Chapter-III

RESEARCH METHODOLOGY

The present investigation entitled, “Meteorology based Prediction Models for Management of Forest Fires in Shivalik Hills, India” was carried out in Kadon beat of Dharampur Forest Range in Solan Forest Division, Himachal Pradesh, India for three consecutive fire seasons during the years 2010, 2011 and 2012. The investigation was carried out under Shoolini University of Biotechnology and Management Sciences, Bajhol- Solan, H.P. (India).

3.1 Methodology

The experimental details with respect to study area and methodology adopted are described below:-

Multistage Random Sampling Technique (Appendix-3.1) for ecological survey was used to select the fire prone areas in Himachal Pradesh. The demarcation of the study area was made on the basis of fulfilment of the following criteria:

1) An area prone to high frequency of forest fires, based on past history of the area
2) Basically a natural forest, normally undisturbed
3) An area representative of the most common vegetation types, demarcated for study

![Maps showing Land use Pattern and Hot Spots of Forest Fire in Himachal Pradesh](image)

Figure 3.1 (a & b): Maps showing Land use Pattern and Hot Spots of Forest Fire in Himachal Pradesh
3.2 Methodology for Fire Prediction

Figure 3.1 (a) depicts the Land Use Pattern in different districts of Himachal Pradesh. The land use pattern of Solan district clearly indicate that forest plantation are surrounded by double cropping (Rabi + Kharif), ‘ghasnis’/grazing lands, gullied or ravenous lands and even some forests were surrounded by scrubs. The Hot Spots of Forest Fires for the last 5 years (2008-2012) in the state of Himachal Pradesh (Figure 3.1b), identified highest number of forest fire incidences in district Solan as compared to other forest divisions. In Solan Forest Division, the forest plantation of Kadon Beat of Dharampur Range is the area with highest frequency of fires, as majority of vegetation is natural and surrounded by national highways, railways, roads, bridal paths and kaccha paths. The forest area is surrounded by 4-5 villages, several picnic spots, grasslands/ghasnis hence the forests are under high demographic pressure.

3.3 Location and Extent of Study Area

The total geographical area of Solan Forest Division is 571.58 sq. km (57,158 ha), out of which 11,743 ha is forest area. Solan is located between 76° 55’ 00” to 77°15’00” E longitude and 30°45’ 00” to 31°10’ 00” N latitude. The area is characterized by extreme hot (Max T > 45°C) at lower elevation during summer season and extreme cold (Min T < 0°C) at higher elevations during winter season. The area receives scanty rainfall with low relative humidity of (28%) when the air temperature goes beyond 35°C and rainfall is scanty (< 10 mm), generally observed during April to end June or before the onset of pre-monsoon showers. Therefore, this period of April to June is considered as peak fire season. The forests in Solan Forest Division have pure and mixed stands of chir pine and mostly conform to Champion and Seth’s Forest type 9C1a for Lower or Shiwalik chir pine forests (Anita, 2001). The forest area lies between 900-2100 m a.m.s.l. The present studies were conducted at four sites in the Solan Forest Division of Dharampur Range, Himachal Pradesh, India for collecting the field data and the details of selected sites are as follow:-

3.3.1 Climatograph of the Study Area

The graphical representation of different weather parameters viz; Maximum temperature, Minimum temperature, rainfall and length of fire season is represented by different line and bar diagrams with effect from 1st April to 31st July during three consecutive fire seasons of 2010, 2011 and 2012.
Weekly averages of all the selected meteorological parameters were taken using Standard Meteorological Weeks (SMW) w. e. f. 10-30 SMW (1st April to 31st July). The weekly averages of maximum and minimum temperatures are shown as line diagrams along y-axis (Figure 3.2). Generally the maximum temperature ranged from 20 to 35 °C during the fire season (10-30 SMW). During fire season 2010, the maximum temperature was recorded in the range of 25 to 35 °C and most of the times weekly temperature was obtained above 30°C between 11-22 SMW (8th April to 23rd June). During 2011 fire season, maximum temperature was reported to be above 30°C during 15-22 SMW. Whereas, the fire season of 2012 recorded maximum temperature in the range of 21-32°C during 10 to 20 SMW (1st April to 9th June) and 30-35°C was recorded in 21-30 SMW (10th June-31st July). Weekly rainfall data was reported as bar diagram along y-axis. Total rainfall of 152.6 mm (47.7+104.9 mm) was received during fire season 2010 on 18th SMW (20-26 May) and 22nd SMW (17-23 June). The rainfall received on 22nd week was sufficient to break the fire season. Whereas, the rainfall pattern was quite unfavourable for the fire season as almost every week light rainfall received (<30 mm) except on 22nd SMW (17-23 June) which reported 46.5 mm rainfall. The total rainfall of 97.4 mm was experienced during fire season 2012 w. e. f. 10th – 30th SMW (1st April-31st July) which was distributed in twenty weeks with weekly rainfall of less than 20 mm. The horizontal bars represent the total length of fire season depending on
weather conditions (temperature and rainfall). The total duration of fire season during 2012 was reported to be of maximum 140 days (10-30 SMW) whereas, the duration of fire season 2011 was reported to be of minimum 56 days (15-22 SMW) followed by 77 days of fire season during 2010 (11-22 SMW).

3.3.2 Study Sites

Four sites were selected along Kadon Beat of Dharampur Range in Solan Forest Division, Himachal Pradesh. The site map selected locations of forest areas for conducting the study is shown in Figure 3.3. As the map is flat it only depicts the enrolments of roads, railway lines, nallahs and boundaries of the forest area and doesn’t indicate any idea about orientations and aspects of sites. All the forests were linked with roads/paths/bridal paths. The Bamboo forests (T1) of Cheola Anji-Matla forest block have been chosen for the study, as represented by the map, the forest plantation is surrounded with Kaccha paths and bridal paths. The bamboo forests are quite away (about 4 km) from the National Highway (NH-22). As far as Site II (Kadon-Sihardi) is concerned, Mixed Pine forests (T2) are linked with railway lines/NH-22/bridal paths/ 4-5m road/kaccha road. The Pine-Oak forest (T3) plantation is linked with road/bridal paths upto some extent and some forest land is having fresh water ‘khools’ as natural source of water bodies which is surrounded by kaccha paths. In Pure Chir Pine forests (T4) of Barog-Nagali forest block of Kadon Beat are linked with railway lines/NH-22/roads/bridal paths/pacca roads/kaccha roads/pathways. The characteristic features of different sites as well as their forest structure are given as:-

3.3.2.1 Site I

The Site I comprises of forest block of Cheola-Anji Matla, situated at an elevation of 900-1200 m. a.m.s.l. along the foothills of Shiwalik hills at latitude of 31.15° N and 76.56° E with more or less flat surface (slope angle: 8-15°) in Kadon Beat of Dharampur Range in Solan Forest Divison.

The working circle contains 2133.3 ha of Reserve and DPF towards northern and southern aspects, Bamboo forests (T1) are the dominant vegetative community with an area of 891 ha (40.2%) is worked intensively under a regular system of its management. These areas are mainly confined to Lugon and Parwanoo Blocks of Parwanoo Range and Joharji Block of Dharampur Range. In Dharampur Range, the total area under reserve forest is 389.6 ha of which 146.0 ha (37.4%) is Bamboo forest.
The total area under Demarcated Protected Forest is 223.7 ha which has 116.4 ha (51.8 %) of bamboo. *Dendrocalamus strictus* is the dominant species found in the tract. Bamboo is found either pure or mixed with scrub or miscellaneous broad-leaved species including *Toona ciliata, Dalbergia sissoo, Terminalia tomentosa* as overstorey whereas the understorey vegetation includes *Prinsepia utilis, Indigofera tinctoria, Anaphalis adnata, Calotropis procera, Datura stramonium, Duranta plumier, Chrysopogon* species, *Cynodon*
dactylon, Eulaliopsis binata, Heteropogon contortus, Phyllostachys chinensis and Themeda anathera. The site selected for investigation is of pure bamboo species with 15-20% other vegetation (Table 3.6). The total area of D244–Cheola-Anji Matla Block of Kadon Beat in Dharampur Forest Range is 12 hectare and the distribution of Bamboo forest is towards northern and southern aspects with 15-25% slope (8.4-14.0°). The site is more or less levelled land with slight up/down slope. The tree canopy is as high as 25-30 m with tree age of 25-27 years. The climate of the site during fire season (April to June) is mainly dry with peak hrs. Ambient air temperature (T) ranges of 35-45°C, relative humidity (RH) of 25-28%, as the area receives no precipitation (RF) and experiences high wind movements (WS) in the range of 5-14 kmph. The total human population of the community living in the nearby forest area is about 300. Their livelihood depends on the forest products extracted from this forest, under study. Information for assessing the perception of people living nearby the forest area with respect to causes of forest fires, ways of fire hazard reduction strategies and participation in fire suppression/management planning was gathered to which 44 persons responded.

