Forest Fire Risk Zonation,
A case study
Pauri Garhwal, Uttarakhand,
INDIA

Pravesh Saklani
January, 2008

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by

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Thesis Assessment Board

Chairman : Dr. Cees Van Westen
External Expert : Shri Sandeep Tripathi
IIRS Examiner : Dr S.P.S Kushwaha
IIRS Examiner : Dr. M.C. Porwal

Supervisors

ITC : Prof. Yousif Ali Hussin
IIRS : Dr. M.C. Porwal

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DEHRADUN, INDIA

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

Abstract

Forest fire has been regarded as one of the major reasons for the loss of biodiversity and degradation of environment. Global warming is increasing its intensity at an alarming rate. Thus one needs to understand the complex biophysical parameters, which are responsible for this disaster.

As it is difficult to predict forest fire, fire risk zone map can be useful for combating the forest fire. Thus the main aim of this study is to generate a Fire risk zone map using Remote Sensing & GIS technique. Remote Sensing data and Toposheet has been used for creating various base layers and further risk zone maps using GIS technique. In modelling technique various parameters e.g. road, village, river, vegetation density, aspect, slope and elevation (DEM) etc are taken into account. In the non-spatial software "Definite" weights are assigned to various parameters according to their importance to fire hazards so that more reliable fire risk zone map can be generated.

The result of this work is the generation of three final maps through three sub-models. The final fire risk zone map has been generated by combining these three maps viz. fuel risk zone map, fire detection map, and fire response risk map by assigning appropriate weights to each maps.

Key Words: Fire risk zone map, Fuel risk sub-model, Fire detection risk sub-model, Fire response risk sub-model.

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1. INTRODUCTION

Fire has been closely associated with mankind from the beginnings of civilization. Discovery of fire and its uses have directly or indirectly permitted man to live and survive to the temperate zone.
Forests are a major natural resource, which play crucial role in maintaining environmental balance. The health of forest in any given area is a true indicator of the ecological condition prevailing in that area. Frequent occurrence of forest fires has been one of the major reasons for the depletion and extinction of most of our valuable plant and animal species. Even human beings are adversely affected either directly or indirectly by the havocs of these killer fires. Thus forest fires are considered to be a potential hazard with physical, biological, ecological & environmental consequences. Forest fire results in partial or complete degradation of vegetation cover thus modifying the radiation balance by increasing the surface albedo, water runoff and raising the soil erosion (Darmawan and Mulyanto, 2001).

1.1. Categories of Forest Fires

The fire in most accepted manner can be defined as that it is uncontained and freely spreading combustion which consumes the natural fuels of a forest i.e. duff, litter, grass, dead branch, wood, snags, logs, stumps, weeds, brush, foliage and to some extent green trees. (Brown and Davis, 1959). Basically forest fires have been categorized in to three categories.
Ground fires: A true Ground fires is not easily predictable as it spreads within rather than top of organic matter. It consumes organic matter like duff, musk or peat present beneath the surface litter of the forest floor. It has unique characteristic of having a smouldering edge with no flame and little smoke. Ground fires are most hard to handle and there should be proper policy and practices for control agencies.
Surface fire: Surface fire is characterized by a fast moving fire, which consumes small vegetation and surface litter along with loose debris.
Crown Fire: Crown fires advances from top to top of trees or shrubs without any close link with surface fire. It is fastest to spread and most destructive for trees and wildlife.

1.2. Important Definitions

The forest fire management is associated with various terms like ‘Risk’, ‘hazard’ ‘danger’ ‘vulnerability’ ‘severity’ etc., if we really want to understand forest fire terminology then these technical terms should be explained properly (Srivastava, 2005).
Fire Hazard: Fire hazard is physical event of certain magnitude in a given area and at a given time, which has the potential to disrupt the functionality of a society, its economy & its environment (Boonchut, 2005).
Fire vulnerability: Fire vulnerability is the degree of loss to biotic and abiotic elements of the environment to a given magnitude of fire hazard. It is expressed in a scale between ‘0’ (no damage) to ‘1’ (total damage.) (Castillo, 2004).

1. As per definition of United Nations ISDR (2002), Vulnerability is a set of conditions and processes resulting from physical, social, economical and environmental factor, which increase susceptibility of community to the impact of hazards.
2. **Amount:** It simply termed as the quantity of elements at risk. e.g. number of peoples, number of trees, number of animals etc.
3. **Capacity:** Capacity is defined as the skills and operational resources to cope up with the fire risk factors so that the damage can be reduced or Capacity is defined as the ability, strength and skills of various elements at risk to use the available resources to cope with the fire risk.
4. **Fire Risk:** Fire risk is expected losses due to fire hazard to various elements at risk over specific time. Thus it is measured in terms of expected loss e.g. economic loss, number of lives loss and extent of physical damage.
   Mathematically fire risk expressed as
   Risk =Hazard * Vulnerability * Amount
   Risk= Hazard*[Vulnerability / Capacity]
5. **Fire Severity:** Fire severity refers to the magnitude of significant negative impact on wildland systems (Simard, 1991).

1.3. Advantages of natural fires

Fire is a natural phenomenon which takes place in forest ecosystem to reduce accumulated fuel. Thus natural fires play crucial role in the maintenance and self balance of the forest ecosystem. If these natural fires are intentionally suppressed it may cause a wild fire in near future. Plants & animals are naturally adapted to natural fire. Thus if the forest fire is natural it plays very crucial role in maintaining the balance of self sustained ecosystem and thus maintaining life on earth.

1.4. Effects of fire

Fire is a vital and natural part of the functioning of numerous forest ecosystems. Human have used fire for thousands of years as a land management tool. Fire is one of the natural forces that have influenced plant communities over the time and as a natural process, it serves an important function in maintaining the health of certain ecosystems. However in the latter part of the twentieth century, changes in the human fire dynamics & an increase in El Nino frequency have led to a situation where fires are now a major threat to many Forests and the biodiversity therein. Tropical rain forests & cloud forests, which typically do not burn on a large scale, were devastated by wildfires during the 1980s & 1990s (FAO, 2001).

Effects of fire should be understood properly in terms of economic loss. We can formulate good public and private forest policy & forest practices for forest management. Apart from physical removal of material from the forest as in logging, fire is the only means of quickly removing large quantities of woody and other vegetative materials. Fire has heat effects which destroys vegetation and kills animals' life. The residual chemical effect are also deleterious for the soil.(Brown and Davis 1959)

1.5. Short term effects

In short term, effects of forest fire consumes vegetation, woody debris and soil organic matter. It also heats soil and water streams. It kills animals which unable to escape due to excessive heat. It also increases air pollution in effected areas due to burning of carbon materials. It affects the daily earners who are dependent on various forest products for their livelihood.

1.5.1. Long term effects

Soil productivity is greatly effected which changes the forest structure & due to which future vegetation development will be effected, and it may induce soil erosion. It will adversely effect abundance, density and distribution of creatures right from microbes to mega fauna. Fire serves an important function in maintaining the health of certain ecosystems, but as a result of changes in climate and in human use and misuse of fire, fires have become a threat to many forests and their biodiversity (Dennis, Meijaard et al. 2001).

1.5.2. Effects of fire on Ecosystem

Forest fires effects globally because it emits lots of carbon leading to global warming & consequently it will lead to biodiversity changes. At regional and local level, biomass stock & hydrological cycle are adversely effected leading to deleterious effects on coral reefs and functioning of plants and animals species are also effected.

Due to increased percentage of smoke in environment, photosynthetic activity is reduced, and thus health of human beings and animals is also effected.

The trees which fall due to forest fires become fuel for coming years & thus the frequency of forest fire increases and it may lead to growth of fire prone species in large quantity. e.g. Phyrophytic grasses. Fire can be followed by insect colonization and infection which disturbs the ecological balance.

The replacement of vast areas of forest with Pyrophytic grasslands is one of the must negative ecological impacts of fire, in tropical rain forests. These processes have already been observed in parts of Indonesia and Amazornia.(Turvey, 1994)

1.5.3. Effects of forest fires on plant diversity

Severe fires have had a significant negative impact on plant diversity. Agricultural clearing is one of the major causes of fire in Tropical forests. In forest where human activities are in excess, the deforestation fires sometimes leads to complete burning of the forest leading the bare soil. Those forests which are not adapted to fire, fire can kill virtually all seedlings sprouts, lianas and young trees, because they are not protected by thick bark. Damage to seed bank, seedlings, & saplings, hinders the recovery of original species.(Woods, 1989).

1.5.4. Adaptations of plants to forest fire

In tropical forest where the fire occurs in almost every dry season, the tree species have adaptation like thick bark, ability to heal scars faster, resprouting of plants from roots or stems. e.g. Mountain ash *(Eucalyptus regrans)* Agee 1993. Many plant species have adaptations to protect their seeds in a cone during forest fires and dispersing them after fire period. e.g. Jack pine *(Pinus banksiana)* and Lodgepole pine *(Pinus contorta).* The ecological importance of forest fire is that it strongly promotes fire tolerant species. Many pine species in North America have thick bark, greater crown base and height for survival against several fires.

1.5.5. Effects of fire on forest fauna

Forest fires very adversely effects animals not only by killing them but also by long term effects such as stress, habitat loss, territories, shelter & food.

The loss of key organisms in forest ecosystem, such as invertebrates, pollinators and decomposers will slow the recovery rate of forest.(Boer, 1989.)

Territorial, habitat & shelter loss: Due to destruction of dead logs & many standing cavities in trees which are the home for many small mammal species such as bats, lemur and cavity nesting birds are effected. Thus many birds and mammals are displaced resulting in loss of wildlife and consequently disturbance of biodiversity.

Loss of food: Due to loss of fruit trees, many animals and birds species are declined as they are dependent for their food on these trees. For example fruit eating birds such as Hornbill has declined dramatically in tropical forests due to forest fire. Population of some small carnivores has declined due to running away of small mammals such as rodents which are food for these carnivores. Arthropods community which are food source for omnivores & carnivores are also destroyed with leaf litter in fire.(Kinnarid and O'Brien, 1998)

1.5.6. Adaptations of animals to forest fire

Grass layer beetle species of Australia's savannas are resistant to fire.(Orgeas and Andersen, 2001)

Fire has been beneficial for moose population. In United States moose and deer although fire resistant species are adversely effected by fire because plant species which are food sources for these animals are fire sensitive. And thus it will effect those animals depending on moose & deer e.g. Gray wolf *(Canis lupus)*

1.6. Research Problem

Apart from other natural hazards like landslides and earthquakes, forest fire is one of the major disasters in the forests of Pauri Garhwal. There are many indigenous and endangered species in the forests of Pauri Garhwal, which are adversely effected due to these forest fires. As per the forest fire statistics, it is clear that the study area is prone to forest fires. The forest fire affects the environment and biodiversity. There are many endangered and indigenous species, which are under a threat due to fire occurrence in the forests. So far, not much work has been done by the administration for identifying the vulnerability zones for various endangered species. Therefore, there is an immediate need to identify the fire risk zone. Hence this study, deals with fire risk zonation of Pauri Garhwal, which is famous for its biodiversity.

1.7. Research Motivation

Forests are valuable wealth of our earth. They play vital role in sustaining life and other processes related with living organisms. They maintain healthy environment and provides ample resources for human development. All living beings directly or indirectly depend on forests.

But forest fires or wild fires are greatest enemy of these mute resources. Forest fires damage much of our forest biomass and cause havoc for various plants and animals by putting them in endangered category or at the verge of extinction. Forest fires whether man made or natural are continuously depleting our enormous biodiversity. As a science student and nature lover, I have been inspired by these killer fires to work something for our forests especially in my study area which is also present in my home state. Pauri Garhwal is very prone to forest fires and much of forest resources and human wealth have been destroyed in it.

1.8. Research objectives

- To detect the recent burnt areas with the help of Remote Sensing data.
- To determine the relationship between the burnt forest areas and different biophysical factors such as slope, aspect, slope, forest type, trees species, forest density, distance to road, distance to villages, distance to rivers, or any other surface water, etc.
- To develop a fire risk zone map using various parameters like fuel type, forest density, distance to roads, distance to villages, distance to rivers or any other surface water, topographic (slope, aspect and elevation).

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1.9. Research Questions

- Can we detect and map recent burnt area using remotely sensed data?
- Are the recent of historical burnt forests area related to any of the biophysical factors (slope, aspect, elevation, forest type, trees species, forest density, distance to roads, distance to villages, and distance to rivers or any other surface water, etc.)?
- Can a fire hazard spatial model be developed using the above analyzed factors? What is the spatial distribution of the areas prone for fire?

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2. LITERATURE REVIEW

Technically, fire is defined as the rapid combustion of fuel, heat and oxygen. All these three elements are in some proportion to start and spread fire. It is a chemical reaction of any substance that will ignite and burn to release a lot of energy in the form of heat and light (Rawat, 2003). To start a fire an external source of heat is required along with a oxygen. Heat is measured in terms of temperature. Fuel is any material capable of burning. In forests, fuels are vegetation, branches, needles, standing dead trees, leaves, and man-made flammable structures (Anon, 1999).

2.1. Causes of forest fires

Basically causes of forest fire have been classified into three main categories

1. Natural

These are the fires which can not be averted as these occurs naturally due to lightening, rolling of stones & rubbing of dry bamboos due to strong wind.

2. Intentional/ Deliberate

Mainly intentional fires are created for the better growth of fodder grass. These fires are also been set by villagers to drive away the herbivores animals which destroy their crops. Sometimes villages get annoyed with forest Department and deliberately set fire without knowing its consequences**.** Villagers also set fire for collecting forest products like honey, gum, Mahua flowers etc. Railway transport also causes forest fires occasionally. Forest Department people can’t do much if the fire is caused deliberately by local dwellers.

3. Unintentional/ Accidental

Unintentional/ Accidental fires are result of carelessness of human beings such as throwing of burning match stick or cigarette/ bidis. Other fires which occur accidentally are the spread of fire from labour camps, from picnic sites and other recreational areas due to human activities.

These types of fires are controlled by certain parameters like its proximity to settlements and distances from roads.

Although it is not easy to account natural or deliberate fires but the areas prone to fires can be detected and mapped.

2.2. Parameters responsible for forests fire

Three factors are required for any fire to take place: These are availability of air, fuel and heat. All these three factors depend on many factors. Forest fire does not depend on any single factor instead its behaviour, intensity and spread depends on various integrated factors.

1. **Vegetation type / density:** Dense and dry vegetation are more susceptible to fire in comparison to moist and sparse one. Moisture content of vegetation delays ignition.

2. **Climatic factors: C**limate plays the dominant role in ascertaining the fire prone areas as they are the main determining factor of vegetation of a given region. Thus drier the climate the more prone is the site for fire.
3. **Physiographic Factors:** Physiographic factors include altitude, aspect and topography of a region. These are the factors, which are mainly responsible for variation in climatic conditions. Thus they indirectly affect the vegetation. Aspect plays one of the major roles in the spread of fire like southern slops which are more or less directly exposed to sun rays are more vulnerable to fire.
4. **Topography:** Topography influence the wind of a particular region like fire travels more rapidly in up slopes.
5. **Edaphic factors:** Soil plays a vital role in the growth, development & anchoring of the vegetation. And vegetation after decay adds to the fertility of the soil.
6. **Distance to Roads:** Any physical activity by man, animal or vehicle on the road can cause an unwanted fire. Thus proximity to the road plays vital role in chance of fire.
7. **Vicinity to Settlements:** In settlement lots of human activities can cause fire in the vicinity of settlement, which can spread a forest fire & cause a lot of havoc.
8. **Main causes of forest fire in Indian content:** Following area the main cause of fire:

    a) Those people who are involved in cutting & stealing of wood and illegal activities in forests sometimes deliberately create fire to drive away the attention of forest department.

    b) Some times Forest Department peoples themselves set fire to clear the blockades of inspection path.

    c) To collect non-wood forest products from interior of the forest villagers use to deliberately set fires.

    d) For getting fresh grass in the next season people sometime create fire deliberately in the fringes of forest area.

    e) Pilgrims who often lights in the temples is also considered reason for the unintentional fires.

