II. LITERATURE REVIEW

2.1. Determinant factors of Forest Fire

The two factors necessary for fires to occur are the presence of flammable fuel and the ignition source. The former depending on climatic, soil and vegetation conditions, and previous fire events, and the latter natural (for example lightening) or anthropogenic. If the ignition source is anthropogenic, it can be caused deliberately (as part of land management), or accidently through negligence (Stolle & Lambin, 2003).

2.2. Environmental Factors Influencing Fire Behavior

Fire behavior is a descriptive term use to designate what a fire does and how it behaves. It estimates what a fire will do and relates to intensity, flame, and rate of spread of specific fire. It is a product of environmental factors which interact with each other includes fuel, topography, weather, and fire. The intensity and speed a fire travels depends on amount and arrangement of the fine dead fuel, moisture content of the dead fuel, wind speed near the flaming zone, and terrain and slope (Gould, 2005). The behavior of a spreading fire is determined by factors such as weather, topography, fuel quantity, and fuel moisture content (Nelson, 2001).

Countryman (1972) in Pyne et al. (1996) presented the concept of the fire environment—the surrounding conditions, influences, and modifying forces that determine the behavior of a fire. Topography, fuel, weather, and the fire itself are the interacting influences that make up the fire environment. This is illustrated as a fire environment triangle with the fire in the center (Figure 2.1).
The fire environment triangle illustrates the influencing forces on fire behavior: fuel, weather, and topography. The fire in the center signifies that the fire itself can influence the fire environment. Based on Countryman (1972).

The changing states of each of the environmental components—fuel, topography, and weather—and their interaction with each other and with the fire itself determine the characteristics and behavior of a fire at any given moment. Changes in fire behavior in space and time occur in relation to changes in the environmental components. From a wildland fire standpoint, topography does not vary with time, but can vary greatly in space. The fuel component varies in both space and time. Weather is the most variable component, changing rapidly in both space and time (Pyne et al., 1996).

2.2.1. Topography

Topography includes the elements of slope steepness, aspect, elevation, and configuration of the land. Variations in topography can cause dramatic changes in fire behavior as a fire progress over the terrain. Although topography may not change in time, it affects the way in which fuel and weather change. The fire environment triangle symbolizes this interaction among the elements. Topography modifies general weather patterns, producing localized weather conditions that in turn affect fuel type and moisture content (Pyne et al., 1996).
Elevation above sea level influences general climate and thereby affects fuel availability. Length of fire season and fuel vary with elevation due to differences in amount of precipitation received, snow melt dates, and greenup and curing dates (Pyne et al., 1996).

Aspect is the direction a slope is facing. Aspect affects fire behavior through variations in the amount of solar radiation and wind that different aspects receive. In general, in the northern hemisphere, south and southwest aspects are most favorable for fire start and spread. These aspects receive more sunshine and therefore have lower humidities and higher fuel temperatures (Pyne et al., 1996).

Solar radiation intensity is greatest when the slope is perpendicular to the sun angle. In the northern hemisphere, fuels on slopes with an easterly aspect will dry out earlier in the day, but not become as dry as those on slopes with a westerly aspect. Slope steepness also affects the radiation intensity and fuel moisture. The slopes where the fuel will be the driest vary with time of year, time of day, and latitude. Thus, as a fire moves over the landscape its behavior can be expected to change with time of day and topographic characteristics because of the variations brought about by the different amounts and intensity of the solar radiation received (Pyne et al., 1996). Slope significantly influences the forward rate of spread of surface fires by modifying the degree of preheating of the unburnt fuel immediately in front of the flames. In a head fire, this is achieved, as with wind, by changing the flames to a very acute angle and with slopes exceeding 15 - 200° the flame propagation process involves almost continuous flame contact. Conversely a down slope decreases the rate of spread of surface head fires (Luke & McArthur, 1978, in Trollope et al., 2002).
2.2.2. Fuel

Fuel is a critical leg in both of the fire triangles: fuel, oxygen, and heat of the fire fundamental triangle and fuel, topography, and weather of the fire environment triangle. Fuel doesn’t cause fire, but it certainly changes the character of a fire, affecting the ease of ignition as well as fire size and intensity (Pyne et al., 1996).

