INVESTIGATION OVER A NATIONAL METEOROLOGICAL FIRE DANGER APPROACH FOR TURKEY WITH GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

INVESTIGATION OVER A NATIONAL METEOROLOGICAL FIRE DANGER APPROACH FOR TURKEY WITH GEOGRAPHIC INFORMATION SYSTEMS

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The aim of this study was to investigate Meteorological Fire Danger Indices for Turkey. A number of internationally implemented fire danger indices were calculated with Fire Danger Processing software and their performances were tested with Mandallaz and Ye's Performance Score Method. As a result, among other meteorological fire danger indices that have been applied by several fire fighting administrations and services, the U.S. National Fire Danger Rating System, Mc.Arthur's Fuel Moisture Model and Forest Fire Weather Index, BEHAVE Fine Fuel Moisture Model and Keetch Byram Drought Index, the Canadian Fire Weather Index was selected as the best performing fire danger index for Turkey. Calibrated with monthly fire history data of the last 5 years' records, the results during the determined fire season were integrated with vegetation cover data for Turkey, derived from

GLC 2000 global land cover data.

Besides, daily performance of the Canadian Fire Weather Index was observed by three consecutive days in August 2006 and the outcomes were evaluated with the information about fire events compiled from newspaper archives. The study is a first attempt for further fire related analysis at the national scale; an attempt to establish an early warning system and a spatial base for mitigation effort for the wild fire phenomenon in Turkey.

Keywords: Meteorological Fire Danger Indices, Rapid Fire Danger Assessment, GIS, Turkey

ÖZ

TÜRKİYE İÇİN ULUSAL BAZDA METEOROLOJİK YANGIN TEHLİKE İNDEKSLERİNİN COĞRAFİ BİLGİ SİSTEMLERİ İLE ARAŞTIRILMASI

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Bu çalışmanın amacı, Türkiye için orman yangını tehlike indekslerinin araştırılmasıdır. Uluslararası alanda uygulanan bir dizi yangın tehlike indeksi Fire Danger Processing yazılımı yardımı ile hesaplanmış olup, indeks performansları, Mandallaz and Ye's Performance Score Metodu ile test edilmiştir. Sonuç olarak, bir çok yangınla mücadele yönetim ve sivil koruma kuruluşlarınca kullanılan A.B.D. Ulusal Yangın Tehlike Dereceleme Sitemi, Mc. Arthur Yakıt Nemlilik Modeli ve Orman Yangını Hava Indeksi, BEHAVE Yakıt Nemlilik Modeli, Keetch Byram Kuraklık Indeksi gibi indeksler arasından, Kanada Yangın Hava Indeksi Türkiye için en iyi performansı gösteren yangın tehlike indeksi olarak bulunmuştur. Aylık bazda 5 yıllık yangın verileri ile kalibrasyonu yapılaran, belirlenen yangın sezonuna ait sonuçlar, GLC2000 küresel arazi örtüsü verisi ile entegre edilmiştir.

Bunun yanısıra, Kanada Yangın Hava Indeksi'nin günlük performansı, 2006 yılı, Ağustos Ayı'na ait üç ardışık gün için gözlemlenmiş olup, gazete arşivlerinden derlenen yangın haberleriyle sonuçlar değerlendirilmiştir. Çalışma, ulusal bazdaki yangınla ilgili ileriki araştırmalar için ve erken uyarı sisteminin kurulması için ilk girişim teşkil edip, Türkiye'deki yangın olgusu için, önlem alma süreci için mekansal bir temel teşkil etmektedir.

Anahtar kelimeler: Meteorolojik Yangın Tehlike İndeksleri, Hızlı Yangın Tehlike Değerlendirme, CBS, Türkiye

To My Parents

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LIST OF ABBREVIATIONS

BA	Burned Area in hectares
BUI	Built Up Index
CFFDRS	The Canadian Forest Fire Danger Rating System
DC	Drought Code
DMC	Duff Moisture Content
EFFIS	European Forest Fire Information System
FFMC	Fine Fuel Moisture Code
FWI	Fire Weather Index
GIS	Geographic Information Systems
GLC 2000	Global Land cover 2000 product
ISI	Initial Spread Index
JRC	Joint Research Center
Mark 3	Mc. Arthur's Grassland Fire Danger Meter
Mark 5	Mc. Arthur's Forest Fire Danger Meter
Mark 5F	Mc. Arthur's Fule Moisture Content in Grassland Fire Danger Meter
MFDI	Meteorological Fire Danger Index
MFDIP	Meteorological Fire Danger Index Processor
NFDRS	National Fire Danger Rating System
NoF	Number of Fires
RS	Remote Sensing

CHAPTER 1

INTRODUCTION

1.1. Objectives

For many world ecosystems, wild land fires have become a major environmental issue recently (Ayanz, 2003). However, the effects and outcomes of wild land fires should not be considered only as an issue of environmental disaster like soil erosion, destruction of water resources, air pollution, desertification, droughts and landslides but also they should be perceived as a matter of socio-economical and political phenomena; as being an industrial activity, protecting individual's and societies' properties and goods and most importantly, as saving lives of people and preventing possible injuries (Taşel, 2002). In this perspective, the study of wild land fires has received attention from very different sciences geographic sciences.

Like other countries in the Mediterranean region, Turkey has suffered from wild land fires every year and considerable amount of forested area has been lost (Figure 1.1). To illustrate, from the year 1937 until 2006, 75.648 forest fire events have been recorded. As a result, 1.563.813 ha of forested area has been lost (General Directorate of Forestry, Forest Protection Department, 2006). It is worth to mention also that Turkey has a considerable amount of forest, 21.212.000 ha, which is 26, 9% of the total area, is forested

(General Directorate of Forestry, Forest Protection Department, 2006), concentrated mostly in north, west and southwestern areas.