2.3. Forest Statistics in Uttrakhand

According to the forest statistics of Uttaranchal for 2005-2006, 67% of total land cover of Uttarakhand is covered with forests. Reference for this statement .Forest area has been classified according to the legal status defined by the government. Figure 2-1 shows the majority of the forest area is reserved (46.07 %).

Figure 2-2 indicates that major forest area is under forest department and 15.73% is under forest panchayat had only small area is under private agencies that means protection and manage of forest is mainly under government. Chir pine is the dominating species in Uttarakhand as shown in the figure 2-3.Pauri Garhwal is the third largest district with forest cover after Uttarkashi and Tehri (figure 2-4). Figure 2-5 clearly shows that Uttarakhand is most adversely affected during the year 1995. But no major fire incidence has been seen after 1998 as most of the fire has been controlled in time. But it is also very evident that forest fires have sprouted time and again due to various reasons. This graph indicates that fire incidences have decreased during the last few years due to government initiatives.Figure 2-6 shows the loss due to forest fires in terms of money. There has been constant

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loss of money and forest wealth. The year 1999 saw a steep rise in expenditure and loss to forest flora and fauna due to forest fires this furthermore emphasized the need to tackle and prevent forest fires.

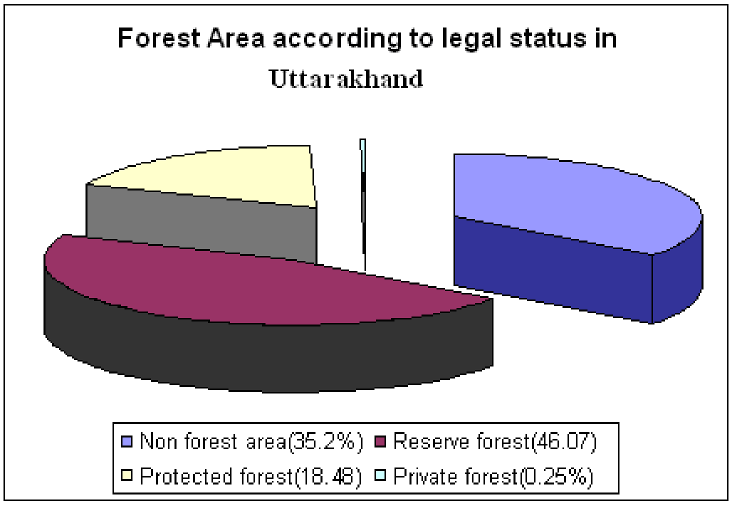

Figure 2-1: Forest Area according to legal status in Uttarakhand (Source: Uttranchal forest statistics 2005-2006. (Forest department Uttarakhand).

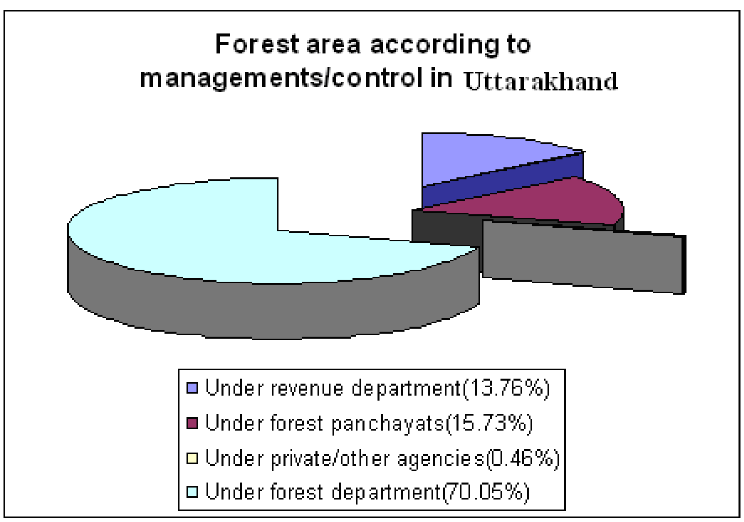

Figure 2-2: Forest area according to managements/control in Uttarakhand (Source: Uttranchal forest statistics 2005-2006. (Forest department Uttarakhand)).

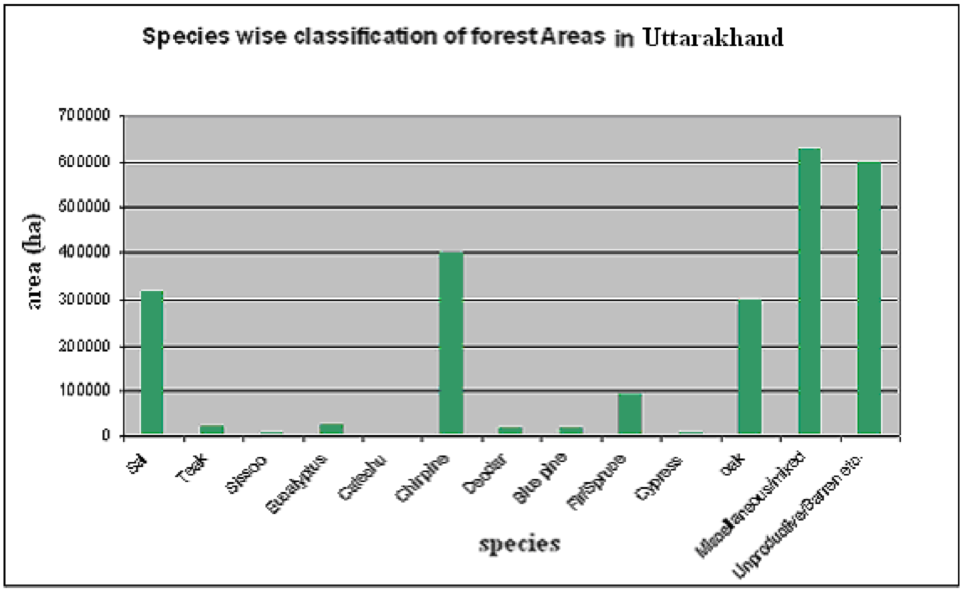

Figure 2-3: Species wise classification of forest Areas in Uttarakhand (Source: Uttaranchal Forest Statistics 2005-2006. (Forest Department Uttarakhand)).

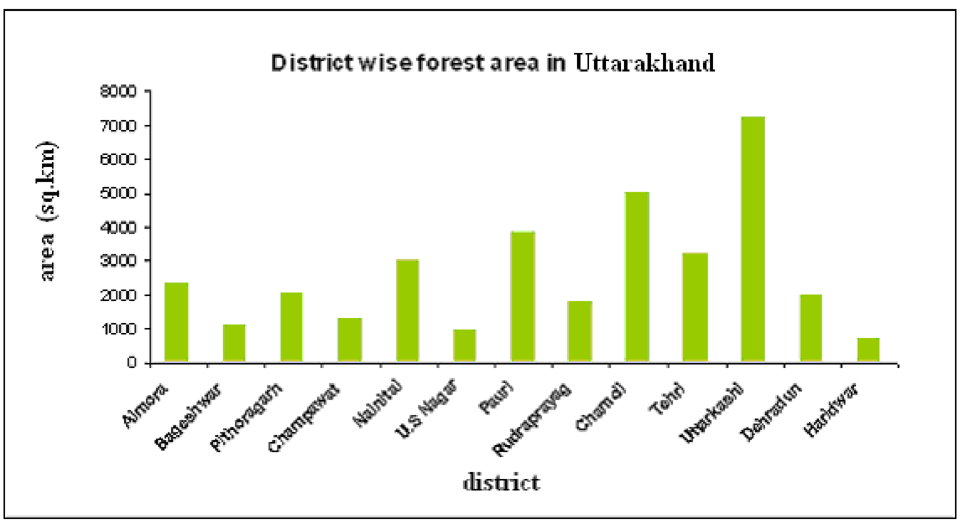

Figure 2-4: District wise forest area in Uttarakhand (Source: Uttranchal forest statistics 2005-2006. (Forest department Uttarakhand)).

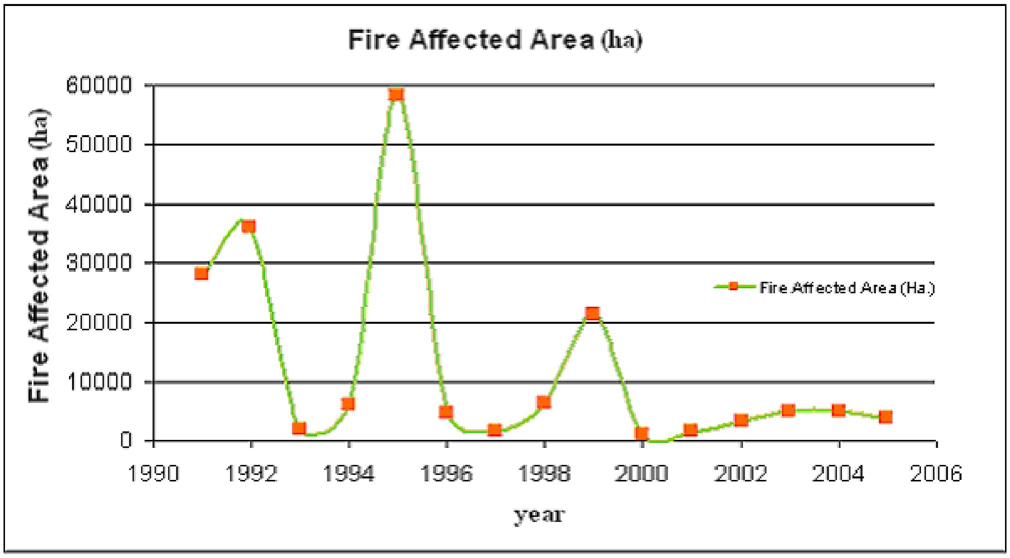

Figure 2-5: Forest fires in Uttarakhand (1996-2005) (Source: uttranchal forest statistics 2005-2006. (Forest department Uttarakhand)).

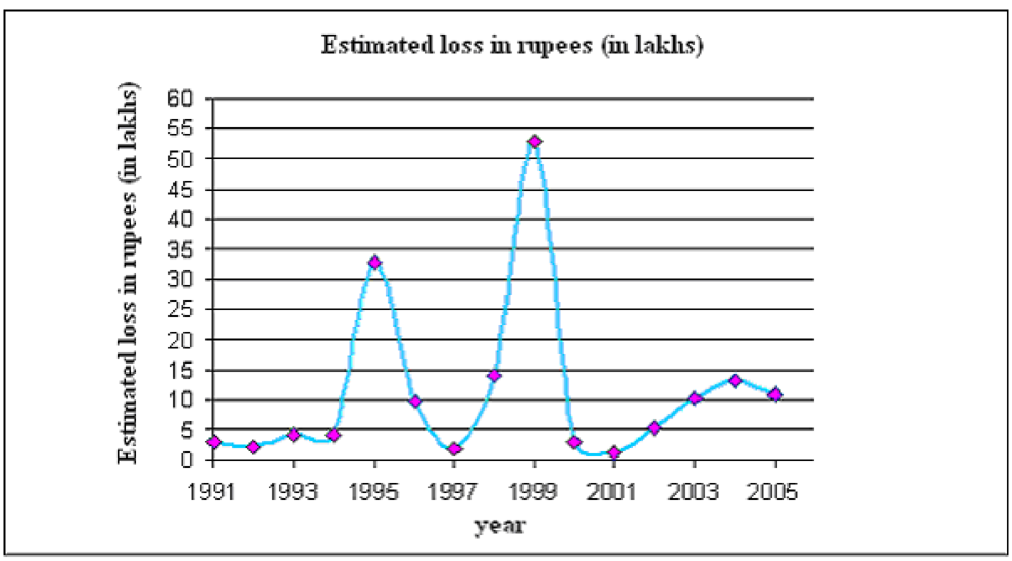

Figure 2-6: Estimated loss in rupees (in Lakhs) (Source: uttranchal forest statistics 2005-2006. (Forest department Uttarakhand)).

2.4. Fire Models

GIS is a system that is capable for collecting, storing, analysing, and disseminating information about areas of the earth (Lillesand and Kiefer, 1974). In short, it is a computer based system that can deal with virtually any type of information about features that can be referenced by geographical location. One of the most important benefits of a GIS is the ability to spatially interrelate multiple types of information, stemming from a range of sources, in a meaningful and efficient way.

Models are the simple representations of the complex real world i.e. models are the approximation of the real world. The complex processes of the living earth are not easy to understand but we can model them in a simple understandable manner. Models are very useful for understanding various processes in real world and thus predicting the future events on the basis of our understanding. This will help us in planning the future action of plan and thus preventing, reducing or controlling the negative event and enhancing positive events i.e. to maintain the balance of the whole life processes in this living earth. Forest fire models are developed and used to understand the different characteristics of forest and other parameters to predict the behaviour and spread of forest fire. Building a model is an art, and cannot be automated. It requires a lot of skill such as knowing the laws of physics, economics, sound sense and experience. Building of model starts with defining the goal of model which includes scope of the model, input parameters, which parameters are taken into account, and which physical models will be ignored and which input parameters are needed. For spatial processes modelling, use of GIS is very useful.

Pattern of forest fire spread are modeled using fine scale mechanistic or broad scale probabilistic approach (McCormick et al., 2002). Former looks at the small scale constraints (e.g. percentage of moisture in fuel) that enable the fire to keep burning whereas in the latter, fire spread is determined by the size and connectedness of fuel patches distributed across the fire landscape. Innumerable forest fire spread models exist for taking decision towards fire management using the spatiotemporal database system. Current models do not account for the causative factors of forest fire occurrence. Forest fire research can be considered as one of the most appropriate areas, where Geographic Information System (GIS) approach can be effectively applied. GIS can take definite advantage of the computer's capability in processing, storage and retrieval of immense data. The use of the GIS approach facilitates in integrating several variables in order to establish and focus on the problem. At the same time, it makes it possible to update or retrieve spatial information in different ways included in the database, to develop various models. It has been stated that when it comes to spatial decision aid, the analytical capability of the GIS has to be enhanced in respect of semi-structured problems involving subjective judgments (Beedasyl et al., 1999). This can be strengthened by any GIS application, which is most appropriate for that site specific condition.