Fuel can be described in terms of both fuel state and fuel type. Fuel state refers to the moisture content of the fuel and whether it is live or dead. Fuel type is a description of the fuel itself. The description of fuel type includes physical properties of fuel, fuel component, and fuel complexes. Fuel properties that affect the way the material burns include quantity, size, compactness, and arrangement.

Fuel components, which are related to the way that vegetation grows may be specified as ground, surface, and crown fuel as well as grass, litter, brush, or overstory. Fuel complexes, which are associations of components include grass and timber with grass and litter understory (Pyne et al., 1996).

Moisture content, expressed as a fraction, is the mass of water held by unit mass of ovendry fuel and is determined primarily by fuel type and weather. It also may be expressed as a percentage of the fuel ovendry weight by multiplying by 100% (Nelson, 2001). Fuel moisture is normally expressed on a dry matter basis and is a critical factor in determining the intensity of a fire because it affects the ease of ignition, the quantity of fuel consumed and the combustion rate of the different types of fuel. The most important influence of fuel moisture on fire behavior is the smothering effect of the water vapour released from the burning fuel. It reduces the amount of oxygen in the immediate proximity of the burning plant material thus decreasing the rate of combustion (Brown & Davis, 1973, in Trollope et al.,
The negative effect of fuel moisture on fire intensity was investigated in the Eastern Cape Province and Kruger National Park in South Africa and is illustrated in Figure 2.2.

Figure 2.2. Effect of fuel moisture on fire intensity recorded in South Africa (Trollope & Tainton, 1986; Trollope & Potgieter, 1985; Trollope et al., 2002).

Fuel load is regarded as one of the most important factors influencing fire behavior because the total amount of heat energy available for release during a fire is related to the quantity of fuel (Luke & McArthur, 1978, in Trollope et al., 2002). Assuming a constant heat yield, the intensity of a fire is directly proportional to the amount of fuel available for combustion at any given rate of spread of the fire front (Brown & Davis, 1973, in Trollope et al., 2002). The highly significant positive effect fuel load has on fire intensity was investigated in the Eastern Cape Province and Kruger National Park in South Africa and is illustrated in Figure 2.3.
Figure 2.3. Effect of fuel load on fire intensity recorded in South Africa (Trollope & Tainton, 1986; Trollope & Potgieter, 1985; Trollope et al., 2002).

2.2.3. Weather

Forest fires are strongly linked to weather and climate (Flannigan & Wotton, 2001). Weather is one of the most important factors affecting the behavior of a fire. The most important components of weather affecting the behavior of a fire are air temperature, relative humidity, and wind speed.

Air temperature plays an important role in fire behavior (Wright & Bailey, 1982, in Trollope et al., 2002). Its direct effect is to influence the temperature of the fuel and therefore the quantity of heat energy required to raise it to its ignition point (Brown & Davis, 1973, in Trollope et al., 2002). Air temperature also has indirect effects via its influence on the relative humidity of the atmosphere and moisture losses by evaporation (Luke & McArthur, 1978, in Trollope et al., 2002). Research in South Africa indicated that air temperature had a highly significant positive effect on the intensity of fires in African grasslands and savannas (Trollope & Tainton, 1986; Trollope & Potgieter, 1985, in Trollope et al., 2002).

The relative humidity of the atmosphere influences the moisture content of the fuel when it is fully cured (Luke & McArthur, 1978, in Trollope et al., 2002). It is
positively correlated with fuel moisture (Wright & Bailey, 1982, in Trollope et al., 2002) and therefore plays an important role in controlling the flammability of fine fuels (Brown & Davis, 1973, in Trollope et al., 2002). Research in South Africa showed that relative humidity had a highly significant negative effect on the intensity of fires burning in African grasslands and savannas (Trollope & Tainton, 1986; Trollope & Potgieter, 1985, in Trollope et al., 2002).

