Chapter-II

REVIEW OF LITERATURE

The forest fires are a common occurrence in most parts of the world and they cause a lot of damage to biodiversity as well as to the local ecology. There have been many studies conducted to know its causes, consequences and then plans made to manage these forest fires. The studies conducted so far are reviewed in brief as comprehensive national, regional or global statistics on wild fires are not available that would allow a reliable and precise comparison of the global fire occurrence in the 1980s and 1990s. However, some general observations can be made. Both decades experienced high inter-annual regional and national variability of fire occurrence and fire impacts. ‘El Nino’ episodes such as in 1982-1983 and 1997-1998 were the most important climatic oscillations affecting area burned and fire impacts in both decades.

2.1 History of Forest Fires Worldwide - An Overview

The single worst wild fire in U.S. history, in both size and fatalities, is known as the Great Peshtigo Fire which burned 3.8 million acres (5,938 square miles) and killed at least 1,500 people in northern Wisconsin and the Upper Peninsula of Michigan during the second week of October in the year 1871. Many sources put the size of the fire at 1.2-1.5 million acres but that included only the area that was completely burned and not the additional 2.3 million acres in surrounding counties that also suffered burn damage. All in all, well over 2,000 people died during the two weeks of extensive fire when close to 5 million acres (7,800 square miles) was burned (October 8-21, 1871) in Wisconsin, Michigan, and Illinois. All of the deadliest wild fires in American history have occurred in the Upper Midwest. Other notable fires were the Hinkley, Minnesota fire of September 1, 1894 that killed 400-800 and the Cloquet, Minnesota fire of October 13-15, 1918 that killed as many as 1,000 (Brown and Smith, 2000).

The worst wild fire in western history and the 2nd largest overall in the United States was the Great Fire of 1910. This massive forest fire burned some 3 million acres (4,700 square miles) in Idaho and Montana beginning on August 20-21, 1910. It killed at least 87 people, mostly ill-equipped firefighters, including a single crew of 28 who were overcome by
the flames near Setzer Creek outside Avery, Idaho. The worst hit town was Wallace, Idaho, of which one-third was razed (Covington and Moore, 1994a & 1994b).

The largest (and deadliest) wild fire in Canadian history as well as in the northeast of the U.S. was the Miramichi Fire of October 7, 1825. An estimated 3 million acres (4,685 square miles) of forest burned in the Canadian province of New Brunswick and in the U.S. state of Maine. At least 160 people died but the toll may have been much higher since an unknown number of loggers in the area may have perished (Simard et al., 1985).

Canada’s largest fire in modern history was the Chapleau-Mississagi fire of May and June, 1948 in northeastern Ontario. It burned 691,880 acres (1,081 square miles) and smoke from the fire was so dense that in Texas streetlights had to be turned on during the daytime in some cities. A smaller but deadlier wild fire, the so-called Porcupine Fire, burned 494,000 acres (772 square miles) in northern Ontario in July 1911. At least 70 people died in several mining camps and communities in the area. A wild fire in Acadia National Park, Maine during October 25-27, 1947 destroyed much of Bar Harbour and burned 2,05,678 acres (321 square miles), and killed 16 (Swetnam and Betancourt, 1990).

The deadliest urban wild fire, however, was that which burned into the cities of Oakland and Berkeley on October 20, 1991. Although only about 1,500 acres burned, the fire consumed 3,500 homes and apartment buildings and killed 25. This fire was caused by a Diablo wind event and remains the deadliest and costliest urban wild fire in U.S. history (Frost, 1998).

Perhaps the largest wild fire in modern world history was that known as The Black Friday Bushfire in Australia’s Victoria State on January 13, 1939. Some 5 million acres burned (7,800 square miles) and 71 died. About 75% of the entire state was affected and 1,100 homes and log mills were destroyed. Ash from the fires fell in New Zealand some 2000 miles to the east (Heinselman, 1978).

Australia’s deadliest wild fire, and the nation’s worst natural disaster, was the Black Saturday Fire of February 7-February, 2009. A swarm of fires burned 1.1 million acres (1720 square miles) and killed 173, many victims died in their automobiles trying to outrun the flames. 3,500 structures burned across the state of Victoria. The exact cause of the fires (aside from drought, heat, and wind) has never been determined although arson is suspected in several cases (Kim et al., 2009).
Figure 2.1: World’s Map showing Hot Spots of Forest Fires (GFMC, 2000)
Statistical evidences suggest that there is a trend of increasing area burned starting in the early eighties and continuing to increase in the 1990s (IPCC, 2007). Wildland fire statistics for National Forests in the western United States also show an increase in area burned from the mid-1980s onward compared to the earlier part of the 20th Century. Summarizing the wildfire trends of the 1980s and 1990s’ in Pacific Northwest forests, it can be concluded that there is no unidirectional tendency. Some areas suffered more fires due to increasing land-use intensity. Other forest regions have become more susceptible to larger and more damaging fires as a result of long-term fire exclusion. An important consideration is the fact that large areas of degraded forests and other wooded lands have been converted to grasslands and shrublands with repeated fires. These grasslands and shrublands are prone to burn much more frequently, inhibiting the succession back to tree cover.

Devastating fires have occurred worldwide and most of these have been caused through human activities including incendiariam and to a small extent by natural sources of ignition. According to United Nations study, the total forest area of the world in 1900 was nearly 7000 M ha and by 1975, it was reduced to 2890 M ha (Haywood, 1995). Severe forest fires have occurred in many countries in Asia, Africa, Europe, North America, South America and Australia. Some of the fire situations of different countries are reviewed as follows:

2.1.1 Fire Situation in South Africa

Huntley (1984) reviewed the fire situation in South Africa and concluded that Natural forests in South Africa cover less than 1 percent of the total area and fire plays an important role on the edges of these forest communities. However, wildfires seldom penetrate the larger patches of mature forest, although charcoal within the soil profiles of some forests indicates that fires may occur in natural forests at intervals of several hundreds of years. Further added that fire is an infrequent, but significant phenomenon in the Arid Savannah Biome, normally occurring after above-average rainfall has been recorded and subsequently a higher biomass production was experienced. In the Moist Savannah Biome fire occurs more frequently at approximately five-year intervals, but as common as annually in places during some seasons.

Industrial forests, such as even-aged *Acacia, Eucalyptus* and *Pinus* plantation stands, cover an area of approximately 1.5 percent of South Africa and are regularly exposed to
wildfire damage, because of the fire history of the host vegetation, and the fire history of the countries of tree origin. Until 1990 fire was mostly excluded from these forests.

Van Wilgen et al. (2000) analyses the fire history of the Kruger National Park in South Africa (1.9 million ha) for different periods in the park’s history and concluded that fires covering 16.79 million ha occurred between 1941 and 1996 (16 percent of the area burning each year on average). Of this area, 5.15 million ha burnt between 1941 and 1957, when limited prescribed burning and protection from fire took place (16 percent burning each year on average). Between 1957 and 1991, 2213 prescribed burns covering 5.1 million ha (46.3 percent of the 10.98 million ha burnt during that period) were carried out.

They further added that lightning fires burnt 2.5 million ha between 1957 and 1996, or 21.6 percent of the area. The mean fire return period was 4.5 years, with intervals between fires from 1 to 34 years. The distribution around the mean was not symmetrical and the median fire interval was 3.1 years. Some areas burnt more often than others, and mean fire return periods ranged from 2.7 to 7.1 years in the 11 major land systems of the park. Fires occurred in all months, but 59 percent of all fires took place from September to November. Prescribed burns were concentrated late in the dry season (September to November). Lightning fires were later, with 84.7 percent of the area burning between September and January. Compared to the year 1989 - which was a year that saw some serious wildfires in Industrial Forests - 1990 and 1991 saw a steady increase in the number of fires experienced in Kwazulu-Natal, from 210 during 1989, to 350 during 1990 and to 510 during 1991. In 1992, a serious drought occurred in most of the Summer Rainfall Regions in the North and East of South Africa. Subsequently, the number of fires reported in the forest regions of these provinces increased to 792, but surprisingly losses from wildfires were less than during 1991, and only 9,333 ha of industrial forests were lost (Meikle, 1993). In 1993, no major fire events were recorded. Towards October 1994, three major plantation wildfires raged in the Sabie District, destroying more than 1,000 ha in each case. During one fire in a SAFCOL plantation in the area, ten firefighters lost their lives when the fire spotted around the team inside Pinus and Eucalyptus stands. Two firefighting vehicles were also burned out in the process and combined losses for the district in terms of timber losses exceeded US$1 million. During 1998 two serious fires occurred in the Tsitsikamma Region. In one of them 60,000 ha of fynbos were burned and 4,000 ha of industrial forests were destroyed. Six people lost their
lives in this fire and 250 were left homeless. Damage to standing timber alone exceeded US$1 million. During January 2000, the Cape Peninsula was devastated by a serious fynbos wildfire, which burned 8,000 ha of fynbos vegetation in that area. Elsewhere in the Western Cape Province an additional 10,000 ha of fynbos burned. In the Cape Metropolitan area 70 houses were damaged or destroyed by the fire and 200 shacks of an informal settlement were also razed in the process. Total fire suppression costs exceeded US$3 million, while insurance claims are expected to exceed US$0.5 billion.

2.1.2 Fire Situation in Germany

In Germany the main fire problem areas are located in the northern portion of the country where predominantly poor soils are associated with continental climate features. The forests in this region between Lower Saxony in the West and Brandenburg in the East (bordering Poland) are dominated by pine (Pinus sylvestris) stands characterised by a relatively high fire hazard.

Muller-Dombois and Goldammer (1990) reviewed the fire situations in Germany as registered with Global Fire Monitoring Centre. The majority of fire damages occurred after the war in the East German territory. Between 1951 and 1960, the average number of 1,761 fires per year were registered with an average burned area of 3,660 hectares per year. In this context, it is important to note that forest land comprises only 28 percent of East Germany.

In West Germany, the conflagrations of the years 1975 and 1976 in Lower Saxony had a strong impact on the statistics for the period 1971 to 1980. The average number of fires rose to 2,107 with an average burned area of 2,884 ha per year. In 1975 the average size of the burned area per fire increased to 5.15 ha. The number of fires and the area burned depend on inter-annual climate variability and ranged from 242 ha in the wet year 1985 to a maximum of 8,768 ha in the hot and dry year 1975. Therefore, the West German statistical figures show that the burned area of 1975 was 36 times larger than in 1985. The importance of the climate is also represented in the average size of the burned area. In East Germany the amounts ranged from 0.52 up to 6.93 ha between 1946 and 1990; whereas West German data show areas from 0.35 to 5.15 ha. After reunification 1992 shows a peak of burned area with 4,908 ha. More than 80 percent of these fires happened in East Germany and a considerable number started on military training areas. They detected that most fires occur in spring and in
high summer. The average number and the average burned area in this period indicate two peaks in April and August.

2.1.3 Fire Situations in Asian Regions

The Asian region suffered extreme wildfire and smoke episodes during the 1990s. Insular Southeast Asia was most affected by several El Nino-Southern Oscillation (ENSO) events in the 1990s, particularly during the extreme ENSO in 1997-98. Extended droughts favoured the application of land-use fires, forest conversion burning (use of fire in land-use change) and extended wildfire situations. The fires have caused impoverishment or destruction of primary and secondary equatorial rain forest ecosystems over large areas. Indonesia was the main source of smoke-haze that affected the entire region for almost one year and affected the health of more than 100 million people living in the region.

Continental South and Southeast Asia continued to experience extended wildfires in the seasonal (deciduous) forests, e.g. monsoon forests and forest savannahs. Human-induced wildfires in the deciduous forests are common since historic times. As a traditional element of forest utilization, especially for improving grazing conditions (silvopastoral land use), or to improve productivity or facilitate harvest of non-wood forest products, these fires partially represent prescribed burning systems. However, many of the fires are not contained and tend to escape as extended wildfires.

In Central Asia, the most challenging fire region is between the steppe and southern boreal forests. Steppe fires exert a tremendous pressure on the adjoining forests. Recent socio-economic changes have led to an increasing occurrence of wildfires in Mongolia and its neighbour countries.