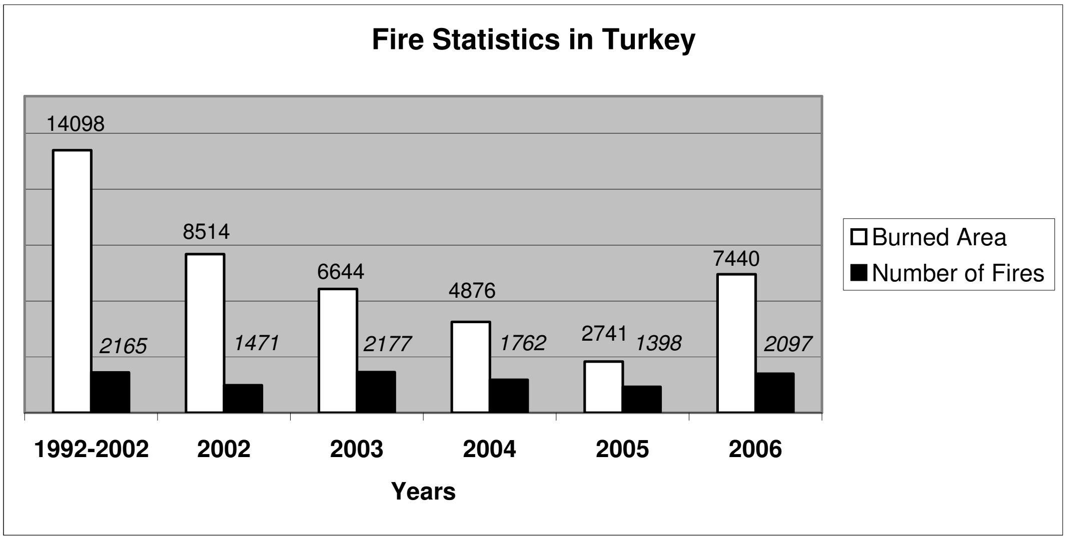


Figure 1 1: Number of Fires in Recent Years in Turkey (General Directorate of Forestry, Forest Protection Department, 2006)

Another point to consider is the causes of fire events in Turkey. While wild land fires may be considered as a part of natural cycle or process, it is important to note that today the causes of wild land fires are originated from human related factors.

To illustrate, in 2005 in Turkey, 71% of the forest fires are originated from human related factors, 20% of them are unknown and only 9% of them can be considered as natural causes (General Directorate of Forestry, Forest Protection Department, 2006). This clearly indicates that forest fires are preventable. This fact is valuable for managers, policy makers and scientists interested in mitigating and evaluating the effects of forest fires.

It is important to mention here about recent contribution and capabilities of Geographical Information Systems (GIS) and Remote Sensing (RS) techniques in terms of forest fire fighting activities as an issue of disaster management (Figure 1.2).

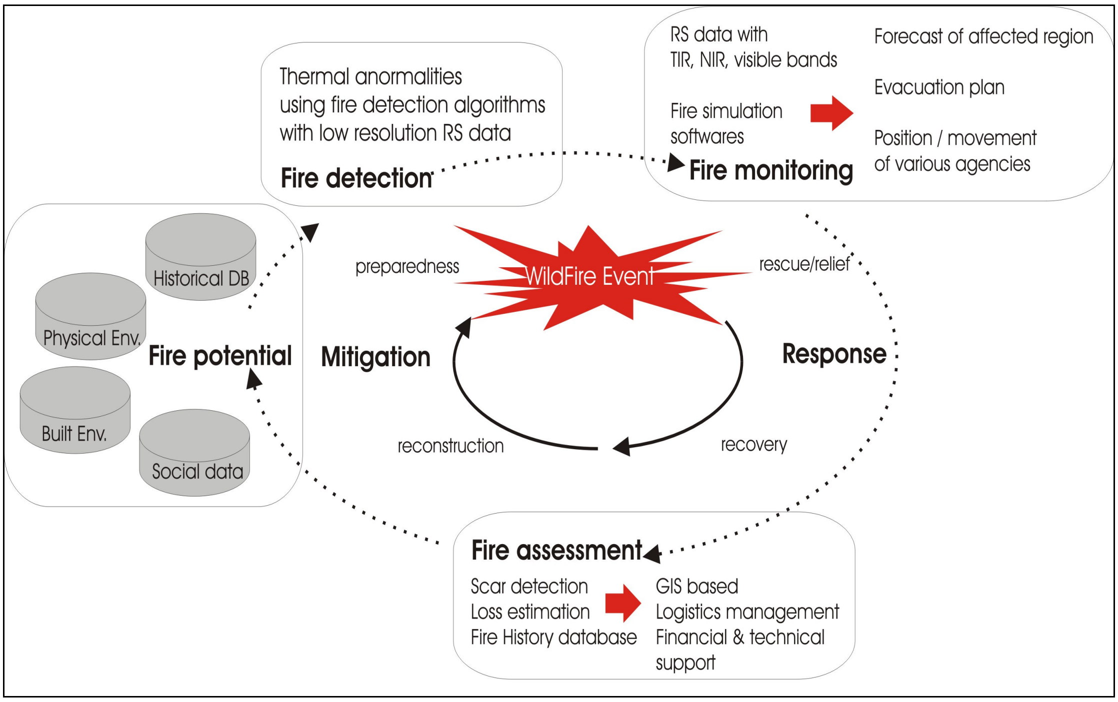


Figure 1.2: Fire Research Cycle, GIS and RS contributions to forest fire studies (based on Klaver R.W. et al., 1997)

Capabilities of GIS and RS techniques in the field of forest fire issues might be probably explained best with the term "*Fire Analysis Cycle*" of Klaver et al. (1997). The Fire Analysis Cycle has mainly four steps, which include mapping the potential for a fire start if there is ignition, detecting the start of a fire, monitoring the progression of a fire, mapping the extent of the fire scars and the progression of vegetation regeneration. While Fire Detection emphasizes on detection of thermal anormalities in remotely sensed scenes, Fire monitoring uses the capabilities of low-resolution airborne sensors and collaborates with fire behavior simulation software.