3.3.2.2 Site II

Kadon-Sihardi Forest Block in Kadon Beat of Dharampur Range has an elevation of 1200-1500 m. a.m.s.l., 30.89° N latitude and 77.09° E longitude towards north-western and southern aspects. The slope varies from 30-50 (16.7°-26.6°) per cent. The vegetation of the site is mixed pine forests (T2). The overstorey species comprises of Pinus roxburghii, Toona ciliata, Dalbergia sissoo, Pyrus pashia, Albizia chinensis, Juglans regia, Celtis australis, Acacia catechu and understorey vegetation of shrubs, herbs and grasses are: Berberis lyceum, Prinsepia utilis, Indigofera tinctoria, Rosa species, Rubus ellipticus, Cariassa carandas, Myrsine Africana, Girardiana heterophylla, Artemisia vulgaris, Calotropis procera, Datura stramonium, Duranta plumier, Rubus macilentus, Rumax nepalensis, Urtica dioca, Viola canescens, Chrysopogon species, Cynodon dactylon, Eulaliopsis binata and Heteropogon contortus. The trees height varied between 15-25 m. According to Solan Forest Division Report (2008-2011) the forest is prone to frequent fires. Other kind of disturbances present in the area are: illegal cutting, resin extraction, grazing, picnic spots, etc. Hence the forest is under high demographic pressure. The forests are used for wood and pulp, paper making, agriculture, horticulture and cattle breeding. The use of fire is common practice in agriculture to renew the green flush of grass for the cattle fodder. The presence of serotinous cones and needles of
pine trees are the main fuel source of fire. Moreover, herbaceous stratum comprising of Gramineae family, favours fire and leads to surface fires. The under storey vegetation during the fire season is dry and get readily ignited with little ignition source like un-burnt matchstick, bidi, electric spark, spark by engine and even with lightening strike. The climate during fire season (April-June) at Kadon-Sihardi Forest Block, is dry with no rainfall, temperature ranges from 30-37°C and relative humidity (RH) of 25-28%. The total population living nearby the forest area is about 400 and for their livelihood they extract various forest products from the forest. Information for assessing the perception of these people as to the causes of forest fires, ways of fire hazard reduction strategies and participation in fire suppression / management planning was gathered through questionnaire to which 53 respondents replied.

3.3.3.3 Site III

At an elevation of 1500-1800 m. a.m.s.l., the Site III is Maltu- Dhar Forest Block in Kadon Beat of Dharampur Range in Solan Forest Division. The area is situated at 30.51°N latitude, 77.15° E longitude along north-western and south-western aspects with slope percentage of 30-75 (16.7°-36.9°). Pine Oak forests (T₃) are the dominant vegetation of the site. The area receives scanty rainfall during peak fire season (April- June).

The over storey tree species are: Pinus roxburghii, Quercus leucotrichophora, Toona ciliata, Albizia chinesis, Celtis australis, Acacia catechu, Terminalia tomentosa and the under storey vegetation of shrubs, herbs and grasses are; Berberis lyceum, Prinsepia utilis, Indigofera tinctoria, Rosa species, Rubus ellipticus, Bauhinia vahlii, Sarcococca saligna, Cariassa carandas, Myrsine africana, Girardiana heterophylla, Artemesia vulgaris, Calotropis procera, Rubus macilentus, Rumux nepalensis, Urtica dioica, Viola canescens, Chrysopogon spp, Cynodon dactyl, Euvaliopsis binata and Hetropogon contortus. The oaks are deciduous; however the leaf shedding period is very short during the year (less than a month or even some species never lose their leaves). The forests comprises of two type of vertical structure, one with 10-15m tree height and the other with 4-9 m height. The herbaceous stratum depends on the density of the forest. It is mainly composed of species belonging to Compositae and Gramineae Family. This forest has more intensive human disturbance as it has many picnic spots towards the National Highway which is the major cause of fire spread due to negligence, carelessness, accidental and intentional. The climatic conditions during fire season (April-June) at Maltu- Dhar Forest Block, generally dry with
rainfall less than 20 mm, temperature ranges from 30-37°C and relative humidity (RH) between 25-28%. The total population of the community living nearby the forest area is about 300. Their livelihood is mainly depends on the forest products and eco-tourism. Information for assessing the perception of these people living nearby the forest area with respect to causes of forest fires, ways of fire hazard reduction strategies and participation in fire suppression / management planning was gathered from 40 respondents.

3.3.3.4 Site IV

The Site IV at Barog Nagali Forest Block in Kadon Beat of Dharampur Range in Solan Forest Division has northern and south-western aspects, situated at an elevation of 1800 - 2100 m. a.m.s.l., 31.12° N latitude, 77.16° E longitude with slope percentage of 45-85 (24.2°- 40.7°). The area receives negligible rainfall during the peak fire season (April-June). The site has pure Chir Pine Forest (T₄) as main vegetation community.

The main over storey tree species is Pinus roxburghii with admixture of Celtis australis, and understorey vegetation of shrubs, herbs and grasses which comprises Berberis lyceum, Rosa species, Bauhinia vahlii, Sarcococca saligna, Myrsine africana, Girardiana

Table 3.1: Characteristic Features of the Selected Sites

<table>
<thead>
<tr>
<th>Forest Blocks</th>
<th>Forest Type</th>
<th>Slope (% &amp; °)</th>
<th>Aspect (orientation)</th>
<th>Elevation (m)</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
<th>Climatic Conditions (Fire Season)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheola-Anji Matla</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SITE II*</td>
<td>Mixed Pine Forest T₂</td>
<td>30-50% (16.7°-26.6°)</td>
<td>NW, S</td>
<td>1200-1500</td>
<td>30.89°</td>
<td>77.09°</td>
<td>Temp.: 30-37°C, R.H.: 25-28%, winds: 3-8kmph, Rainfall: Nil</td>
</tr>
<tr>
<td>Kadon- Sihardi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SITE III*</td>
<td>Pine-Oak Forest T₃</td>
<td>30-75% (16.7°-36.9°)</td>
<td>NW, SW</td>
<td>1500-1800</td>
<td>30.51°</td>
<td>77.15°</td>
<td>Temp.: 30-37°C, R.H.: 25-28%, winds: 3-8kmph, Rainfall: &lt;10m</td>
</tr>
<tr>
<td>Maltu- Dhar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SITE IV*</td>
<td>Pure Chir Pine Forest T₄</td>
<td>45-85% (24.2°-40.7°)</td>
<td>N, SW</td>
<td>1800-2100</td>
<td>31.12°</td>
<td>77.16°</td>
<td>Temp.: 27-32°C, R.H.: 25-28%, winds: 3-5kmph, Rainfall: &lt;10mm</td>
</tr>
<tr>
<td>Barog- Nagali</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Total population of different sites (SITE I : 300, SITE II : 400, SITE III : 300 & SITE IV : 350) and about 12-15% Respondents were selected from each site.

heterophylla, Artemesia vulgaris, Rumax nepalensis, Urtica dioica, Viola canescens, Chrysopogon species, Cynodon dactylon and Hetropogon contortus. The pine trees are as high as 30m with tree canopy of 60-80%. This Forest is under high demographic pressure as pine trees are cut and used for several purposes. The use of fire is a common practice in burning of grassland to renew the grass for cattle. The pine species are highly susceptible to fire due to the presence of resin containing pine needles as well as cones. The herbaceous stratum in the forest is mainly of Graminea and members of Compositae Family. The climatic condition during fire season (April-June) at Barog-Nagali Forest Block is generally dry with rainfall less than 20 mm, temperature ranges from 27-32°C and relative humidity (RH) of 25-28%. The total population of the community living nearby is about 350. Their livelihood is mainly depends on the forest products. Information for assessing the perception of these people living nearby the forest area with respect to causes of forest fires, ways of fire hazard reduction strategies and participation in fire suppression / management planning was gathered to which 52 responded.