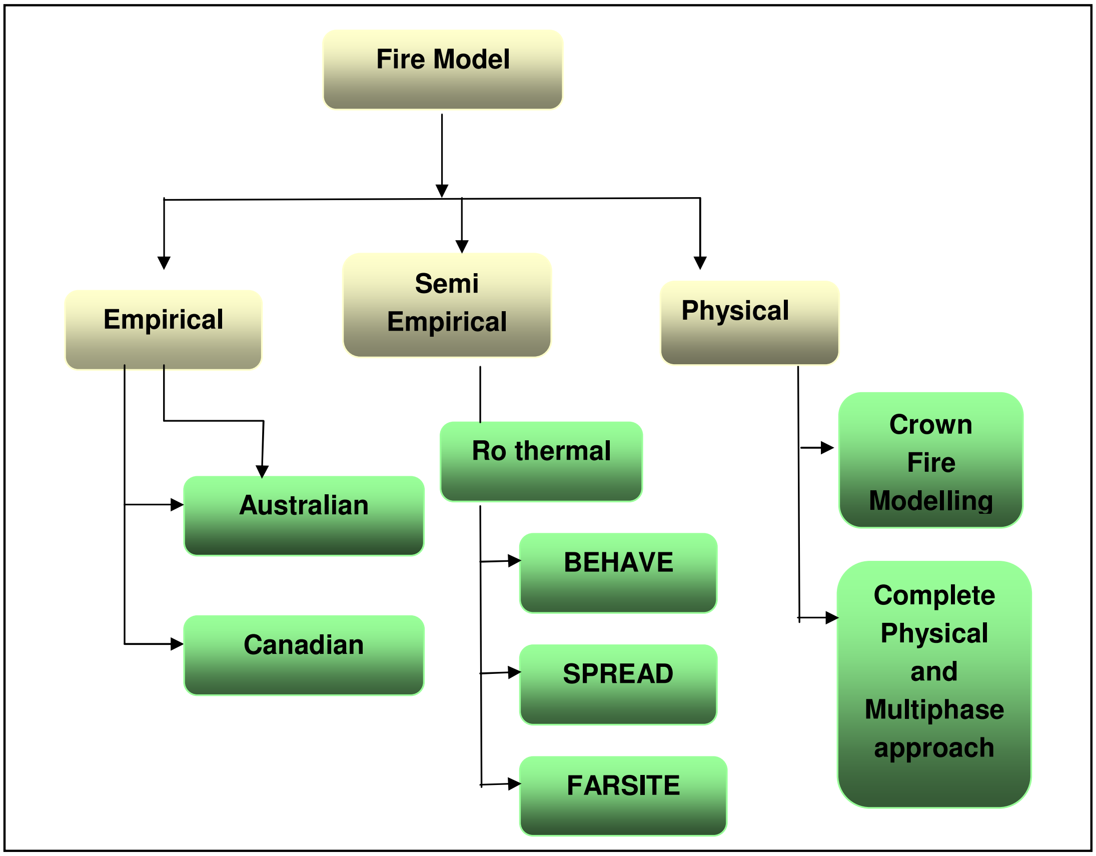

Figure 2-7: Flow chart showing types of fire models

(1) **Empirical Models:** Totally based on statistics. Also known as stochastic models.
(2) **Semi empirical Models:** These models are based on the conservation of energy i.e. the energy transfer to the unburned fuel is proportional to the energy released by the combination of the fuel.
(3) **Physical Models:** These are the most reliable models, but to develop such models one requires a good knowledge and understanding of the physical relations sufficient to achieve the desired objectives.

Basically forest fire models are classified into four main groups**:**

(1) Fire Risk Models: For pre-fire planning, it combines various parameters including weather, vegetation, and topography. The final map thus produced is quantitatively divided into different zones. These types of models are termed as Deterministic Models. On the other hand, statistical models use fire danger indices, estimated form regression models, **e.g.** generalized linear models to estimate probabilities of fire occurrence under various environmental conditions.

(2) Fire Behaviour Models (Fire Suppression): These model types are developed and used to characterize the propagation and spread of fires under different environmental conditions.

Fire spread models are classified into three classes**:**

- Physical(Albini[1](The oretical or analytical)
- Empirical [Rothermal[19](statistical)
- Statistical[Mc Master[14]]

The one-dimensional models has been used to model fire growth in two dimension using various approaches such as dividing the forest bed into various cells with different probability of burning depending on the conditions of the cell and other surrounding cells. (Beer and Enting, 1990.)

(3) Fire Effect Models: These have been defined to predicate the effect of forest fire in different components of eco-system.

(4) Expert system Models: These models have been developed to imitate the actual fire event. The purpose is to provide the management tools for initial strategies, and evaluate the capabilities of fire protection organization. It combines stochastic components with deterministic components and expert opinions.(Fried and Gilless 1988.)

3. STUDY AREA

Garhwal Himalayan region has its own rich & diverse historical traditions & religious important because of its geographical location, cultural heritage & social background. People of Garhwal Himalayas are hard working and laborious. As the urban area of Pauri Garhwal situated near pilgrimage route it gives opportunity to the people of Pauri Garhwal to intermix with the visitors from the different parts of the country. The main characteristic of typical garhwali is short, stout, hard working and honest. They are simple, shy and closest to the nature. The society is mixed one, includes Brahmins, Rajputs, Harijans (Scheduled Castes) and Janjats (Scheduled Tribes). Each caste has been sub-divided into sub groups & sub castes. Although intercaste marriages are not popular but exceptions are accepted. Agriculture & animal husbandry are the main source of their livelihood.

The land of Pauri Garhwal is blessed with spectacular view of snow clad ranges of Himalayas, charming valleys and surrounding meandering river, dense forests & hospitable people with a rich culture.

3.1. Location

The study area lies in the district Pauri Garhwal, Uttarakhand in India. It lies between 23^{o}45’ to 30^{o}15’ latitude and 78^{o}24’ to 79^{o}28’ longitude. Its area is about 5230 sq.km. The other districts which surround Pauri Garhwal are Chamoli, Rudraprayag and Tehri Garhwal in North, Bijnor and Udham Singh Nagar in South, Almora & Nainital in East, and Dehradun & Haridwar in West.

Administratively Pauri Garhwal is divided into 9 Tehsils viz, Pauri, Lansdowne, Kotdwar, Dhumakot, Srinagar, Satpuli, Dhumalkot and Yamkeshwar and 15 developmental blocks viz, Kot, Kalijikhal, Pauri, Pabo, Thalisan, Brinokhal, Dwarikhal, Dugadda, Jaihrikhal, Ekshwer, Rikhnikhal, Yamkeshwar, Nanidanda, Pokhra and Khirsu.

Pauri Garhwal’s headquarter is situated in Pauri which is located at the height of 1650m and has a population of 24,743. It is situated among the deodar forests and on the northern slopes of the ridge and provides one of the ice clad mountain chain.

The main rivers of this district are Alakananda, Nayyar. Nayyar River is major tributes of Alaknanda. At the Eastern & Western Nayyar confluence to give rise major Nayyar River.

High Ranges in the Nayyar Catchments include Thallisian (Dudatoli – Chakisain ridge) Baijro (Pokhra – Demdeval ridge), Khirsu – Mandakhal (Pauri – Adwani – Kanskhet ridge) Bironkhal (Landsdowne – Gumkhal – Dwarikhal ridge) & Rathwadhab (Dugadda – Kandi ridge) The extensive forests of Pauri Garhwal provides base for many industries, local fuel needs, fodder resources and ecological balance. Due to variations in altitude, climate, rock & soil etc., different forest types occur in this area. The statistics of year 1999-2000 shows that total forest area of district is 443977 hectares, which amount to 59% of total district land cover. The land which comes under forest dept. is 366212 hectares.

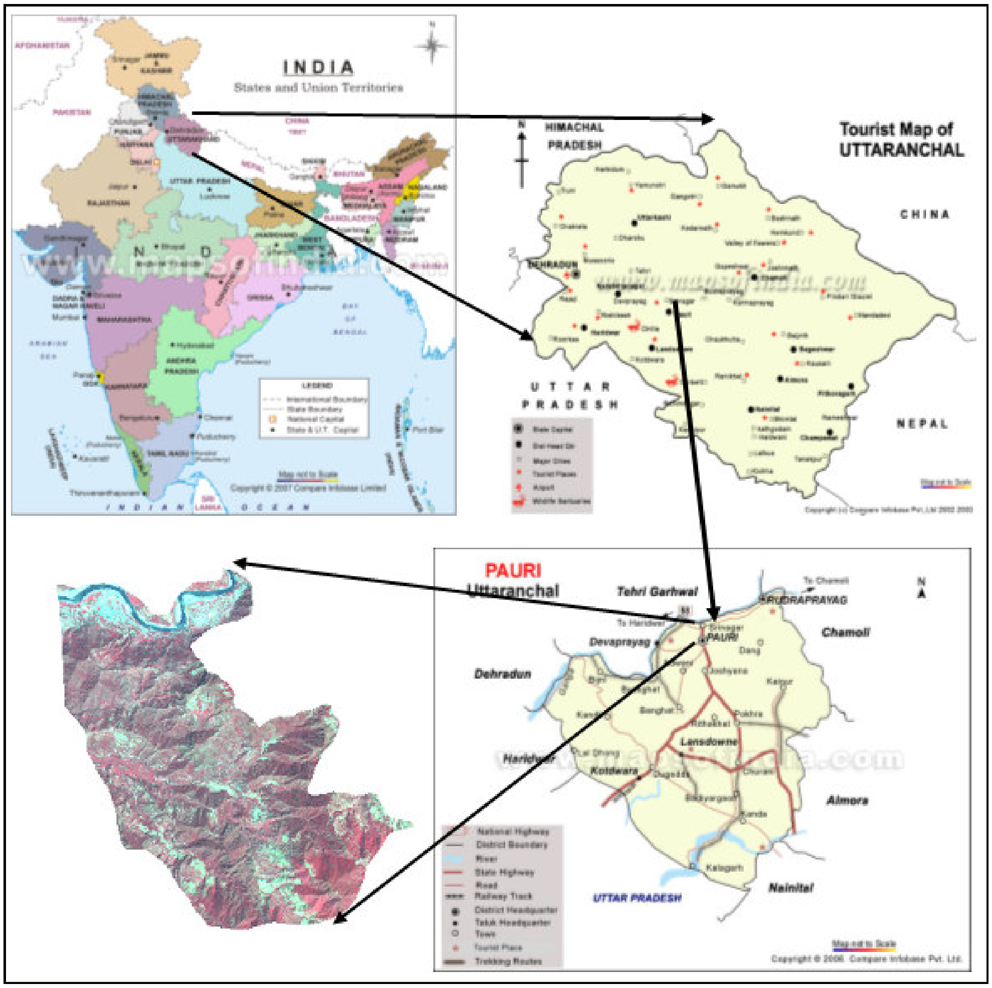

Figure 3-1: Location map of study area (source: www.mapsofindia.com)

3.2. Climate

Pauri Garhwal is known for its pleasant climate. It has a Sub-temperate to temperate climate. The maximum temperature recorded at Kotdwar in the month of June which is 45°C and while in Dudhatoli temperature rises only to 25°C. The maximum temperature recorded in the month of January is about 1.3°C. The mean monthly temperature for the region ranges from 25°C to 30°C (Appendix-1)

Its hilly terrain and dense forest slopes receives adequate rainfall during mid June till mid September. In winter occasional rain fall also takes place. 90 percent of rainfall occurs during monsoon. The average rainfall in the district is 218 cm. Relative humidity varies between 54 to 63 percent. In winter temperature falls to freezing point and higher mountain regions receive some snow.

3.3. Geomorphology

Geomorphology plays a very important role in deciding the composition of mineral constituents of a area. Thus it plays important role in the vegetation composition of that area.

3.3.1. Soil

Soil effects the vegetation of the area which is the main parameter in the characterization of forest fire and thus indirectly effects the whole environment of the particular area. There are mainly two main types of soils:

Pedogenic soils: These are produced by the long exposure of rocks to air, water, wind and also by chemical weathering and rock slides. The rocks from which these types of soils are derived in the study area are Granite Genessic, schistose & phyllite rocks. These soils are rich in silica and limestone soils are rich in calcium carbonate.

Transported soils: The soils which are brought by streams are termed transported soil i.e. the parent bodies producing these soils are far away. Some of these soils have mixed origin of glacial & fluvio-glacial origin. These soils are silty to clayey loam and are very fertile. High amount of organic matter is present in brown forest soils. The katil soils are stony, immature and very poor. Soils of upraon are gravely ab/nd sandy loams, they are brown of Talaon. Talaon soils are brown in colour with clayey texture. Erosion rate is high due to stony texture of these soils.

3.3.2. Minerals & rocks

Himalayas are always been considered as an unexplored rich of natural resource of rocks & minerals. A number of metal ores (copper, lead, zinc, silver, gold, iron ore etc) are already known to local people. The mineral industries in Garhwal Himalayas are underdeveloped because of unawareness & un-exploitation of these natural resources.

Some of the mineral resources which are available & can be exploited in the study area are limestone, gold, graphite, sulphur etc. Lime- Produced from limestone is used in making cement. Lime stone deposits are detected in lansdown & Srinagar. Similarly Alaknanda valley near Srinagar is full of sulphur & graphite ores. Laldhang is rich in hard coal. Gold deposits are found in upper Shivalik hills reaches in Kalachur region of Pauri Garhwal.

There three main lithotectonic units in the Nayyar catchments, first the Almora crystalline in the north & North eastern parts of Thalisain, Bironkhal, Pabo & Pauri, second as Sedimentary belt of Jaunsar, Krol-Tal sequence in Rikhnikhal, Bironkhal & Jahrikhal Blocks and third as Shivalik belt.

Krol limestone is quarried for Sugar industry, lime and some refractory. Gypsum is also found in krol limestone. Quartizites are used as building & rock materials & phyllites & slates are used as roof tiles. Lead & Zinc minerals are found in Bironkhal & Thalisain area. Mica flakes are also present in Almora crystalline & river sand; gravels are used for construction purposes.

3.4. Forests

The different types of forest in my study area are:

Khair/sisso forests: These forests occur in lower area and are also termed as Riverie forests. Main species of this forest are Acacia catechu (Khair), Shorea robusta (Sal), *Dalbersia sisso* (Shecham), *Bombex ceiba* (Bamboo). There are different species of Bamboo.

1. **Chir Pine Forests:** These forests are extensively present in my study area. The important species are *Pinus roxburghii*. These occur between altitudes of 900 meters to 1500 meters. Other tree species are *Cedrela tona* (Toon), *Anoegissous latifolia*, and *Ehertia leavis*. The density varies from 0.3 to 0.6, forests are more dense in areas which are away from human settlements, intensive growing, on sandy soil etc.
2. **Oak Forests:** These are present at an altitude of 800 m & above. Important species of these forests are – *Quercus semicarpifolia* (Banj) *Q. incana* (Banj), *Rhododendron arboreum* (Burans), *Rhus panjabencis, Cedrela Toona* (Toon), *Vitis Himalayansis*. The density of these forest ranges from 0.4 – 0.8 percent. Undecomposed humus is present in the form of thick layer in soil. Moisture is also present in these forests.
3. **Deodar Forests**

   These are present at higher elevation and its species are *Cederus deodara*. In cooler aspect deodar is accompanied by blue pine *(Pinus exelsa),* silver fir & spruce.

3.4.1. Utilization of forests

There are lots of timbers, paper; match industries are located in the Ganga plain adjoining Garhwal hills which are dependent on chir pine and deodar forest for the supply of raw material. Kattha industry is dependent on Khair forest. Pine forests are used for tapping resins which are utilized in resin and turpentine factories. These forests produce pulp wood (for paper industry), wood for match industry, Gums, tannins, paints, fibers, canes and other minor forests products. Local people depend on these forests for fuel wood and fodder, thatching of roofs, agricultural implements, house building purpose, furniture. 90% cattle graze in these forests.

3.5. Demography

Population has been constantly increasing in the study area and thus a lot of pressure and dependency on the forest resources has increased. Also due to human interference frequency of forest fire has also increased. Consequently loss of habitat of wildlife has been seen and as a result human animal conflicts have also increased in resent years. According to 1991 census the population statistics of the district area as follows:

Table 3-1: Population statistics

Year		Total population	S.C. Population	S.T. Population
1981	Male	267810	36835	639
	Female	303798	38067	458
1991	Male	326378	45046	859
	Female	345163	45636	641
2001	Male	331061	52528	888

	Female	366017	54125	706

3.6. Water Resources

Instead of plenty of water available, the drinking water problem is main among the locals. The water resources available here are not fully exploited for drinking water, irrigation, hydel, fresh water products etc. in full capacity due to shortcoming of non-economic planning and poor management, shortage of capital resources, non cooperation from locals, hard geographical features etc. In spite of various rivers and natural water resources this problem prevails to large extent.

The Alaknanda River flows along the western border of the district and separate Pauri Garhwal district from border districts of Tehri Garhwal, Dehradun, and Haridwar. The river can be exploited for drinking water needs at various places like Srinagar, Baisghat, and Swargashram etc.

There are many other streams which can also be used / exploited for drinking water purpose are western Ramganga, Malini, and Khoh.