Fire assessment refers to reconstruction and recovery phases of the event. Burned area detection is a good example for this kind of analysis. On the other hand, Fire Potential analysis is probably the most important one among other phases and strongly related with preparedness.

Fire Potential analysis is to determine the factors leading to a potential forest fire event. It relies on historical data, physical environment data, built environment data and data regarding to socio-economic features of the area of interest. To sum up, with spatial data management and visualization capabilities, GIS in the field of forest fire fighting activities build strong basis for Forest Danger Rating (Allgöwer et al., 2003).

However it should be noted that better fire potential estimation with GIS depends on the quality of data used in the process. Since the dataset and variables are abstractions of nature, any kind of estimation or modelling approach will contain some degree of errors. Despite of these drawbacks, recent studies and projects conducted all over the world have indicated that GIS are still good candidate to assess fire danger in a geographical sense.

From GIS point of view, a set of cartographic variables is needed. These variables are mainly related to weather, topography and vegetation cover, which are often referred as 'Fire Triangle' to in literature (Contryman, 1972 and Pyne et al 1996). Among these three major components of Fire Triangle, weather inputs are more dynamic compared to topographic features and vegetation cover inputs, which are often considered as permanent aspects (or as parameters changing over a long time period) of a fire event.

There has been a debate on the factors – fuel accumulation and meteorological variability, that controls fire occurrence. Some authors like Minnich (1983, 2001) and Chou (2001) claim that systematic extinction of wildfires will result in a fuel load that will trigger larger fires under the extreme weather conditions. Without fire suppression, there are frequent and small fire events, but fewer and larger fire events. By creating fragile patterns of landscape elements, large wild land fires can be prevented. On the other hand, authors like Moritz (1997) and Keeley (1999) argues that there is no relationship between the probability of large fires and fire suppression in terms of occurrence, but the primary reason for large wild land fire events has been the extreme weather situations. Considering the fact that wild land fire events have complex nature and have many causative agents, both approaches alone might fail to explain the large wild fire events (Pinol J. et al., 2005). Rothermel (1983) clearly stated that both weather patterns and fuel availability together play an important role in determining the fire occurrence. Therefore, an integrated approach should be a matter of concern. More detail on this debate will be given in Section 2.1.2.

In this study, the main focus was given to meteorological variables in determining the fire danger in Turkey. The aim was to determine the best explanatory fire danger index for wild land fire events in Turkey, by means of computing danger indices, which rely on only meteorological parameters. The reason for the adoption of meteorological fire danger indices as an approach to determine fire prone areas of Turkey was that these danger indices provide rapid and useful information by expressing the state of the atmospheric conditions, which influence both fire ignition and propagation increasing vegetation dryness and provides oxygen for fire propagation (Chuvieco et al., 1999). Besides, they are measured frequently over national or regional scale without any further necessary measurement (Ceccato, 2001). This computational efficiency enables forest authorities, administrations and fire fighters to conduct an early warning system.

However, since both weather parameters and fuel availability play an important role for wild land fire occurrence, the fire danger information generated by meteorological fire indices was integrated with vegetation information for Turkey. Integration of vegetation cover data was expected to improve the reliability of the fire danger estimated by meteorological variables.

A number of meteorological fire danger indices were selected for explaining the forest fire phenomenon in Turkey. The candidate Fire Danger Indices were evaluated according to their performances against different fire related scenarios. The best performance showing danger index was calibrated with fire records of last 5 years and as a result, five ordinal classification (very low, low, moderate, high and very high) of the selected meteorological fire danger was obtained. This classification scheme was integrated with global land cover information for Turkey to refine the outputs of fire danger study for Turkey.

1.2. Outline of the Thesis

In Chapter 2, recent approaches to assess fire danger were discussed. The focus was given on meteorological fire danger indices and internationally applied meteorological fire danger indices were presented. Based on several criteria cited in literature, a set of fire danger indices was chosen for Turkey. A brief background, technical description, advantages and drawbacks of each candidate fire danger indices were discussed. The following part provides an overview about these indices based on the variables they operated with and a comparison between these candidate indices were presented.

In Chapter 3, description of the necessary dataset was given. Information about meteorological variables from the year 1975 till 2004, fire records of the 5 year (between 2001 and 2005) and information about different land cover data for Turkey were provided.

In Chapter 4, necessary processes were explained in detail so as to calculate the candidate indices. The results of candidate fire danger indices were visually presented and evaluated.

In Chapter 5, the performances of each candidate indices were tested based on Mandallaz and Ye's Performance Testing Score Method. Several scenarios regarding to number of fire and burned area variables were used to differentiate the strength of the candidate indices.

In Chapter 6, the results of the best performing index were calibrated with fire history data by assigning index values to appropriate danger classes. Namely, index values of the selected fire danger index were converted into an ordinal classification scheme, changing from very low level to extreme level of fire danger. In addition, the calibrated results of the best performing index was integrated with vegetation cover data to have a more realistic fire danger assessment for Turkey. Therefore, a brief discussion about two global land cover products – MODIS Terra Level 3 land cover product and GLC 2000, land cover product derived from SPOT VEGETATION, was necessary. The advantages and drawbacks of each product were also mentioned. A fire danger classification, based on different forest types was included. In addition, the daily performance of the selected index was evaluated. For this purpose, three consecutive days, 19^{th}, 20^{th} and 21^{st} of August in 2006 were selected. The calibrated results of each day were compared with the information about fire occurrences gathered from newspaper archives.