Arkhipov et al. (2000) reported that the largest number of wildfires of the 20th Century occurred in the 1990s. A recent analysis reveals that the number of wildfires and the area burned in Kazakhstan grew exponentially during the last 50 years. He further added that extreme fire years were 1963, 1974 and 1997. The most extreme fire season occurred in 1997 when a total of 2,257 wildfires affected 2,16,950 ha large crown fire in Altai in 1997 (Markakol Ranger Station) generated a fire storm in which 17 firefighters were killed. The wood losses from wildfires in Kazakhstan for the period 1991 to 2000 were calculated as 92
million $US in domestic wood prices. The costs of these losses in world prices exceeded 400 million $US.

2.1.4 Fire Situation in Indonesia

Wildfires escaping from land-use fires are becoming more and more regular, especially during episodic droughts (inter-annual climate variability) associated with the El Nino-Southern Oscillation (ENSO) event. Similar report was published by Lennertz and Panzer (1984) that the first large fire and smoke episode in the second half of the twentieth century in Indonesia occurred during the ENSO event of 1982-1983. The fire scene in the Indonesian and Malaysian provinces of Borneo was set by extreme drought and by extensive slash-and-burn land-clearing activity that resulted in a large number of escaped fires. In East Kalimantan alone, 3.5 million ha were affected by drought and fire. Of the total area, 0.8 million ha was primary rain forest, 1.4 million ha logged-over forest, 0.75 million ha secondary forest (mainly in the vicinity of settlement areas), and 0.55 million ha peat swamp biome. Goldammer and Seibert (1990) then estimated total loss due to mega fires that affected the overall land area of Borneo exceeded 5 million ha.

Goldammer and Crutzen (1993) reported that sequence of severe ENSO-related droughts over the last two decades, combined with human disturbance of rain forests and indiscriminate use of fire, have led to massive wildfires. This burning has produced dramatic changes in fire regimes and the overall size of degraded land area. Experience in East Kalimantan and other parts of the region have shown that important rain forest species are able to survive the irregular, non-uniform impacts of a single forest fire. However, because of altered microclimate, species composition, forest structure, and fuel availability the fire hazard in these damaged ecosystems has increased. A second and a third wildfire tend to burn with higher intensity and severity, thus leading to more complete destruction of the forest structure and the overall biodiversity of the flora and fauna. Similar observations were made regarding the Brazilian Amazon forest by Nepstad et al. (1999).

In Southeast Asia, repeated wildfires in conjunction with land use impacts have led to the formation of large areas of degraded Imperata cylindrica grasslands. The majority of these grasslands are subjected to a one-year fire return interval, often purposely burned by local people to prevent the growth of woody and forest species.
The wildland fire and smoke-haze episodes in Indonesia during the 1980s and 1990s have been largely influenced by the occurrence of droughts triggered by the El Nino-Southern Oscillation (ENSO) and the associated increase in wildland fire danger. During and after the ENSO and fire episodes of 1987, 1991, 1994 and 1997, only limited research has been accomplished on the extent and damage caused by fire and atmospheric pollution. In 1996 the Environmental Impact Management Agency (BAPEDAL) released fire statistics for the period 1984-1994 that were published in International Forest Fire News (Makarim and Deddy 1997). They revealed that in most years wildfires affect between 15,000 and 25,000 ha. Extreme years were 1991 (1,99,000 ha) and 1994 (4,06,000 ha). The figures on fire occurrence released by the Indonesian Ministry of Forestry for 1994 included burning activities other than wildfires for the first time. According to the Ministry a total land area of 5.1 million ha was affected by fire in 1994.

In 1997-1998 Indonesia experienced a fire episode that exceeded the size and impact of the 1982-1983 fires (Goldammer et al. 1999; Hoffmann et al. 1999a; Siegert and Hoffmann 2000). A prolonged and severe fire season occurred during the ENSO of 1997-1998. Six months of drought occurred in 1997. Following a short period of rainfall in December 1997, the drought continued through May 1998. During the 1997 ENSO event large fires occurred in Sumatra, West and Central Kalimantan and Irian Jaya/Papua. In 1998 the greatest fire activity occurred in East Kalimantan. These widespread fires resulted in dense haze across Southeast Asia, causing respiratory health problems as well as transportation delays and accidents on land, air and sea. Economic costs were estimated at over US$9.3 billion (ADB, 1999) and the smoke-haze resulting from the fires led to disagreements with neighbouring countries (i.e. Malaysia, Brunei and Singapore). All the fires of 1997-1998 were human-caused. The majority of the fires were due to land speculation and large-scale forest conversion as a result of inadequate and unenforced land use policies. In addition, fires in settlement/transmigration areas were caused by land use conflicts, carelessness or hunting. However, the lack of inter-agency coordination to respond and suppress the fires played an important role in the severity and extent of the fire situation.

Although strong winds and prolonged drought contributed to the rapid spread of wildfires, Indonesia’s inadequate initial attack and large-fire suppression capacities were not sufficient to deal with the situation. These conditions continue to exist. The Indonesian
province of East Kalimantan was the area most severely affected by the fires. Burned area is estimated at 5.2 million ha for 1997-1998, about 25 percent of the entire province (Hoffmann et al. 1999b). As a result of the 1997-1998 fires, East Kalimantan’s forests are now more susceptible to fire during normal dry seasons due to the degraded forest condition and the accumulation and alteration of native fuel complexes.

In 1999, fires occurred in Sumatra, West Kalimantan and Central Kalimantan. In Kalimantan over 400 fire events were detected in a single day in August using NOAA-AVHRR imagery. Although the 1999 fires did not reach the extent of those in 1997-1998, the risk of severe fires remains if another ENSO event occurs as predicted in 2001-2002. As documented in the statistics of Global Fire Monitoring Centre (2000), the total area of 9,655,000 ha was burned during 1997-1998 wildland fires.

2.1.5 Fire Situation in Malaysia

The worst forest fires experienced by Malaysia were in 1982/83 when almost one million hectares of natural forest burned in Sabah. This was at the same time when numerous fires affected Borneo and 3.2 million ha in Kalimantan. However, for Malaysia this was the only case where natural forest fires of this magnitude were ever recorded. Subsequently, forest fires continued to occur in Malaysia but the extent was less and mainly located in secondary conversion forests, forest plantations and degraded forests. Forest fires have been reported as early as the 1970s in the pine plantations and the 1980s in the Acacia mangium plantations. Forest fire data on 1992-1997 reported that total area burned during this period was 5687 ha and all the fire incidences took place by human interference in one way or the other.

The fires mainly involved peat and beris (heath) forest and bush areas. The fires burned in a slow and patchy manner, but were widespread. The fires spread slowly through the thick peat layers, making it extremely difficult to detect and extinguish them. In such areas, although the surface fires are extinguished, the peat underground will continue to burn unless a large amount of water is used to completely drench the peat layers. Consequently, those involved in extinguishing the fires had a difficult time, because they lacked the necessary tools and experience and they were not trained to handle forest fires. In addition,
the remoteness and ruggedness of the terrain exacerbated the problem even further. In many of the affected areas, there were also logistical problems.

It is obvious from the above records that incidences of forest fires mainly occurred in forest plantations, degraded peat swamp forests and logged-over forests. The frequency of occurrences also increases appreciably during the *El Nino*-Southern Oscillation (ENSO) years where prolonged dry spells are experienced. During 1997/98 fire situations, total area burned was 2799 ha as recorded with Forest Department Peninsular Malaysia and Forest Research Institute Malaysia statistics. The 1997 haze reached a critical level i.e., Air Pollution Index (API) reached 500. This caused much inconvenience and economic disruption in Malaysian economy. Other than health impacts, the haze has caused various other quantifiable losses. Although the cost of the health impacts is small, the overall impacts from other sectors were quite large. According to the Economy and Environment Program for Southeast Asia (EEPSEA) study, the estimated incremental cost of the haze damage to Malaysia during the months of August to October in 1997 was RM816 million (Dennis, 1999 and de Groot et al., 2007).

Thus, the problems caused by forest fires in the ASEAN region have assumed a new and serious dimension that needs to be addressed sufficiently. Large areas of forestlands have been devastated, resulting in economic losses that run into billions of dollars, degradation of our environment and irreversible losses of valuable biological diversity. The episodes of forest fires and haze in the last two decades, namely in 1982/83, 1990, 1991, 1994 and 1997/98 should serve as useful lessons to be more cautious and undertake all efforts to ensure that we are prepared in the future. The ENSO dry spells will come and the fires will recur. The intensity of the problem will then depend on our state of preparedness to face the crisis, as well as the degree in which we are able to implement the various preventive measures.

### 2.1.6 Fire Situation in Thailand

In Thailand, 25 percent of the country is covered by forests, or 12.97 million hectares. The Deciduous forests comprise 53 percent of the total forested area, while evergreen forests make up 47 percent. Human-caused fires have long been a component of various forest ecosystems. They occur annually during the dry season from December to May with the peak period in February and March. In a normal year, the most common surface fires mainly take
place in Dry Dipterocarp forests and in Mixed Deciduous forests. During extended drought conditions related to the *El Nino*-Southern Oscillation (ENSO) event, fires spread, to a certain extent, into Dry Evergreen, Hill evergreen or even into some parts of the Tropical Rain forest. In certain extremely dry sites, forests may burn twice per fire season. Although other types of fire are not typical to the forests of Thailand, in the recent *El Nino* episode of 1997-1998, a notable number of crown fires took place in Pine (*Pinus* spp.) plantations. Peat-swamp forests desiccated appreciably and a number of ground fires occurred as well. The most severe fires took place in 1998 when the country was affected by the last *El Nino* episode. During that time, a number of large fires broke out in various parts of the country. Fire took place at Phu Kadong National Park in Loei Province, Northeastern Thailand in early March. One thousand nine hundred and twenty hectares of Pine Forest and Hill Evergreen Forest were severely burnt. Impacts caused by this fire were tremendous because the burnt site is not only a watershed area but also one of most famous tourist spots in the country. Simultaneously, these major fires took place at Doi Intanon National Park in Chiangmai Province, Northern Thailand in mid March. The fire lasted for five days and consumed 480 ha. of Dry Forest as well as Hill Evergreen Forest in the sensitive watershed area. The fire killed about 20 percent of mature trees. Damages caused to the watershed area were far beyond the assessment capabilities. This fire also took place at Kao Yai National Park in Nakornrachasima Province, Northeastern Thailand in late March. This fire lasted for seven days and burnt 1,440 ha. of Dry Evergreen Forest. In addition to killing 30 percent of mature trees, the fire caused high mortality of wild animals, mainly wild chickens and their eggs, snakes and other small reptiles. This fire took place at Pru Todang Swamp forest, which is the country's only true Peat-Swamp Forest. This peat fire lasted for nearly two months from late April to late June. Fire destroyed 1,280 ha. of invaluable Peat-Swamp Forest. About 80-90 percent of mature trees were killed, along with all undergrowth. The affected area was nearly denuded after this fire. Smoke emitted from this fire covered the sky over Naratiwat Province in southern Thailand for almost two months. Hundreds of patients, mainly children and elderly, were treated in hospitals for their respiratory problems. A number of firefighters, including the correspondent who commanded the fire suppression operations, were also treated due to the same sickness.

Many of the forest fires that occurred during the years 1997 and 1998 have been linked to a drier climate and have been attributed to events such as *El Nino*-Southern
Oscillation (Narendran, 2001). Regional vegetation fire patterns in South and Southeast Asia by satellite remote sensing have been established by Malingreau et al. (1995) and confirm the high regional fire activity during the dry season.

2.1.7 Fire Situation in Bangladesh

In Bangladesh the total forested area affected by wildfire is 1,500 ha per year. Damages are limited to plantations that are established in the south and southeast of the country. The teak forest of the Chittagong Hill Tracts in the south experience fire, which is set intentionally by the Jhumias (hill people) for cultivating the land for agriculture. Some forests of Cox’s Bazar area (Napitkhali Range) are also affected. In this forest *Dipterocapus turbinatus* seedlings or regeneration are affected. Most forest fires occur in the Sitakundu Range (near Chittagong). These fires are set intentionally to stimulate the growth of *Imperata cylindrica*. The grass is used for thatching and therefore has a high commercial value. In the southeastern part (Sylhet) fire incidence are observed in bamboo forest.

2.1.8 Fire Situation in China

In China, the occurrence of forest fires varies from year to year depending on interannual climate variability. Furthermore, the variations of fire occurrence, fire size, and fire severity are closely related to the accumulation of combustible material in the forest. The major portion of forest fire occurrence is concentrated in a small number of regions (*High Fire Occurrence Regions*). Statistics reveal that the highest number and largest sizes of forest fires occur in the five provinces: Heilongjiang, Inner Mongolia, Yunnan, Guangxi and Guizhou (Shu Lifu and Xiaorui, 2002).