The combustion rate of a fire is positively influenced by the rate of oxygen supply to the fire (Brown & Davis, 1973; Cheney, 1981, in Trollope et al., 2002) hence the effect of wind speed on fire behavior. Wind also causes the angle of the flames to become more acute. With increased wind velocities the flames are forced into the unburnt material ahead of the fire front resulting in more efficient preheating of the fuel and greater rates of spread in surface head fires (Luke & McArthur, 1978; Cheney, 1981, in Trollope et al., 2002). It was stated that increased wind speeds cause greater rates of spread and therefore more intense fires (Brown & Davis, 1973; Luke & McArthur, 1978, in Trollope et al., 2002). However, flame height does not necessarily increase with increased wind speeds because these cause the flames to assume a more acute angle and this may prevent the ignition of aerial fuels.

2.3. Human Factors of Fire Ignition

There is no fire without a cause. The factors necessary for fires to occur are presence of flammable fuel and an ignition source. The ignition source of fires can be natural causes (for example lightening) or human causes (anthropogenic) (Bachmann & Allgöwer, 1999; Stolle & Lambin, 2003). In general, natural causes don’t seem to be of great interest for the wildfire research community. Most of the
Fires are caused by human activities and that is where most of the research emphasis is laid on (Bachmann & Allgöwer, 1999).

Forest fires in Indonesia are usually human induced (Santoso, 2006). Human causes of fire can be categorized as direct cause—setting up fires as method or tool for land clearing (Tomich et al., 1998; Applegate et al., 2001; Santoso, 2006) and indirect caused—human activities that favour the occurrences and potentially increase the risk of fires such as logging, road development, resettlement, etc. (Santoso, 2006).

As point out by Bowen et al. (2000), in the Indonesian context, development can be often equated to opening access to large tracts of sparsely populated Forest Land for other uses. This is particularly the case in the outer islands of Sumatra and Kalimantan where huge areas have already been unlocked by large-scale logging, by clear felling for agro-industrial crops, by oil and gas exploration, and in pursuit of transmigration programme.

Logging *per se* starts no fires but indirect effects have been, and continue to be, devastating (Bowen et al., 2000). Initially primary forests are humid, have a closed canopy with little undergrowth and have a low fire risk. However where logging roads penetrate primary forest, humidity become lower, wind speeds increase, and there is always a ready supply of drier fuel available, therefore the risk to fire is considerably increased (Nicolas and Beebe, 1999).

The agro-industrial crop arrives and takes over the area once the forests have been logged. Ideally the new estate crop is established at the start of the next rainy season to allow it to gain a rapid control of the site and suppress weed growth. But
often far greater areas are cleared at one time than planted. In either case the open
ground encourages the rapid colonization by herbs particularly the grass *Imperata
cylindrica* (alang-alang). The area then becomes highly vulnerable to repeat fires
in the next dry period (Bowen *et al.*, 2000).

2.4. The Role of Remote Sensing and Geographical Information System in
Forest Fire Assessment

2.4.1. Fundamental of Remote Sensing and Geographic Information System

Remote sensing is the science and art of obtaining information about an object,
area, or phenomenon through the analysis of data acquired by a device that is not
in contact with the object, area, or phenomenon under investigation (Lillesand &
Kiefer, 1994). It is a scientific technology that can be used to measure and
monitor important biophysical characteristics on earth. Remote sensing is one of
the main sources of data for a GIS. It can be defined as a process of gathering data
about the surface of the Earth and the environment from a distance, usually by
aircraft or space sensors (Jensen, 1996).