These water resources can also be exploited for irrigation and power generation. For e.g. hydroelectric project is already in progress in Pauri Garhwal Srinagar.

3.7. Topography

Topography of Pauri Garhwal is mainly mountainous except of Bhabar region. The highest point of the area is 3116 meters at Dudatoli and the lowest point of the area is 295 meters near Chilla (Haridwar). Dorbi village is located at highest level i.e. 2480 meters.

The cross profiles of the fluvial valleys show convex form with sleep valley sides, interlocking spurs descending towards the main channel, hanging valleys, water falls & rapids and terraced agricultural fields on the gentle slopes on the valley sides. The villages are confined mainly on gentle slopes of the ridges on the fluvial terraces. Thailisain has maximum forest cover while Pauri Block has minimum.

Roads a frequently spread and most of the area is approachable by roads. Roads are not permanent and frequently get affected by landslips, slides, dusty etc.

The district Pauri Garhwal has unique set of ecological characteristics as it includes forests, meadows, savannah grasslands, marshes and rivers, as well as diverse wildlife, geology and other phyto-geographically distinctive peculiarities. The diverse topographical & climatic factors give remarkable biodiversity to the district. Forest dominates in the phyto-geography & constitutes major valuable natural resource.

3.8. Flora and Fauna

Flora and fauna contributes to the biotic components of forest ecosystem.

Flora

Ferns: More than 120 species of ferns are identified in the region. They are abundant in the months of June, July and September.

Trees: The important trees of hills of study area are wild cherry, wild apple, spindle wood, Oak, popular, fig, holly, *Rhododendron*, Horse Chest nut, Masuri Berry, Dogwood & hill Tuna. At higher region forests are accompanied with Himalayan *Cypress Deodar*, Blue Pine, Fir and long leafed Pine.

Medicinal Plants: Medicinal plants are:-
Acacia arabica (Babul) – used to yield gum.
Egle marmelos (Bel) – its fruit used in diarrhea and dysentery.
Artemesia vulgris (Pati) – Used to stomach problem and in fever.
Boenning_hausenia albiflora (Pisu-ghas) – used as medicine in poultry.
Bauhinia verigata (Kachnar) – used in dyspepsia and flatulency also promote suppuration.
Berberis lycium (Kingora-ki-jar) – used in eye diseases.
Bombax malabaricum (Semal) – used in asthenic cases, as stimulant and tonic, also as an emetic and aphrodisiac.
Cinnamomum tamala tej (Bark), Tejpat (leaves) bark and leaves are used as carminative, aromatic, and stimulant in coughs and dyspepsia.
Aconitum hetrophyllum (Root) – used as tonic and febrifuge

Fauna

The study area is highly rich in wildlife.

Animals – Some important animals are tiger, panther, civet cat, leopard cat and jungle cat (belongs to cat family). Himalayan silver fox and jackal are common. Among deer species musk deer & Barking deer are common. Sambhar & Gural, Bear, Porcupine are also seen. Among flying mammals bat is common. Adorable animals of the region are chipmunk, the rhesus monkey & flying squirrel.

Birds: - As many as 400 varieties of birds are found in Himalayan region out of them species spotted in my area are – the Jewel thrush, black headed oriole, black headed yellow bulbul, rosy minivet, laughing thrush, golden beaked wood pecker, blue fly catcher, goosander, Brahminy duck & green shank, grey headed fishing eagles. At an altitude of 5000 feet woodpecker, thrush & warbler could also be seen. And at the height of 8000-11000 feet Grosbeak, Rock Thrush, Crested Black Tit & Red headed Laughing Thrush are seen.

4. MATERIALS AND METHODS

4.1. Spatial Data

a. **LISS-IV Images of resolution 5.8 meters**: The LISS-IV images has been acquired for my study area from NRSA Data Centre, Hyderabad. The LISS-IV camera is a multi-spectral high-resolution camera with a spatial resolution of 5.8m at nadir. The swath at multi-spectral mode is 24 km and at mono mode is 70 km. This camera can be operated in two modes of Mono and Multi-spectral. In the Multi-spectral mode, data are collected in three spectral bands Band 1 (520nm-590 nm), Band 2 (620nm-680nm) and Band 3 (760nm-860nm).

b. **Toposheet:** A Toposheet, No. 53 J/16 of Survey of India at the scale of 1:50000 is used for preparation of base map.

4.2. Non – Spatial Data

Data on recent fire accident from Forest Department records has been collected
Socio-economic data and data related to moisture content of the study area.
Spatial data is acquired from NRSA Hyderabad and non–spatial data have been collected from different sources such Forest Research Institute (FRI) and Forest Department.
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4.3. Instruments/ Field Equipment/ Materials

A quadrat of 50 × 50 cm: Has been used for the collection of sample vegetation for moisture estimation.
Weighting machine is used for taking weight of the wet samples immediately after collected in the field. This is also used to weight the sample after drying for calculating the moisture percentage.
Geographic positioning system (GPS): It has been utilized in the field for locating the position and elevation of the areas surveyed and also for locating and collecting positions of burnt areas. It has also been used for the collection of spatial data of the samples collected.
Field notebook, pen, pencil & rubber etc: These are used in the field for writing notes.

4.4. Software used

ArcInfo and Arcview: GIS softwares used for the generation of different attribute (risk) maps using different tool bars in it.

Erdas/ Imagine: It is also GIS software very useful for Georeferencing and Remote Sensing data analysis and initial classifications of satellite data. Thus, it is used for the initial interpretation and classification of my satellite data.
Definite: This is non-spatial GIS software and is very useful software in decision making process. Thus this is used in this work for assigning weights to different parameters.

4.4.1. Pre-processing of data

Geo-referencing: Raw digital satellite images are not suitable for immediate use therefore geometric correction required which is known as geo-referencing. Random systematic distortion of images is corrected by analyzing distributed ground control points, which are taken from field using GPS. GCP points were selected based on there known ground location that can be easily identified on the digital imagery. These points include rivers, road intersections and other distinct features with respects to there ground coordinates (latitude and longitude). A map to image model was generated by using least square fit method, wherein perfect registration of the two images was obtained. The geocoded imagery was transformed through polygonic projection using Geographic Lat long and then registered with the map scale (1:50,000) of study area, this facilitates the data to be overlaid in perfect registration with other cartographic layers, thus, will enable comparison with cartographic data. For determining the pixel values of output matrix (geocorded imagery) from the original input image matrix is done by re-sampling using nearest neighbour approach. All the spatial data should be in same co-ordinate system for GIS & spatial analysis. We can project the location from an ellipsoidal on to a planner surface using any of the three ways viz., cylindrical, azimuthal & conical projection. Selection of the projection depends on the location of the study area on the earth surface. In my case polygonic projection system with Everest ellipsoid and India-Nepal datum has been used. The main purpose of geometric correction is that whatever measurements to be made on the map will coincide accurately with the corresponding measurements of the ground.

4.4.2. Standardization of Data

The spatial data which has been obtained from different sources such as Forest Department and other Institutions are obtained on different scales. It is therefore necessary to bring them to a uniform scale so that further GIS and spatial analysis could be done easily. As I am using 1:50,000 scale Survey of India map, therefore all the thematic layers which I will generate will be on 1:50,000 scale.
Data which has been collected are both quantitative and qualitative in nature. Qualitative data is nominal and quantitative data is measured in internal or ratio scale. Within these two there exists nominal scale. In this study all the data are brought into four categories like very high, highly, moderate and low. Colour has been used to show these categories as per Beritin's visual.

Deleted: For my

4.4.3. Data Processing in GIS

Satellite imagery is used for classification. Supervised classification has been carried out in ERDAS for generating a vegetation map and the burnt area map.

4.4.3.1. Burnt area detection

Vegetation of any area reflects very strongly in infra red portion of electromagnetic radiation (Lillesand and kiefer, 2000). Thus the vegetation appears in different shades of red colour in infra red. But in a forest fire burnt areas, absorbs all the radiations and consequently it will appear black in colour in false colour composite. These burnt area are digitized and been validated during my field work. It has also been seen that if the vegetation grows on these burnt areas in future the vegetation will appear light green in true colour and light red in infra red region of electromagnetic radiation. Also the vegetations thus grows will not be very healthy. But with coming years the vegetation will flourish if fire does not occurs. And if fire is continuous every year it will destroy the vegetation completely.

4.4.3.2. Generation of vegetation and density map

The under story and over story represent the total fuel available for the fire. It is therefore important to generate a vegetation map of study area, in order to classify the vegetation into zones of different associations (e.g. evergreen, semi-evergreen, moist-deciduous etc.). For the generation of vegetation map, combination of field knowledge, expert opinion, supervised classification and other information obtained form forest departments are utilized. Apart form this, for ground truthing GPS location and existing map of forest department has been used and finally the vegetation map has been generated.

Any spatial data that we will use in GIS should be shown in map form for generation of maps of thematic layers is the primary requirement. The forest type and density map are prepared on screen visual interpretation and ground verification.

Vegetation density map shows different types of Flora in the study area along with its density (density is the number of plant species per unit area). This map is utilized for the creation of fuel risk map as different density & type of vegetation plays a very curial role in the intensity of forest fire.

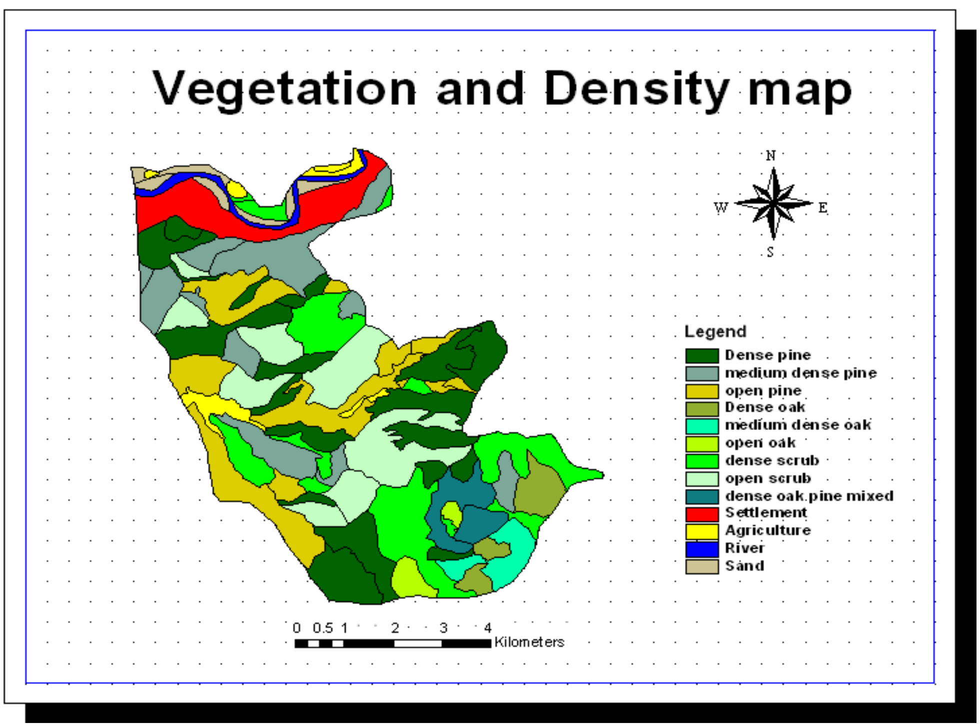

Figure 4-1 : Vegetation type and density map

4.4.3.3. Generation of base layers

All the base layers have been generated on a scale of 1: 50000 on a Survey of India Topo sheet of my study area, in accordance with the data collected from forest department and other sources. Digitization of various vector layers in the form of points (Fire Stations), line (Roads, rivers) and polygon (village) has been prepared. Layers of different land features and administrative and management units has been prepared.

Village block map has been digitized and extracted from the topo sheet. Similarly Road map and river map have been digitized and extracted. Contour map has been digitized and extracted from the topo sheet of scale 1:50000 at 40m spacing. All these maps are already georefrenced. A simple flow chart for the generation of base layers is shown in figure 4-2.

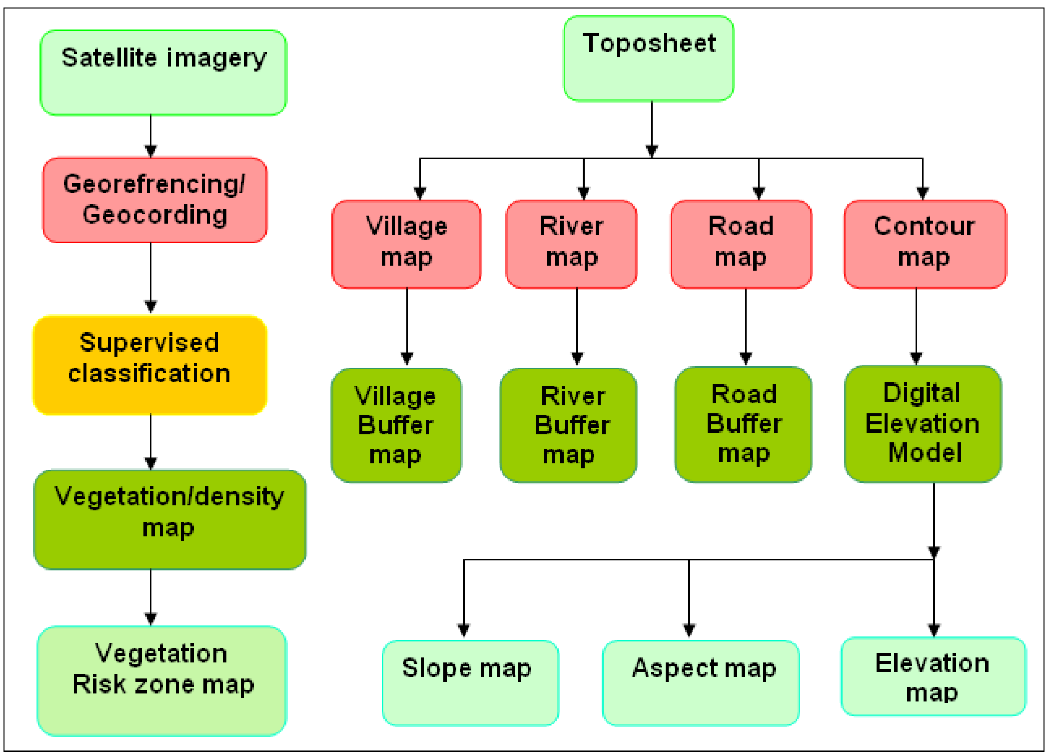

Figure 4-2 : Generation of base layers

Generation of Village map

Village is one of the important factors, which plays an important role in forest fire as there is a lot of human activities/movements on village, which could influence forest fire accidents. In detection risk sub-model, village plays an important role and people on the villages could easily detect them. Thus closer to the village less are the chances of fire. In response risk sub-model, if the forest fire is detected closer then response is more fast and easy, particularly if the fire place is closer and reachable by the forest Department people. The village map is shown in figure 4-3.

Generation of Road map

Similar to village, road has also enough human activities and vehicle movements although less than villages. Road map (figure 4-4) has been used for the generation of road buffer map used in fire response sub model. As the distance from the road increases response time also increases. This map is also used in fire detection sub model as it is used for viewshed analysis.

Generation of River map

Rivers are the natural barriers and thus play a very important role in fire situation because if the water body comes in between the fire station and the effected area then, reaching that place will be very difficult & it will take a lot of time to reach there. Thus these play a very crucial role in response risk sub model. The river or drainage map is shown in figure 4-5.

Generation of fire station map

These maps are very important as the distance of effected area to the fire station is one of the determining factors of the spread & control of forest fire i.e. with increase in distance from the fire station will lead to more chances of uncontrolled spread of forest fire. Fire station map is shown in figure 4-6.