In these provinces, the numbers of forest fires accounted for 42.5 percent of the whole country, and the damaged area accounted for 75 percent of the area affected by fire in the whole country during the period 1950-1998. During this period more than 15,000 forest fires occurred and affected more than 20 million ha of forest lands. The most prominent fire years were 1951, 1955, 1956, 1961, 1962, 1972, 1976, 1977, 1979 and 1987.

In 1987, a large fire situation occurred in the Greater Xingan Mountains, Heilongjiang province. During these fires, 213 persons were killed and the burned area reached 1.33 million ha. Of this area, 8,90,000 ha were damaged, with a loss of 39.6 million cubic meters of wood.
volume. Thus, the forest cover rate of these regions has decreased by 14.5 percent from 76 percent to 61.5 percent.

The fires caused high mortality to large areas of young, mature, and over mature forest stands. The extreme fire severity not only led to the destruction of forest and forest floor cover, but also affected forest structure, biodiversity, micro-and macroclimate, and water regimes. It resulted in the reduction of the protection function of the forests, e.g. the protection of watersheds, soil conservation, and climate. Research revealed that the denudation of land surface resulted in changes of micro-climatic patterns, destruction of organic layers, and loss of water retaining capability.

During the 1990s (1990-1999) an average annual number of 5,324 fires affected forests with an average annual area burned of 1,22,036 ha.

**Table 2.1 : Major Forest Fires across different Countries during 1990s**

<table>
<thead>
<tr>
<th>Country</th>
<th>Year of Fire</th>
<th>Causes</th>
<th>Burnt Area</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America (Yellowstone National Park)</td>
<td>1988</td>
<td>Human, climate variations, lightening</td>
<td>250,000 ha</td>
<td>Ecological Monographs, 1997</td>
</tr>
<tr>
<td>Israel</td>
<td>1995</td>
<td>Incendiariism</td>
<td>8,153 ha</td>
<td>IFFN-15</td>
</tr>
<tr>
<td>Mongolia</td>
<td>1996</td>
<td>Human</td>
<td>3 million ha</td>
<td>UNEP</td>
</tr>
<tr>
<td>Brazil</td>
<td>1997</td>
<td>Human, climatic variations</td>
<td>3.3 million ha</td>
<td>INPA, UNEP</td>
</tr>
<tr>
<td>S-E Asia</td>
<td>1997</td>
<td>Human, climatic variations</td>
<td>4.5 million ha</td>
<td>UNEP</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1997</td>
<td>Human, climatic variations</td>
<td>750,000 ha</td>
<td>WWF, UNEP</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>1998</td>
<td>Human, climatic variations, lightening</td>
<td>2 million ha</td>
<td>UNEP, UNDAC, National Forest Fire Centre of Russia</td>
</tr>
<tr>
<td>Greece</td>
<td>1998</td>
<td>Human</td>
<td>1 million ha</td>
<td>WWF</td>
</tr>
</tbody>
</table>

(Source: Narendran, 2001)

Where: -

WWF : Worldwide Fund for Nature
UNEP : United Nations Environment Programme
UNDAC : United Nations Disaster Assessment Committee
NRC : Natural Resources Canada
IFFN : International Forest Fire News
INPA : Amazon National Research Institute
Although the number of forest fires in the Northeast accounts for just five per cent of all forest fires in China, these fires involve as much as 60 percent of national fire losses. The South and Southwestern regions account for 95 percent of fires, but just 40 percent of total annual fire losses. Fire seasons peak in May and October in the Northeast, while in the Southwest the peak fire season is from January to April. Across China, humans cause more than 95 percent of forest fires. In the Northeastern forest regions, however, lightning accounts for up to 30 percent of fire occurrences in some years.

2.1.9 Forest Fires in India

India constitutes one of the mega bio-diversity zones of the world, abundant with unique and diversified floral and faunal wealth. With 6, 90,899 square kilometers of forest cover, India is one of the richest areas of bio-diversity in the world. Including environmental benefits, the forests of the country are economically also very rich. If we take the example of conifers only, India has about 1.7 m. ha of productive conifer forest, with various valuable timber species i.e. fir, spruce, deodar, kail, teak, sal and chir pine.

Figure 2.2: Map of India showing Hot Spots of Forest Fires (GFMC, 2000)
Estimated growing stock of these forests is over 200 million cubic meters, the monetary value of which comes to be more than Rs. 40,000 to 60,000 millions (Bahuguna, 1999). Due to increasing population pressure need, this exemplary land ecosystem of the world is struggling for its survival. Increasing human interference in the natural forest ecosystem has also tremendously increased the forest fire incidences. Forest fire is one of the causative factors, which periodically covers large forest areas destroying timber, other properties and wildlife etc. The ecosystems are under severe threat due to recurrent fires apart from other anthropogenic pressures on the forests, which is attributed to the forest degradation, soil erosion, reduced productivity etc. Every year one or other part of the forests in India is facing the agony in the cruel hands of mankind by putting fire intentionally or unintentionally in the forests causing severe damage to the regeneration as well as to the soils.

In India, there is no comprehensive study data made to indicate the loss of forests in terms of area burnt and value, volume, regeneration etc. The available forest fire statistics are not reliable, as in most of the cases it is under-estimated. The reason behind this is probably the fear of accountability. Despite all this, some scanty data is available about forest fire in various forms.

Table 2.2: Major Forest Fires in Indian States (India State of Forest Report, 2011)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>State/Year</th>
<th>Location</th>
<th>Area affected (ha.)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Uttarakhand, 1995</td>
<td>Uttarakhand hills</td>
<td>3,75,000</td>
<td>Kaushik, 2004</td>
</tr>
<tr>
<td>2.</td>
<td>India, 1999</td>
<td>Ganga Yamuna watershed</td>
<td>80,000</td>
<td>Kaushik, 2004</td>
</tr>
<tr>
<td>5.</td>
<td>Gujrat, Feb., 2009</td>
<td>Gir Forest, Gujrat</td>
<td>32.38</td>
<td>Anonymous</td>
</tr>
<tr>
<td>6.</td>
<td>2009-March India</td>
<td>Taboda Reserve Forest</td>
<td>50</td>
<td>Anonymous</td>
</tr>
<tr>
<td>7.</td>
<td>2009-March India</td>
<td>Chamundi Hills</td>
<td>20</td>
<td>Anonymous</td>
</tr>
<tr>
<td>8.</td>
<td>April 2009, India</td>
<td>Bahadson Beer</td>
<td>200</td>
<td>Anonymous</td>
</tr>
<tr>
<td></td>
<td>Uttarakhand, April 2009</td>
<td>Chamoli/Gochar/Devprayag/Rishikesh</td>
<td>5</td>
<td>The Hindu, April 21, 2009</td>
</tr>
<tr>
<td></td>
<td>2009 India</td>
<td>Way Land</td>
<td>424</td>
<td>Anonymous</td>
</tr>
<tr>
<td></td>
<td>Maharashtra, Jan-May, 2010</td>
<td>Mumbai</td>
<td>10300</td>
<td>Anonymous</td>
</tr>
<tr>
<td></td>
<td>Nagaland 18-Feb-10</td>
<td>Tuesang District in Nagaland</td>
<td>4</td>
<td>Anonymous</td>
</tr>
<tr>
<td></td>
<td>H.P. June-10</td>
<td>Himachal Pradesh</td>
<td>19,109</td>
<td>Anonymous</td>
</tr>
<tr>
<td></td>
<td>Tamil Nadu, 2011</td>
<td>Ooty in Nilgiris</td>
<td>10 hectares (Reserve Forest)</td>
<td>TOI, TNN March 8, 2011</td>
</tr>
</tbody>
</table>
Forest Survey of India in a countrywide study in 1995 estimated that about 1.45 million hectares of forest area is affected by fire annually in the country (FSI, 1995). According to assessment of the Forest Protection Division of the Ministry of Environment and Forest, Government of India, fires in India annually affect 3.73 million hectares of forests (Table 2.2). In the context of India, according to the recent State Forest Report, the forest cover in India is 67.5 M ha, constituting 20.5 % of its geographical area, represented by 41.68 M ha of dense forest and 25.87 M ha of open forest.

Bahuguna and Lal (1989) reviewed the study made by Forest Survey of India about percentage of forest fire prone areas in different parts of the country as 51% of forest area in Assam and Gujarat, 93 % in Arunachal Pradesh, 67% in Bihar, 69% in Himachal Pradesh, 46 % in Jammu and Kashmir, 45% in Karnataka, 76% in Madhya Pradesh, 94% in Meghalaya and Orissa, 87% in Nagaland, 58% in Uttar Pradesh and 33% in West Bengal are subjected to repeated annual fires (Table 2.3).

**Table 2.3: Extent of Fire Incidence in Forest Areas of the Country**

<table>
<thead>
<tr>
<th>State/District</th>
<th>Forest Area (ha)</th>
<th>Sample Plots (No.)</th>
<th>Extent of fire incidents (ha)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Very Heavy</td>
<td>Heavy</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>14826.71</td>
<td>2037</td>
<td>60.58</td>
<td>5.75</td>
</tr>
<tr>
<td>Assam</td>
<td>15427.88</td>
<td>2482</td>
<td>70.91</td>
<td>0</td>
</tr>
<tr>
<td>Bihar</td>
<td>5317.01</td>
<td>296</td>
<td>57.718</td>
<td>0</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>10269.40</td>
<td>4878</td>
<td>163.7</td>
<td>0</td>
</tr>
<tr>
<td>Jammu &amp; Kashmir</td>
<td>3331.75</td>
<td>428</td>
<td>7.5</td>
<td>0</td>
</tr>
<tr>
<td>Haryana &amp; Punjab</td>
<td>1180.72</td>
<td>45</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Karnataka</td>
<td>13223.30</td>
<td>1780</td>
<td>59.71</td>
<td>30.33</td>
</tr>
<tr>
<td>Manipur</td>
<td>15154.00</td>
<td>1880</td>
<td>0</td>
<td>151.54</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>1962591</td>
<td>1947</td>
<td>136.53</td>
<td>23.07</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>8165.54</td>
<td>1355</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>9905.00</td>
<td>1659</td>
<td>26.75</td>
<td>0</td>
</tr>
<tr>
<td>Nagaland</td>
<td>14954.91</td>
<td>1128</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Orissa</td>
<td>20143.38</td>
<td>2972</td>
<td>204.42</td>
<td>78.5</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>20178.79</td>
<td>2446</td>
<td>71.39</td>
<td>0</td>
</tr>
<tr>
<td>Sikkim</td>
<td>1707.77</td>
<td>401</td>
<td>47.12</td>
<td>0</td>
</tr>
<tr>
<td>Tripura</td>
<td>6445.36</td>
<td>555</td>
<td>34.59</td>
<td>0</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>23164.09</td>
<td>2825</td>
<td>871.43</td>
<td>0</td>
</tr>
<tr>
<td>West Bengal</td>
<td>5764.81</td>
<td>1471</td>
<td>4.77397</td>
<td>0</td>
</tr>
<tr>
<td>Dadra &amp; Nagar</td>
<td>186.49</td>
<td>62</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Grand Total</td>
<td>208973.5</td>
<td>307.47</td>
<td>1817.12</td>
<td>289.19</td>
</tr>
<tr>
<td>Percentage</td>
<td>0.87</td>
<td>0.14</td>
<td>5.16</td>
<td>43.06</td>
</tr>
</tbody>
</table>

(Source: Bahuguna and Lal, 1989)
Raghava and Raghava (1995) figured government assessment of forest loss of about 9 crores in the country due to forest fires, on an average annually. However, Sexana and Rai (1997) reported 54.7% and 50% of the total forest area was under fire during 1997 in India and Himachal Pradesh, respectively.