In order to predict the forest fires in Shiwalik hills based on meteorological models, various morphological, meteorological and social aspects were studied during the course of investigation under the following four sub-heads:

3.4 Existing Fire Management Strategies and their Efficacy
3.5 Fire Weather Characteristics and their correlation to Fire Strike Rate
3.6 Social Management – People’s Perceptions
3.7 Environmental Management through Predictive Models

3.4 Existing Fire Management Strategies and their Efficacy

The available secondary data on fire incidences, area burnt, their causes and fire protection measures were collected from Divisional Head Office of Dharampur Range i.e., Solan Forest Division, Solan. Decadal Data (2000-2010) on incidences of forest fires, area burnt and estimated loss was recorded from Annual Reports of Solan Forest Division. Detailed information about the adoption of modern techniques and equipments used for prevention and control of forest fires before and after 2000 was recorded. Records on the involvement of communities living nearby the forest areas with the formation of Joint Forest
Management Committee (JFMC) in different forest ranges of Solan Forest Division for forest management w. e. f. 2003 to 2012 was also collected from Solan Forest Division. Reports were also gathered from various other agencies like police station for number of FIR’s during fire seasons under consideration, news papers reporting forest fires and visited the Departmental Forest Office several times for assistance in collecting the forest vegetation information as well as for identification of different forest plantations during the fire seasons of 2010, 2011 and 2012.

To evaluate the efficacy of fire protection strategies, the collected secondary data as well as the data collected during the three consecutive fire seasons of 2010, 2011 and 2012 were converted for fire density, area burned density, mean of the area burned by each fire, the burned forest area per year in per cent and the fires size class were calculated as developed by Ramos (2000):

3.4.1 Area Burned Density (ABD):

Amount of hectares of forest burned for each 1000 hectares of forest was evaluated area burned density for calculating the effective damage caused by fire incidences in different study areas using the equation:

$$\text{ABD} = \frac{\text{Total area burned in hectare}}{1000 \text{ hectare}}$$

3.4.2 Mean of the Area Burned per Fire (ABF):

It is the relationship between the amount of hectares of forest burned and the amount of forest fires that occurred and calculate the total area burned in hectares by all different fire incidences as under:

$$\text{ABF} = \frac{\text{Total area burned in hectare}}{\text{fire incidences}}$$

3.4.3 Percentage of the Forest Surface Burned (PFS):

It is expressed as the per cent of burnt surface divided by the forest surface. The data on fire affected area were analysed using percentage of forest surface burned method by the equation:-

$$\text{PFS} = \frac{\text{Area burned}}{\text{total forest area}} \times 100$$

3.4.4 Fire Size Class:

The grouping of the forest size class was done as recommended by Ramos (2000) for the evaluation of effectiveness of the forest fire suppression studies as given below:-
Table 3.2: Fire Size Class (adapted from Ramos, 2000)

<table>
<thead>
<tr>
<th>Size Class</th>
<th>Area (ha)</th>
<th>Denomination</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0-1</td>
<td>Very small</td>
</tr>
<tr>
<td>II</td>
<td>1 - 4</td>
<td>Small</td>
</tr>
<tr>
<td>III</td>
<td>4 - 40</td>
<td>Medium</td>
</tr>
<tr>
<td>IV</td>
<td>40 - 200</td>
<td>Big</td>
</tr>
<tr>
<td>V</td>
<td>&gt;200</td>
<td>Very big</td>
</tr>
</tbody>
</table>

Five causal factors viz; Presence of Electric wires/Transformers (F₁), Villages Near the forest area (F₂), Distance of Road from the forest area (F₃), Escaped fires by any reason (F₄) and Mischievous Fires due to Interference (F₅) were considered for evaluation of fire incidences causes in the selected forest types.

3.5 Fire Weather Characteristics and their Correlation to Fire Strike Rate

3.5.1 Fire Weather Characterization

The topography of the sites was converted to percentage by using the following formula: -

\[
\text{Slope in degree (°)} = \tan^{-1}(\text{slope percent/100})
\]

The following observations were recorded to understand the meteorological factors and their correlation to strike fire.

All the four forest Blocks of Dharampur Range in Solan Forest Division, Himachal Pradesh were selected for assessing the fire weather characterizations. The following factors were adhered to for recording field observations: -

- Dharampur was the main field research station where the samples were stored, dried and weighed
- The samples were collected from the north and south facing slopes and brought to main research field laboratory with in a period of 2.0 hrs to maintain uniformity in time of observations, for all the four sites
- Similarity of steepness of slopes at each site towards different aspects/ orientations was maintained
• Similarity of stand composition and density on both the north and south facing slopes were also maintained

3.5.1.1 Meteorological Observations

Daily observations were recorded by using sling Psychrometer at 1400-1600 hrs on temperature and relative humidity as suggested by Lawson and Armitage (2008). Wind observations (direction and speed) were recorded using Beaufort Scale as given by Taylor et al. (1997). Precipitation was recorded through different automatic rain gauges installed at different locations of district Solan. Before any paired comparisons of micrometeorological conditions among the sites were made, the accuracy of all the sensors (air temperature, relative humidity, wind direction and speed) was tested by running them for a week under the same environmental conditions and comparing the resulting values with Portable Weather Station (Delta-T) as well as Thermo hygrograph installed nearby before shifting them to each study site. The data were recorded in all the 4 forest types at different aspects in the similar way. In the first fire season (April-June 2010), the data recorded was tested for its accuracy with respect to other instruments. Hence, the observations recorded during subsequent fire seasons were used for micro-climatic studies on fire weather conditions. To maintain the uniformity of weather conditions the observations were recorded from 1st April- 13th June, 2011 and 1st April-30 June, 2012. The area experienced heavy rainfall of >100 mm after 13th June, 2011 which ended the fire season by decreasing the temperature conditions as well as increased the wetness by increasing the relative humidity of the atmosphere. Moreover, the conditions of the bedding material/forest floor had been changed to wet. Whereas, the weather conditions remained dry during the year 2012 and the area experienced no rainfall before 3rd July, 2012. The details of standard methods as given by IMD, Pune were used for recording different observations as under:-

3.5.1.1.1 Air Temperature

Sling Psychrometer was used to record the dry and wet bulb temperatures. The Psychrometer was spun to allow the air to flow over the thermometers and temperatures obtained after ventilation of both the thermometers were recorded at 1.5 m above the ground level. For wetting the wet bulb thermometer distilled water was used. The data were recorded at four different places towards different aspects selected at all the four sites of different forest types selected for investigation in Dharampur Range of Solan Forest Division and the average values were considered as final readings. Aluminium pointers/ tags were fixed at all
the four positions for recording Psychrometric readings at afternoon hrs between 1400 hrs to 1600 hrs.

3.5.1.1.2 Relative Humidity

After recording the dry and wet bulb readings, a Psychrometric Table (which provides direct calculated values for relative humidity, dew point and vapour pressure of the area) was used to obtain the values of corresponding dew point temperature and relative humidity for the measured conditions.