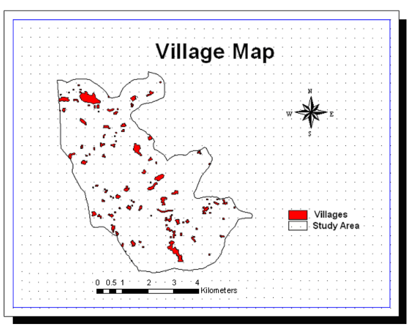

Figure 4-3 : Village map

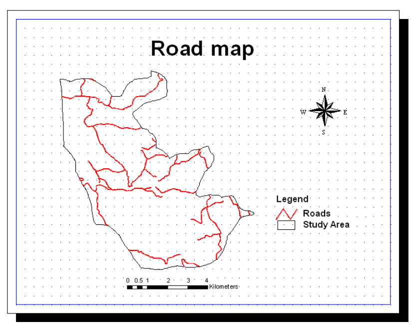

Figure 4-4 : Road map

(increase the size of these 4 maps – make all the maps of same size, as figure 4.1)

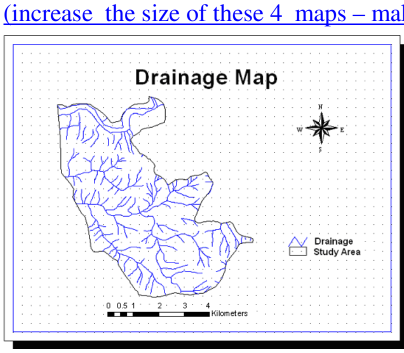

Figure 4-5: Drainage map

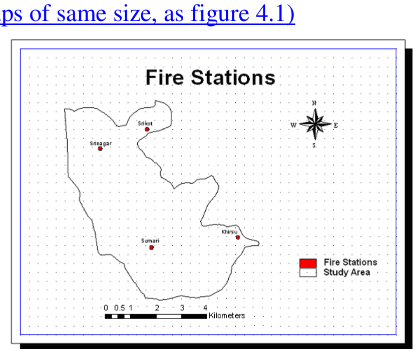

Figure 4-6 : Fire Stations

Generation of Contour Map

Contour is the lines on a toposheet having same elevations. Different elevations play an important role in determining the intensity of forest fire. As with increase in elevations fire chances decreases, due to decrease in oxygen/Air supply & lowering of pressure, fire intensity & spread will decrease. The main purpose of contour map (figure 4-7) is to generate Digital Elevation Model.

Digital Elevation Model

Topography of an area is a basic parameter that is imperative in any fire risk mapping system. Digital elevation model is generated through interpolation of contour map. Interpolation is calculation of the intermediate values between two known values. In contour interpolation GIS software calculates the elevation values of the intermediate area where elevations of the contour lines are known. DEM (figure4-8) is used for the generation of Slope map, Aspect map and Elevation map.

All the maps thus generated have been given attributes to input the data in GIS and make it computer readable. DEM (digital elevation model) has been generated with the help of contour map in ARCVIEW. DEM has been utilized for the preparation of slope map. Attributes are given to the map. DEM is again utilized for the preparation of aspect map. Required attributes are also assigned to the map.

The fire station which has already been digitized form topo sheet as point layer has been buffered and the buffer map of the fire stations has been created.

Different vegetation and different densities are crossed to generate the fuel type map i.e. different combination of density and vegetation will have different fuel properties. Which means burning capacity and accordingly attributes are also given to the map.

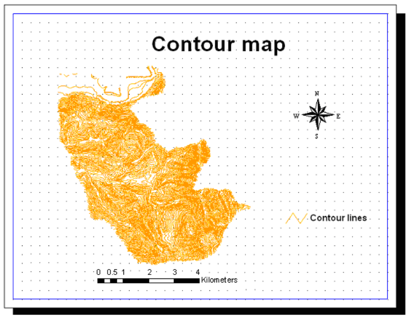

Figure 4-7 : Contour map

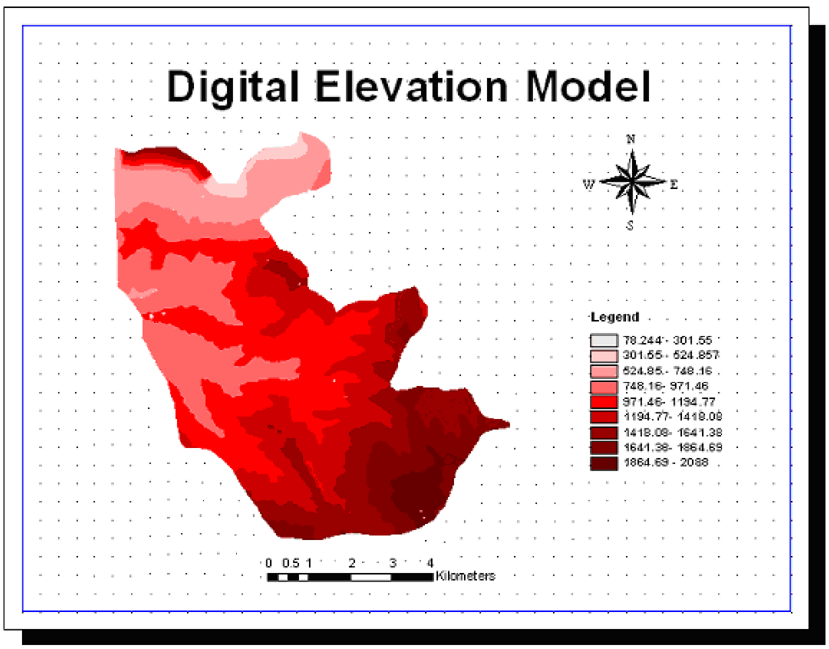

Figure 4-8 : Digital Elevation map

4.4.4. Forest fire risk zonation

For this three sub-models are used to produce three different maps namely – Detection risk map, response risk map, fuel risk map. All these maps combined giving different weightage to different maps to produce the final fire risk map.

4.4.4.1. Field Work

The satellite image of LISS-IV has been used for validation purpose. The field visit has been conducted on last week of July 2007 for the purpose collecting the GCPs' of different vegetation types and burnt areas. The samples of different vegetation type are collected to determine their moisture contents. For calculating surface fuel content per unit area randomly 10 quadrates of area 50 cm × 50 cm are laid in the study area and harvested the vegetation type in each quadrate representing different vegetation type and density. And weights of different samples before and after drying are recorded and the result is used in the given formula for obtaining fuel content (Table 4-1).

Fuel moisture content = Wet weight – Dry weight/wet weight * 100

Table 4-1 : Moisture content with location

Site Name	Location	Wet weight (gms)	Dry Weight (gms)	Moisture content (%)
Ratora	30 13 06 N, 78 47 54 E	250	112.3	55.08
Ghargaon	30 12 52 N, 78 48 27 E	250.2	115.1	53.99
Athana-dang	30 12 59 N, 78 47 15 E	0.6	0.22	63.33
Dharigaon	30 12 42 N, 78 48 26 E	0.8	0.26	67.5
Sarana	30 12 45 N, 78 48 52 E	125	89.4	28.48
Mashure	30 12 36 N, 78 49 22 E	0.7	0.48	31.4
Barori	30 12 30 N, 78 49 48 E	250	175.2	29.9
Jalethagaon	30 12 34 N, 78 50 07 E	0.9	0.37	58.88

Collection of different non-spatial data from, Forest Department and other organizations.

4.4.4.2. Analytical Hierarchical process (AHP)

Spatial multicriteria decision analysis is a process that combines and transforms geographical data (input) into a resultant (output). The multicriteria decision making procedures define a relationship between the input map and the output map. This procedure utilises the geographical data, the decision maker's preferences, and the manipulation of the data and preference according to the specified decision rules. Multicriteria analysis has been used for the evaluation of geographical events (Malczewski 1999).

Analytical hierarchical prosess is a decision-aided method developed by Saathy. Its aims at quantifying relative priorities for a given set of alternatives in a ratio scale, based on the judgements of a decision maker as well as the consistency of the comparison of alternatives in the decision making process. This method has been forced to an effective and practical approach that can consider complex and structured decision. The AHP is proposed in this research in order to assess weightages for various parameters influencing the forest fire. T weights have been decided following the analytical approach suggested by Saathy (1990). A spatial process model has been developed for the decision making.

In this study, a hierarchy is used to organise decision making criteria. Pairwise comparison matrixes were made between criteria at each level of the hierarchy and possible alternative causes of decision. These comparison matrixes, lead to priority vector, which are the weights for respective layers. These priority vectors propagated through the hierarchy to get the final priority vector and thus the weights.

Forest fire depends on various factors with different influence on it. Different parameters have different characteristics which play their own role in the ignition and spread of forest fire. Therefore every parameter in contribution in forest fire is not equal. Some parameters plays more significant role then others in forest fire. Thus there is a need to identify the characteristics of different parameters and their effect on forest fire and to assign them weightage according to their contribution to forest fire.

The assignment of weight has been done in Definite. After giving scores to the parameters according to field experience and expert opinions is problem definition in Definite. Pairwise comparison has been done taking two parameters at a time. After the completion of pairwise comparison the software will calculate the pairwise comparison matrix giving appropriate weightage (priority vector) to all the parameters used. The weights are used in the models for the calculation of the final map. This procedure will increase the reliability of the intermediate and final maps.

Pair-wise comparison matrix technique in used in response risk sub model for generation of response risk map, similarly this method has been applied in detection risk sub model & fire risk sub model. At last, the result maps/layers of these sub-models have been assigned weights with the help of similar technique for the production of my final forest fire risk zone map.

Classification of different criterias into different risk values for Fuel risk sub model: The following tables (table 4.2 to 4.9) shows different risk class with different value range of different parameters. These tables are used in the reclassification of different risk maps in the models.

Table 4-2: Slope type with risk values

Class Name	Risk value	Slope values
Very High	4	30-90 % (Very steep)
High	3	15-30 % (moderately steep)
Moderate	2	5-15 % (slopping)
Low	1	0-5% (flat to gentle slope)

Table 4-3: Aspect with risk values

Class Name	Risk value	Aspect values
Very High	4	SE (South-East)
High	3	SW (South-West)
Moderate	2	NE (North-East)
Low	1	NW (North-West)

Table 4-4: Elevation with risk values

Class Name	Risk value	Elevation values (meters)

Very High	4	1425-1700 1700-1975
High	3	1150-1425 1975-2250
Moderate	2	875-1150 2250-2525
Low	1	119-875 2525-2800

Classification of different criteria's into different risk values for Fire response risk sub model:

Table 4-5: Slope friction and risk values

Class Name	Risk value	Slope friction values
Very High	4	105-115 %
High	3	75-105 %
Moderate	2	40-75 %
Low	1	0-40 %

Table 4-6: Elevation frictions with risk values

Class Name	Risk value	Elevation friction values
Very High	4	1800-2200
High	3	1400-1800
Moderate	2	1000-1400
Low	1	119-1000

Table 4-7: Cover type frictions with risk values

Class Name	Risk value	Cover friction values
Very High	4	Natural Forest
High	3	Shrub Land, Plantation
Moderate	2	River, Agriculture, etc
Low	1	Road, Village

Classification of different criteria's into different risk values for Fire detection risk sub model:

Table 4-8: Fire detection with risk values

Class Name	Risk values	Viewshed class
Low	1	Visible
Very High	4	Not Visible

Table 4-9: Risk values for various Sub-models

Class name	Risk value	Sub-models
Very High	4	Fuel risk Sub-model
High	3	Fire Detection Sub-model
Low	1	Fire Response Sub-model

Weights which have been calculated in definite for the models have been described in the following tables (table 4.10 to table 4.21). Final weights are shown in the last columns of weighted matrix tables. Comparison matrix is calculated using the risk values as given in table 4-2 to 4-7. After that, weighted matrix is calculated by dividing each value by its row total. The final weights are calculated by taking the average of each column in weighted matrix table. Consistency Ratio is also calculated (in software) to judge our consistency in assigning weights to our parameters. This is done by using the eigenvalue (lambda maximum) to calculate the Consistency index (CI) as follows:

$$\mathbf{CI = (\lambda_{max} - n/\ n\text{-}1)} \quad \text{where n is the matrix size}$$

The consistency of the judgement can check by calculating the consistency ratio (CR) of CI with appropriate value from Average random consistency (RI). Thus **CR = CI/RI.**

Table 4-10: Comparison matrix of Fuel Risk Sub-model

	Fuel/density	Slope	Aspect	Elevation
Fuel/density	1.00	1.333	2	4
Slope	0.75	1.00	1.5	3
Aspect	0.5	0.666	1.00	2.00
Elevation	0.25	0.333	0.50	1.00
Total	2.5	3.32	5	10

Table 4-11: Weighted matrix of Fuel Risk Sub-model (CR = 0.003)

	Fuel/density	Slope	Aspect	Elevation	Priority vector/Weight
Fuel/density	0.4	0.4007	0.3999	0.4	0.4
Slope	0.3005	0.289	0.3	0.3	0.3
Aspect	0.2	0.19	0.2	0.202	0.2
Elevation	0.09	0.1	0.1.008	0.1	0.1

Table 4-12: Comparison matrix of Viewshed maps

	Village	Road	Fire Station
Village	1	0.333	0.25
Road	3	1	0.25
Fire Station	4	1.333	1
Total	8	2.666	2

Table 4-13: Weighted matrix of Viewshed maps

	Village	Road	Fire Station	Priority

				vector/Weight
Village	0125	0125	0125	0125
Road	0.375	0.375	0.375	0.375
Fire Station	0.5	0.5	0.5	0.5

Table 4-14: Comparison matrix of Fire Detection Sub-model

	Non visible	Visible
Non visible	1	4
Visible	0.25	1
Total	1.25	5

Table 4-15: Weighted matrix of Fire Detection Sub-model (CR= 0.005)

	Non visible	Visible	Priority vector/Weight
Non visible	0.8	0.8	0.8
Visible	0.2	0.2	0.2

Table 4-16: Comparison matrix of Cover Friction

	Natural forests	Agricultural/plantatio n	River	Roads/Village
Natural forests	1.00	1.333	2	4
Agricultural/plantatio	0.75	1.00	1.5	3

n				
River	0.5	0.666	1.00	2
Roads/Village	0.25	0.333	0.5	1.00
Total	2.5	3.333	5	10

Table 4-17: Weighted matrix of Cover Friction (CR =0.008)

	Natural forests	Agricultural/plantation	River	Roads/Village	Priority vector/Weight
Natural forests	0.4	0.4	0.4	0.4	0.4
Agricultural/plantation	0.3	0.3	0.3	0.3	0.3
River	0.2	0.2	0.2	0.2	0.2
Roads/Village	0.1	0.09	0.1	0.089	0.1

Figure 4-18: Comparison matrix of Fire Response Sub-Model

	Cover	Elevation	Slope
Cover	1	2	4
Elevation	0.5	1	2
Slope	0.25	0.5	1
Total	1.75	3.5	7

Figure 4-19: Weighted matrix of Fire Response Sub-Model (CR = 0.07)

	Cover	Elevation	Slope	Priority vector/Weight
Cover	0.571	0.489	0.571	0.57
Elevation	0.285	0.286	0.286	0.28
Slope	0.143	0.098	0.143	0.14

Table 4-20: Comparison matrix for Fire Risk model

	Fuel	Detection	Response
Fuel	1	1.333	4
Detection	0.75	1	3
Response	0.25	0.333	1
Total	2	2.67	8

Table 4-21: Weighted matrix for Fire Risk model (CR = 0.005)

	Fuel	Detection	Response	Priority vector/Weight
Fuel	0.5	0.49	0.5009	0.5
Detection	0.375	0.374	0.375	0.375
Response	0.125	0.119	0.125	0.125

4.4.4.3. Fuel Risk Sub Model

For the generation of fuel risk map, the fuel type map thus generated is classified into four risk zones taking in account vegetation type, vegetation density and moisture content of each zone. This will create final fuel risk map for the creation of Fire risk zone map.