Table 2.4: Forest Fire Incidences in Indian States & UTs during 2008-2011

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>State/UTs</th>
<th>2010-11</th>
<th>2009-10</th>
<th>2008-09</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Andaman &amp; Nicobar</td>
<td>0</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Andhra Pradesh</td>
<td>1119</td>
<td>1837</td>
<td>2442</td>
</tr>
<tr>
<td>3</td>
<td>Arunachal Pradesh</td>
<td>485</td>
<td>576</td>
<td>786</td>
</tr>
<tr>
<td>4</td>
<td>Assam</td>
<td>1322</td>
<td>2511</td>
<td>1901</td>
</tr>
<tr>
<td>5</td>
<td>Bihar</td>
<td>81</td>
<td>397</td>
<td>143</td>
</tr>
<tr>
<td>6</td>
<td>Chandigarh</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Chhattisgarh</td>
<td>1074</td>
<td>2835</td>
<td>2849</td>
</tr>
<tr>
<td>8</td>
<td>Dadra &amp; Nagar Haveli</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>Daman &amp; Diu</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>Delhi</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>Goa</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>Gujarat</td>
<td>101</td>
<td>179</td>
<td>182</td>
</tr>
<tr>
<td>13</td>
<td>Haryana</td>
<td>5</td>
<td>29</td>
<td>21</td>
</tr>
<tr>
<td>14</td>
<td>Himachal Pradesh</td>
<td>6</td>
<td>125</td>
<td>168</td>
</tr>
<tr>
<td>15</td>
<td>Jammu &amp; Kashmir</td>
<td>7</td>
<td>30</td>
<td>117</td>
</tr>
<tr>
<td>16</td>
<td>Jharkhand</td>
<td>192</td>
<td>1314</td>
<td>430</td>
</tr>
<tr>
<td>17</td>
<td>Karnataka</td>
<td>370</td>
<td>428</td>
<td>604</td>
</tr>
<tr>
<td>18</td>
<td>Kerala</td>
<td>10</td>
<td>106</td>
<td>166</td>
</tr>
<tr>
<td>19</td>
<td>Lakshadweep</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>Madhya Pradesh</td>
<td>1451</td>
<td>2386</td>
<td>2894</td>
</tr>
<tr>
<td>21</td>
<td>Maharashtra</td>
<td>882</td>
<td>1789</td>
<td>2257</td>
</tr>
<tr>
<td>22</td>
<td>Manipur</td>
<td>1275</td>
<td>2487</td>
<td>1477</td>
</tr>
<tr>
<td>23</td>
<td>Meghalaya</td>
<td>879</td>
<td>1743</td>
<td>1010</td>
</tr>
<tr>
<td>24</td>
<td>Mizoram</td>
<td>1691</td>
<td>4675</td>
<td>3434</td>
</tr>
<tr>
<td>25</td>
<td>Nagaland</td>
<td>919</td>
<td>1654</td>
<td>984</td>
</tr>
<tr>
<td>26</td>
<td>Orissa</td>
<td>780</td>
<td>2515</td>
<td>2087</td>
</tr>
<tr>
<td>27</td>
<td>Puducherry</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>28</td>
<td>Punjab</td>
<td>10</td>
<td>56</td>
<td>41</td>
</tr>
<tr>
<td>29</td>
<td>Rajasthan</td>
<td>86</td>
<td>117</td>
<td>96</td>
</tr>
<tr>
<td>30</td>
<td>Sikkim</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>31</td>
<td>Tamil Nadu</td>
<td>34</td>
<td>148</td>
<td>276</td>
</tr>
<tr>
<td>32</td>
<td>Tripura</td>
<td>634</td>
<td>1127</td>
<td>717</td>
</tr>
<tr>
<td>33</td>
<td>Uttar Pradesh</td>
<td>198</td>
<td>737</td>
<td>370</td>
</tr>
<tr>
<td>34</td>
<td>Uttarakhand</td>
<td>85</td>
<td>855</td>
<td>631</td>
</tr>
<tr>
<td>35</td>
<td>West Bengal</td>
<td>197</td>
<td>224</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>13898</td>
<td>30892</td>
<td>26187</td>
</tr>
</tbody>
</table>

(Source: India State of Forest Report 2011)
The identification of fire sensitive zones as well as the fire seasons is likely to help in formulation of effective forest fire control strategy in terms of prevention, alertness, mitigation, fund allocation and deployment of personnel and equipment. FSI to the States in the year 2010-11 has generated basic data on the pattern of forest fire in the country which can be used for preparing national level strategy for early warnings and burnt area assessments. A total of 13,898 fire incidences were reported by 2011 (Table-2.4).

Srivastva (1999) reported that 17,852 wildfires were registered in India between 1980 and 1985, affecting an area of 5.7 million ha. The frequency of fires is rising as the biotic pressure on forest resources is increasing. According to an assessment of the forest protection division of the Ministry of Environment and Forests, Government of India, 3.73 million ha of forests are affected by fires annually in India creating a financial damage of Rs. 440 crores. Other losses due to these fires included loss of soil fertility, soil erosion, loss of employment, drying up of water resources and loss of bio-diversity.

Bahuguna and Singh (2002) also reported that fires brought a major change in the microclimate of the region in the form of soil moisture balance and increased evaporation. The dense smoke from the fires affected visibility up to 14,000 feet.

Roy (2004) reported that fire is a recurrent phenomenon due to higher levels of water stress during summer in tropical deciduous forests. While statistical data on fire loss is weak, it is estimated that the proportion of forest areas prone to forest fires annually ranges from 33% in some states to over 90% in others.

2.2 Existing Fire Management Strategies and their Efficacy

The vulnerability of the Indian forests to fire varies from place to place depending upon the type of vegetation and the climate. The coniferous forests in the Himalayan region comprising of Abies spp., Picea smithiana, Cedrus deodara, Pinus roxburghii and Pinus wallichiana etc. are highly prone to fire. Forest fire is a major cause of degradation of India’s forests. Hence, the purpose of collecting the relevant literature is to investigate the effect of various factors for effective prediction, suppression and improvement in management of forest fires.

The knowledge about where, when and why do forest fires start is essential to assure appropriate fire policy and its management. The ability to understand and predict the patterns
of fire ignitions will help managers and decision makers to improve the effectiveness of fire prevention, detection and fire fighting resources allocation. Hence, analysis of key factors, driving fire ignitions are essential for understanding the patterns of fire occurrence in any region.

There is evidence that the earliest use of fire by hominids occurred more than one million years ago although solid evidence date from less than 300,000 to 400,000 years (Pausas and Keeley, 2009; Weiner et al., 1998). Natural fire regimes have been increasingly altered by humans for many thousands of years at least, so that in most regions of the world, human activities have become much more important than natural sources of ignition (Goldammer and Crutzen, 1993). This is especially true for Europe and particularly for the Mediterranean Region with its long history of human intervention in the ecosystems (Thirgood, 1981).

Bassi and Kettunen (2008) and Velez (2009) studied the causing factors for forest fires in Europe and found that some of the major anthropogenic causes are associated with land management such as burning of agricultural and forestry residues, land burning for pasture renovation or the use of machinery. However, there are many other factors that are also known to cause fires, including arson, accidents with electric power lines and railways or the fire use associated with forest recreation.

### 2.2.1 Worldwide Fire Management Strategies

Prescribed burning is being used in the forest regions of many countries. The major goal of prescribed burning is to reduce the load of fuels (combustible materials) which in conjunction with the meteorological factors are determining the intensity and severity of a forest fire. Prescribed burning operations observe meteorological factors (wind, temperature, humidity and relative humidity), moisture of fine fuels and stability of the atmosphere. Downed woody materials and the litter layer are burned out under control. In the Northeast forest region, the most common method is to burn after frost or immediately after snow melt. Forest sites with difficult topographical characteristics can be treated by prescribed fire efficiently. Thus, the use of prescribed fire to reduce forest fuels is of significant importance for preventing very large and destructive wildfires (Wade and Wilhite, 1981; Johansen, 1981, 1984 and 1987; Lunsford, 1987; Wade and Lewis, 1987).
Patterson et al. (2003) used prescribed fire for long leaf pine stands at Southeast America as a good tool to manage forest fires, improper or incorrect use could lead to undesired consequences and repeated prescribed fire every two to 10 years is essential to perpetuate ecosystems.

However, Shu Lifu and Xiaorui (2002) studied the trends of forest fires and area burnt in the Daxinganling forest region (Northeast China), a lightning detection and monitoring system has been established to identify and locate fires started by lightning. They constructed greenbelt as fuel breaks to effectively prevent the spread of wildfires. Fuel breaks on which fire-resistant trees, fruit trees, and other economic plants are grown are designed to slow down or halt the spread of a wildfire. These systems can produce economic benefits to the area, conserving the water and soil, and improving ecological conditions. The change of tree and other vegetation composition on fuel breaks can prevent the spread of forest disease or insect pests. Economic, socio-economic, and ecological benefits all can be achieved through a network of fuel breaks. The total length of greenbelt fuel breaks in China at the end of the year 2000 is 172,100 km. A framework of a forest fire prevention system has been established based on administrative leadership, regulations, information, firefighting units, socio-economic cooperation and fundamental firefighting facilities. Therefore, the frequency of destructive forest fires and area burned has dropped sharply.

Similar studies were reported by Xavier et al. (2005) in Western Australia as the extent of prescribed burning has been in gradual decline for many years possibly because of reactions by the public to smoke and using prescribed fire on an annual basis as a tool to maintain an effective fire break may not allow enough time for the soils to fully recover (Gill and Moore, 1997).

Nicolas and Beebe (1999) developed the appropriate standards in Indonesia for fire management techniques i.e. fire breaks, fuel breaks and wetting agents after mega fires during 1997 and 1998. Support from private companies, government and non-governmental organizations were taken for trainings in fire fightings and management. Zero-burning methods of land clearance are imposed to the companies. Public awareness and community based fire management system need to be identified and included in the fire protection mechanisms. The route to success is to motivate the local communities for prevention of fires, as well as paying them to form volunteer fire crews. Volunteer fire fighters from community
need a social protection system with accident insurance. This is an absolute necessity because fighting the fire is dangerous, thus the private companies might pay for that social security cover. As a further incentive to community involvement, properly trained and equipped village fire crews can be paid to patrol close to the village and to maintain the fuel breaks on the concession boundaries. Fire management Standard Operating Procedures (SOPs) for prevention and suppression depend on the current and expected short-term fire danger rating, as well as on long-term predictions for \textit{El Nino} occurrence and severity. The intent is that drought, a rising fire danger and weather forecast when taken together, trigger pre-planned fire prevention, pre-suppression, and suppression activities.

Agee and Skinner (2005) recommended silvicultural operations in dry conifer forests for fire reduction fuel management. Decreasing the surface fuel accumulation or modify the canopy structure by pruning, removing the ladder fuels, raising the canopy base and minimizing the vertical fire development.

Fernandes and Rigolot (2007) studied the fire ecology and management of Maritime pines (\textit{Pinus pinaster}) at Western Mediterranean Basin. The recommendations were, minimization of pine stands losses to wildfire calls for prompt and effective fire detection and fire fighting deployment and action. Management of fire hazard reduction by fuel management are advisable (Rigolot, 2002; Graham et al., 2004).

Williams et al. (2008) adopted the guidelines of FAO (2006) for fire management which provide a framework for countries to improve fire management through education, training, awareness raising, extension and information sharing services. Fire management varies in different localities and to practice good fire management approaches through educating the public, bonus system, regulation of public uses and law enforcement. These guidelines are adopted by many countries including India.

Kilahama (2011) advocated integrated fire management strategies through deforestation and degradation program. Several case studies from Australia, Mexico and the United States of America highlighted the importance of community access to land and natural resources, particularly in relation to fire-management decision-making. A case study from Mozambique shows how Community Based Fire management (CBFM) can generate income via carbon credits. The publication defines current limiting factors of implementation while underlining the importance of effective partnerships within and outside the communities (FAO, 2011).
2.2.2 Forest Fire Management Strategies in India

Fire protection was one of the first prescriptions that put into effect when forest management on scientific lines was introduced in India in the nineteenth century. According to the Constitution of India, the central and state governments in the country are enabled to legislate on forestry issues. The implementation part of the forest policy/programmes lies with the state government. Thus, fire prevention, detection and suppression activities are the responsibility of the state governments’ forestry departments. The policy, planning and financing are the primary responsibility of the Central Government. There is generally no separate department for carrying out forest fire management in the states. The regular staff of the forest departments in the states carries out various activities of forest fire management. During forest fire seasons in some of the divisions, fire watchers are recruited by the state governments as a special provision. At the central level, the Ministry of Environment and Forests is the ministry responsible for forest conservation and protection. Forest fire management is administered by the “Forest Protection Division” of the Ministry, which is headed by a Deputy Inspector General of Forests.

Anita (2001) conducted her study in fire affected chir pine forests of mid hills region of Himachal Pradesh. She concluded that frequent fires with low intensity does not affect either forest community or degrade the site but repeated yearly fires reduce species diversity due to degradation of the habitat. Hence, control burning is better management practice as found by her study in the year 2001 irrespective of environmental issues.