Most of the Geographic Information System definitions focused on two aspects of
the system that are technology and/or problem solving. The technological aspects
define GIS as a computer based system that provides four sets of capabilities to
handle geographically referenced data, including data input, data management
(data storage and retrieval), manipulation and analysis, and data output (Aronoff,
1989). Whereas GIS as a problem solving defines GIS as a decision support
system involving the integration of spatially referenced data in a problem solving
environment. The system contains a set of procedures that facilitate the data input,
data storage, data manipulation and analysis, and data output for both spatial and attribute data to support decision-making activities (Cowen, 1988; Grimshaw, 1994, in Malczewski, 1999).

2.4.2. Remote Sensing for Fire Detection and Fire Monitoring

Traditional ground-based visual detection methods are not always appropriate for offering reliable information on fire location, size and intensity due to the small field of view and difficult terrain. Remote sensing has proven to be a valuable data source in different phases of fire management both before (prevention) and after the fire (damage assessment). Remote sensing observation has significant advantages over conventional fire detection and fire monitoring methods because of its repetitive and consistent coverage over large areas of land (Martin et al., 1999).

Fire produces four forms of signal that are easily observed from space (Robinson, 1991, in Martin et al., 1999): direct radiation from active fires (heat and light); smoke; post-fire char; and altered vegetative structure (scar). Fire detection from satellite images initially focused on analysing the first type of signal (Martin et al., 1999).

There are a number of satellites and aircraft-borne remote sensing systems which can contribute to fire monitoring from space, including NOAA-AVHRR, Landsat-TM and MSS, SPOT, GOES, DMSP, ERS-ATSR, and JERS. The temporal, spectral, and spatial characteristics of these instruments provide a wide range of sensing capabilities and some of them have been shown to be well adapted to fire detection application. NOAA-AVHRR and GOES have provided long-term
operational systems, allowing low cost direct reception and near real-time fire information (Martin et al., 1999).

The usefulness of operational near real-time fire detection from space is obviously very much dependent on observation frequency. Meteorological satellites are more appropriate because of their high repetition coverage. The geostationary GOES satellite series offer images every 30 minutes but only covers the American continents. The polar orbiting NOAA-AVHRR series acquire images over the same area every 12 hours for the same satellite, and cover the entire world (Martin et al., 1999). Therefore NOAA-AVHRR has been used most extensively for detecting and monitoring forest fires.

Temporal resolution of AVHRR data may also be used to follow the spatial evolution of large fires, providing significant information for fire behavior modeling. AVHRR images can provide valuable information because of the possibility of monitoring fire growth at least every 6 hours (when using two NOAA satellites, morning and afternoon). Coarse spatial resolution of AVHRR data restrict this potential to large fires, whose size and duration are enough to be followed in time series of AVHRR image data (Martin et al., 1999).

2.4.3. Remote Sensing for Fuel Cover Mapping

In the context of fire management, fuel maps are essential information requested at many spatial and temporal scales for computing spatial fire hazard and risk and for understanding ecological relationships between wildland fire and landscape structure (Keane, 2001, in Giakoumakis et al., 2002; Lasaponara & Lanorte, 2006).
As point out by Bachmann and Allgöwer (1999), the fuel complex research can be classified in at least two main fields: the classification of fuels and fuel moisture estimation. In terms of fuel classification, it includes studies ranging from discriminating between fuel and non-burnable land cover to sophisticated fuel structure analysis which is mainly based on field investigations or classifications of aerial or satellite imagery. Another important parameter that influences the probability of fire occurrence is the fuel moisture content. As it has a high temporal variability, it is studied intensely in remote sensing, such as using Normalized Difference Vegetation Index (NDVI).

Landsat characteristics represent a good compromise between spectral and temporal resolutions and have an adequate spatial coverage for fuel maps generation. Most commonly, the generation of fuel maps from remote sensing images have been based in the analysis of medium to high-resolution sensors, such as Landsat MSS and Landsat TM data (Kourtz, 1977; Burgan & Shasby, 1984; Dixon et al., 1984; Yool et al., 1984; Agee & Pickford, 1985; Castro & Chuvieco 1998; Vasconcelos et al., 1998; Van Wagtendonk & Root, 2002, in Riaño et al., 2002).