Chapter 7 is devoted to discussions, recommendations and future work.

CHAPTER 2

METEOROLOGICAL FIRE DANGER INDICES

In this Chapter, current methods for Fire Danger assessment were discussed. Although discussions were more concentrated on meteorological fire danger indices, brief information and examples of other recent approaches were presented here. In addition, advantages and disadvantages were examined.

2.1. Methods for Fire Danger Assessment

Before discussing about current approaches to assess fire danger, the scope of the term ‘fire danger’ should be clarified.

In literature, the fire danger is often associated with numerical indices calculated based on different temporal scales like daily, weekly and monthly referring to meteorological conditions that might lead to fire ignition and fire propagation (Figure 2.1). The purpose of calculating these indices is to quantify and indicate the level of fire danger for the area of interest (Ayanz et al., 2003). The outcome of fire danger assessment is generally expressed with fire danger levels, ranging from low to high and commonly used in operational wild land fire management.

Moreover, currently these danger levels are represented as broad scale maps by means of Geographic Information Systems indicating areas with different fire danger levels and can be published on Internet (Allgöwer et al., 2003).

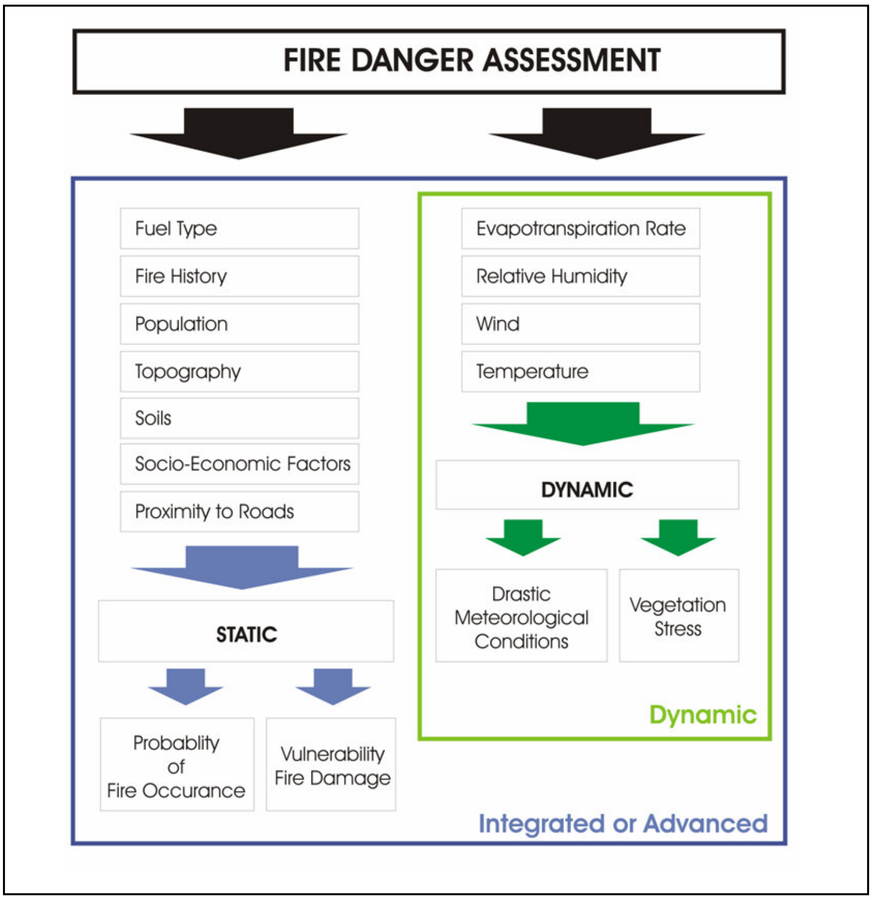


Figure 2.1: Dimensions of Fire Risk Assessment (based on Ayanz et al., 2003)

Various indices can be found that have been suggested by different authors. These indices for fire danger assessment are different not only in terms of their spatial scale of applicability but also in terms of their temporal scale. Spatial dimension of indices vary from local to global scale; whereas temporal dimension of indices vary from short-term to long-term.

Since the study area was determined as national scale, in this point it might be important to mention about classification of fire risk indices in their temporal domain. Broadly there are two kinds of fire risk indices in temporal domain:

- Long Term Indices and
- Short Term Indices

2.1.1. Long Term Indices

According to Ayanz et al. (2003), long-term forest fire risk indices are indicators of stable conditions that favor for fire occurrence.

Input parameters for long-term indices do not change frequently as in the short-term indices and are often considered changing monthly or yearly. It is also important to note that long-term indices enable to understand the spatial pattern of fire events and is used to determine areas with high danger of fire due to their fundamental conditions that leads fire occurrence.

The variables of long term indices for a fire danger rating system can be listed as topography, vegetation, weather patterns, accessibility, land property type, distance to cities, soils, fire history and water availability. Among all the geographical variables, most of the fire danger systems include mostly weather pattern, vegetation coverage, topography and fire history (Andrews 1996, in Pyne et al., 1996). Moreover, according to the definition of *'Fire Triangle'*, topography, fuels and weather (Contryman, 1972 and Pyne et al., 1996) are three components that best assess fire potential at any scale and information level. It is also important to note that the variables for long-term indices are often averaged over a given period of time. There are three widely accepted indices of this kind:

- Fire Probability Index,
- Vulnerability (likely Damage) Index and
- Statistical Index.