Fuel risk = F/d *0.4+S*0.3+A*0.2+E*0.1

Where F/d =Fuel type and density

S = Slope

A = Aspect

E = Elevation

I had calculated this fuel risk map in map calculation option in ArcView. The simple flow chart of fuel risk Sub model is shown in figure 4-9.

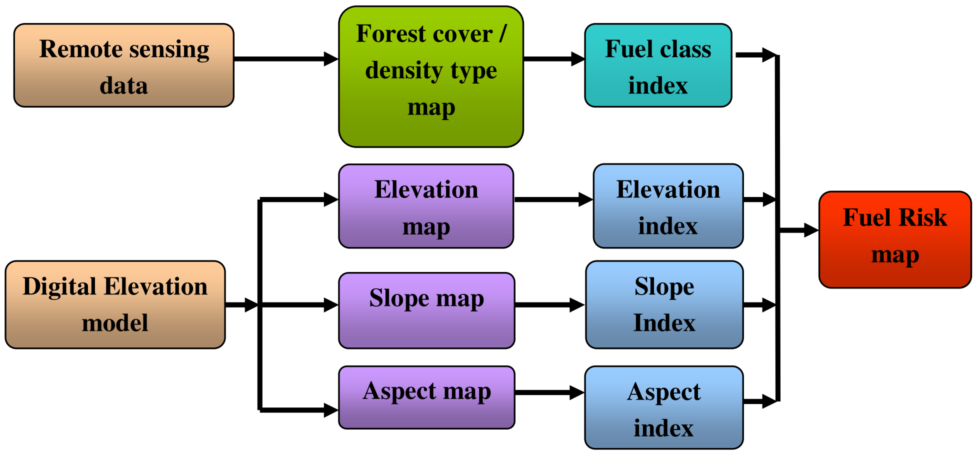

Figure 4-9: Fuel Risk Sub Model

The basic requirements for the fuel risk sub model are Remote sensing data and DEM.

Generation of Vegetation risk zone map

Vegetation map has been generated taking in account the vegetation characteristics like type density and moisture content of the area where the vegetation grows. It is generated by reclassification of vegetation map into four risk classes. Figure 4-10 shows the risk class on the bases of vegetation density and moisture content.

Generation of Elevation Risk Zone map

This map has been generated using DEM. Elevation is important as with increase in elevation oxygen supply will reduce and thus the chances of fire decreases with increase in elevation. Figure 4-11 shows the elevation risk zone map.

Generation of Aspect risk zone map

Different aspect will be exposed to sun with different angle and for different duration which will affect the moisture content of the area. Thus aspect map with different risk zones are generated as under in figure 4-12.

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Generation of Slope risk zone map

With increase in angle of slope, fire risk increases hence slope risk zone map (figure 4-13) has been generated.

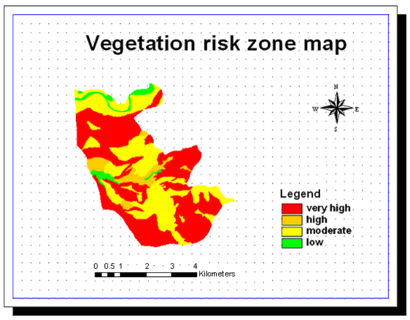

Figure 4-10: Vegetation risk zone map

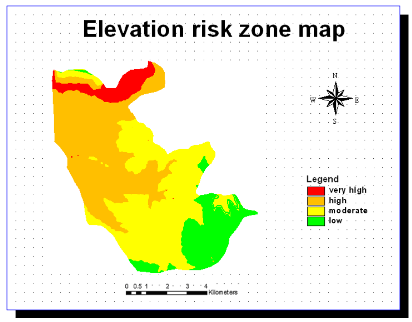

Figure 4-11: Elevation risk zone map

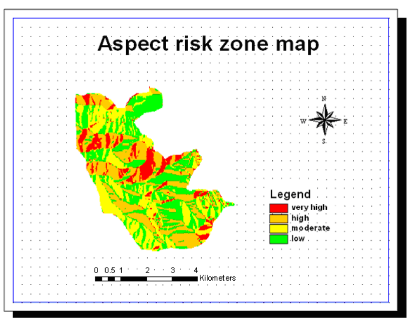

Figure 4-12: Aspect risk zone map

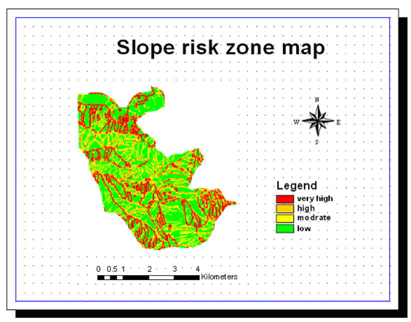

Figure 4-13: Slope risk zone map

Increase the size of all these 4 maps also.

4.4.5. Fire Detection sub model

For the detection risk sub model viewshed analysis technique is used. For this Digital elevation model is used. Road Polyline map and DEM are overlayed and viewshed analysis is carried out with the help of the option calculate viewshed in Arcview. It will generate the viewshed map for road. The same procedure I repeat with the village and fire station maps also. In this detection risk sub-model I had given more weightage to settlements then to fire station and then to the road.

Detection risk = 0.125(DEM + V) + 0.375(DEM + R) + 0.5(DEM + FS)

Where V = Village/ settlements viewshed,

R = Roads viewshed

FS = Fire station viewshed.

Fire detection sub-model is shown in the figure 4-14. Finally the Fire Detection map is generated by giving very high risk to non visible areas and low risk value to visible area as follows.

Detection risk = (NV*0.8) + (V*0.2)

NV = Not visible

V = Visible

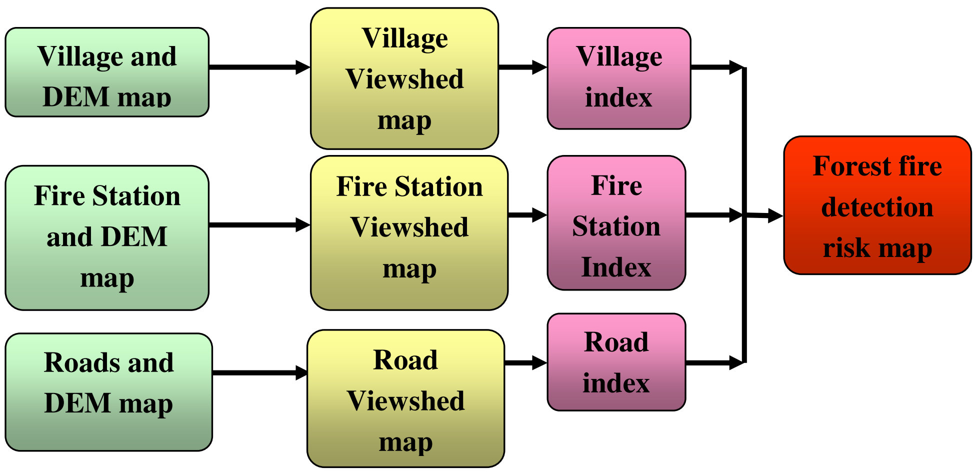

Figure 4-14: Fire Detection sub model

The base layers required for the generation of fire detection map are Road map, village map, fire station map. This is the map which tells us about the visibility of the fire and how easily the fire could be detected for quick response. Therefore in this map settlements, & roads & fire stations are taken into consideration along with elevation. The viewshed map will show the areas which are visible or not visible from some particular points (examples: Road, Village, fire stations). Thus those areas which are not visible come under high risk zone and those which are visible easily are in low risk zone. The final risk map which has been generated in detection risk sub-model is as follows. Viewshed map of fire station map is shown in figure 4-15. Similarly viewshed maps of road map (figure 4.16) and village maps (figure 4.17) are generated.

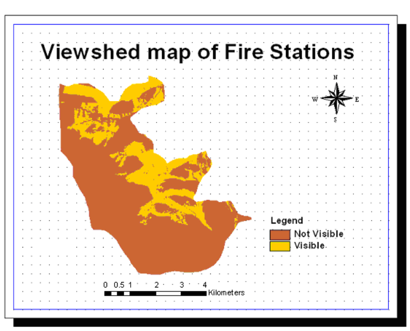

Figure 4-15: Viewshed map of fire stations

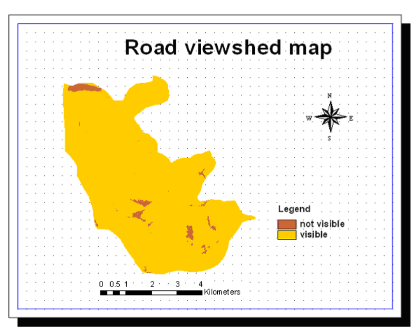

Figure 4-16: Road viewshed map

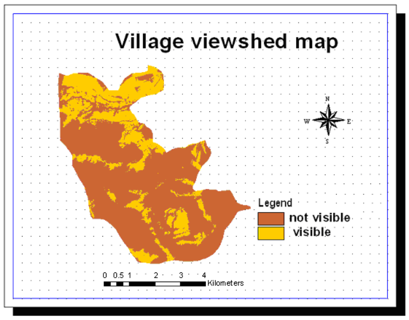

Figure 4-17: Village viewshed map

4.4.5.1. Fire Response Sub-Model

Buffer zones of road map for hundred meters are created into four risk/ friction zones. Similarly risk values are given to different slope angles giving more risk value to more stepper slopes. In the same way, elevation map is also created by giving higher elevation more values and lower elevations less values. Cover type is also responsible for response because different cover type offers different values like villages, roads, rivers etc.

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I had combined these entire friction risk map to produce total friction map and then added the fire station/Headquarters zone map to produce the final response distance/time map.

CO = (N/F*0.4 + PL*0.3+ RV *0.2 + RO/V I*0.1)

Where CO = Cover Response,
N/F = Natural forests,
PL = Plantation,
RO/VI = Roads/villages, and
RV = Rivers.

RS = (CO*0.57 + E *0.28 + S*0.14)

Where RS = Response Sub-model,
CO = Cover response,
E = Elevation response,
S = slope response.

Fire response Sub- model is shown in the flow chart in figure 4-18.

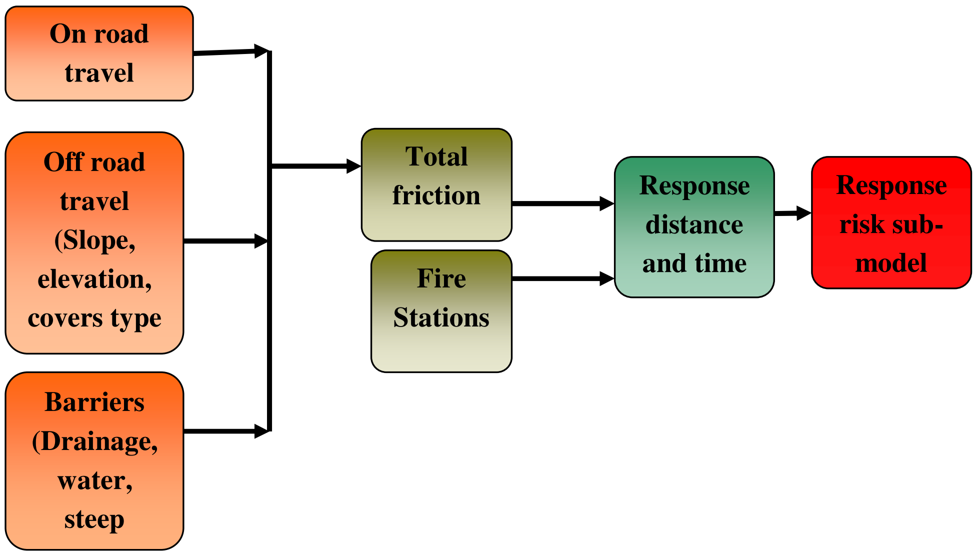

Figure 4-18: Fire Response Sub-Model

The friction maps thus produced are shown in the following figures:

1. **Cover friction map:** This map has been generated giving different land covers with different risk values as described in table 4-8. Thus the map generated is shown in figure 4-20.

2. **Elevation friction map:** With increase in elevation, friction increases Thus in this map, (figure 4-21) higher values are given to higher elevations.

3. **Village friction map:** In this map, (figure 4-22) more friction value is assigned to areas away from villages.

4. **Road friction map:** In road friction map, (figure 4-23) less friction values are assigned to areas near to roads due to easy assess. This map shows that most of the areas nearer to roads come under low risk zone which appears in green.

5. **River friction map:** In river friction map, (figure 4-24) more friction value is given to areas near to rivers thus also more risk values. This map shows that areas which are near to rivers are considered high friction thus appears red that is high friction consequently highly risky if forest fire gets big.

6. **Slope friction map:** In slope friction map, (figure 4-25) more values are assigned to more sloppy areas. Here green portion are more or less flat to moderately sloppy areas thus offers less friction contrary to red portions which are more sloppy and more risky.

Fire station buffer zone map

This map is generated by creating buffer around fire stations of 400meter spacing and assigning lower risk value to the nearer zone (figure 4-19).

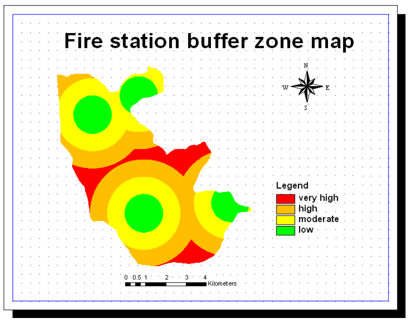

Figure 4-19: Fire station buffer zone map

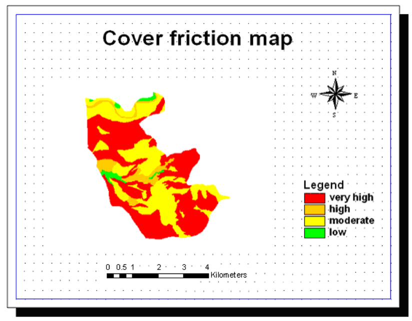

Figure 4-20: Cover friction map

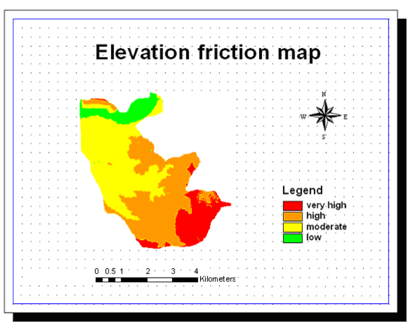

Figure 4-21: Elevation friction map

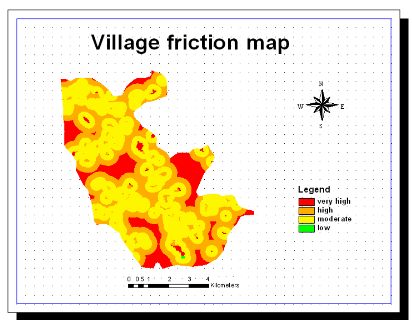

Figure 4-22: Village friction map

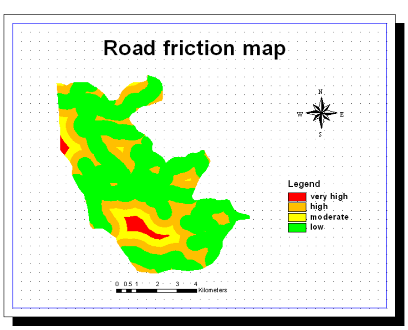

Figure 4-23: Road friction map

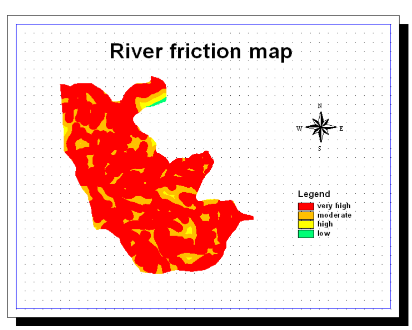

Figure 4-24 : River friction map

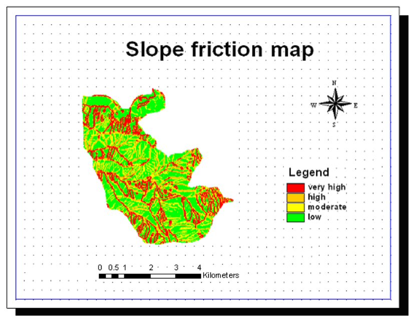

Figure 4-25 : Slope friction map

4.4.5.2. Fire risk zone map

The fuel risk map, detection risk map and response risk map thus produced are combined in map calculation option in ArcView giving appropriate weightage for each map to produce the final fire risk zone map (figure 4-26).

