calculation function the value were ranging from 11 to 45. Based on the statistics of different weight classes, the map is reclassified into five areas as very low, low, moderate, high and very high. In this the poor and very poor area constitute 23% of area and moderate to very high risk is 77%.

As fuel is the main factor in the occurrence of fire the fuel index has been given weight of four and aspect slope and elevation is given weight of two. The road and settlement index was not given any additional weight as these act both as hazard and barrier to fire management. Inhabitants using them initiate the fire, but in the event of fire the roads and inhabitants of settlements are used for controlling the fires. In the map calculation function the value ranges from 16 to 108. After reclassifying the area under low and very low is 17% and area from moderate to very high is 83%. Further in another analysis fuel index was given weight of four and only aspect and slope was given weight of two. The reason is because the elevation variation is from 300 to 1320 m only and contrary to the fact that higher elevations are cool and fire does not spread there as fast as lower elevation but in present study area higher weight has been given to higher elevation. As in this case the higher elevation will help in spread of fire and more over only about 1.5% area is more than 1000m elevations. In the map calculation function the value ranged from 14 to 99 and 14% area is in low and very low risk area and 86% from moderate to very high fire risk areas and broadly agrees with the fire control map of the range (Figure 20 and 21 Table 15).

Figure 20. Fire Control Map
5.10. Validation of fire risk model

Validation of the model and its operation will require much more input than what was available and discussed in this study. With limited options and time it was attempted to do justice to the fire risk modelling. The model has been attempted to validate within itself using the weights assigned to different layers, and subsequently inter-validated with ground truth for the applicability and, to certain extent, integrity of model.

5.10.1. Intra-Validation

All the six layers generated for obtaining the cumulative fire risk area are important parameters. In the first instance all parameters were integrated without assigning any weight, and the output result was compared with the fire control map. The result showed a smaller area than fire risk area. Subsequently weights were assigned to the parameters that play a role in ignition and spread of fire. Different fire risk maps were generated and compared. The cumulative fire risk area, calculated by assigning a weight of four to the fuel index layer, and two to the aspect and slope layers generated a map with broad agreement with the fire risk areas.

5.10.2. Inter-Validation

The inter-validation is a more appropriate analysis in practical application of the fire risk model. For all layers sufficient ground truthing was done, and the final output fire risk map was compared with the fire control map of the area, and the area was also visited with park officials and staff. The very high risk areas falls in Amgadi block, Dogadda block, Luni block, Mundal block and...
Rawasini block of the area. The fire occurrence of the last five years in these blocks is in agreement with the result. As per the study, 2% area (338 ha) is very high fire risk. The fire occurrence in lesser area (Table 2) may be because of taking quick preventive action and controlling it in smaller area only. The moderate to very high fire risk area as per the study and giving weights to fuel, slope and aspect indexes comes to about 86% of the area. The fire control map of the area maintained shows more than 90% area having fire risk. But the map has no scale, and some areas with no fire risk are shown as fire risk areas. The result of the study is broadly in agreement with the moderate to very high fire risk areas.

In the absence of a scale map temperature, rainfall, moisture content, humidity and wind velocity of study area, an attempt has been made to use the remote sensing technology and the GIS softwares to generate the forest fire risk map of the area. It is imperative to mention here that the results may be broadly in agreement with an unscaled map maintained for administrative purposes but it is not claimed for certainty that the results of the study are accurate. More study is required in assigning the weights also. To calculate the effect of understory in fuel type index the contribution of the undergrowth i.e. herbs and shrubs up to 2 m height need to be calculated. It could not be done in the present study because of heavy rains and time constraints, and only surface fuel content was calculated. The total fuel content per unit area, which includes surface fuel content, will give better idea of assigning the weights in fuel type index.

<table>
<thead>
<tr>
<th>Fire Risk</th>
<th>Area (Ha)</th>
<th>% Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>795.24</td>
<td>4.6</td>
</tr>
<tr>
<td>Low</td>
<td>1584.72</td>
<td>9.2</td>
</tr>
<tr>
<td>Moderate</td>
<td>7910.64</td>
<td>45.8</td>
</tr>
<tr>
<td>High</td>
<td>6661.80</td>
<td>38.5</td>
</tr>
<tr>
<td>Very High</td>
<td>338.40</td>
<td>2.0</td>
</tr>
</tbody>
</table>
5.11. Conclusions with regard to objectives

Fire risk modelling using multi criteria analysis and integrating different layers resulted in developing fire risk assessment of study area. Different weights assigned as per the importance of parameters makes the model accommodative in similar geomorphological areas with necessary changes. Analysis of parameters and weights contributed in developing the model was achieved. As per the result of study the recommendations for future fire management is suggested for enhancement of existing conventional fire control measures.