While the former focuses on fuel sources and additionally includes topographic and socio-economic variables, the latter operates on assigning to each cell a vulnerability degree and takes potential erosion derived from soil data, slope and the rainfall, level of protection and proximity of urban areas. On the other hand, Statistical Index is an unsupervised statistical analysis in order to identify and as objectively as possible, the variables that best explain the fire phenomenon (Ayanz et al., 2003).

2.1.2. Short Term Indices

Being also referred as dynamic indices (Figure 2.1), short-term indices operate on variables that change rapidly over time and emphasize on fire ignition and propagation. The aim of short-term indices is to derive information about vegetation status. This can be done either through vegetation indices calculated from satellite images using remote sensing techniques or meteorological indices. Short tem indices can be categorized further under three headings,

1. Vegetation stress indices
2. Fire potential indices
3. Meteorological Indices

Aim of the vegetation stress indices is to quantify the amount of water in plants, because vegetation structure and moisture condition have a strong influence on the ignition and the propagation of forest fires. Whereas, fire potential indices rely on a set of vegetation variables like live-ratio, moisture content of small dead fuel and fuel type (Ayanz et al., 2003).

Recent studies in remote sensing field indicate promising results to derive moisture content information through several vegetation indices like Moisture Stress Index (Rock et al., 1986 in Danson and Bowyer, 2004), Moisture Component, Normalized Difference Water Index (Hunt and Rock, 1989 in Maki et al., 2004) and Relative Water Content (Inoue et al., 1993 in Maki et al., 2004). The logic behind computing vegetation indices with remotely sensed data is to obtain information about live vegetation moisture content. Since if the live moisture content of a specific vegetation type is high, there will be a lower chance of fire danger, while if the moisture content is very low, which means that the vegetation type is dry and there is a high potential of fire danger.

The effort on determining live fuel moisture from remotely sensed data is important but also marginal for fire danger studies (Chuvieco et al., 2004), since the most dangerous causative agent is the dead fuel accumulation under the tree canopy (Dimitrakopoulos and Papaionau, 2001), which needs ground truth verification. Besides, to derive live moisture content from remotely sensed data needs further requirements like fuel type classification and extensive knowledge about plant biochemistry (Ceccato, 2001).

While vegetation indices concern live moisture content for fire danger assessment, meteorological Indices, on the other hand, are designed to rate the component of fire danger that changes with weather conditions (Camia et al., 1999). Recently several forest fire and civil protection services around the world like Canadian Forestry Service in Canada (van Wagner, 1987), National Interagency Fire Center in the USA, Joint Research Center in Italy (Ayanz et al., 2003) and Portuguese Meteorological Institute in Portugal (Gonçales et al., 2006) have used meteorological fire danger indices as early warning system. Detailed information about meteorological indices will be given in Section 2.2.

Having mentioned about different approaches for fire danger assessment, it is necessary to make brief overview here. Besides temporal difference as their names suggest, the main difference between long term and short-term fire indices is that long-term danger indices take into account variables that change very slow during time and are considered, therefore, as permanent, whereas short term indices mainly focuses on temporally changing aspects like vegetation moisture content and weather patterns of fire event. It is also remarkable that weather input for short-term indices, weather input refers to daily or weekly changing parameters, whereas for long-term indices, it refers to averaged values of a given period of time. The reason for that is to provide highest stability over time and is the case of the statistical approach of this kind (Ayanz et al., 2003). For example, after high intensity rain or in the case of burned area, short term indices will be very sensitive both in terms of meteorological and vegetation status, which will result in misleading results (De Luis et al., 2001). On the other hand, for long-term studies, flattened parameter values might be less suitable for developing early warning systems or be not sufficient in terms of rapid response in the case of a fire event.

To conclude, there is no single uniform approach for fire danger assessment in literature. The adoption of the methodology (either short term or long term) depends highly on the data availability, temporal scales and the purpose.

2.2. Introduction to Meteorological Fire Danger Indices

Weather is one of the most important components of the ‘Fire Triangle’ and surely the most dynamic. Hence historically, in terms of fire danger assessment studies, the main focus has been given to weather parameters. Several meteorological fire danger indices have been applied and used by forest fire services and civil protection services to assess fire danger around the world. Despite the fact that these meteorological fire danger indices are numerous and were developed for a specific geographical area, today some important meteorological fire danger indices have been accepted internationally. In the following section, the candidate indices were presented and overviewed.

2.2.1. Meteorological Fire Danger Systems in the world

According to Willis et al. (2001), either locally or internationally implemented, a fire danger rating system should have the following properties:

- The ability to predict fire danger both reliably and consistently;
- The ability to predict fire danger on a daily basis,
- The ability to apply throughout the country,
- The ability to accommodate the full range of possible conditions that affect fire behavior,
- The ability to use currently available data,
- The capability to perform satisfactorily in environments like area of interest.

Having listed the features of an ideal fire danger index, it was also beneficial to present here most important examples of fire danger indices implemented in other countries, although there is not a common method to assess forest fire danger.

In spite of this, some of the fire danger indices have proved to be more promising when applied in different conditions from the ones they were developed for and are currently implemented in different areas in the world. These indices have been described in Camia et al., (1999):

- The Canadian Fire Weather Index and five sub-component,
- U.S. national Fire Danger Rating System (NFDRS),
- Mc.Arthur Fuel Moisture Model developed in 1967
- Mc.Arthur Model revised in 1980 with three sub-components,

On the other hand,

- BEHAVE Fine Fuel Moisture and
- Keetch Byram Drought Index (KBDI)

are also widely known indices in literature and their contribution was expected to be important as well, so these indices were also taken into the scope of this study. Finally, 6 major meteorological fire danger indices along with 13 sub components were analyzed in this study. Suitability of these internationally implemented meteorological fire danger indices based on the criteria listed above, were discussed in Section 2.3.