FRM = (FR *0.5+ DR * 0.375+RR *0.125)

Where FRM = Fire risk zone map,

FR = Fuel risk map,

DR = Detection risk map.

RR = Response risk map.

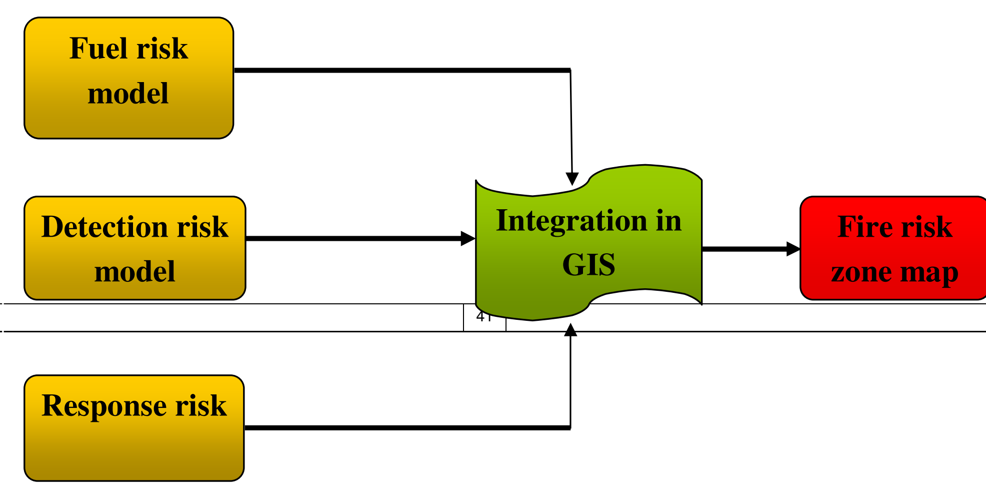

Figure 4-26 : Flow chart of fire risk model

5. Results and Analysis

Analysis is done to understand the behaviour of different parameters responsible for forest fires. This analysis is further useful to come to some conclusions so that prevention, control & other management programs could be discussed and implemented properly to reduce if not stopped, these forest fires which had been considered one of the major and serious problems in forests.

5.1. Burnt area detected

Burnt areas have been identified in the satellite image and for validation field visit is conducted. Most of the green vegetation appears in red and infra-red region of the electromagnetic radiations. But if the vegetation due to forest fire, the burnt areas always appears dark because it will absorb all radiations Figure 5-1 shows the vegetation map with burnt area. Burnt area is represented with the black colour.

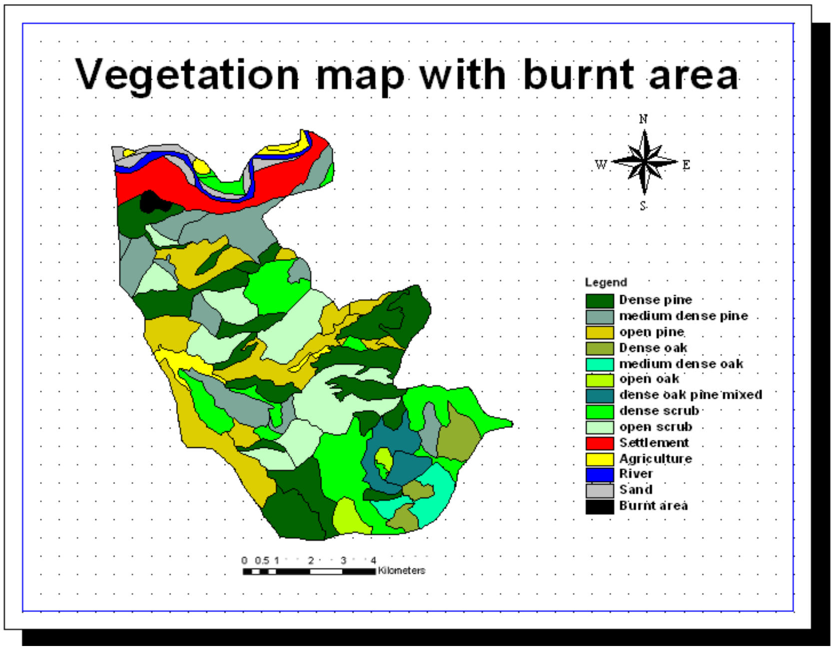

Figure 5-1: Burnt forest area

5.2. Generation and analysis of Fuel Risk map

This map shows the different risk zones in accordance with the properties of fuel and other land features such as vegetation, aspect, slope and elevation which affect the characteristics of fuel. The fuel risk map finally comes as follows. The table 5-1 shows that 13.7 sq. Km. lies in very high fuel risk zone and needs the management of fuels. Red portion which represent the high risk area, is facing towards Sun, have more fuel accumulation, and are sloppy. As fuel has been assigned more value contribution of vegetation type and density to fuel risk zone map is more. The map thus produced is shown in figure 5-2.

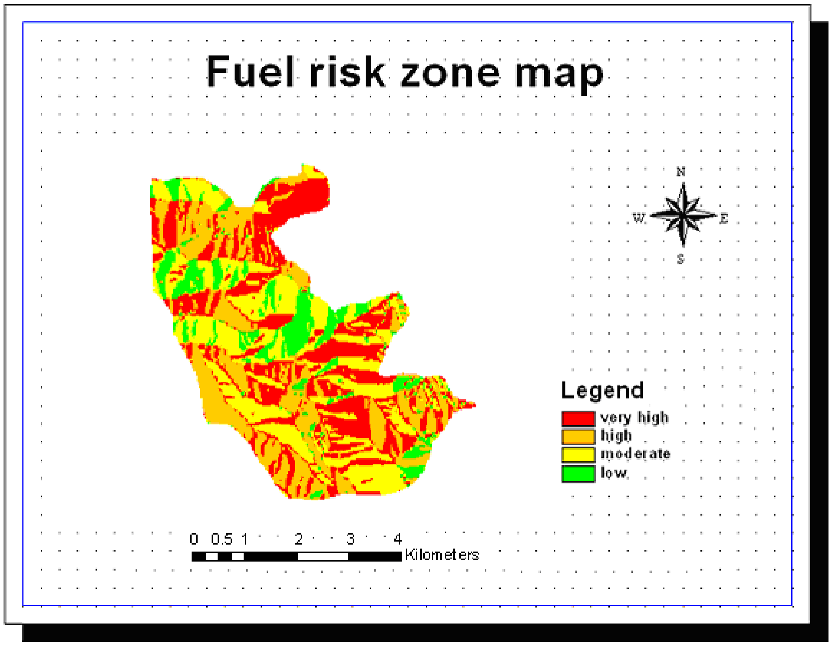

Figure 5-2 : Fuel risk zone map

Table 5-1: Area of fuel risk zone map

Risk value	Colour	Area (Km^2)
Very high	Red	13.71
High	Orange	11.72
Moderate	Yellow	12.87
Low	Green	4.98

5.3. Generation and analysis of Fire Detection map

This is the final viewshed map (figure 5-3) produced by combining all three viewshed maps with appropriate weights. The visible areas are placed under low risk zone as these fires are easily seen and therefore can be combated easily. Not visible areas are in high risk zone.

Detection map: This map has been generated by giving very high risk value to not visible areas of viewshed map and low value to visible area of the viewshed map. The final map of fire detection sub model is in figure 5-4. Thus the areas which are away from villages, roads, and fire stations comes under high risk zone which is shown with red colour.

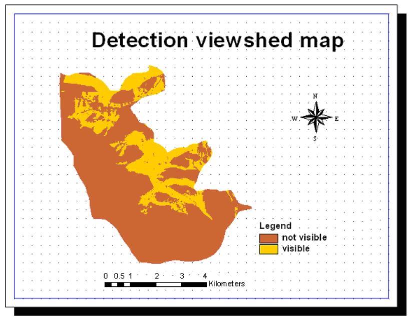

Figure 5-3: Detection viewshed map

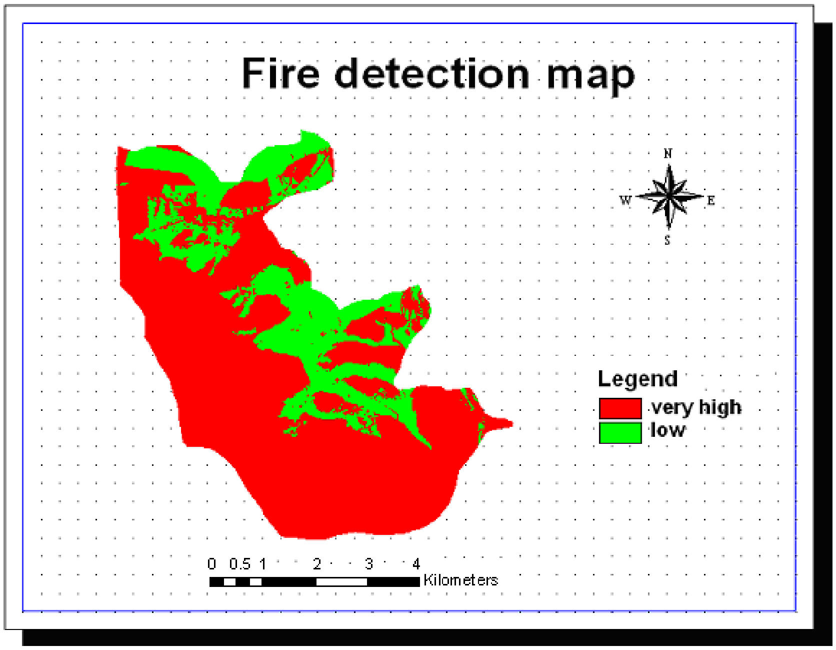

Figure 5-4: Fire detection map

Determination of area:

In detection map, it has been found that 32.4 sq. Km (table 5-2) is under high risk zone and this large area comes under high risk because the fire in this area remains undetected for long thus needs management.

Table 5-2: Area of Fire detection map

Risk value	**Colour**	**Area (Km^2)**
Very high	Red	32.38
High	Orange	
Moderate	Yellow	
Low	Green	11.19

5.4. Generation and analysis of Fire Response map

This map shows the effect of different factors such as roads, Slope, elevation, cover type, rivers etc on the response of the forest department people on getting the news of fires i.e. the friction offered by different land features. As all these obstructions increase the time of response, the final friction map is shown in figure 5-5. In this map distance from the head quarter or forest fire station is also taken into account as distance is also an important factor in response. The response risk map of the study area is shown in figure 5-6. Table 5-3 shows areas of different risk zones. As natural forests is assigned with more weightage contribution of vegetation type and density map is more in this map. It is clear from the friction map, vegetation type and density map that dense and pine forests are in high-risk zone. Similarly contribution of River can be analysed and river area is comes under high-risk zone. In the final fire response map, it is clear that mostly low risk zone lies in and round fire stations. Table 5-3 shows that about 11.6 sq. Km. lies under high friction risk zone area.

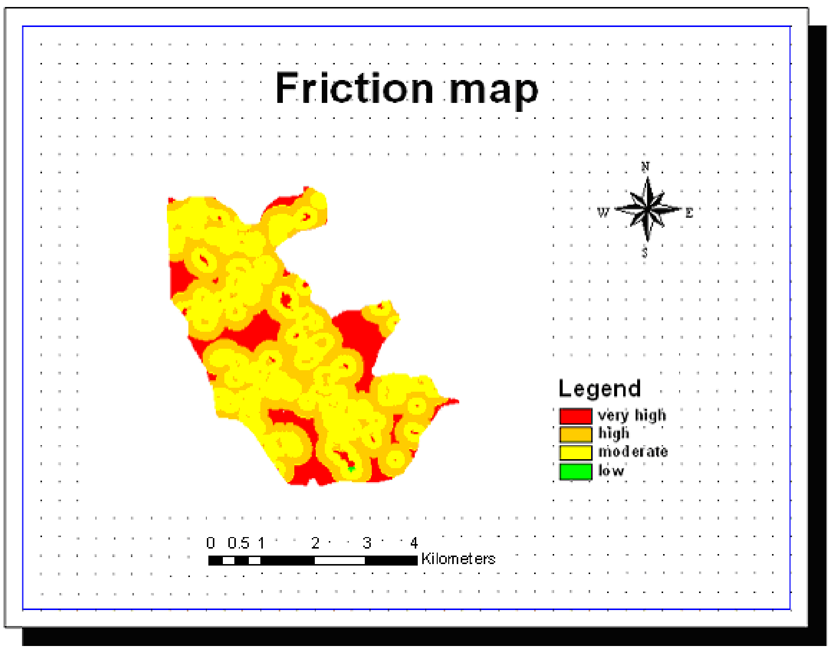

Figure 5-5: Cover Friction\Responce map

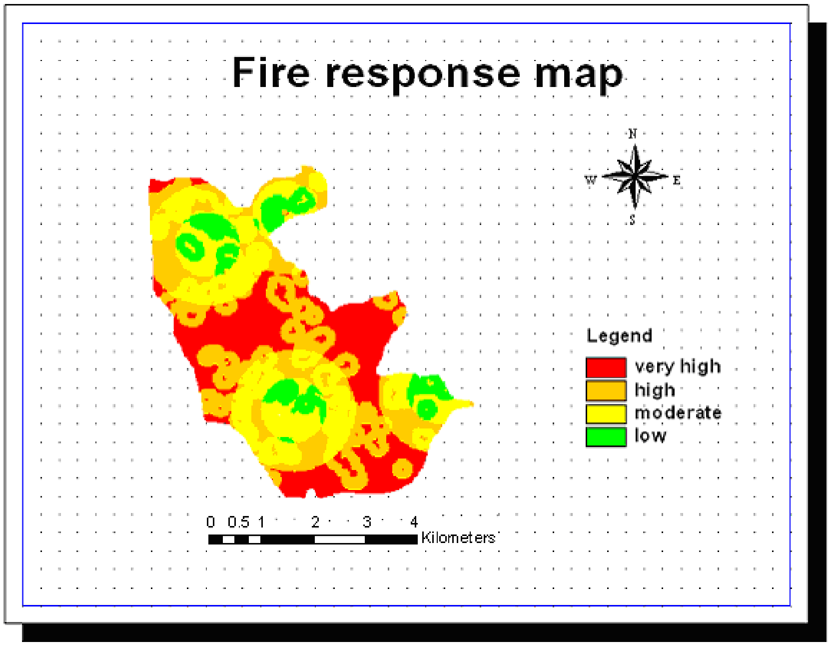

Figure 5-6: Fire response map

Table 5-3: Area of fire response map

Risk value	**Colour**	**Area (Km^2)**
Very high	Red	11.66
High	Orange	13.49
Moderate	Yellow	13.61
Low	Green	4.34

5.5. Generation and analysis of fire risk map

The forest fire risk zone map is shown in figure 5-7. The final fire risk zone map has been generated by combining the response risk map, detection risk map and fuel risk map. Table 5-4 shows that, maximum area comes under high risk zone. In the generation of this map fuel risk map has been given maximum weight therefore the contribution of fuel risk map is more in this map as is easily evident by comparing forest fire risk map with the fuel risk map.