5.12. Conclusions from study

- The proposed study was found useful in identifying the fire risk areas.
- The application of remote sensing data and GIS is useful in fire risk assessment in larger areas with addition of more inputs.
- The study has addressed the research questions of parameters influencing the risk of fire and their relative importance for which the inputs were available.
- The criteria used for fire risk modeling in the study affirmed that forest type is the most important factor in the modeling Dry and degraded forest contribute more in ignition of fire.
- The cumulative fire risk equation used in assigning weights to different parameters in the study makes the equation accommodative for different forest areas with topographic variations.
- The result of the study will be useful for further research on forest fire management.
6. Future Fire Management Recommendations

The concerned forest managers and researchers have acknowledged the fire risk model developed with GIS and remote sensing and parameters used in developing the model in forest fire risk assessment of the study area. Moderate to very high fire risk areas need to be given top priority in taking the timely management decision and action to prevent occurrence of fire in the area.

6.1. Recommended requirements at implementation level

6.1.1. Fire Records

At different management levels the map of the area, past fire occurrences and area with high risk of fire should be available.

6.1.2. Preventive Measures

- The entire study area is vulnerable to forest fires during summer seasons.
- All existing fire lines need to be cut and burn annually during winter. Weeds that need to be removed and burnt completely have invaded some fire lines.
- All the existing forest roads in side the area and all the compartment lines also serve as fire lines. Both sides of forest roads up to 10 m distance need to be cut and burn.
- Firewatchers must be engaged during fire season.
- Strict vigilance needs to be maintained to any kind of public entry inside park during fire season.

6.1.3. Public Awareness and Educational Programmes for Local People

- It is important to raise the level of awareness of local people regarding fauna, flora and to help in protecting the environment. Without the cooperation of the local people it would be difficult to protect the area.
- One way of enthusing the local people is to run educational programmes, through mass contacts, meetings and multimedia programmes on forest fire damages.
- The local people should be made aware about the provisions of law and punishment regarding forest fire caused intentionally. The people cooperating in extinguishing fires should be rewarded properly.
6.1.4. Quick Detection

- Fire watchtower need to be constructed in selective high elevation points and connected with wire less network and telescopes.
- All the staff including firewatchers must be equipped with Walkie-talkie sets and other logistics for fire fighting.

6.1.5. Fire Fighting

The logistics should be placed at high fire risk areas with a small fire fighting squad. This squad will be ready all the time to reach any spot in the fire-affected area during summer season and help local staff in controlling the fire. Small fires should be controlled by fire fighting squad and local staff.

6.1.6. Fire Fighting Equipments

The fire fighting squad should be equipped with the following equipments.

- At least 10 drums for water of 200 liters capacity each.
- At least 25 Knapsack sprayers
- 10 Fire-Extinguishers
- 10 Axes, 10 bill-hocks and 10 sickles
- A medium size truck for quick transporting of squad

6.2. Communications

6.2.1. Wireless network and Tele-communication:

For the effective fire management of Chilla Range a high frequency communication systems need to be improved.

6.2.2. Surface Communication:

All the existing forest roads inside Chilla Range are not in satisfactory condition. These roads need to be maintained.

6.3. Recommendation requirements at policy makers level.

- Modernization of the fire fighting system
- To develop a fire danger rating system.
- Readiness for coordination in the event of fire becoming uncontrollable as fire has no administrative boundaries.
- Adequate allotment of resources for prevention and control of fire.
- The conventional fire-fighting plan must be changed to the latest fire fighting techniques.
- There should be emphasis on capacity building through the training of modern fire fighting methods adopted in other countries.
The conflict between the department and the people dependent on forest need to be minimized by addressing their needs. The concept of Joint forest management involving the people living in the area for management can reduce the fires.

The rules and regulations of the national park should not be inhibitory to the fire management practices, e.g. selection felling of dead and dry trees, improvement in road network, introduction of fire resistance species as fire belts and controlled burning.

Establishing a forest fire research institute using the latest remote sensing and GIS techniques.