Nanda and Sutar (2001) conducted a study in the Bolangir, Deogarh and Sundergarh districts of Orissa, India on management of forest fire through local communities. Their study concluded that community based initiatives were encouraging and the most feasible mode to manage forest fires. They correlated the relation between dependency of community living in close proximity over different forest products and forest protection initiatives. It was found that the frequency of occurrence and the management of forest fires could be controlled only after the dependent community had started to feel the scarcity of resources.

Bahuguna and Singh (2002) reported the implementation of Modern Forest Fire Control Methods in India under which state governments are provided financial assistance for fire prevention and control. This assistance is being used by the state governments for
procuring hand tools, fire resistant clothes, fire fighting tools, radios, fire watch towers, fire finders, creation of fire lines, research, training and publicity on fire fighting. This project is carried out in fourteen states including Himachal Pradesh and covers more than 70 percent of the forest area of the country. Similarly, Jaiswal et al. (2002) used satellite imageries and GIS for forest fire risk zone mapping. They suggested that precise evaluation of forest fire problems and decisions on solutions can only be possible when a forest’s risk zone mapping is available to the management authority.

Joachim et al. (2007) discussed different issues on forest fire during workshop on forest fires in India to be held at Madurai. They reviewed the extent, justification and policies of forest fires in India. The policy on fires in Indian forests has historically been one of strict suppression. This was first officially articulated in the Indian Forest Act of 1927, which considered the setting of fires a punishable offence. Yet, even today, almost a century later, fire continues to be an annual phenomenon in almost all Indian forests. In addition, it made mandatory for all forest-dependent people to provide assistance in preventing and controlling fires. The extant National Forest Policy (1988) also stresses forest protection against encroachment, grazing and fire. Furthermore, it advocates the adoption of modern fire management practices for the prevention and control of forest fires. In the wake of this, there have been a series of centrally sponsored forest fire protection and control schemes since 1985, each of which has laid particular emphasis on the adoption of modern techniques and equipment in the prevention and control of forest fires. In addition, a set of national guidelines on forest fires, which was issued to all states in 2000, stressed the importance of community involvement in forest fire prevention and control through the Joint Forest Management (JFM) Program. The JFM committees have been established at the village level to involve people in forest protection and conservation. At present there are 36,165 JFM committees throughout the country, covering an area of more than 10.24 million hectares. These JFM committees have been given responsibilities to protect the forests from fires despite other responsibilities. For this purpose, the Modern Forest Fire Control plan is being revised and JFM is being made an integral component of the forest fire prevention strategy.

Sehgal and Sharma (2007) documented report on micro-macro level institutional mechanism for fire protection. They documented that micro level fire protection measures adopted by forest department included counter firing, construction of water storage tanks, fire
watchers, fire fighting and involvement of local bodies such as gram panchayats, mahila mandals, yuva mandals etc. for training and informing fire incidences. Macro level protection measures reported by them as construction of fire lines, removal of inflammable material, control burning and watch towers.

Kanga et al. (2011) using Geospatial approach for forest fire risk modeling for Taradevi Range of Shimla Forest Division in Himachal Pradesh, concluded that the greater danger from fire occurs during the months of April to June in higher temperatures periods. The study area is prone to fire because of the presence of dominant species of pines which are highly susceptible to fires due to the presence of resins. They derived five categories of forest fire risk ranging from very high to very low. The categories formed by using various factors instigating forest fire risks included vegetation type, slope, aspect, elevation and distance from the road and settlements.

2.2.3 Efficacy of Fire Protection Measures

Bahuguna and Singh (2002) discussed fire situation in India during International Forest Fire News, held at Geneva, Switzerland. In India, Joint Forest Management (JFM) Committees have been established at the village level to involve people in forest protection and conservation. For this purpose, the Modern Forest Fire Control plan is being revised and JFM is being made an integral component of the forest fire prevention strategy. Use of aircraft and helicopters has not been very cost effective in the fire management program and the Air Operation Wing is being closed down. For emergency purposes, however, a provision for hiring aircraft for transportation of crews and water is being maintained. The Government of India has issued national forest fire prevention and control guidelines. Salient features of the guidelines include identification of vulnerable areas on maps, creation of a data bank on forest fires, evolving fire dangers, fire forecasting system, provisions for a crisis management group, involvement of JFM committees and efficient enforcement of legal provisions. Thus, JFM committees are proved to be fruitful in detecting/ preventing and controlling of forest fires more efficiently than before.

Sehgal and Sharma (2007) studied the efficiency of forest fire protection management strategies by emphasizing the role of Joint Management Committees for better management
through better detection, better suppression and better management with the involvement of community living nearby.

Marcos and Maria (2011) evaluated the efficiency of forest fires protection in Pinar Del Rio Cuba for the last 10 years since 2000-2009. They used fires density, area burned density, mean of the area burned by fire, the burned forest area per year in percent and the fires size class as indicators of efficiency of forest fires. The improvements on fire detection methods and in the communication/reporting systems are likely to have also contributed to the detection and reporting of more fires definitely play important role in improving the efficacy of fire protection measures.

2.2.4 Human Interference

Fire is one of the oldest tools known to humans. It has been used as a management technique in land clearance for centuries. For the thousands of farmers, ranchers and plantation owners on the edge of the agriculture frontier pushing into forests, fire is the obvious mechanism. It is normally the least expensive and most effective way of clearing vegetation and of fertilizing nutrient poor soils. Fires are normally lit at the end of the dry season and under most normal conditions these fires can be controlled. However if the rains fail, as they do in many parts of the tropics in El Nino years, the results can be catastrophic, as the fires burn out of control.

Earlier studies on human factors of fire risk were based on indirect variables obtained mainly from censuses and survey sources (Cunningham and Martell, 1976; Alteobellis, 1983; Donohue and Main, 1985) and were mostly non-spatial. Of late the human factors were analyzed spatially. (Chuvieco and Congalton, 1989; Vega-Garcia et al., 1995).

Gorte (1995) studied the beneficial effects of fire on ecosystem in Australia. If fire is a paradox - it can kill plants and animals and cause extensive ecological damage, but it is also extremely beneficial, the source of forest regeneration and of nutrient recycling. Then it is also the nature’s way of recycling the essential nutrients, especially nitrogen. For many boreal forests, fire is a natural part of the cycle of the forest and some tree species, notably Lodge pole Pine and Jack Pine have serotinous cones and they open and seeds germinate only after they have been exposed to fire. Mountain ash, a flowering tree of temperate Australia also
requires a site to completely burn and be exposed to full sunlight for the species to regenerate. Fire in these circumstances is essential. Burning quickly decomposes organic matter into mineral components that cause a spurt of plant growth and can also reduce disease in the forest. But it is important to remember that fires under extreme weather conditions can be devastating to these forests.

During the last decades, a number of studies have been conducted mainly in different regions of the United States, but also in some European countries in order to gain some specific understanding regarding different aspects of Wildland fires and specifically on the interaction between communities and fire. Several surveys have been conducted to understand the perception and acceptability of communities regarding fire management programs (Beebe and Omi, 1993; Shindler, 1986; Loomis, 2001 and Blanchi et al., 2006).

Bahuguna (1999) discussed the forest fire prevention and control strategies in India. He concluded that in India there are very few cases of fire due to natural causes. The majority of the forest fires (99 percent) in the country are human caused. It is widely acknowledged that most of these fires are caused by the people deliberately and have a close relationship to their socio-economic conditions. Grazing, shifting cultivation and collection of minor forest products by villagers are major causes of fires. Carelessness of the picnickers, travelers and campers are also responsible for forest fires.

Nepstad et al. (1999) conducted his experimental research in Amazon on the damages caused by fire in tropical forest ecosystem which are characterized by high levels of humidity and moisture. They do not normally burn and are extremely prone to severe fire damage.

Eva and Lambin (2000) studied fires and land cover changes in tropics and observed that fire plays multiple roles in land use, it is a tool for hunting, clearing forests, maintaining grasslands, controlling pests and managing crops but during dry years, fires that escape during land clearing can destroy unmanaged or protected forests.

Cardille et al. (2001) studied the environmental and social factors influencing wildfires in the upper mid west, USA. They found that population density was the most important variable in the multivariate models. This variable was positively correlated with ignition occurrence i.e. a higher probability of ignition in the more populated areas. In several other studies worldwide population density was also found to be positively related to wildfire
ignitions. Land cover was also hypothesized to be a determinant factor causing ignitions because different kinds of human activities (land uses) lead to different levels of risk, like those implicating an active of fire (traditional burning to eliminate agricultural residues), and because different land covers have different fuel characteristics (moisture and flammability), which can determine fire ignition and initial spread. They found that land cover showed a strong influence on the probability of fire ignition.

Prestemon and Butry (2005) documented the human factor for fire risk based on distance to roads, to settlements or to specific land uses. Similar reports were published in several studies (Vasconcelos et al., 2001 and Mollicone et al., 2006)

Badia and Pallares (2006) also found a higher ignition frequency at higher elevations in a rural area of north-eastern Spain. Additionally, lightning-caused ignitions have been described to be more likely to occur at higher elevations.

Maingi and Henry (2007) tested the relationship between monthly unemployment rate and arson fires but found no correlation between them. One approach to evaluate the human influence on forest fires is to outline the means of livelihood and assess the harmfulness or utility of fires to people. If fires are useful, forests can be burned in a controlled manner or ignited intentionally and allowed to burn freely. On the other hand, if forest fires are considered harmful, human-caused ignitions are accidents and efforts are usually made to suppress fires.

MMA (2007) reported in its report that the results indicated that agriculture is a very important factor influencing fire starts. Also contributing to this high ignition incidence are the higher population densities usually present in these areas (in comparison to forested and uncultivated areas) and that the herbaceous vegetation in many Mediterranean agricultural areas is easier to ignite and the fires propagate more easily than in other fuel types, especially during the summer when fuel moisture is very low. The high ignition incidence in urban-rural areas may also be explained by the co-occurrence of agricultural activities and a high human presence. Forests, shrublands and sparsely vegetated areas also showed a positive influence on the multivariate models, but their influence was considerably lower.

Catry et al. (2010) reported that the probability of occurrence of fire ignition depends on distance from the roads, 98% of all ignitions occurred at less than 2 km from the nearest
road and 85% were within a distance of 500 m. Most commonly, these studies are based on cartographic and statistical information managed through Geographical Information Systems (GIS), which serve also as a framework for the integration of human factors into synthetic fire risk indices (Yool et al., 1985; Chuvieco et al., 2003; San Miguel-Ayanz et al., 2003; Morehouse et al., 2006).

According to Forest Department, Himachal Pradesh (Annual Administrative Report, 2007-2008), the main reason of fire was attributed to the carelessness of villagers/travelers passing through the forest and discarding cigarette butts. The department reported that during the period under consideration 550 cases of forest fires were detected affecting an area of 8,393 ha. Most wildfires in forests and woodlands today are caused by people as a result of the misuse of fire for conversion of forests to agricultural lands, maintenance of grazing and agricultural lands, extraction of non-wood forest products, hunting, and clearing of land for mining, industrial development or resettlement. Forest fires may also result from personal or ownership conflicts and negligence (e.g. campfires, cigarette butts).

These committees operational in various states are assisting the forest department in forest protection (including fire prevention and control) and managements, though the extent of participation and contribution to efforts varies. Efforts initiated by several researchers in different parts of the country proved to be fruitful (Nair, 1992; Singh, 1997; Bahuguna, 1999; Netalkar, 1999; Saigal, 1999; Srivastava, 1999a & 2000 and Bahuguna & Singh, 2002).