Most of the techniques that have been employed for fuel type mapping of satellite imagery have been based on differences within spectral information (Giakoumakis et al., 2002). New classification techniques such as object-based classification or object oriented classification which is based on the fuzzy concept, is an approach that uses not only spectral information, but also spatial information of image objects, have recently been developed (Giakoumakis et al., 2002; Mitri & Gitas, 2006). The concept here is that information necessary to interpret an image is not...
represented in single pixels, but in meaningful image objects. Segmentation, the first step in the object-oriented approach, involves merging the pixels in the image into image object primitives called objects or segments with a certain heterogeneous and homogeneous criterion. In comparison with pixels, image objects carry much more useful information and, therefore, can be characterized by far more properties, such as form, texture, neighbourhood or context, than pure spectral or spectral-derivative information (Baatz & Shäpe, 2000, in Mitri & Gitas, 2006).

Object-oriented classification models have been developed and applied on Landsat TM, resulting in the accurate mapping of burned areas in the Mediterranean. When comparing the results obtained from the object-based classification with those derived from a pixel-based classification technique (maximum likelihood) for burned area mapping, it was found that the use of fuzzy classification applied to image objects resulted in a reduction in the number of misclassified pixels and that the accuracy of the classification results was improved by a minimum of 18% (Mitri & Gitas 2004, in Mitri & Gitas, 2006).

Object-oriented classification models have also been developed and applied on Landsat TM and IKONOS imagery for fuel type mapping in the Mediterranean (Giakoumakis et al., 2002). The study were focused on determining which of the fuel type classes of Prometheus system could be detected via remote sensing, and comparing the results of the two satellite images and detecting their respective advantages and disadvantages.

Prometheus system is a fire behavior fuel type systems developed by European researchers in the framework of the Prometheus Project. The Prometheus system
is based mainly on the type and height of the propagation element, and it comprises seven fuel types (Riaño et al., 2002). The system has been modified and standardized by Giakoumakis et al. (2002). According to the standardization, fuels are divided into 7 types as shown in table 2.1.

Table 2.1. Fuels Classification of Prometheus System Adaptation

<table>
<thead>
<tr>
<th>Class</th>
<th>Fuel Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Land Fuel</td>
<td>This category comprises grasslands consisting of agricultural and herbaceous vegetation. Such fuel is thin and dry during the summer period, and consequently fires spread quickly and at a low flame altitude</td>
</tr>
<tr>
<td>2</td>
<td>Low-lying Shrubs</td>
<td>This category comprises grasslands, low-lying shrubs (30-60cm) and a high percentage (30-40%) of herbs. In this category are also included lumbered areas in which lumbered remnants still exist</td>
</tr>
<tr>
<td>3</td>
<td>Medium Shrubs</td>
<td>This category comprises medium to large-sized shrubs (0.60-2.0m). Land coverage can be greater than 50%. Areas of natural or artificial regeneration can also be included</td>
</tr>
<tr>
<td>4</td>
<td>Tall Shrubs</td>
<td>This category comprises tall shrubs (&gt;2.0m) and areas consisting of young tree groves, resulting from regeneration</td>
</tr>
<tr>
<td>5</td>
<td>Forest areas with no under story</td>
<td>This category comprises areas where undergrowth has purposely been removed, either by controlled burning (not done in Greece) or via mechanical or chemical methods. In this category, low-spreading fires are the most common</td>
</tr>
<tr>
<td>6</td>
<td>Forest areas with medium understory</td>
<td>This category comprises forests where the leafy part of the tree is much higher than the uppermost parts of the understory. The understory usually consists of low-lying shrubs. Fires characteristic of this category are low with various densities and can sometimes develop to much larger fires under extreme climate conditions</td>
</tr>
<tr>
<td>7</td>
<td>Forest areas with high and dense understory</td>
<td>This category comprises forests with high and dense undergrowth where the distance between the leafy part of the tree and the undergrowth is small, or there is a merging of the two. This type favors severe and high density fires</td>
</tr>
</tbody>
</table>