Establishing metrological stations at fire prone areas.

6.4. Further research potential

There is further scope of carrying research in forest fire modeling in continuation or independently.

After establishing the meteorological station, more parameters like wind velocity, relative humidity, rainfall data can be added in the model.

A study of correlation and regression analysis for different land features as slope, elevation, aspect, roads, settlements etc with the fire risk areas. These variables can be used independently or in combination in multiple variable regressions.

A study can be done on impact of socio-economic conditions and conflict factor with the settlers in the park, on the probability of fire occurrence.

6.5. Implementation of model

This model can be developed for other areas having topographical variations. For a flat area with no slope and elevation other parameters will have to be used.

Constant monitoring of the implementation of the model is required at every stage with updating of fuel type maps and land features.

6.6. Relations with other environmental issues

The use of fire model for wild life management and also the fuel type maps thus produced can be used for studying and showing distribution of wild life in the park and suitability of sites for different wild life. The model is a good tool for ecotourism with the information about wild life, forest types and fire risk areas.

The model will be useful in addressing the environmental issues like air pollution, water conservation, soil conservation, preserving the microclimate and living environment. The migration of the settlers in the area caused by the fire will be averted.
7. REFERENCES


Artsybashev, E.S., 1983. Forest Fire and Their Control, Oxonian, New Delhi.


Dull, W., 2002. Assistant Director of Engineering USDA Forest Service Washington, presentation slides on Satellite Earth Application Observation Applications in Wildfire Management


Management Plan of Rajaji National Park (Uttaranchal) for the period 2000-2010.


8. Appendices

8.1. Appendix 1

Table 2. Extent of fire incidence in forest areas of the country (based on the inventory conducted by the Forest Survey of India)

<table>
<thead>
<tr>
<th>State/District</th>
<th>Forest Area (ha)</th>
<th>Sample Plots (No.)</th>
<th>Extent of fire incidents (ha)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Very Heavy</td>
<td>Heavy</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>14826.71</td>
<td>2037</td>
<td>60.58</td>
<td>5.75</td>
</tr>
<tr>
<td>Assam</td>
<td>15427.88</td>
<td>2482</td>
<td>70.91</td>
<td>0</td>
</tr>
<tr>
<td>Bihar</td>
<td>5317.01</td>
<td>296</td>
<td>57.718</td>
<td>0</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>10269.40</td>
<td>4878</td>
<td>163.7</td>
<td>0</td>
</tr>
<tr>
<td>Jammu &amp; Kashmir</td>
<td>3331.75</td>
<td>428</td>
<td>7.5</td>
<td>0</td>
</tr>
<tr>
<td>Haryana &amp; Punjab</td>
<td>1180.72</td>
<td>45</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Karnataka</td>
<td>13223.30</td>
<td>1780</td>
<td>59.71</td>
<td>30.3</td>
</tr>
<tr>
<td>Manipur</td>
<td>15154.00</td>
<td>1880</td>
<td>0</td>
<td>151.54</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>19625.91</td>
<td>1947</td>
<td>136.53</td>
<td>23.0</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>8165.54</td>
<td>1355</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>9905.00</td>
<td>1659</td>
<td>26.75</td>
<td>0</td>
</tr>
<tr>
<td>Nagaland</td>
<td>14954.91</td>
<td>1128</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Orissa</td>
<td>20143.30</td>
<td>2972</td>
<td>204.42</td>
<td>78.5</td>
</tr>
</tbody>
</table>
## FIRE RISK ASSESSMENT FOR FIRE CONTROL MANAGEMENT IN CHILLA FOREST RANGE OF RAJAJI NATIONAL PARK UTTARANCHAL (INDIA)