In the following section, information about the working principles and structures of the mentioned fire danger indices were presented. The equations of fire danger indices described are taken from Camia et al., (1999):

2.2.1.1. Mc.Arthur Fuel Moisture Model (McArthur 67)

Historically, Mc.Arthur's Fire Danger Rating System (Mc.Arthur 1958) has been used as the standard Forest fire danger rating system in eastern Australia since the late 1950's. This index developed by Mc. Arthur so that it included inputs of long term drought (Keetch Byram Drought Index), recent rainfall, temperature, relative humidity and wind speed (Ayanz et al., 2003). Detailed information about Keetch Byram index is described in Section 2.2.1.5.

Mc. Arthur's 1967 Fuel Moisture Model is calculated with the following (Equation 2.1):

$$m = 5.658 + 0.04651 H_a + 3.151 * 10^{-4} \frac{H_a^3}{T_a} - 0.1854 T_a^{0.77} \tag{2.1}$$

As can be seen, this index relies on H_a- air relative humidity (%) and T_a- Air temperature (℃) and m, here, refers to Mc. Arthur Fuel Moisture index value. This equation is strictly valid under the following conditions (Viney, 1991) (Equation 2.2):

$$5(\%) < H_a < 70(\%)$$
$$10℃ < T_a < 41℃$$
$$42.5\text{-}1.25\ T_a < H_a < 94.5\text{-}1.35\ T_a \tag{2.2}$$

2.2.1.2. Mc.Arthur's Forest Fire Danger System (McArthur 80)

After several empirical wild land fire observations until 1973, Mc. Arthur's index has been improved (Mc. Arthur, 1966) (Figure 2.2.). There are four components of Mc. Arthur's redeveloped fire danger system.

The first sub-model is called Drought Factor, which is the fine fuel availability model and addresses the availability of the surface fine fuels through meteorological parameters like rainfall and days past since last rain fall. In addition, it uses also Keetch Byram Drought Index (KBDI), which is calculated from daily maximum temperature, rainfall and annual rainfall parameters. More information about KBDI will be given in Section 2.2.7. The logic behind Drought Factor sub-model accepts that the fine fuel availability can be extracted from through moisture in the soil and the air above (Ayanz et al., 2002).

The second sub-model is Surface Fine Fuel Moisture, which is the surface fine fuel moisture estimation. Based on daily temperature and relative humidity values. The model assumes that the flat is flat and the forest has moderate cover. Various characteristics of the topography, forest density, cloudiness, windiness are not taken into account in the area of interest.

The third sub-model is Rate of Spread, which is the combination of two previous sub-models – Drought Factor and Fuel Moisture sub-model. The wind speed information is added to fine fuel moisture and availability information derived from the second sub-model. Final sub-model is the Suppression Difficulty sub-model, which is based on the relationship between the spread of fire (derived from wind speed parameter) and surface fine fuel moisture content. It is accepted that dryness of the fine fuel together with the wind speed will affect the suppression difficulty (Ayanz et al., 2002).

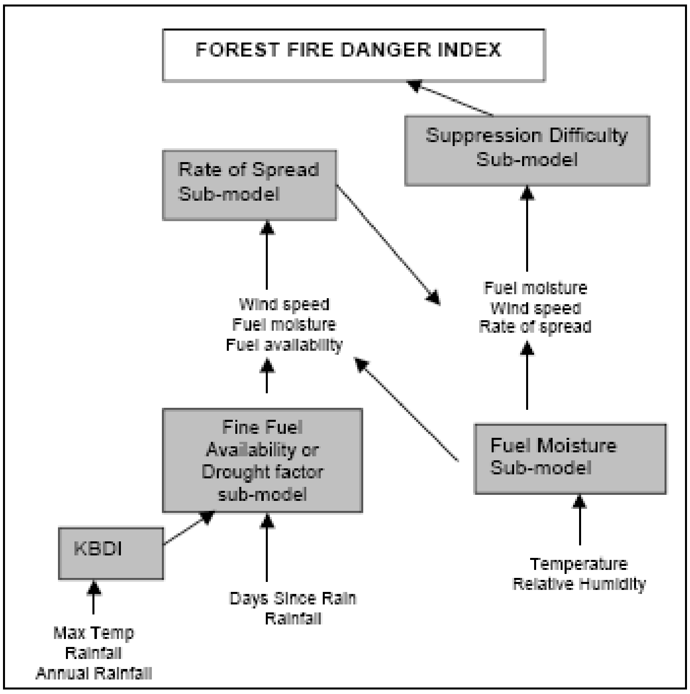


Figure 2.2: Diagram of Mc. Arthur's Forest Fire Danger Index and sub-components (Refer Section 2.2.1.5 for detailed information of Keetch Byram Drought Index - KBDI.)

Having mentioned about the theoretical composition of the Mc.Arthur's re-developed fire danger index, in terms of mathematic expressions, there exist three sub-components (Camia et al., 1999).

- Mark3 Grassland Fire Danger Meter,
- Mark5F Forest Fire Danger Meter and
- Mark5 Fuel Moisture Content in Grassland Fire Danger Meter

Mark3 is represented by the equation of one of the Mc. Arthur's fire danger meters, used in Australia for fire danger rating and fire behavior assessment (Equation 2.3 - 2.5.).

$$F = 2.0 * \exp\left(-23.6 + 5.01 * In\left(C\right) + 0.0281 * T - 0.226\sqrt{H} + 0.633\sqrt{V} \right) \tag{2.3}$$

Where, *F* is Mark3 component, *C* is degree of curing (%), *T* is air temperature (°C), *H* is air relative humidity (%) and *V* is wind speed (km/h).