3.5.1.1.3 Wind Measurements (speed and direction)

A Beaufort scale (Appendix-3.2) was used to represent the in-stand wind conditions at 2 m height during peak burning hours (1400-1600 hrs). The data was recorded in m/s and then converted to different scales as per the requirement of different model predictions. Wind speed data was then converted to effective wind speed after incorporation of slope factor and aspect factor (lee side and windward side) using effective wind speed at different slope percent and different aspects as suggested by Lawson and Armitage (2008). Wind direction was estimated by considering simple mechanism of wind direction i.e. the wind touches the face. Estimation of wind direction was carried out by tagging small flag on the tree branch (free from any obstacle) at a height of 2m from ground. The flag was also used as a fixed place for recording of wind observations during fire seasons. All the observations were recorded in the same manner at all forest types in all the four aspects during the fire seasons (1st April-13th June, 2011 and 1st April-30 June, 2012). The observations recorded during fire season 2010 were used for calibration of instruments and the data was used for accuracy tests of the instruments used. The wind conditions were also observed from synoptic charts during the study period.

The conversion factors used for recorded wind speed at 2m height to effective wind speed at different slope angles and aspects adapted from Rothermal (1983) Model for Fire Behavior Predictions (FBP). Effective wind speed is the combined effect of Mid flame wind speed and the slope equivalent wind speed at 10m height in the direction of maximum spread (head fire). Effective wind speed is used to determine the shape (length-to-width ratio) of a point source fire. Mid flame wind speed is the estimated wind speed at a height above the surface fuel equivalent to the height at Mid flame. This is the wind input required for estimating fire spread using the Rothermel (1983) surface fire model. It is generally derived
from the Surface up to (20-ft) Wind based on sheltering from an upper canopy or flame height based on fuel bed depth.

3.5.1.1.4 Precipitation

The observations of 24 hrs rainfall recorded at automatic rain gauges installed at various locations in district Solan. The data were downloaded from weather forecast as received from IMD, Shimla on every Tuesdays and Fridays during the three consecutive fire seasons (April- June) of 2010, 2011 and 2012.

3.5.1.1.5 Other Meteorological Observations

Clouds are important indicators of atmospheric stability and fuel moisture shading. Hence the sky conditions were observed with special reference to cloud amount in percentage. Sudden changes in the wind shifts are important indicators of breaking inversions. The sky conditions were noted immediately before destructive samplings were taken from all the locations selected. The type / height of the cloud as well as the amount and opacity of the clouds were recorded (Table 3.3). The three mainforms of cloud are cumuliform, stratiform and cirriform. Cumuliform clouds are puffy with distinct elements or cells. They form when moist, conditionally unstable air is initially forced upwards, the moist air cools as it rises, and then reaches saturation and condenses to form a visible cloud. Stratiform clouds develop in uniform layers and have a smoother appearance. They form when stable air is brought to saturation either by the addition of moisture or by cooling of the air. Cirriform clouds are thin, wispy hair-like clouds (Ahrens, 2002). There are three levels or stages that clouds exist in the atmosphere. A basic cloud chart (given in Table 3.3) is used to describe the cloud formations.

Atmospheric pressure, maximum temperature and minimum temperature data were downloaded daily from GPRS based Automatic Weather Station installed at Kasauli and Nauni for the past 24 hrs from 1st April to 15th June, 2010, 1st April to 15th June, 2011 and 1st April to 30th June, 2012 depending on the length of fire season (generally estimated from 1st week of April to June/ pre-monsoon shower > 5 mm). Vapour Pressure was evaluated using Hygrometric Tables (above 900 ft. elevation) w. r. t. Dry/Wet bulb Temperatures. Sky conditions and time of sampling were noted at every sampling event.
Table 3.3: Sky Observations (Ahrens, 2002)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Observation</th>
<th>Sky Condition (fraction of sky covered by clouds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sunny</td>
<td>&gt;1/10 during the day</td>
</tr>
<tr>
<td>2</td>
<td>Clear</td>
<td>&gt;1/10 during the night</td>
</tr>
<tr>
<td>3</td>
<td>Mostly sunny or mostly clear</td>
<td>1/10 to 2/10</td>
</tr>
<tr>
<td>4</td>
<td>Passing clouds</td>
<td>1/10 to 3/10</td>
</tr>
<tr>
<td>5</td>
<td>More sun than clouds</td>
<td>3/10 to 5/10</td>
</tr>
<tr>
<td>6</td>
<td>Scattered clouds</td>
<td>1/10 to 7/10</td>
</tr>
<tr>
<td>7</td>
<td>Partly cloudy</td>
<td>3/10 to 7/10</td>
</tr>
<tr>
<td>8</td>
<td>Mixture of sun and clouds</td>
<td>3/10 to 7/10</td>
</tr>
<tr>
<td>9</td>
<td>High level clouds</td>
<td>5/10 to 7/10</td>
</tr>
<tr>
<td>10</td>
<td>More clouds than sun</td>
<td>5/10 to 7/10</td>
</tr>
<tr>
<td>11</td>
<td>Party sunny</td>
<td>3/10 to 7/10</td>
</tr>
<tr>
<td>12</td>
<td>Broken clouds</td>
<td>6/10 to 9/10</td>
</tr>
<tr>
<td>13</td>
<td>Mostly cloudy</td>
<td>8/10 to 9/10</td>
</tr>
<tr>
<td>14</td>
<td>Cloudy</td>
<td>10/10</td>
</tr>
<tr>
<td>15</td>
<td>Overcast</td>
<td>&gt;9/10</td>
</tr>
<tr>
<td>16</td>
<td>Low clouds</td>
<td>&gt;9/10</td>
</tr>
</tbody>
</table>

The sky conditions as defined by general cloud type as well as in tenths of the celestial concave occupied by clouds. Sudden changes in weather conditions such as high wind speeds/ lightening/thundering/hailstorms etc. were also observed during the fire seasons under consideration.

### 3.5.1.1.6 Diurnal Observations

Diurnal observations were recorded on clear days from 0830 to 1730 hrs with one hour interval in the selected forest sites at all the locations on April 13, 2010, May 13, 2011 and April 12, 2012 to explore the hourly trends of temperature, relative humidity and wind patterns along different altitudes and aspects.

### 3.5.2 Fuel Characterization

A general forest floor survey was conducted at each location using destructive sampling and percent coverage of litter, moss and plant species recorded. A destructive sampling method was used over the consecutive fire seasons to collect weekly data at peak drying/burning periods of the day at 1400-1600 hrs (Van Wagner, 1985) on litter and moss moisture content through various drying and wetting periods along altitudinal variations.
with north and south facing slope as described by Wotton et al. (2005) was used for collecting the samples as given in Figure-3.4.

**Figure 3.4 : Sampling protocol for Forest Floor Characterization** (Wotton et al., 2005)

3.5.2.1 Destructive Sampling Technique

Destructive sampling method was used to measure mean gravimetric moisture content by collecting the samples at each sampling location using a 900 cm\(^2\) grid. Each fuel loading replicate was broken down into independent loading layers: surface needles (non-rotten needles at least two thirds above the forest floor), deep needles (blackened and rotten needles buried in forest floor), woody debris (twigs, cones, bark above and below the surface), moss tips (top 2 cm of moss), moss (green and brown moss minus the tips), and duff (decaying dark material below the moss and above the mineral soil) (Figure 3.4). Averages amongst the three replicates for each substrate layer were used to determine a value for total fuel loading at each site. Moss and duff depths were recorded for each location and averaged for the site.

3.5.2.2 Weekly Samples for Moisture Content

Weekly samples for moisture content were taken from the sites on a rain-free day throughout the length of the fire season. At each site, samples were collected from the three designated sampling locations using the same sampling technique as described for destructive sampling method. The sampling day was divided into two hour target intervals starting at
1400 hrs and ending at 1600 hrs. The destructive samples were collected every week during the fire seasons (1\textsuperscript{st} April-13\textsuperscript{th} June, 2011 and 1\textsuperscript{st} April-30 June, 2012) during 1400-1600 hrs.