Source: Giakoumakis et al., 2002

Satellite imagery is not always possible to recognize all these classes in their exact form. The main problem lies in the detection of the understory that may exist in a
forest area and cannot provide enough information for such a detailed classification. Fuel type classification for Landsat TM has been adapted to overcome that problem as shown in table 2.2 (Giakoumakis et al. 2002).

Table 2.2. Fuels Classification of Prometheus System Adaptation for Landsat TM

<table>
<thead>
<tr>
<th>Class</th>
<th>Fuel Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No vegetation</td>
<td>Consists of bare land areas, resulting from fires or human activities such as settlements, streets, fire cuts etc.</td>
</tr>
<tr>
<td>2</td>
<td>Low, sparse shrubs, agricultural land</td>
<td>This class includes the first 2 classes of the Prometheus system</td>
</tr>
<tr>
<td>3</td>
<td>Dense shrubs</td>
<td>This category comprises the 3rd and 4th classes of the Prometheus system</td>
</tr>
<tr>
<td>4</td>
<td>Broadleaved trees</td>
<td>the 5th, 6th and 7th classes of the Prometheus</td>
</tr>
<tr>
<td>5</td>
<td>Coniferous forest</td>
<td>Standardization</td>
</tr>
</tbody>
</table>

Source: Giakoumakis et al., 2002

2.4.4. The Use of GIS in Fire Risk Assessment

A comprehensive consideration for fire risk implies taking into account a wide range of variables. A common terminology distinguishes between the concepts of risk associated to the beginning of a fire (fire ignition risk or flammability) and to the spreading of an active fire (fire behavior risk or fire hazard). In each case, different variables and different risk weights should be considered. However, both approaches require being capable of integrating different spatial variables. GIS provide tools to create, transform and combine geo-referenced variables. Therefore, GIS can spatially integrate several hazard variables related to fire risk and providing tools for risk analysis (Chuvieco, et al., 1999).
The applications of GIS to fire risk modeling have considered a wide range of hazard variables, depending on the specific characteristics of fire events in the different test sites. Nevertheless it can be summarized into several important variables, such as topography (elevation, slope, aspect, and illumination), vegetation (fuel type, moisture content), weather patterns (temperature, relative humidity, wind, and precipitation), accessibility to roads and camping sites, land property type, distance to cities, soils, fire history, and water availability (Chuvieco, et al., 1999).

2.5. Methods for Forest Fire Risk Mapping

Forest fire risk assessment is very important for fire management, it may be considered at different spatial and temporal resolutions: global and local; short-term, and long-term fire risk estimation. Global scales can contribute to establish general guidelines for fire management at continental level, while local scales are adapted to specific fire prevention resources of small regions (Chuvieco, et al., 1999).

2.5.1. Short-Term (Dynamic) Fire Risk Estimation

Short-term estimation of risk is required to take update decisions on fire prevention and suppression activities, which should ideally provide daily estimations of fire risk and it is commonly based on weather data, although recently satellite information is also being considered (Chuvieco, et al., 1999). Although the physical basis to estimate fire risk has many similarities in the different ecosystems, the actual formulation varies from one country to another,
and therefore a great diversity of indices is available since many of them have been developed primary for a specific geographic area (Marzano, et al., 2005).

2.5.1.1. Keetch-Byram Drought Index (KBDI)

Keetch and Byram (1968) designed a drought index specifically for fire potential assessment. It is a number representing the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff and upper soil layers. It is a continuous index, relating to the flammability of organic material in the ground (Pyne et al., 1996).