Mark5F is the equation of one of the McArthur's fire danger meters, used in Australia for fire danger rating and fire behavior assessment (Equation 2.4) and *F* is Mark5F component and *D* is Drought factor.

$$F = 2.0 * \exp\left(-0.450 + 0.987 * In\left(D\right) - 0.0338 * T + 0.0234 * V\right) \tag{2.4}$$

Mark5 represents the fuel moisture content estimation included in the equation derived by Noble et al. (1980) in Camia et al., 1999, from the Mark 3 version of McArthur's fire danger meter for grassland. The following equation is to calculate Mark5 component (Equation 2.5), where, M is fuel Moisture content in percentage:

$$M = \frac{(97.7 + 4.06 * H)}{(T + 6.0)} - 0.00854 * H + \frac{3000.0}{C} - 30.0$$

(2.5)

As can be seen from the formulae given above, the components Mark3, Grassland Fire Danger Meter and Mark5, Fuel Moisture Content in Grassland Fire Danger Meter depend on degree of curing (D) (Figure 2.3).

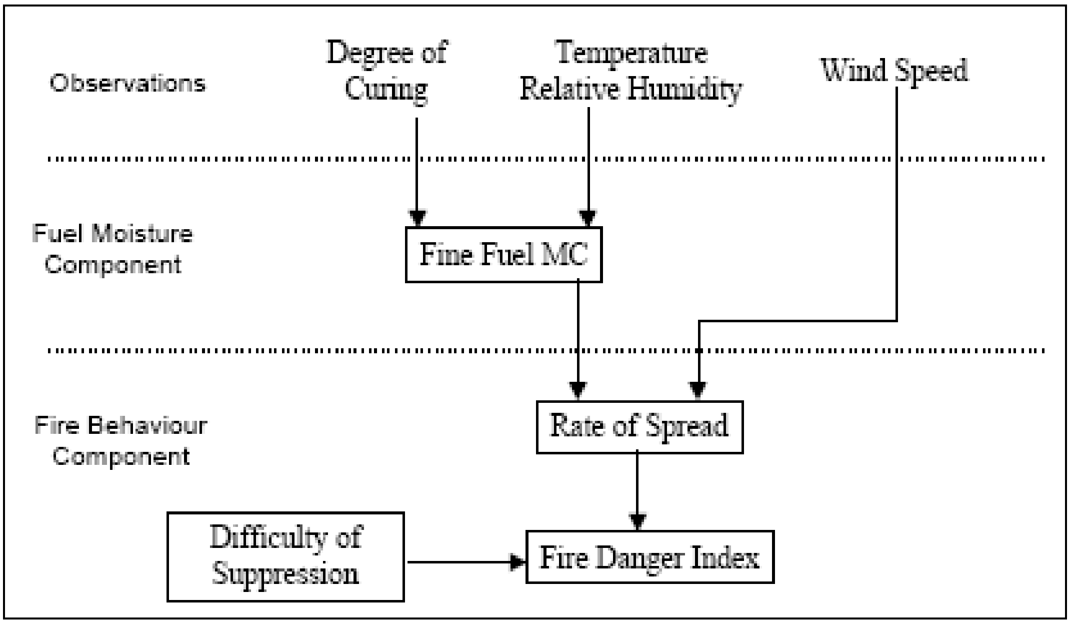


Figure 2.3: Diagram of Mc. Arthur's Mark3 and Mark5 component

It is described by Willis et al. (2001), as the proportional weight of dead grass to live grass. Therefore, degree of curing is an important factor in estimating fire behavior and potential fire spread. Degree of curing can be estimated in three methods:

- Visual Inspection
- Remote sensing
- Deriving information from soil moisture

Studies in Australia and New Zealand have shown, visual inspection methods underestimated the actual degree of curing obtained after several sampling campaign.

On the other hand, remote sensing techniques have shown both encouraging and unsuccessful results. In other words usage of remotely sensed data for degree of curing is highly depend on the vegetation cover and type in the area of investigation.

Since abstraction of degree of curing from remotely sensed data requires a set of calculation and observation of changes in vegetation status over long years, this technique remains beyond the scope of this study.

Current researches have focused on the relationship between degree of curing and soil moisture. The idea behind this approach is that the soil moisture has a direct influence on vegetation growth and also water content of vegetation. Following this theory, the sub components of the Canadian Fire weather Index, Duff Moisture Content (DMC) and the Drought Code (DC), which will be mentioned in the following section, have been used (Anderson and Pearce, 2005).

Although the outcomes of these studies were quite promising, direct application of this technique to the case in Turkey remains quite questionable; hence there is no sampling data available to make validation. On the other hand, still the degree of curing values for Australian conditions was used in the calculation phase in this study. However, the results of this assumption were not promising for Turkey. This will be discussed in the evaluation section of this part. In conclusion, since there is no data available about degree of curing in Turkey, mark3 and mark5 components of Mc.Arthur 80 fire danger index will be ignored. To sum up, the calculation will be based on Fuel Moisture Model Mc.Arthur 67 and Mark5F Forest Fire Danger Meter component of Mc.Arthur 80.

The system of Mc.Arthur takes only meteorological inputs into consideration. In this respect, it is claimed by Ayanz et al, (2003) that sub components of the system for calculating vegetation moisture content cannot meet fully the necessities of a Fire Danger Rating System and should be integrated with fuel data and topographic parameters. However, its simplicity and easy to use have led many researches and many forest services to implement Mc.ArthurFire Danger Rating System. Another advantage of the system is that it is insensitive to the accuracy of the input data.