Care was taken to collect the samples from the sites which were not strongly sheltered (close to boles of trees, under leaning trees or areas of a typical vegetation density), from uncharacteristically open areas, from depressions in the forest floor that were clearly wetter, from areas obviously compressed from walking or kneeling or from areas where the litter has become unnaturally compacted (animal or hiking trails).

Dead needles litter were collected from the forest surface and placed in an air-tight metal container until it was two-thirds full. Needles which showed signs of decay or were buried more than a third of their length in the moss were avoided. Organic material such as bits of moss, green needles, bark, small twigs or herbaceous vegetation were removed from the sample before sealing the sample bags.

Before collecting moss-tips, the depth of the moss layer was measured. The scissors were used to clip the top two centimetres from the surface of the moss and placed in the sample bag. Once the sample bags were full of appropriate materials, they were sealed with aluminium foil and labelled with the sample site, location and time. They were returned to the lab for drying as soon as possible to avoid condensation and formation of mould. After 24 hours in an oven at 60°C, the samples were removed and weighed immediately ‘dry’ as proposed by Barbara and Valette (2010) for dead fuels. After discarding the sample and recording the value of empty sample bag, the gravimetric moisture content was calculated using the equation:-

\[
\text{Moisture Content (\%)} = \frac{('wet' – 'dry')}{('dry' – empty)} \times 100
\]

OR

\[
\text{FMC} = 100 \frac{(M_i – M_f)}{M_f}
\]

Where: \(M_i\) is the initial mass or wet mass of fuel and \(M_f\) is the final mass or its dry mass.

The standard vegetation fuel layers are calculated as under :-

1) **FFMC** : The upper layer named surface fine fuel layer moisture content (FFMC), which is taken as 0-1.5 cm thickness from the surface, as standardised by Wotton et al. (2005).

2) **DMC** : The middle layer loosely compacted organic material called green moss layer and designated as duff layer moisture content, has variable thickness of 1.5 to 7 cm as standardised in destructive sampling technique.
3) **DC**: The third brown duff layer contains deep decomposed organic matter and named as drought content with variable thickness up to a maximum limit of 18 cm. (Fig. 3.4).

### 3.5.2.3 Vegetation Characterization

Due to the altitudinal variations in the study areas which lies between 2000 – 6000 ft above mean sea level. There are two general climates which the sites fall in i.e., subtropical and sub temperate. The four different sites were selected in each forest block of kadon beat of Dharampur Range of Solan Forest division represent these conditions. The selected forest blocks, Cheola-Anji Matla (Site I), Kadon-Sihardi (Site II), Maltu-Dhar (Site III) and Barog-Nagali (Site IV) is representative of forest vegetation type, Bamboo forest ($T_1$), Mixed Pine forest ($T_2$), Pine-Oak forest ($T_3$) and pure Chir-Pine forest ($T_4$), respectively. Furthermore, at all four sites, at least three sub-sites were selected for each forest type towards different geographical aspects i.e., north facing high/low and south facing high/low.

#### 3.5.2.3.1 Phyto-Sociological Observations

In each selected location, the phyto-sociological study on existing vegetation was made during 2010 fire season. Vegetation data were collected by using 10 randomly distributed quadrats of 10 x 10 sq. m for trees, 20 quadrats of 5 x 5 sq. m for shrubs and 100 quadrats of 1 x 1 sq. m for herbs and grasses as per Mishra (1968).

#### 3.5.2.3.2 Circumference at Breast Height (CBH)

For trees, CBH (Circumference at breast height, 1.37 m from the ground) was measured. Quadrate data were pooled to estimate density, frequency, total basal area and relative values of density, frequency, total basal area (Mishra, 1968; Muller and Ellenberg, 1974). Densities of trees, shrubs and herbs were calculated on per hectare basis. The tree density in each quadrate of 10 x 10 sq. m was pooled for 10 quadrates.

#### 3.5.2.3.3 Tree Height

Allometric observations were recorded by measuring the stand height with the help of multimeter (Ravi multimeter) as given by (Chaturvedi and Khanna, 2000).

#### 3.5.2.3.4 Tree Age

Tree age was calculated by stump analysis of fallen trees in each location as well as recorded from Annual Reports of Solan Forest Division, Solan reported under different blocks of Dharampur Forest Range.
3.5.2.3.5 Tree Diameter (DBH)/ Volume

Tree diameter (diameter at breast height or DBH at 1.37 m) was calculated using CBH /3.14. DBH and tree height of each species recorded during quadrate studies was used to estimate tree volume by using volume tables of that species.

3.5.2.3.6 Understorey Vegetation (shrubs/ herbs and grasses)

The understorey structures on the experimental sites were visually compared with other re-growth areas and through fuels of selected experimental sites were structurally representative of fuels in other re-growth areas. We then classified them into 3 strata as described by Cheney et al. (1992).

3.5.2.3.6.1 Surface Fuels

The fuel components are generally horizontal and compact and comprise the leaf bark and twig litter of the overstorey and understorey plants. All combustible materials lying on the ground and the fuel ladder that are responsible for propagating the surface fires include the fuel components like, leaf barks, twigs, pine needles, pine cones, tree seedlings, stumps, downed dead round wood, dead branches, litter of the over storey/under storey vegetation.

3.5.2.3.6.2 Near-Surface Fuels

This layer contains grasses, low-shrubs and trailers and has surface fuel components of leaves, bark, and twigs suspended within it. The orientation of the fuel components is variable but there is a substantial proportion of upright material which clearly divides this layer from the compacted surface layer.

3.5.2.3.6.3 Elevated Fuels

This layer includes shrubs and juvenile understorey plants up to a height of 2 m. The orientation of the individual components is generally upright. The height and fraction of vegetation cover of each layer within a 1 x 4 m² sample area was measured.

3.5.2.3.7 Vegetation Cover :

The detailed forest vegetation cover in each forest type i.e., Bamboo forest (T₁), Mixed Pine forest (T₂), Pine-Oak forest (T₃) and pure Chir-Pine forest (T₄) is shown in Table 3.4 :-
Table 3.4: Forest Ecology of Dharampur Range, Solan Forest Division, HP-India

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Botanical Name</th>
<th>Local Name</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trees</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td><em>Pinus roxburghii</em></td>
<td>Chir</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><em>Quercus leucotrichophora</em></td>
<td>Oak</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td><em>Cedrus deodara</em></td>
<td>Deodar</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td><em>Toona ciliata</em></td>
<td>Tooni</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td><em>Dalbergia sissoo</em></td>
<td>Shisham</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td><em>Pyrus pashia</em></td>
<td>Kainth</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td><em>Albizia chinensis</em></td>
<td>Siris</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td><em>Juglans regia</em></td>
<td>Akhrot</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td><em>Celtis australis</em></td>
<td>Khirik</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td><em>Acacia catechu</em></td>
<td>Khair</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td><em>Terminalia tomentosa</em></td>
<td>Sain</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td><em>Dendrocalamus strictus</em></td>
<td>Male Bamboo</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Shrubs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td><em>Berberis lycium</em></td>
<td>Kashmal</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td><em>Prinsepia utilis</em></td>
<td>Bhekhal</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td><em>Indigofera tinctoria</em></td>
<td>Kathi</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td><em>Rosa species</em></td>
<td>Kuja</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td><em>Rubus ellipticus</em></td>
<td>Akha</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td><em>Bauhinia vahlii</em></td>
<td>Thor</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td><em>Sarcococca saligna</em></td>
<td>Diun</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td><em>Carissa carandas</em></td>
<td>Karaunda</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td><em>Myrsine africana</em></td>
<td>Jhunjhara</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td><em>Girardiana heterophylla</em></td>
<td>Bichhu buti</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><strong>Herbs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td><em>Anaphalis adnata</em></td>
<td>Bujlu</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

read Table 3.4 (continued)
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Botanical Name</th>
<th>Local Name</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>Artemesia vulgaris</td>
<td>Khardar</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Calotropis procera</td>
<td>Aak</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Datura stramonium</td>
<td>Dhatura</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Duranta plumier</td>
<td>Duranta</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Rubus macilentus</td>
<td>Akha</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Rumex nepalensis</td>
<td>Jungli Palak</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Urtica dioica</td>
<td>Bichhu butti</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Viola canescens</td>
<td>Banafsa</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