One important aspect for preventing future fire disasters is the level of awareness that can be gained by an early warning system such as fire danger rating (Hoffmann et al., 1999b). The Integrated Forest Fire Management (IFFM) Project has developed a fire danger rating system (FDRS) for East Kalimantan based on the Keetch-Byram Drought Index (KBDI). In 1995 the index was modified and adapted to the conditions in East Kalimantan (Deeming, 1995). A similar FDRS is used by Forest Fire Prevention and Control Project (FFPCP) in South Sumatra (Nicolas and Beebe, 1999).

2.5.2. Long-Term (Static-Structural) Fire Risk Estimation

Long-term estimation addresses the general, more permanent, planning of fire fighting resources, which is related to the more structural factors that affect fire ignition or fire propagation, such as topography or terrain characteristics, vegetation structure, human activities or weather patterns. These factors can be considered stable at least during a whole fire season, therefore they do not need to
be updated frequently. Two to five year updates are accurate enough for fire management (Chuvieco, et al. 1999).

There are some common methods used in long-term fire risk estimation, such as qualitative methods, quantitative methods based on expert knowledge (multi-criteria evaluation techniques), regression techniques (linear regression and logistic regression), and artificial neural networks (Chuvieco, et al. 1999; Marzano, et al., 2005).

2.5.2.1. Logistic Regression Model

One quantitative approach to obtain a fire risk index is to calculate the weights of the different variables using regression analysis techniques such as logistic regression. In the context of fire risk assessment, fire occurrence (usually expressed as number of ignition points/areas or as a proportion of burned area) is the dependent variable, while fire danger variables (slope, fuels, fuel moisture, road network, recreational areas etc.) are the independent ones. Coefficients of regression become the weights of each danger variable to produce the synthetic fire risk map (Marzano, et al., 2005).

Logistic regression is a quite flexible tool, since it accepts the input of a data set composed of continuous and/or categorical variables as well as non-normally distributed one. Several independent variables can be included in the model. Its main characteristic refers to the binary format of the dependent variable (Chuvieco, et al., 1999).
Thoha (2006) applied logistic regression on forest fire prediction in peatland areas in Bengkalis, Riau Province. There are nine determinant variables used to predict forest fire occurrences and the result is as follows:

\[
\text{Log (ODDS) Fire Probability} = -0.4742 + 0.001578 \times \text{precipitation} - 0.005033 \times \text{peat depth} - 3.822925 \times \text{XDPIT} - 0.00000857 \times \text{distance to road} + 0.0000054 \times \text{distance to settlement} + 0.00000191 \times \text{distance to plantation} + 0.0000032 \times \text{distance to agriculture land}
\]

2.5.2.2. Multi-Criteria Evaluation Technique

Multi-criteria Evaluation (MCE) or Multi-criteria Analysis (MCA) is a decision-making tool developed for complex multi-criteria problems that include qualitative and/or quantitative aspects of the problem in the decision-making process (Mendoza et al. 1999). The MCE techniques (Barredo, 1996, in Chuvieco, et al. 1999) may be a good alternative to reduce the subjectivity of this assigning process, since the opinion of experts may be quantitatively assessed. Moreover, each expert’s opinion may be weighted according to his/her degree of knowledge in the field or the study area. The MCE techniques have been used for fire danger mapping, weighting each danger variable after the expert’s opinion in two different scenarios (Alcázar et al., 1990, in Chuvieco, et al. 1999).

Multi-criteria analysis can be implemented using Analytical Hierarchy Process (AHP) (Saaty, 1980). The AHP method approaches decision making by arranging the important components of a problem into a hierarchical structure similar to a family tree. The AHP method reduces complex decisions into a series of simple comparisons, called Pairwise Comparisons, between elements of the decision hierarchy. By synthesizing the results of these comparisons, AHP can provide the best decision and provide a clear rationale of the choice (Mendoza et al. 1999).