Kanga et al. (2011) conducted geospatial study for forest fire risk assessment at Tara Devi Range of Shimla Forest Division of Himachal Pradesh. They found that forest fire risk zones were delineated by assigning knowledge base weights to the classes of all the layers according to their sensitivity to fire or their fire –inducing capability. They used different parameters in determining the forest fire risk modeling. Parameters are distance from settlement, distance from the road and assigning the Index Values based on fire rating class such as 1000-1200m represents very low fire rating class was given Index Value of 1 whereas 0-200m represents very high fire rating class was assigned 6 Index Value. Finally, concluded that in the study area 5% (0.57km$^2$) area of total area falls under very high risk prone area, 22% (2.61km$^2$) area is under high risk prone, 38% (4.52km$^2$) area is under moderate risk and 32% (3.75 km$^2$) area under low risk and only 3% (0.35 km$^2$) under very low forest fire risk.
2.3 Fire Weather Characteristics and their correlation to Fire Strike Rate

As fire is a chemical reaction it needs heat, oxygen and fuel to start and carry on, as it is established in the fire fundamental triangle (Pyne et al., 1996). Therefore, the probability of occurrence of it depends on the ignition causes and environmental preconditions (Bachmann and Allgower, 2000). Among these are the vegetation characteristics, fuel quality and distribution, weather along different altitudes, topography, aspects are the influencing factors to influence forest fire (Grimm, 1984; Whelan, 1995). Many fire weather indices have been developed to study the interaction of meteorological variables on fire behavior (Nesterov, 1949; Molga, 1962; Keetch and Byram, 1968; Chandler, 1986).

Jarvis and Linder (2000) studied the role of precipitation in boreal forests that, precipitation rarely limits vegetation growth. However, dry climates with sparse vegetation, increasing rainfall enhances growth in the wet season, which increases the spatial continuity of the fuels and causes more intensive fires in the dry season. Similar studies were reported by Flannigan and Wotton (2001). They observed that less rainfall during the growing season (which is also the fire season) leads to more fires during the same year.

Bonan (2002) studied that climate influences forest fires directly by controlling lightning, fuel moisture and wind conditions. However, the influence of climate on fires is more complex, as climate is also a key factor influencing vegetation, the burning fuel. Hence, drier weather increases the impact of forest fires.

Lynch et al. (2004) studied the relationship between precipitation and frequency of forest fires showed indirect influence of climate on fires. Increasing precipitation can lead to the dominance of easily flammable conifers and therefore to a higher incidence of fires.

Though, in recent years the possibility of integrating an early warning system based on fire weather indices under study on the similar lines is scanty. Parameters like temperature, humidity and quantity of inflammable material on the forest floor are used to work out fire indices. Numerical Weather Prediction Models (MM5 / MSM/T-254 / T-80 / DMO) have been found useful tools for predicting these meteorological parameters for weather forecasting several days in advance. Jaiswal et al. (2002) used digital data available from the moderate resolution imaging spectro-radiometer (MODIS) satellite under Indian Remote
Sensing Satellite (IRS) ID LISS III for monitoring forest fires in different forest fire prone areas of the country.

2.3.1 Temperature and Relative Humidity

Yoshino (1984) observed the diurnal pattern of temperature and found that nocturnal inversions (increase of temperature with height) occur when cold air takes form in the valley bottom as air sinks along the contours of the landscape. Similarly, Grimm (1984) conducted a study on fire and other contributing factors controlling the big woods vegetation of Minnesota in the mid-nineteenth century and concluded that high temperatures, low relative humidity and winds are typical weather conditions for a fire development, because these conditions reduce fuel’s drying time and spread of fire.

The ability of an air mass to hold water is a non-linear function of air temperature. A rise in temperature increases the amount of moisture the air volume can hold, which is reflected by a decrease in the relative humidity and increase in the vapor pressure deficit (Environment Canada, 1987). Based on the absorption and desorption isopleths curves of the equilibrium moisture content relationship, a dropping relative humidity value will result in a lower equilibrium moisture content value. An increase in vapor pressure value will increase evaporation from the surface of the fuel and thus the drying rate.

Uhl and Kaffman (1990) studied deforestation, fire susceptibility and potential tree responses to fire in the east Amazon and found that the vegetation of the area was dense and close resulted in modification of microclimatic conditions which reduced the relative evaporation and maintained high soil humidity as compared with an area with less vegetation cover.

Barry (1992) conducted an experiment on the effect of local topography on temperature and relative humidity and revealed that altitude is the main factor controlling variation in ambient temperature in mountainous terrain. The influence of atmospheric humidity, expressed as relative humidity on the fuel moisture content of trees under dry conditions is an important factor in determining such things as the rate of spread of forest fires. The effect of relative humidity includes the fuel combustion rate, rate of spread of the
flame front, smoke production and the rise of smoke plumes in the atmosphere and the increase or decrease in probability of ignition from spotting.

Whiteman (2000) published a general description of vegetation and fuel characteristics of a slope dependent on aspect angle in the northern hemisphere in his book on mountain meteorology that the aspect angle determines a slope’s exposure to sunlight and prevailing winds, which in turn modify precipitation, temperature, humidity and fuel regimes. As the sun moves across the sky, its rays will become nearly perpendicular to different aspects and slopes at different times causing large variations in heating across a site. South facing slopes in the northern hemisphere receive the most solar radiation throughout the summer season. Incoming radiation may be the primary meteorological parameter affecting fuel flammability prior to ignition. Energy from the sun influences both the temperature of the fuel surface and in turn its moisture content. Long wave radiation is released from the fuels during cool, clear nights, sometimes cooling the fuel beyond the dew point causing surface condensation. Fuels that are not directly exposed to the open sky will not lose as much heat or gain as much fuel moisture content.

Nelson (2001) revealed that forest fuel moisture is determined by adsorption and desorption. Adsorption is determined by precipitation and relative humidity, while desorption is dependent on temperature, relative humidity, radiation and wind. These determinants of fuel moisture vary considerably both spatially within Finland and temporally between seasons. Both lightning and wind are components of weather that directly influence fire ignition or fire behavior. Several components of weather influence fuel moisture directly, such as precipitation, air humidity, temperature, radiation and wind but their effect is noticeable only after a time lag. Moisture content in forest fuels is inversely related to ignition probability. Its presence increases the time needed for preheating of a particle and its burning time as moisture must be evaporated before the fuel temperature can exceed 100 °C. He also studied the moisture content of the dead fine fuels is dependent on the structure and composition of the fine fuel, the surrounding environmental conditions and the moisture content of the underlying organic material and soil. Most of the woody material and vegetation found on the forest floor consists of cellulose, hemicellulose, lignin and extractives (some of which may be volatile). The relative amount of each of these materials varies by species and the higher the concentration of cellulose materials, the more hygroscopic the fuel
becomes. Each component of the forest floor reaches a steady level of moisture content after being exposed for an extended period of time to air with constant relative humidity and temperature. This equilibrium moisture content (EMC) occurs when the vapor pressure in the atmosphere around a fuel particle equals the vapor pressure within the fuel particle (vapor pressure is a measure of a substance’s ease of evaporation).

Catchpole (2002) investigated fire properties and burn patterns in heterogeneous landscapes in Australia and found that terrain’s slope has several effects on fire’s distribution. In case of a fire on a slope, the flames establish a strong contact with ground surface, which heats up the fuel and favours the fire’s spread. Therefore, the movement of a fire is slower if it begins on a summit and is faster if begins on a canyon. This behavior can also explain why a rough topography can constitute a fire barrier.

Beverly and Wotton (2007) investigated that the moisture present in a fuel particle determines the amount of energy required to raise that piece of fuel to temperatures at which ignition occurs readily. Small changes in the moisture content of fine fuels have great impacts on the likelihood of a source of ignition sustaining open flame. The moisture content of the fine fuels also dictates the forward rate of fire spread through its influence on the Initial Spread Index (ISI) component of the Fire Behavior Prediction (FBP) System.

Sharple et al. (2009a) derived a simple index for assessing fuel moisture contents under Nielsen and Kellerman, USA climatic conditions. It can be quickly and easily applied in the field conditions to provide dimensionless measure of fuel moisture contents. The index calculations require measurements of dry-bulb temperature readings and relative humidity. They also compared the index values with other complicated models developed by other researchers and found the best results from their simple derived index.

### 2.3.2 Wind (Speed and Direction)

Chandler et al. (1983) observed that wind speed directly influenced the fire ignition and behavior. It influenced the combustion by feeding oxygen-rich air in the combustion zone and by altering the path of hot gases. Normally a more important effect than spotting for the rate of spread of a fireline downwind is the bending of flames and plumes, thus preheating fuels effectively.
Oke (1978) observed that daytime surface heating creates unstable conditions and hence the upward movement of warmer air; conversely, nighttime cooling creates a layer of colder stable air closest to the surface. This daily cycle contributes to variations of wind speed and turbulence within the canopy, as well as to diurnal changes in the height of the planetary boundary layer.

Monteith and Unsworth (1990) derived wind profile equation under thermally neutral atmospheric conditions. The result showed that the mean wind velocity increases logarithmically with height for several metres above the surface (bare soil or vegetation).

Miyanishi (2001) observed the transition from smouldering to flaming combustion was enhanced by the increased availability of oxygen due to wind. In some cases, burning pieces of fuel can be blown to another location and start a fire. Rather than calling these ignitions as such, these might be propagations of fire from the area in which it was intended to burn (e.g., a fire spreading from a campfire or from a prescribed area).

Drebs et al. (2002) concluded that there is little spatial variation in regional scales in mean wind speeds in Finland compared to the variation in flash density and variation in most determinants of fuel moisture. In areas with significant topographical variation, wind patterns can also control the location and the amount of precipitation received locally. Orographic effects can produce thundershowers as moist air masses are uplifted over physical barriers.

Ruck et al. (2003) and Coutts & Grace (2005) conducted various studies covering the physics of airflows over forested terrain, the mechanical and physiological effects of wind on trees and the nature and extent, management implications of damage caused by storms. Wind couples vegetation to the atmosphere, mixing air from above the turbulent boundary layer with that close to the leaves and stems. In the process, it transfers momentum energy into the canopy, while reducing concentration gradients of atmospheric constituents, including oxygen and CO₂, water vapour and heat, between vegetation surfaces and the atmosphere. These functions are crucial to the maintenance of plant growth and survival. Wind is also a major factor influencing the establishment and spread of forest fires. Wind also significantly increases the horizontal travel of burning pieces of fuel, which can help a fire spreading downwind jump over fuel breaks (spotting) such as streams (Nelson, 2003).
Viegas (2006) studied that wind speed and direction influences the shape of a fire front which in turn influences the rate of spread of fire and hence, its probability in crossing the fire breaks. The study revealed that herbaceous fuel load tends to propel eruptive fire behavior characterized by sudden changes on the rate of spread in some sections of the fire front.

Lawson and Armitage (2008) recorded wind speed at 10 m above the ground for the calculation of fuel moisture in a forest clearing. As the wind speed observed above a plant canopy is a function of synoptic processes moderated by local topography. Topography adds multiple complications to estimating fuel moisture content. The angle and aspect of individual slopes can create complex interactions between soil type, vegetation pattern, drainage patterns, species diversity and other biological processes. It greatly influences wind, channeling winds into preferred directions and increasing or decreasing wind speed depending on atmospheric stability. In mountainous areas the prevailing winds are often the result of this channeling by the physical features of the landscape. A fire ignited on level ground with no wind and an even fuel distribution will burn outwards in a circle. If a slope is encountered, the shape will elongate in the upslope direction. McArthur (1967) states that a ten-degree slope will double the rate of spread of fire and a twenty-degree slope will increase the spread four times. Similarly, each ten-degree down slope will halve the forward rate of spread.

A firebreak is defined as a strategically located block or strip on which flammable vegetation cover has been permanently reduced or completely removed (Green, 1977) to reduce the intensity and rate of fire spread (GAFLC, 2005).

Mooney (2010) studied the effectiveness of fuel break in Canada's Boreal Forests and the behaviour of a wild land fire depends on many parameters such as wind speed and direction. Fire behavior and spread also depend on fuel characteristics (load, moisture parameters), weather factors (wind, temperature and humidity) and topography and hence, in accessing firebreak effectiveness, the effects of these factors are considered. Even with maintained firebreaks, dead standing trees along firebreaks pose a potential fire hazard by creating chimney fires which can shoot out through hundreds of feet to cross a firebreak. At
wind speeds of more than 15 mph the probability of embers being carried across a firebreak increases. Under heavy fuel load of 1 tonne/hectare and extreme weather conditions where wind speed reaches 90 km/hr, a firebreak will not stop a fire in the absence of suppression.

Mafoko and Phillimon (2011) evaluated the effectiveness of firebreaks in northern Botswana, Australia. They investigated the influence of weather factors (wind direction, wind speed and temperature) and vegetation structure (type and load). The purpose of the analysis was to propose ways to increase firebreak in order, efficiency to reduce fire spread and to recommend firebreaks that needed re-alignment. Additionally, the findings will be used in guiding the fire management strategy and policy implementation in the country. The results indicated that the angle at which the fire crosses a firebreak did not matter much as fire managed to cross at an angle of 90° as well as at diagonal angles. Roads serving as firebreaks did a better job of stopping fire as they had a wider road reserve of 30 meters on either side and most trees on the road reserves had been removed. They recommended that the firebreaks must be widened through prescribed burning (patch burns) to reduce fuel load.