**Grasses**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Botanical Name</th>
<th>Local Name</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>Chrysopogon species</td>
<td>Dholu</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>33</td>
<td>Cynodon dactylon</td>
<td>Makora</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>34</td>
<td>Eulaliopsis binata</td>
<td>Bhabbar</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Heteropogon contortus</td>
<td>Lamb Sariala</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>36</td>
<td>Phyllostachys chinensis</td>
<td>Chinese bamboo</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Themeda anthera</td>
<td>-</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*T1 = Bamboo Forest,  T2 = Mixed Pine Forest,  T3 = Pine-Oak Forest  and  T4 = Pure Chir-Pine Forest*

### 3.5.2.4 Ignition Test

Ignition threshold of dead fuel layer was determined by conducting ignition tests in all forest types under different aspects on weekly basis. Small samples (about 30 g) of dead fuel layer were collected at respective sites / locations and their ignitability was determined using a simple match test as suggested by Lawson et al. (1997). The tests were conducted under open conditions at their respective sites / locations at afternoon hours of 1400-1600 hrs after collection of destructive samples. A stop watch was used to record the time taken to ignite the small sample of 30-50 g as collected from the forest floor.
3.6 Social Management – People’s Perceptions

3.6.1 Social Awareness Evaluation

A social investigatory survey was carried out to obtain information that could be useful to describe the community’s perception of forest fire risk and also explain their behaviour and attitude towards mitigation strategies, roles in planning the fire hazard reduction management plans, etc. Questionnaires and data sheets are tailored for interviewing the key informants and households (Appendix-3.3). The questionnaire was tested on a sample of people living nearby the forest area to ensure its readability, understanding and relevance. The questionnaire was delivered in local language. A total of 21 questions were included in the questionnaire (a combination of Likert–scaled and open-ended questions) especially designed to fulfil the objectives. Special emphasis was given to demographic values and socio-economic contexts. Data analysis included whether the people lived in fire-prone or non-fire-prone areas, the gender and age of the population, their living standards and whether people had lived in the area for the last 10 years or more.

3.7 Predictive Models for Effective Management of Forest Fires

The Canadian Forest Fire Danger Rating System (FDRS) was tested for predicting the forest fires in the study area on regional basis. This System has two sub-components; Fire Weather Index (FWI) Model and Fire Behaviour Prediction (FBP) Model. The rating was based on fire weather observations, moisture contents of different layers of forest fuels.

The Fire Weather Index (FWI) was developed by Van Wagner (1987) for prediction of Fire Danger Rating System in Canada for coniferous forests stands. The observation of fuel moisture contents of three fuel bed layers provide relative indicators of general fire danger across the landscape based on weather. The dead fine fuel on forest floor named as fine fuel Moisture: FFM, second dead green partially decomposed organic layer moisture content named as duff moisture: DMC and the third brown deep decomposed organic layer moisture content named as drought moisture: DC concerning larger fuels.

The remaining three indices are the Fire Behaviour Indices of Fire Danger Rating System. The indices are; ISI, BUI and FWI. 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. ISI and BUI 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.

In Canadian Forest Fire Weather Index System (FWI), first of all moisture content codes of each of three standard vegetation fuel layers are calculated for the current day (code FFMC for the upper layer 1.2 cm thick; code DMC- for the middle layer 7 cm thick, and code DC for the lower layer 18 cm thick). The following is for previous day are also taken into account along with data on weather in the midday (air temperature and relative air humidity, wind speed, gross rain precipitation for the previous 24 hours). Impact of the three codes and wind speed is synthesized in the FWI reflect the burning intensity of standard fuel, intensity of standard fuel.

It comprises three fuel moisture codes representing different layers in the forest floor and three fire behaviour indices the Fine Fuel Moisture Code (FFMC), a numerical rating of the moisture content of surface litter and other cured fine fuels on the forest floor. The code is the expression of the water content of litter and dead fuels. It indicates the relative ease of ignition and flammability of fine dead fuels.

The Duff Moisture Code (DMC), a numerical rating of the average moisture content of loosely compacted organic layers of moderate depth (about 7 cm thick) in the middle forest floor layer as shown in the diagram (Figure-3.4). It also provides an estimate of fuels of medium size available for combustion. The Drought Code (DC), a numerical rating of the average moisture content of deep compact organic layers in the forest floor. It represent rating of the water content of deep, compact organic layer in the soil and is a good indicator of seasonal drought effect on a large size fuels.

The Initial Spread Index (ISI), a numerical rating of the expected rate of fire spread. It provides an estimate of the expected propagation of the flame front, without considering the fuel variability. It combines the effect of FFMC and of wind. The Buildup Index (BUI), a numerical rating of the total amount of fuel available for combustion, and the Fire Weather Index (FWI), a number rating fire intensity that is used as a general indicator of fire danger.
Figure 3.5: Basic Structure of Canadian Fire Weather Index (Van Wagner, 1987)
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).

Table 3.5: Descriptions of Indexes of the Fire Danger Rating System and their Contributions to Fire Management (adapted from Stocks et al., 1989)

<table>
<thead>
<tr>
<th>INDEX</th>
<th>Description</th>
<th>Contribution to Fire Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Weather Index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFMC</td>
<td>Numerical rating of the moisture content of litter and other fine fuels</td>
<td>Indicates the relative ease of ignition and flammability of fine fuels</td>
</tr>
<tr>
<td>DMC</td>
<td>Numerical rating of the average moisture content of loosely compact organic layers of moderate depth</td>
<td>Gives and indication of fuel consumption in moderate duff layers and medium-sized woody material</td>
</tr>
<tr>
<td>DC</td>
<td>Numerical rating of the moisture content of deep, compact organic layers</td>
<td>Useful indicator of seasonal drought effects on forest fuels and the amount of smouldering in deep duff layers and large logs</td>
</tr>
<tr>
<td>Fire Behaviour Prediction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISI</td>
<td>Numerical rating of the expected rate of forward fire spread</td>
<td>Combines the effects of wind and FFMC on rate of spread without the influence of variable quantities of fuel</td>
</tr>
<tr>
<td>BUI</td>
<td>Numerical rating combining DMC and DC</td>
<td>Represents the total amount of fuel available for combustion</td>
</tr>
<tr>
<td>FWI</td>
<td>Numerical rating combining ISI and BUI</td>
<td>Gives a numerical rating of fire potential and fire intensity</td>
</tr>
<tr>
<td>HFI</td>
<td>Numerical rating of head fire intensity</td>
<td>Head Fire Intensity is the numerical ranking of difficulty of control for specific fuel types</td>
</tr>
</tbody>
</table>

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 ISI, BUI and FWI components are collectively called as Fire Behaviour Prediction Indices. 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 fire effects (de Groot et al., 2003).