<table>
<thead>
<tr>
<th>State</th>
<th>Area (km²)</th>
<th>Population (1000)</th>
<th>Average Daily Fire Incidents</th>
<th>Average Fire Incidents per Day</th>
<th>Number of Fires</th>
<th>Total Fire Incidents</th>
<th>Total Area (km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rajasthan</td>
<td>20178.79</td>
<td>2446</td>
<td>0</td>
<td>99.03</td>
<td>4348.12</td>
<td>14763.26</td>
<td>896.99</td>
<td>0.87</td>
</tr>
<tr>
<td>Sikkim</td>
<td>1707.77</td>
<td>401</td>
<td>0</td>
<td>18.14</td>
<td>544.84</td>
<td>1097.67</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Tripura</td>
<td>6445.36</td>
<td>555</td>
<td>0</td>
<td>361.75</td>
<td>5293.65</td>
<td>755.37</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>23164.09</td>
<td>2825</td>
<td>0</td>
<td>2092.5</td>
<td>11124.1</td>
<td>907605</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>West Bengal</td>
<td>5764.81</td>
<td>1471</td>
<td>0</td>
<td>656.43</td>
<td>1356.52</td>
<td>3444.31</td>
<td>302.76</td>
<td>0.00</td>
</tr>
<tr>
<td>Dadra &amp; Nagar</td>
<td>186.49</td>
<td>62</td>
<td>0</td>
<td>0</td>
<td>180.895</td>
<td>5.5947</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Grand Total</td>
<td>20897.35</td>
<td>307.47</td>
<td>1817.1</td>
<td>289.19</td>
<td>89998.34</td>
<td>101952.188</td>
<td>4154.07</td>
<td>0.00</td>
</tr>
<tr>
<td>Percentage</td>
<td>0.87</td>
<td>0.14</td>
<td>5.16</td>
<td>43.06</td>
<td>48.79</td>
<td>1.99</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>
8.2. Appendix 2

METEOROLOGICAL DATA

Station: New Forest, Dehradun Year-2002

Average Values for 10 years 1993 to 2002

<table>
<thead>
<tr>
<th>Month</th>
<th>Rainfall (mm)</th>
<th>Relative Humidity (Percent) 0830 hrs</th>
<th>Temperature (degree C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max.</td>
</tr>
<tr>
<td>January</td>
<td>44.7</td>
<td>87</td>
<td>19.3</td>
</tr>
<tr>
<td>February</td>
<td>62.1</td>
<td>80</td>
<td>21.7</td>
</tr>
<tr>
<td>March</td>
<td>55.5</td>
<td>67</td>
<td>26.3</td>
</tr>
<tr>
<td>April</td>
<td>39.0</td>
<td>53</td>
<td>31.7</td>
</tr>
<tr>
<td>May</td>
<td>58.3</td>
<td>52</td>
<td>35.1</td>
</tr>
<tr>
<td>June</td>
<td>227.8</td>
<td>68</td>
<td>33.8</td>
</tr>
<tr>
<td>July</td>
<td>552.5</td>
<td>85</td>
<td>30.7</td>
</tr>
<tr>
<td>August</td>
<td>612.7</td>
<td>87</td>
<td>30.0</td>
</tr>
<tr>
<td>September</td>
<td>257.1</td>
<td>81</td>
<td>29.9</td>
</tr>
<tr>
<td>October</td>
<td>43.6</td>
<td>75</td>
<td>28.8</td>
</tr>
<tr>
<td>November</td>
<td>3.8</td>
<td>80</td>
<td>25.6</td>
</tr>
<tr>
<td>December</td>
<td>10.7</td>
<td>87</td>
<td>21.9</td>
</tr>
<tr>
<td></td>
<td>1967.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8.3. **Monthly Average Data**

Station: New Forest, Dehradun

Year-2002

<table>
<thead>
<tr>
<th>Month</th>
<th>Average daily temperature (deg. C)</th>
<th>Average Relative Humidity (Percent)</th>
<th>Average vapour Pressure (mm of Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max.</td>
<td>Min.</td>
<td>Mean</td>
</tr>
<tr>
<td>January</td>
<td>19.7</td>
<td>4.1</td>
<td>11.4</td>
</tr>
<tr>
<td>February</td>
<td>21.9</td>
<td>6.4</td>
<td>13.9</td>
</tr>
<tr>
<td>March</td>
<td>27.0</td>
<td>10.8</td>
<td>18.9</td>
</tr>
<tr>
<td>April</td>
<td>32.7</td>
<td>14.4</td>
<td>23.5</td>
</tr>
<tr>
<td>May</td>
<td>35.3</td>
<td>18.9</td>
<td>26.4</td>
</tr>
<tr>
<td>June</td>
<td>33.8</td>
<td>21.1</td>
<td>26.7</td>
</tr>
<tr>
<td>July</td>
<td>32.8</td>
<td>22.7</td>
<td>27.1</td>
</tr>
<tr>
<td>August</td>
<td>30.3</td>
<td>22.7</td>
<td>25.8</td>
</tr>
<tr>
<td>September</td>
<td>29.2</td>
<td>18.4</td>
<td>23.2</td>
</tr>
<tr>
<td>October</td>
<td>29.2</td>
<td>13.3</td>
<td>20.8</td>
</tr>
<tr>
<td>November</td>
<td>25.8</td>
<td>8.1</td>
<td>16.5</td>
</tr>
<tr>
<td>December</td>
<td>22.8</td>
<td>4.8</td>
<td>13.1</td>
</tr>
</tbody>
</table>
### 8.4. Monthly Average Data