2.3.3 Fuel Characteristics and Strike Rate

Fuel moisture content (FMC) plays a paramount role in the reaction of wildland and forest fuel to heat exposure. Water vaporization uses an important amount of energy due to the high heat capacity of water. It increases the concentration of nonflammable gases in the mixture of gases of combustion, and reduces their ability to initiate and sustain the combustion process by increasing the endothermic part of the combustion reaction. For live fuels, a given FMC is the balance between the water inputs throughout foliage and roots system and the water outputs by plant evapo-transpiration. Each species adopts specific strategies to resist drought, and to limit its own water reserves at a level which permits the survival of the plant, or at least part of it. In contrast, dead material is not regulated by physiological mechanisms; its moisture content depends only on the water exchanges regulated by physical laws. The moisture content of a given fuel is obtained by drying the fuel.

Chandler et al. (1983) studied the physical fuel characteristics influence the likelihood of ignition, fire behavior and fire spread in different fuel types. Characteristics such as fuel
particle size and shape, fuel load or quantity, fuel distribution and proportion of dead and live fuels, have a strong influence on fire behavior.

Similar study was reported by Susott (1984) who conducted the experiment on heat requirement for pre-ignition of three woody fuels used in wildfire modelling. He defined the first phase of ignition as pre-ignition. During pre-ignition a heat source provides heat to the fuel. The temperature of the fuel starts rising. During this endothermic reaction the energy that is absorbed from the ignition source is used to increase the temperature of the fuel and the moisture it contains. In the process volatiles start being released in the gas phase. At the temperature of 100°C a significant amount of energy is consumed for evaporation of the moisture in the fuel. The amount of heat required to convert a unit mass of water into vapour without a change in temperature is 2257 kJ/kg and is called “the specific latent heat of vaporization”. The amount of heat necessary to ignite 1 kg of fuel, measured in kJ/kg, is called the “Heat of Pre-ignition”. Obviously, it is dependent on the amount of moisture present in the fuel. The more moisture in the fuel, the more energy is needed to evaporate the water and then bring the dry fuel to ignition temperature.

Hill et al. (2000) studied fuel continuity and the distribution of different types of shrublands. Shrub fuels are generally characterized by high fuel loads consisting of elevated fine dead material and low bulk density. The presence of volatile compounds in the foliage can be an important contributor to flammability. Other studies by many workers were in tune with it (Marsden & Catchpole, 1995 and Pyne et al., 1996).

Saito (2001) reported the behaviour and ecological effects of forest fires and concluded that once the density of flammable volatiles is sufficient, ignition can occur providing there is enough oxygen present. Ignition is marked by the onset of flaming. Ignition temperature has been defined as the critical temperature that the fuel needs for burning to begin and reported the ignition temperature of 350°C. Many authors reported different range of ignition temperatures (Anderson, 1970; Susott, 1984; Wilson, 1985; Liodakis et al., 2002) due to its dependence on fuel type (Susott, 1984). Moisture content and amount of fuel being heated also appear to affect ignition temperature (Xanthopoulos, 1990). The ignition probability for a given fuel is the probability that an ignition source has an effective heat equal to or greater than the heat required for pre-ignition (Schroeder, 1969).
Dimitrakopoulos (2002) developed seven fuel models for Mediterranean vegetation types in Greece for input into the US BEHAVE fire prediction system. The fuel models were based on physical characteristics of the fuels: fuel loads of different size classes, litter load and depth, total fuel load and average height and cover of shrub layers.

Satoh et al. (2003) studied the measurement and observation of flaming probability of dried leaves for forest fire initiation due to lit cigarette. They concluded that the properties of all ignition sources and the heat transfer to the fuel are affected by the presence of wind. This is especially true when the heat source itself, such as a cigarette, is combustible. The wind may favour this combustion but if it is too strong it may even lead to extinction of the heat source. Fuel moisture influences all aspects of fire behavior, including ease of ignition, availability of fuel for combustion and the rate of combustion of each fuel class based on size and live or dead condition (Brown and Davis, 1973; Chandler et al., 1983; Pyne et al., 1996).

Larjavaara et al. (2005a) reported that fuel moisture content (FMC) as the primary variable in ignition and flammability studies with the greatest influence on fuel ignitability. Similar reports were published by many (Xanthopoulos and Wakimoto, 1993; Cheney and Sullivan, 1997; Lawson et al., 1997, Atreya, 1998; Anderson, 2000; Nelson, 2001; Plucinski, 2003 and Fernandes et al., 2002).

Xanthopoulos et al. (2006) reported that most of the wildland fires around the world are human caused (Whelan, 1995; Perry, 1998 and Weber, 2000). Natural causes such as lightning or volcanoes are only prominent in specific regions. For example, lightning ignitions are most likely to occur in high-elevation areas (McRae, 1992; Latham and Williams, 2001 and Anderson, 2002). Anthropogenic ignitions are of two types: deliberate and accidental. Deliberate ignition is used for prescribed fire or arson. Accidental ignitions are usually a result of negligence. Determining the probability of an ignition source is practically impossible due to the variety of sources and their causes. The probability of ignition sources varies spatially, depending on land use and temporally due to weather conditions, season and day of the week (Catchpole, 2001). Some effort has been devoted recently to the prediction of specific causes such as cigarettes that can be used for prevention planning (Dainier, 2003).
Beverly and Wotton (2007) conducted their research on modeling the probability of sustained flaming based on weather observations and fuel moisture conditions to predict the value of fire weather index components. They concluded that the moisture present in a fuel particle determines the amount of energy required to raise that piece of fuel to temperatures where ignition occurs readily. Small changes in the moisture content of fine fuels have great impacts on the likelihood of a source of ignition sustaining open flame. The moisture content of the fine fuels also dictates the forward rate of fire spread through its influence on the Initial Spread Index (ISI). The ISI indicates the basic relative rate at which a fire will spread when the upper fuel layer is dry. The ISI increases positively with increases in the FFMC.

Accidental ignition sources are numerous. They may find their way on the fuels either truly accidentally or due to human negligence. They include sparks, matches, cigarettes and car exhausts. Studies using discarded cigarettes as firebrands dropped on pine needles and dead grass have found that ignition seldom occurs, even when the FMC is very low (Countryman, 1980 and Markalas, 1985). Car exhaust systems have been found to ignite grass by direct contact for varied periods of time (Knight and Hutchings, 1987). Spark ignitions can come from mechanical sources, such as bulldozers and slashers scraping rocks and careless use of welding and grinding equipment (Luke and McArthur, 1978) and electrical sources, including spark ignitions from power lines (Rowntree and Stokes, 1994; Conroy, 1996). They can also come from other fires such as fireplaces or barbeque fires. Sparks need to come into contact with dry fine fuel for ignition to succeed as they only produce small amounts of heat for short times (Cheney and Sullivan, 1997).

2.3.4 Forest Vegetation and Forest Fires

Several spatial studies on landscape, vegetation ecology, forest structure, composition were conducted in different areas in India (Tendon et al., 1988; Singh and Mishra, 1995; Ravinder et al., 1997; Puri et al., 1994; Ludhiyal et al., 1995 and Rao et al., 1997).

Nelson (2001) studied that the moisture content of the dead fine fuels is dependent on the structure and composition of the fine fuel, the surrounding environmental conditions and the moisture content of the underlying organic material and soil. Most of the woody material and vegetation found on the forest floor consists of cellulose, hemicellulose, lignin and extractives (some of which may be volatile). The relative amount of each of these materials
varies by species and the higher the concentration of cellulose materials, the more hygroscopic the fuel becomes. In dead fuels, the permeability of the fuel to water and the moisture diffusivity of the fuel affect the processes through which water is stored or transported. Water is stored mainly in the cellulose of plant material where it either condenses in voids or is bonded to crystalline regions of cellulose bonds in the cell wall. The point at which the cell walls are saturated with water and extra moisture begins to condense as a liquid is known as the fibre saturation point ($mfsp$). The value for $mfsp$ generally used by fire practitioners is 30% moisture content. Moisture diffusivities are generally influenced by differences in mass density, particle size, shape and extractive content however, it is generally assumed that diffusion in foliage such as pine needles occurs in a similar way to wood structures.

Catchpole (2002) studied the fire properties and burn patterns in heterogeneous landscapes of Australian continent. The study revealed that the characteristics of a fire, like the intensity and the heat generated, are influenced by vegetation type and quantity and composition of the available fuel found in the area. Fuel could be either living organic matter (grass, bushes, trees or canopy) or dead organic matter (dead bark, branches, twigs, leaves etc.). The arrangement, size density, distribution, moisture and chemical composition of these materials, are the factors that determine the fire intensity. Therefore fire’s spreading speed and released energy are highly depending on the above mentioned factors.

Agee and Skinner (2005) gave basic principles of forest fuel reduction treatments and the key role of fuel in fire behavior and effects. They concluded that only fuel can be addressed by management action, which makes its treatment at the stand and landscape levels as its characterization is of paramount importance to the overall wild land fire management process. Fuel characterization and classification leads itself to the assessment of fire hazard, which in the context of fire risk analysis generically refers to the potential fire behavior for a vegetation type (Bachmann & Allgower, 2000 and Hardy, 2005).

Cruz et al. (2005) predicted the rates of spread in crown fires are often twice the spread of the surface fire. On the other hand, Rothermel (1991) examined seven crown fires in conifer forests of the northern Rocky Mountains where the surface fuels could be represented by fuel model 10, “times litter and understory” and found that the average rate of
spread for the crown fires was 3.34 times faster than predicted for surface fire, with a standard deviation of 0.59. This difference can be explained by the much lower rates of spread exhibited by fuel model 10 type fuels, when compared with shrub fuel models (Anderson, 1982). It is extremely important that the fuels beneath the canopy are described well by the fuel model used for obtaining estimates of surface fire rate of spread (ROS).

Alexander (2007) developed a mathematical model for fuel treatment and gave the limits for fuel accumulation before fire management. He concluded that the fuel characterization and classification leads to the assessment of fire hazard, which in the context of fire risk analysis generically refers to the potential fire behavior for a vegetation type. Fuel description and classification typologies depend on the inputs requirements of the models used to estimate the fire behaviour characteristics, i.e. the physical determinants of fire spread and heat release rates (Countryman, 1974). Of these influences, only fuel can be addressed by management action, which makes its treatment at the stand and landscape levels the cornerstone of a proactive approach to wildfire mitigation (Agee and Skinner, 2005; Fernandes and Botelho, 2003). Given the key role of fuel in fire behaviour and effects, its characterization is of paramount importance to the overall wild land fire management process.

Bourgeau-Chavez et al. (2007) use satellite imaging radar (ERS-1 and ERS-2) to provide point source weather and moisture data to improve the accuracy of fire weather indexes in boreal Alaska. Images from the Moderate Resolution Imaging Spectro radiometer (MODIS) have also been used to measure large-scale global weather patterns, including changes in the radiation budget, cloud cover and processes in the lower atmosphere, although the fineness of the resolution may not be fine enough to evaluate individual mountain climatology.

Alessio et al. (2008) studied the flammability of some mediterranean species and found that wild land and forest fuel is basically constituted of living material (needles and leaves, twigs of various diameters, branches, trunks, and parts of the root system) and of dead material, partially decomposed (litter and duff) whose characteristics are altered during the decomposition process. Fuel material is essentially composed of carbon, nitrogen, oxygen and hydrogen. In addition, and depending on the species, their environment, their stage of
development, and their physiological state, this material also contained oligo elements which intervene in the photosynthesis and growth processes but which very rarely plays a role in the initiation processes of a fire. Fuel material, particularly issued from Mediterranean tree and shrubs species, is rich in organic oils and in organic volatile compounds and terpenes (Pinaceae and Cupressaceae) whose flash points are low; this characteristic largely contributes to the ignition and spread of fire.

2.4 Social Management – People’s Perceptions

Many of the publications cited information on perceptions of peoples’ awareness about fire risk and hazard reduction strategies varies geographically and can depend on factors such as environmental knowledge, past experience with forest fire and length of residency (Cortner et al., 1990; Winter and Fried, 2001). Gardner et al. (1985) found support for flexible fire suppression policies such as prescribed burning, though professionals working in forest management held more positive attitudes toward this practice than did recreation groups and the general public hence concluded that greater knowledge of fire effects results in the recognition of the positive benefits of prescribed burning.