Impact of other fire danger factors (vegetation character and state, ignition sources, etc.) is taken into account by means of empirical regional scales i.e. the fuel characteristics, its drying conditions based on weather conditions as well as the major ignition sources such as in bamboo forests the major ignition source is dry grasses, high temperature and high wind speed resulted in striking of bamboo clumps which produce sufficient heat to ignite the dry grass underneath.
3.7.1 Calculations for Canadian Fire Danger Rating System

The details of symbols / abbreviations as well as different equations used for calculations of different codes and indices are presented below:

3.7.1.1 Canadian Fire Weather Index (FWI) Model

3.7.1.1.1 Fine Fuel Moisture Code (FFMC)

**Range : 0 – 250**

The following equations are required for FFMC calculations:

\[
\begin{align*}
    m_o &= 147.2(101-F_o)/(59.5 + F_o) \\
    k_o &= 0.424 \times [1-(H/100)^{1.7}] + 0.0694 \times W^{0.5} \times [1-(H/100)^8] \\
    E_d &= 0.942 \times H^{0.69} + 11e^{(H-100)/10} + 0.18 \times (21.1-T) \times (1-e^{-0.115H}) \\
    E_w &= 0.618H^{0.753} + 10e^{(H-100)/10} + 0.18 \times (21.1-T) \times (1-e^{-0.115H}) \\
    k_d &= k_o \times 0.581 \times e^{0.0385T} \\
    m &= E_d + (m_o - E_d) \times 10^{-kd} \\
    \Delta F &= (T-70)(0.63-0.0065 F_o) \\
    F &= F_1 + \Delta F \\
    F_1 &= (F_o/100) \times f(r_o) + 1-C \\
    F(r_o) &= -56-55.6 \times \ln{(r_o+0.04)}, 0.02 < r_o < 0.055 \\
    F(r_o) &= -1-182 \times \ln{(r_o+0.04)}, 0.055 < r_o < 0.225 \\
    F(r_o) &= -14-8.25 \times \ln{(r_o+0.075)}, 0.02 < r_o < 0.225 \\
    C &= 8.73 \times e^{-0.1117F_o} \\
    FFMC &= 59.5 \times (250-m) / (147.2 + m)
\end{align*}
\]

It indicates the dryness of the smallest forest fuels (surface litter, leaves, needles, small twigs, etc), derived from yesterday's FFMC and the local noon ambient air temperature, relative humidity, wind speed and 24-hour precipitation.
**Figure 3.6:** Schematics for Calculations of Fine Fuel Moisture Code

The FFMC is calculated as follows:-

1) The previous day’s F becomes \( F_o \).
2) a) If \( r_o > 0.02 \) calculate \( f(r_o) \) by one of Equations 3.10 a, 3.10b, 3.10c  
   b) Calculate C by Equation 3.11  
   c) Calculate \( F_r \) by Equation by 3.9
3) Calculate \( E_d \) by Equation 3.3
4) Calculate \( m_o \) from \( F_o \) (or \( F_r \) if rain) by Equation 3.1
5) a) If \( m_o > E_d \) , calculate \( k \) by Equation 3.2  
   b) Calculate \( m \) by Equation 3.5
6) a) If \( m_o < E_d \) calculate \( E_w \) by Equation 3.4  
   b) If \( m_o < E_w \) , calculate \( m \) by Equation 3.6
7) If \( E_d > m_o > E_w \) , let \( m = m_o \)
8) Calculate \( F_I \) from \( m \) by Equation 3.1
9) Calculate F by Equation 3.7

10) Add $\triangle F$ to $F_I$ to get $F$ (Equation 3.8)

11) Compute $F$ as a function of $m$ by Equation 3.11a.

There are three restrictions on the use of these equations:

1) Equation 3.9 must not be used when $r_o<0.02$; that is, in dry weather the rainfall procedure must be skipped.

2) $F_r$ cannot theoretically be less than zero. If a negative answer results from Equation 3.9, it should be raised to zero.

3) The right-hand bracketed quantity in Equation 3.7 must always be positive, which it no longer is when $F_o$ exceeds 97. Therefore, when $F_o>97$, set $f$ equal to zero. Within these restrictions, the FFMC equations will handle any values of rain, temperature, humidity, or wind, and give a sensible answer.

Where:

$m_o$ - fine fuel moisture content from previous day

$m$ - fine fuel moisture content after drying

$E_d$ - fine fuel EMC for drying

$E_w$ - fine fuel EMC for wetting

$k$ - log drying rate, FMC, $\log_{10} m$/day

$f(r_o)$ - rainfall function in FFMC

$C$ - correction term in FFMC

$F_0$ - previous day’s FFMC

$F_r$ - FFMC after rain

$F_T$ - FFMC before temperature adjustment

$\Delta F$ - temperature adjustment for FFMC

$F$ - present day’s final FFMC
3.7.1.1.2 Duff Moisture Code (DMC)

Range: 0 - Unlimited

Derived from yesterday’s DMC and the local noon dry bulb temperature, relative humidity and 24-hour precipitation.

DMC (P) is calculated as :-

\[ P_r = 244.72 - 43.43 \ln (M_r - 20) \]  \hspace{1cm} (3.12)

\[ r_c = 0.92 r_o - 1.27 \] \hspace{1cm} \text{-----------------Van Wagner (1985)} \hspace{1cm} (3.13)

\[ M_o = 20 + e^{(5.6348 - P_o / 43.43)} \] \hspace{1cm} \text{-----------------Van Wagner (1987)} \hspace{1cm} (3.13b)

\[ M_t = M_o + 1,000 r_c / (48.77 + b r_c) \] \hspace{1cm} (3.14)

\[ b = 100 / (0.5 + 0.3 P_o), \hspace{0.5cm} P_o < 33 \] \hspace{1cm} (3.15a)

\[ b = 14 - 1.3 \ln P_o, \hspace{0.5cm} 33 < P_o < 65 \] \hspace{1cm} (3.15b)

\[ b = 6.2 \ln P_o - 17.2, \hspace{0.5cm} P_o > 65 \] \hspace{1cm} (3.15c)

\[ K = 0.1052 \times (T - 30) \times (100 - H) \times L_e \times 10^{-5} \] \hspace{1cm} \text{----- Van Wagner and Pickett (1985)} \hspace{1cm} (3.16)

\[ K = 1.894 \times (T + 1.1) \times (100 - H) \times L_e \times 10^{-6} \] \hspace{1cm} \text{-----Van Wagner (1987)} \hspace{1cm} (3.16a)

\[ P = P_o (or P_r) + 100 K \] \hspace{1cm} (3.17)

**L_e** is **effective day length** = 9.0 hr \hspace{1cm} \text{------- Van Wagner and Pickett (1985)}

Where :-

- \( M_o \)- duff moisture content from previous day
- \( M_r \)- duff moisture content after rain
- \( M \)- duff moisture content
- \( k \)- log drying rate DMC, \( \log_{10} \) M/day
- \( L_e \)- effective day length in DMC, hours
- \( b \)- slope variable in DMC rain effect
- \( P_o \)- previous day’s DMC

**starting value of DMC = 6** \hspace{1cm} \text{--------- Lawson and Armitage (2008)}

\( P_r \)- DMC after rain, \hspace{0.5cm} P - DMC
3.7.1.1.3 Drought Code (DC)

Range: 0 – Unlimited

Derived from yesterday’s DC and the local noon dry bulb temperature and 24-hour precipitation.

It can be calculated as :-

\[ Q = 800 e^{D/400} \]  \hspace{1cm} (3.18)

\[ r_d = 0.83 * r_o - 0.05 \]  \hspace{1cm} (3.19)

\[ Q_t = Q_o + 100 * r_d \]  \hspace{1cm} (3.20)

\[ V = 0.2 * (T - 27) + L_f \]  \hspace{1cm} (3.21)

\[ D = D_o * (\text{or } D_t) + 0.5 * V \]  \hspace{1cm} (3.22)

\[ L_f = \text{effective day length at DC} \]
**Starting value for DC is taken as 1.39**  -------- Van Wagner and Pickett (1985)

Where :

- \( Q \) - moisture equivalent of \( DC \), 0.01 inch water
- \( Q_o \) - moisture equivalent of previous day’s
- \( Q_r \) - moisture equivalent after rain
- \( V \) - potential evapotranspiration, units of 0.01 inch water per day
- \( D_o \) - previous day’s \( DC \)

*starting value of DC=15*  ----------------- Lawson and Armitage (2008)

- \( D_r \) - DC after rain
- \( D \) – DC

**Figure 3.8: Diagrammatic representation of Calculations of Drought Code**
3.7.1.2 Canadian Fire Behaviour Prediction (FBP) Model