**Station:** New Forest, Dehradun  
**Year:** 2002

<table>
<thead>
<tr>
<th>Month</th>
<th>Average daily temperature (deg. C)</th>
<th>Average Relative Humidity (Percent)</th>
<th>Average vapour Pressure (mm of Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max.</td>
<td>Min.</td>
<td>Mean</td>
</tr>
<tr>
<td>January</td>
<td>19.7</td>
<td>4.1</td>
<td>11.4</td>
</tr>
<tr>
<td>February</td>
<td>21.9</td>
<td>6.4</td>
<td>13.9</td>
</tr>
<tr>
<td>March</td>
<td>27.0</td>
<td>10.8</td>
<td>18.9</td>
</tr>
<tr>
<td>April</td>
<td>32.7</td>
<td>14.4</td>
<td>23.5</td>
</tr>
<tr>
<td>May</td>
<td>35.3</td>
<td>18.9</td>
<td>26.4</td>
</tr>
<tr>
<td>June</td>
<td>33.8</td>
<td>21.1</td>
<td>26.7</td>
</tr>
<tr>
<td>July</td>
<td>32.8</td>
<td>22.7</td>
<td>27.1</td>
</tr>
<tr>
<td>August</td>
<td>30.3</td>
<td>22.7</td>
<td>25.8</td>
</tr>
<tr>
<td>September</td>
<td>29.2</td>
<td>18.4</td>
<td>23.2</td>
</tr>
<tr>
<td>October</td>
<td>29.2</td>
<td>13.3</td>
<td>20.8</td>
</tr>
<tr>
<td>November</td>
<td>25.8</td>
<td>8.1</td>
<td>16.5</td>
</tr>
<tr>
<td>December</td>
<td>22.8</td>
<td>4.8</td>
<td>13.1</td>
</tr>
</tbody>
</table>
8.5. Monthly Average Data

Station: New Forest, Dehradun      Year-2002

<table>
<thead>
<tr>
<th>Month</th>
<th>No. of Rainy days</th>
<th>Total Rainfall (mm)</th>
<th>Bright Sunshine (hrs)</th>
<th>Average wind Velocity (Km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4</td>
<td>34.8</td>
<td>6.7</td>
<td>1.4</td>
</tr>
<tr>
<td>February</td>
<td>6</td>
<td>110.9</td>
<td>6.7</td>
<td>1.9</td>
</tr>
<tr>
<td>March</td>
<td>2</td>
<td>63.1</td>
<td>8.6</td>
<td>2.0</td>
</tr>
<tr>
<td>April</td>
<td>3</td>
<td>65.6</td>
<td>9.0</td>
<td>2.0</td>
</tr>
<tr>
<td>May</td>
<td>4</td>
<td>28.7</td>
<td>9.7</td>
<td>2.1</td>
</tr>
<tr>
<td>June</td>
<td>12</td>
<td>134.2</td>
<td>7.8</td>
<td>2.0</td>
</tr>
<tr>
<td>July</td>
<td>8</td>
<td>121.5</td>
<td>6.3</td>
<td>2.1</td>
</tr>
<tr>
<td>August</td>
<td>18</td>
<td>483.3</td>
<td>3.1</td>
<td>1.5</td>
</tr>
<tr>
<td>September</td>
<td>11</td>
<td>275.9</td>
<td>6.7</td>
<td>1.5</td>
</tr>
<tr>
<td>October</td>
<td>5</td>
<td>54.9</td>
<td>9.1</td>
<td>1.3</td>
</tr>
<tr>
<td>November</td>
<td>0</td>
<td>0.0</td>
<td>8.3</td>
<td>1.0</td>
</tr>
<tr>
<td>December</td>
<td>0</td>
<td>0.3</td>
<td>7.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
<td>1373.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>