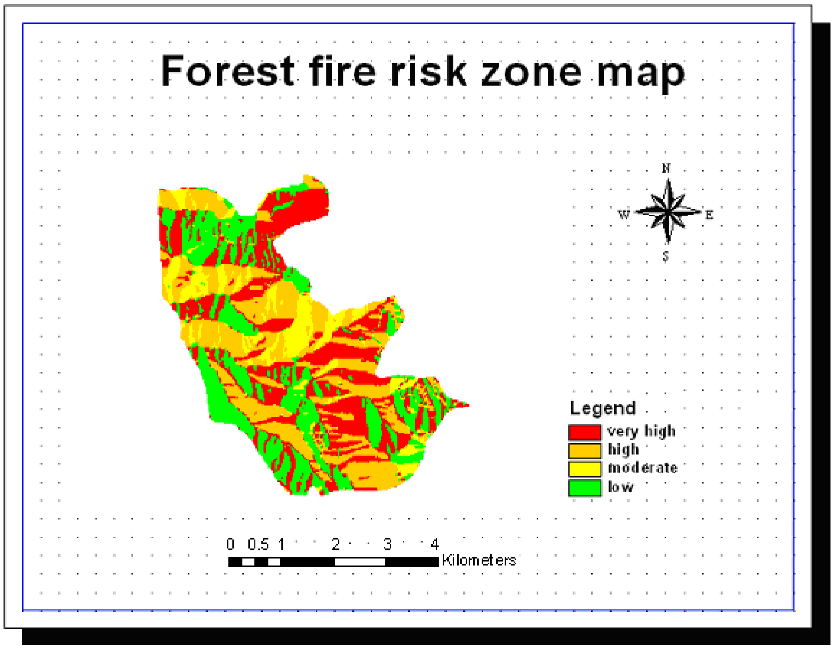

Figure 5-7 : Forest fire risk zone map

Table 5-4: Area of fire risk map

Risk value	**Colour**	**Area (Km^2)**
Very high	Red	10.22
High	Orange	10.11
Moderate	Yellow	12.11
Low	Green	10.60

6. Discussions

As different parameters are taken into account for analysing their effects in forest fire in different sub-models therefore, generating a fire risk zone map by using GIS modelling and Remote Sensing technique is a complicated task. A through knowledge of the study area and the characteristic of not only the vegetation of the study area, but also the characteristic of the entire environment of the area under study are required. Apart from this it requires a lot of patience and time to know the area, so that a more accurate and reliable map can be generated for the use by the people who are interested and also to the Forest department people who can use the map for fire management purposes. Thus, a good risk map can further be used to generate other vulnerability map for various endangered species for conservation purposes.

The fuel risk zone map which has been given maximum weightage in the final forest fire risk zone map is generated by the combination of vegetation risk zone map, aspect risk zone map, slope risk zone map and elevation risk zone map. Vegetation type /density map plays the major role in the ignition and spread of fire and thus more weightage is assigned to this parameter. This could also be seen by comparing the vegetation risk zone map with final fuel risk zone map. Similarly contribution of slope, aspect, and elevation could be analysed by comparing their respective risk maps with the final fuel risk map.

In the detection risk sub-model, village has been given more weightage because at the most of the times villagers can detect fire in the forest and can take necessarily actions. Therefore their contribution to final fire detection map is more, which is also evident by comparison of village detection map with the final fire detection risk map.

Generally Forest department people are quick and alert on the outbreak of forest fire if there are no major obstructions. Once fire is detected, it can be managed by proper response. Therefore fire response map has been given least weightage for the final fire risk zone map.

Considering, the vegetation, fuel and density as major parameters for outbreak of fire, the maximum weightage has been assigned to fuel risk zone map for generating the final fire risk zone map. Thus its contribution to the final fire risk zone map is substantial. It is also evident by comparing the final fire risk zone map with the fuel risk zone map.

6.1. Role of Fuel in forest fire

Different vegetation types have different resistance characteristics towards forest fires. Such as thickness of break, moisture content, size of foliage. Apart from these characteristics density of the vegetation also affect the occurrence of forest fires. Thus different vegetation types with combination of characteristics will have different behaviour towards ignition of forest fire, i.e. different vegetation types behaves as different fuel type is different characteristics combination.

6.2. Role of aspect in forest fire

Different aspects will have different exposure to the Sun rays both in angle and distance. Thus those aspects which are in direct exposure to Sun rays and close to the sun, are more likely to catch fire as fuel is dried very fast. The opposite will be true if Sun rays are away both in direction and angle.

6.3. Role of slope in forest fire

With increase in slope, forest fire spread increases because the flame comes in direct contact with the fuel with increase in slope percentage, and with increase in slope accessibility to the fire affected areas becomes difficult & unreachable after further increase in slope. Thus, slope plays a crucial role in fire spreading. Suppression of fire is also heavily influenced by slope because it affects the rolling materials and safety. Reported that vegetation on smooth, broad slopes tends to burn more completely compared on slopes containing water or cliffs, this interrupted the forward movement of fire. Higher elevations tend to have more rain availability. Thus fires are less severs there.

6.4. Significance of response risk map

Response risk map is very important as it not only takes into consideration the time taken to respond & take decisions, but also the resistance offered by different land features (manmade or natural) and also the distance of the forest fires, and both these factors depends on many features such as slope, cover type, roads and other barriers.

Slopes between 1-10% will not affect too much to respond map, but after that the respond time is adversely affected till 110-120% slope & after this, it will be inaccessible

Different features like road, elevations, density etc and other barrier those are responsible for increasing the time to respond. Thus the friction map is generated using DEM, road map, settlement, river map & different cover type & density maps. These maps are re-classified into four risk values. Now this land feature map along with slope & elevation map is added in map calculation in Arcview. Resultant map is again re-classified to the desired class like risk value from attribute value table. Distance from headquarters & Fire stations can also calculated by buffer zonation to be added in final response risk map.

The significance of his response risk sub-model is that it tells us about the resistance offered by various barriers to tackle forest fire. Other significance is that response risk map along with detection risk map & fuel risk map will give a fire risk map which will be very helpful in management & planning. The significance of this map is to find out alternative routes to the effected areas before the occurrence of forest fire so that response time could be reduced.

6.5. Significance of Fuel Risk Map

Different fuel types i.e. different species of plants have different fuel characteristic and these fuel characteristics also depends on slope aspect, fuel density, elevation etc. Thus the fuel risk map is one of the very important maps in determining the fire risk zones.

6.6. Significance of detection risk map

Fires which we can detect easily are easy to suppress and it will cause less-havoc contrary to those fires which remain undetected for long time which will not only cause a lot of damage to the biomass but also to the environment and the wild life. This map is significant as this map helps forest management to find the place where monitoring is needed and fire watch towers should be installed.

6.7. Significance of Fire Risk map

This is one of the very important maps for Forest authorities because this map shows those areas which are highly prone to forest fires. So that more attention could be paid to those areas for pre fire, post fire and during fire period. So that less damage to biodiversity and Environment occur, wastage of money could be reduce

7. Conclusion and Recommendations

The method adopted in this study takes into consideration various factors which influence the forest fire such as vegetation type and density, aspect, slope, elevation, distance to road and villages and resistances offered by various land features with appropriate weightage to these factors according to their contribution to fire thus this method is much reliable for generating fire risk zone map.

After the analysis of fire detection map, it is clear that much of the area comes under high risk zone as these areas are not visible from any points of settlements and roads. Thus, it is concluded that fire watch towers are required to be erected to make these areas visible.

In fire response risk map areas having high risk values shows that these areas are not reachable thus alternative ways to combat fire in these areas is required.

Thus forest fire is considered one of the very destructive forest hazards as it destroys the natural resources within a very small span of time it becomes very important to take some prevention & control measures and to implement affectively & efficiently. Now for efficient & effective forest fire management, we require adequate logistic infrastructure, Funding for prevention & suppressing of forest fire but for any prevention & control management, we need through & detailed knowledge on the areas which are prone to the forest fire. For this we, have to analyse different parameters, which are responsible for forest fire. As much of the areas remain undetected in the study area due to various terrain conditions, management for early detection of fire is needed for further reduction in damage. Likewise, it is important that we should have a thorough knowledge on the resistance provided by different land features in reducing & suppressing the forest fire. All these analyses i.e. responding time & distance, detection & fuel characteristics can easily be integrated & analyzed in GIS for the detection of forest fire prone areas and also analyzing the detection of fire & response.

7.1. Answer to the research Questions

The answer to the research question of my study is described below:

1. **Burnt area detection:** Using the remotes sensing (LISSIV) data burnt areas can be detected by locating the dark areas in the forest areas and then for validation field visit is carried out and the burnt areas are located with the help of GCP.
2. **Answer to second question (Different parameters effect)**

- **Effect of elevation map**

With the increase in elevation forest fire intensity decreases thus less burnt areas will be seen with increase in elevation

- **Effect of slope map**

With the increase in slope, fire intensity increases thus burnt areas will also increase.

- **Effect of aspect map**

As sun moves from east to west towards south, more heat will be occurred there and more fire frequency thus will be more in burnt areas with darker shads due to fire every year.

- **Effect of vegetation/density map (fuel map)**

Different vegetation will show different fuel characteristics. Thus vegetation with more density and less moisture content is more prone to fire than to those with more moisture with less dense. Thus the later will show less burnt marks then former.

- **Effect of road village/map**

As the distance from the road and villages increases, the chances of fire decreases due to less human activities. On the other hand roads and villages also help to detect and suppress forest fire in time. Thus areas which are detectable from villages and roads are less prone to fire spread thus less burnt marks.

- **Effect of River map**

Areas near to river are less prone to fire thus less fire and less burnt area.

3. **Answer to third question**

Yes, a fire hazard spatial model can be developed using the parameters by creating different base layers of different parameters and then reclassifying them into fire risk values and then integrating them into one map giving appropriate weights to different parameters in GIS environment.

7.2. Recommendation

The similar type of research could be implemented in other areas with same type of situation with some adjustment to specific sites.

7.2.1. Recommendation for my study area

- Patrolling should be increased and strengthened to check poaching. They sometime deliberately burn the forest area to driving away the animals and for diverting the attention of the forest department people.
- More fire lines are needed in the forest areas.
- People should be made aware about the consequences and cause of forest fire specially man made.
- Forest department should always remain alert especially during summer.
- Modern technologies should be used for the prevention and Control of forest fire.
- Certain areas need some fire towers where fire is not easily detected in time.
- Government should not compromise on the environmental issues such as forest fire hazard and should sanction more budget for using modern technology, for installing watch towers, and other infrastructure so that not only forest fires but also other forest related problems could be tackled side by side.
- People who are totally dependent on forests should use the resources sustainable or some alternative way of livelihood should be told to them.
- There should be separate department for reducing forest fire accidents in different stages, so that fire control measures could be handled independently and effectively.
- There is urgent need to initiate research in the field of fire detection, behaviour and fire ecology for better management of forest fires

- Precaution, human caused fires through education and environment, modification, i.e. agricultural activities, engineering works, people participation etc. will be helpful to control forest fires.
- Fire fighting resources should be made available to fire fighters.
- Introduction of forest fuel modification system at strategic points.
- Joint forest management committees are to be established at village level. These committees are given responsibility to protect forest from fire. But a separate committee should be made for forest fire because in case time is wasted it becomes very difficult to control forest fire.

7.2.2. Recommendation for Further Research

- To make the fire risk zone map and other parameters more reliable one can add climatic variables such as wind speed, wind direction, relative humidity and rain fall and temperature data.
- Other models like fire spread models and fire behaviour models can be incorporated.
- One can also take into consideration other environment models, which are dealing with the issue of pollution etc.
- Using important parameters and adjustments one can carry out re- research in state, national or global aspect.
- One can also do vulnerability mapping taking into consideration, the number of houses in each village, the population of each village, or agriculture per capital income of each village, and area of different villages.

7.3. Final words

Forest fires are consuming lots of valuable money, time and resources. It is very difficult to estimate the cost of the forest resource wealth. If these resources are being used and destructed, our future generation will be affected very badly both physically and mentally and it may not only cause threat to our wildlife but also to mankind in near future. So let us pledge today to safeguard our environment by taking responsibility not to exploit the natural resources rather try to preserve them from natural hazards and those who are intended to destroy them intentionally or unintentionally. And make more and more people aware regarding the importance of these resources.

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9. Appendices

Appendix -1: Weather data for the year 2005 and 2006

Year	Average	Max	Avg	Max	Min	Average	Max	Min	Avg	Max	Total
2006	WS	WS	RH	RH	RH	AT	AT	AT	SR	SR	RG
Jan	0.49	2.04	85.21	99.99	53.76	10.48	17.01	5.58	0.08	0.61	0.7
Feb	0.6	2.76	70.04	95.68	36.1	16.96	24.66	10.62	0.13	0.71	1.9
Mar	0.61	3.93	62.63	93.1	29.55	18.53	26.92	11.88	0.17	0.65	80.5
Apr	0.65	4.9	52.76	86.11	22.22	23.22	32.62	15.52	0.24	1.03	19.7
May	0.65	5.16	66.83	91.38	37.25	26.68	35.39	20.51	0.25	1.02	528.4
Jun	0.57	4.47	65.65	91.27	37.55	27.59	35.3	21.6	0.25	1.13	163.2
Jul	0.41	3.09	87.44	98.91	65.35	27.53	33.1	24.09	0.21	1.19	194.8
Aug	0.42	3.26	89.53	99.99	65.88	26.29	31.97	23.19	0.21	1.22	107.5
Sep	0.49	2.9	83.47	98.81	56.94	25.42	31.57	21.24	0.19	0.97	11.4
Oct	0.57	3.02	77.51	98.21	46.39	21.21	28.11	15.94	0.15	0.77	20.4
Nov	0.56	2.13	78.31	98.95	46.66	15.88	22.57	10.65	0.1	0.65	1.4
Dec	0.52	1.99	84.27	98.9	53.58	11.51	17.95	6.89	0.05	0.59	26.4
Year	Average	Max	Avg	Max	Min	Average	Max	Min	Avg	Max	Total
2005	WS	WS	RH	RH	RH	AT	AT	AT	SR	SR	RG
Jan	0.43	2.19	90.84	99.99	64.21	9.66	15	6	0.08	0.62	2.6
Feb	0.51	3.12	86.08	99.99	57.12	12.52	18.17	8.42	0.11	0.75	0.1
Mar	0.62	3.78	73.2	97.13	39.26	18.3	26.17	12.44	0.18	0.94	100.4
Apr	0.14	0.97	49.39	82.26	20.69	22.62	31.95	14.85	0.25	1.03	221.7
May	0.26	2.03	51.61	81.65	22.51	25.49	35.2	18.15	0.28	1.1	520.35
Jun	0.69	6.05	54.52	81.19	28.33	29.43	38.22	22.38	0.21	1.09	158.35
Jul	0.38	3.35	89.73	99.7	67.43	26.65	32	23.66	0.19	1.18	198.43
Aug	0.45	3.25	86	99.11	61.84	27.05	32.83	23.31	0.23	1.05	222.6
Sep	0.39	2.55	90.83	99.9	72.58	24.35	28.72	21.43	0.15	0.89	341.4
Oct	0.54	2.43	87.98	99.9	62.38	19.88	25.1	16.02	0.16	0.76	14.7
Nov	0.56	1.8	87.57	99.9	56.01	12.93	19.61	8.29	0.11	0.67	1
Dec	0.52	1.68	87.24	99.9	53.66	9.2	16.33	4.35	0.05	0.57	4.3
											908.8

WS = Wind speed (m/s) RH = Relative Humidity (%) AT = Air Temperature (deg C) SR = Solar Radiation (KW/m2) RG = Rain Gauge (mm)