Srivastava (1999) and Bahuguna and Singh (2002) supported the incorporation of educational ways to improve the prescribed fire programs to the residents living nearby the forest areas. Similar studies were reported by many workers in in Florida by Jacobson et al. (2001). Public support is critical to the success of fire hazard reduction strategies. Unfortunately, little is known about the communities’ perceptions of fire management issues in fire prone areas of the country. Attempts to elicit peoples’ participation in fire control offers hope of minimizing the damage caused by forest fires. The National Forest Policy (1988) and Joint Forest Management (JFM) Guidelines (1990) of the Government of India acknowledged and endorsed this system of management, which supports the involvement of village communities and non-governmental organizations (NGOs) in the regeneration, management and protection of degraded forests. In this context Joint Forest Management (JFM) assumes an important role in fire prevention and control. Despite the initial efforts it must be stated that there is a tremendous gap of expertise and available methodologies of socio-economic and cultural approaches in integrating people into operational fire management systems.
Om Prakash and Sharma (2008) also supported the role of social participation in management of forest fires in Bilaspur Forest Circle of Himachal Pradesh. The findings were further confirmed by regression analysis. They concluded that the perception of local people about the causes of forest fires in their locality were due to accidental. Lighted cigarette/bidis thrown in the forest area, accidental fires by fuel wood collectors, honey collectors were reported to be the main reasons causing accidental forest fires. However, they reported the lack of interaction and incentive/compensation provided to people by the Forests Department significantly adversely affected their participation in the control of forest fires.

2.5 Forest Fire Management through Predictive Models

Fire danger is also highly sensitive to daily variations in air temperature, relative humidity, wind speed, and precipitation, all of which control fuel moisture and hence whether a fire will smoulder, burn, or go out after ignition. In circum boreal regions e.g. much of the forest area burnt yearly burns within just a few days during favorable synoptic weather patterns (Flannigan and Wotton, 2001; Skinner et al., 2001). Knowledge of such preconditions may help in the development of efficient forecasting systems for extreme fire seasons (Beckage and Platt 2003) thereby aiding the development of more effective wildfire fighting strategies. Ecological and environmental effects of forest fires are highly variable, difficult to predict and influenced by fire behavior, vegetation type, topography, climate, pre and post-burn weather and other factors (Weber & Taylor, 1992 and McCullogh, 1998). Fires can be classified by their behaviour and intensity. Surface fires burn through material like litter, shrubs, dead wood etc. on soil surface. Crown fires are invariably ignited by surface fires and burn through the crowns of standing trees. Ground fires burn in subsurface organic fuels such as duff layers under Arctic tundra or taiga or in organic soils of swamps and bogs (McCullogh, 1998). Forest fuels directly influence fire intensity (e.g. heat production per unit area) through fuel accumulation (or fuel load), distribution and moisture content characteristics. Fuel includes wood such as dead trees, logs, and slashes (tree tops, branches, and other logging debris). Fine fuels include dead needles, leaves and litter. In areas with a high accumulation of fuels, fires may burn hotter, move more slowly and have more profound ecological effects than in areas with low fuel accumulation.
Many fire weather indices have been developed to provide fire managers with a guide to how the meteorological variables are interacting and their effect on fire behaviour. Forecasts of these indices can be produced from numerical weather prediction models several days in advance.

Other models are frequently used in fire management, both in assessing hazards and during active fire suppression. Fuel loadings are often related to the current moisture status of surface litter or upper soil layers. Luke (1953) derived fire danger rating index and the index is still working throughout in eastern Australia. This weights the important factors - temperature, relative humidity, wind speed and fuel state.

The most pertinent weather parameters to fire danger rating include temperature, relative humidity and wind speed (Deeming et al. 1977; Cohen and Deeming, 1985). Wind direction is a critical factor in fire behaviour and fire spread. It has been evaluated along with the NFDRS weather parameters in order to better understand the usefulness of increasing model resolution for a range of fire weather forecasting requirements.

Numerous studies have evaluated the performance of Mesoscale Models, and in particular the MM5. Several studies have also compared the performance of the MM5 at different resolutions. The National Fire Danger Rating System (NFDRS) is used by fire weather forecasters and fire managers throughout the United States to monitor and anticipate the potential for dangerous wildfires. The NFDRS is also used to help to plan the timing and assess the potential outcome of controlled, prescribed fires used for managing fuels and vegetation resources. The statistical approach is based on developing a semi-parametric logistic regression model. Andrews and Bradshaw (1997) demonstrated the use of logistic model for generating probability curves relating daily fire activity in a given forest to NFDRS indices from the closest weather station. The regression model estimates two fire danger probabilities: probability of fire occurrence and conditional probability of large fire event. Probability of fire occurrence was defined as the probability of at least one fire of any size occurring in a given one-degree grid cell during a given month of a year. The probability of a large fire event was defined as the probability of the occurrence of a burn area greater than 400 ha (≈ 1000 acres) given at least one fire occurrence in the one-degree cell during a given
month of a year. The product of the above two probabilities was used as a measure for fire danger.

The Canadian Fire Weather Index was developed by Van Wagner (1985) and further modified during 1987. It is mainly developed for coniferous forests stands where it calculates fuel moisture values for three layers of fuel bed and provides relative indicators of general fire danger across the landscape based on weather. Litter (fine fuel Moisture: FFM), duff (Duff moisture: DMC) and the drought code concerning larger fuel (DC). The FFMC is combined with wind velocity to calculate the initial spread rate (ISI) of a wildfire. While the DMC and DC is combined to the Build up index (BUI) which estimates the amount of dry fuel to sustain a wildfire. All indices are then combined into the FWI index which gives estimation about the overall fire danger situation and is used to classify and communicate fire danger. The FWI System components are calculated using daily temperature, relative humidity, wind speed and 24-hour rainfall data collected at peak burning hours (1400-1600 hrs). The FWI is used by Southeast Asian Countries especially in Malaysia and Indonesia to develop a difficulty of control indicator for grassland fires.

Fujioka and Tsou (1985) have calculated Fosberg Fire Weather Index (FFWI) developed by Fosberg (1978) using temperature, relative humidity and wind speed, assumes constant grass fuel and equilibrium moisture content as a function of the input weather variables. FFWI has been used for seasonal fire danger forecasting to provide a first look of global wildfire condition (Roads et al., 1995) despite its use of constant fuel information. FFWI offers a significant skill in explaining the fire occurrence at a monthly scale. Goodrick (2002) modified the Fosberg Fire Weather Index (FFWI) by incorporating the Keetch-Byram drought index (KBDI) to formulate fuel availability. This improved the relationship between FFWI and areas burned in Florida.

The Fire Behaviour Prediction (FBP) System provides quantitative indicators of fire danger at the stand type level based on fuels weather (via the FWI System) and topography. The FWI and FBP Systems have been used to estimate the probability of human-caused fire (Martell et al., 1987), potent fire activity (Forest Canada Fire Danger Group 1992) and fires effects (de Groot et al., 2003) and are often applying a predictive fashion to prepare in advance of serious fire problems (de Groot 1989a). They have been used to estimate fire
emissions (Taylor and Skinner, 2003; Amiro et al., 2001) and therefore can be readily adapted to predict smoke and haze. The FWI System has been used in various applications in numerous other countries including the United States (Brenner et al., 1997), New Zealand (National Rural Fire Authority, 1993), Russia (Stocks et al., 1998), Fiji (Alexander, 1989), Mexico (Lee et al., 2002), European countries (San-Miguel-Ayanz et al., 2003) and in Southeast Asian countries i.e., Malaysia and Indonesia (de Groot et al., 2007) for developing fire danger rating system (FDRS). The FWI System was used as the foundation to develop the FDRS that would serve as an early warning system for serious haze and fire problems. FDRS decision aids which detail fire management actions (such as fire prevention, detection, or suppression mobilization activities) may occur at different fire danger levels because of local fire issues and fire management guidelines. The main tasks of the Southeast Asia Fire Danger Rating System Project were to conduct the initial calibration of the FWI System to regional conditions to facilitate development of FDRS based fire management decision aids to address local fire problems and to strengthen technical development, coordination, management and integration of fire systems in the region.

Simard et al. (1985) developed an extreme fire potential index based on NFDRS indices and employed a threshold value of the index that captured a large number of extreme fire event days with a minimum number of false alarm days.

Pant et al. (1996) attempted to provide estimates about forest fire damaged areas using digital satellite remote sensing data in the Tehri district of Garhwal Himalaya. The study area is characterized by hilly and mountainous terrain supporting varied forest types and composition controlled by altitude, a variety of land use/land cover types along with perpetual snow cover on the mountain peaks. Pine is the dominant forest type and is most susceptible to fire almost every year particularly near habitation.

Other studies attempted to give insight in the use of Remote Sensing and GIS for fire management. Spatial modeling and analysis have been done in GIS environment for identification of areas prone to fire risk and subsequently response routes were suggested for extinguishing forest fires (Jain et al., 1996 and Porwal et al., 1997). Some of the necessary components contributing to the fire behaviour viz., fuel (vegetation types), topography (slope and aspect etc.) and the causes of fire (i.e., roads and settlements) have been given due weight
ages. The study has been done in part of Rajaji National Parks covering an area of approximately 115 km$^2$. The topography is variable within the altitude ranging between 300-700 m above msl. The climate is subtropical type with the temperature varying from 13.1 °C in January to 38.9 °C in May and June. The area is dominated by moist Siwalik Sal Forest, Moist Mixed Deciduous Forest, Dry Mixed Deciduous Forest, Chir Pine and Shrubs.

Forest fires cause significant damage to the forest ecosystem. In Central Himalayan region forest fires occur between April to June annually when the weather is hot and dry. Usually the south facing slopes are prone to fire due to direct sun insulation and inflammable litters of pine and dry deciduous trees at the forest floor. The presence of habitation, roads, footpaths etc., and their distance from such sites indicate an additional yardstick for the occurrence of forest fires. Extensive forest area during summer of 1995 in the Western and Central Himalaya drew wide attention of the forest managers and environmentalists. As stated by WMO (1978) the physical laws that control the behaviour of wildland fires are the same in both tropical and sub-tropical areas. The main difference is the relative importance of natural and man-made fires. WMO (1982) in a review of wildland fires in the tropics states that over 90 per cent of fires are caused by the activities of man.

Kafka et al. (2000) while working in southern Alberta used climate station input, topographic data and fuel distributions to compute daily potential head fire intensity (HFI) and for percentiles of occurrence. The resulting quantitative maps can be used to identify areas of extreme fire behavior potential for fire and forest management either before or during a fire.

Saglam (2002) used Statistical Models to assess the fire danger situations for fire prone areas in the southern and western part of Turkey. The Model used weather data and fuel moisture contents in normally stocked even aged Red Pine and Black Pine stands. Fire danger situations were mapped using GIS and suggested the overall fire management planning. Whereas, Jaiswal et al. (2002) calibrated the digital data available from the moderate resolution imaging spectro-radiometer (MODIS) satellite under Indian Remote Sensing Satellite (IRS) ID LISS III was used for monitoring forest fires in different forest fire prone areas.
Preisler et al. (2004) developed a spatially and temporally explicit logistic model, on per square kilometer-day scale, to estimate probabilities of large federal fires in Oregon using National Fire Danger Rating System indices deduced from a regional simulation weather model to estimate probabilities and number of large fire events on monthly and one degree grid scales. The weather model simulations and forecasts are ongoing experimental products from the Experimental Climate Prediction Center at the Scripps Institution of Oceanography. The monthly average Fosberg Fire Weather Index, deduced from the weather simulation, along with the monthly average Keetch-Byram Drought Index and Energy Release Component, were found to be more strongly associated with large fire events on a monthly scale than any of the other stand-alone fire weather or danger indices. These selected indices were used in the spatially explicit probability model to estimate the number of large fire events. Preisler et al. (2004) used probability based models for estimating the fire danger risks from wildfires in western United States.

Sharples (2009) studied the effect of slope, aspect and elevation on fire weather predictions and used physical relationships to adjust the fire weather inputs in calculating the fire weather indices in order to better extrapolate the estimations of moisture conditions across the landscape. Simultaneously, Sharples et al., (2009a & 2009b) developed a simple index model for assessing the fire danger rating based on fuel moisture, relative humidity and ambient air temperature on daily basis.