3.7.1.2.1 Build Up Index (BUI)

**Range: 0 - Unlimited**

A relative measure of the amount of fuel available for combustion. BUI Derived from the DC and DMC. It was calculated by the following formulae:

\[ U = 0.8 \times \frac{P \times D}{P + 0.4 \times D} \quad \text{if } P \leq 0.4 \times D \quad (3.23) \]

\[ U = P - [1 - 0.8D/(P + 0.4D)] \times [0.92 + (0.0114 \times P)^{1.7}] \quad \text{if } P > 0.4D \quad (3.23a) \]

Where:

- \( U \) – Build up index
- \( P \) – DMC
- \( D \) – DC

3.7.1.2.2 Initial Spread Index (ISI)

**Range: 0 - Unlimited**

A relative measure of how quickly a fire can be expected to spread. Derived from the FFMC and wind speed. ISI was calculated as follows:

\[ f(W) = e^{0.05039W} \quad (3.24) \]

\[ f(F) = (91.9 \times e^{-0.1386m}) \times [1 + m^{5.31}/(4.93 \times 10^7)] \quad (3.25) \]

\[ R = 0.208 \times f(W) \times f(F) \quad (3.26) \]

Where:

- \( W \) = windspeed at noon, km/h
- \( f(W) \) = wind factor
- \( f(F) \) = fine fuel humidity factor
- \( m \) = water content in fine fuel after drainage
- \( R \) = ISI
37.1.2.3 Fire Weather Index (FWI)

Range: 0 – Unlimited

FWI is the relative measure of potential fire intensity/energy available to be released during fire ignition process. The FWI is a good indicator of overall fire danger, derived from the BUI and ISI.

Compute \( f(D) \) as:-

\[
f(D) = 0.626 \ U^{0.809} + 2 \quad \text{if } U \leq 80 \quad (3.27)
\]

\[
f(D) = \frac{1000}{(25 + 108.64 \ e^{-0.023U})} \quad \text{if } U > 80 \quad (3.27a)
\]

\[
B = 0.1 \ R \times f(D) \quad (3.28)
\]

\[
S = \exp(2.72 \times (0.434 \ \ln(B))^{0.647}) \quad \text{if } B > 1 \quad (3.29)
\]

\[
S = B \quad \text{if } B \leq 1
\]

Where :-

- \( f(D) \) - duff humidity factor
- \( R \) - Initial Spread index (ISI)
- \( U \) - Build up Index (BUI)
- \( B \) - FWI (intermediate form)
- \( S \) - FWI (final form)

3.7.1.2.4 Head Fire Intensity (HFI) or Daily Severity Rating (DSR)

Range: 1 – 6

Head fire intensity is a numerical ranking of difficulty of control for specific fuel types. Flame length is a main visual manifestation.

HFI can be calculated as :-

\[
HFI \text{ or } DSR = 0.0272 \times (FWI)^{1.77} \quad (3.30)
\]
3.7.1.3 Validation of Fire Danger Rating System

The FWI system sub-indexes (ISI, BUI and FWI) were related to observed and simulated fireline intensity in Bamboo and Pine based forest stands in Dharampur Range of Solan Forest Division, Himachal Pradesh. The fireline intensity was calculated through observed rate of fire spread, fuel loading and heat of combustion.

3.7.1.3.1 Calculations of Byram’s Fireline Intensity

Fire intensity calculations were carried out by using Byram’s (1959) fire intensity formula for calculating the single point source of fire intensity, which he defined as the rate of heat energy release per unit time per unit length of fire front (regardless of its depth or width), incorporates these fundamental features:

\[ I = H \times w \times r \]  

(3.31)

Where:

- \( I \) = fire intensity (kW m\(^{-1}\))
- \( H \) = net low heat of combustion (kJ kg\(^{-1}\))
- \( W \) = quantity of fuel consumed in the active fire front (kg m\(^{-2}\)) and
- \( r \) = linear rate of fire spread (m s\(^{-1}\))

Alexander (1982) provided details on how to calculate and interpret the fire intensities. Fire intensity thus defined can vary more than 1000-fold (i.e. 10-100,000 kW m\(^{-1}\) or even more) and can be calculated for the head, back or flanks of the fire (Catchpole et al., 1992) or any portion of fire perimeter.

For practical purposes H is generally considered as constant and its value is taken as \( H \approx 18,000 \text{ kJ/kg} \). For field observations, in the absence of rate of spread measurements for fireline intensity was estimated from flame length. Byram (1959) gave simple empirical relationship between flame length and fire intensity as:

\[ I = 300 L^2 \text{ (Byram, 1959)} \]  

(3.32)
Where: \( L = \) flame length (m), represents the distance between the objects such as trees, farmhouses, paths, any other landmark and the flames.

Establishment of fire danger classes based on fireline intensity relations with difficulty of suppression activities have been developed for supporting this type of decision making. These systems convert the meteorological and climatic information into qualitative ratings of fire behaviour characteristics such as rate of spread, fuel available for combustion and finally the fireline intensity. The numeric limits of fire danger classes for conifer forest fuels were adapted from Alexander and Cole (1995).

### 3.8 STATISTICAL ANALYSIS

The various observations recorded and measured during the study period were statistically analysed using different methods of analysis. Different analysis was done depending on the experimental set up. Thus under each experiment, the details of analysis is given below :-

#### 3.8.1 Existing Fire Management Strategies and their Efficacy

Determining the interaction of forest type and causal factors of fire ignition in all the four forest types during 2010, 2011 and 2012 fire seasons were determined in all the forest types were analysed using SPSS (2005). For estimation of efficacy of fire management strategies, the methods given by Ramos (2000) for calculating distribution of forest fires in different fire size classes as qualitative and quantitative methods for estimating the efficiency of management practices.

To determine the significant interaction among different forest types (4) and fire causing factors (5) on area burnt (ha) during the fire seasons of 2010, 2011 and 2012 were analysed using RBD design and two way ANOVA for evaluating the critical difference among forest types and causal factors.

#### 3.8.2 Fire Weather Characteristics and their correlation to Fire Strike Rate

The significant differences among fire weather parameters in four different aspects and forest types were calculated using two way ANOVA in completely Randomized Block Design. The statistical analysis of yearly interactions was carried out using Least Square Fit Model using JMP 8.0 Statistical Package (Parsad et al., 2010 and SAS, 2010). Karl Pearson correlations and linear/ non-linear regression analysis were carried out to understand the role
of various weather parameters with fuel moisture contents. Further the mean ignition time was regressed with fuel moisture contents in all the forest types to evaluate the strike rate.

3.8.3 Social Management: People’s Perceptions

Data collected from the questionnaire was entered into the Excel sheets and the responses were analysed using SPSS (2005) software. The first step of the analysis was to examine the reliability of general attitudes toward prescribed burning and mechanical thinning as well as specific belief dimensions using Ordinal coefficient of alpha and a threshold of $\alpha > 0.70$ (Zumbo et al., 2007). Confirmatory factor analysis was used as a more stringent test of fit of the hypothesized basic belief dimensions to the data. The demographic details of the survey respondents of the study area included gender, age, educational attainment, land holdings, living standards, cattle and income sources.

3.8.4 Environmental Management through Predictive Models

Calibration of Canadian Fire Danger Rating System (Van Wagner, 1987) was done for fire prone areas of Dharampur Range, Solan Forest Division, Himachal Pradesh-India. Several mathematical models were tested under Fire Weather Index sub-indexes and Fire Behaviour Prediction Models for Fire alerts, suppression and management practices. Simple linear and non-linear regressions models were also tested for significance of each variable of the models and its role in fire prediction management practices. The models were further verified by observed and measured fireline intensity model given by Byram (1959). The equations that are fit to the data as a function of different components of Fire Behaviour Prediction model were analysed by non-linear regression analysis. Finally the fireline intensity was subsequently related to the FWI to produce the fire danger classes associated with the difficulty of suppression activities.