2.2.1.3. The Canadian Fire Weather Index (FWI)

FWI has three basic and two intermediate subcomponents and one final output (Figure 2.4). These components take the previous the weather condition of the previous date into account. Respectively, these components are Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC) and Drought Code (DC) and focuses on moisture content of different fuel layers. The first three codes rate the moisture content of fuels with different response times to changes in weather conditions (time lag), accounting respectively for short term (FFMC), mid term (DMC) and long term (DC) dryness (Camia et al., 1999).

The two intermediate indices are based on these basic indices. Initial Spread Index (ISI) is based on FFMC and wind speed and represents rate of spread alone without the influence of variable quantities of fuel, whereas Build Up Index (BUI) is based on the DMC and the DC and represents the total fuel available to spreading fire. (Van Wagner, 1987)

The final index called Fire Weather Index (FWI) is based on these intermediate indices and properly scaled. It represents the intensity of the spreading fire as energy output rate per unit length of fire front (Camia et al, 1999).

Calculation procedure of FWI and its five sub component indices was quite complex, interrelated and requires many intermediate sub calculations, therefore this part was skipped. Instead of presenting the formulae of the system, it was rational to present the input requirements of each sub components instead. The procedure is cited by Camia et al. (1999).

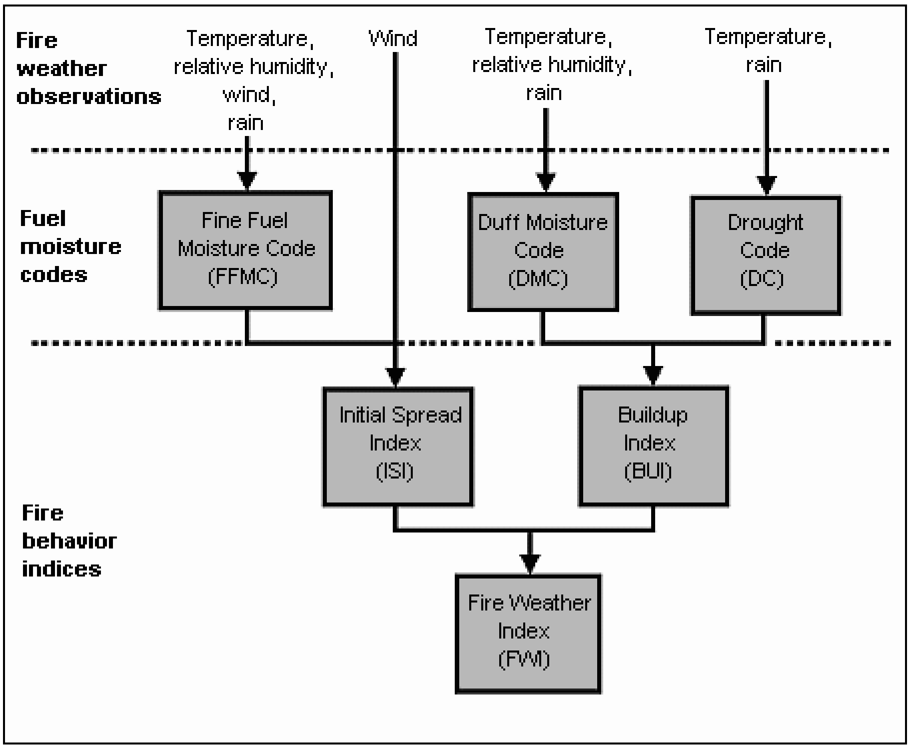


Figure 2.4: Diagram of FWI and sub-components

As can be seen from the Figure 2.4, DC depends on Temperature and rain inputs, while additionally DMC takes relative humidity into account and finally FFMC adds wind parameter into the equation.

ISI requires wind and FFMC information, while BUI and FWI are derived as combinations of intermediate codes.

Several studies undertaken in different parts of the world have shown strong correlations between human-cause fire and FFMC and high correlation between area burned and the ISI component of FWI. In these studies reasonable association between observed values of FWI and fire records has been noticed (Haines et al., 1986; Viegas et al., 1999 in Ayanz et al., 2002).

In addition to this, FWI has been adopted to use by several fire services and research groups around the world such as New Zealand, Fiji, Alaska, Venezuela, Mexico, Chile, Argentina and Europe, thus this indicates the reliability of the system internationally (Willis et al., 2001).

2.2.1.4. U.S. National Fire Danger Rating System (NFDRS)

The first nationally implemented trial goes back to 1972 (Deeming et al., 1972) and in 1988 NFDRS was updated (Burgan, 1988). The important change was that 1000 hour dead fuel sub model was introduced to the system, instead of nine, twenty fuel models were constructed and models to compute fuel moisture for live herbaceous and woody fuels were added. The system aims to construct the worst-case scenarios by using meteorological data. Another improvement to the system was made in 1988. The major addition was taking the effects of long-term drought into account by using the Keetch-Byram drought index so as to increase the contribution of the amount of available dead fuel (Ayanz et al, 2003).

The NFDRS is one of the most complex fire danger systems. This system is a mathematical model aiming to predict fire ignition probability and fire behavior potential, if the fuel load and topographic parameters are introduced.

These sub models are Spread Component, Burning Index and Energy Release Component. However, in this part of the study, the sub models of this system, which are solely based on weather inputs, will be taken into consideration.

NFDRS has four Fuel Moisture Component sub models (Figure 2.5.):

- NFDRS 1 hour time lag
- NFDRS 10 hour time lag
- NFDRS 100 hour time lag
- NFDRS 1000 hour time lag

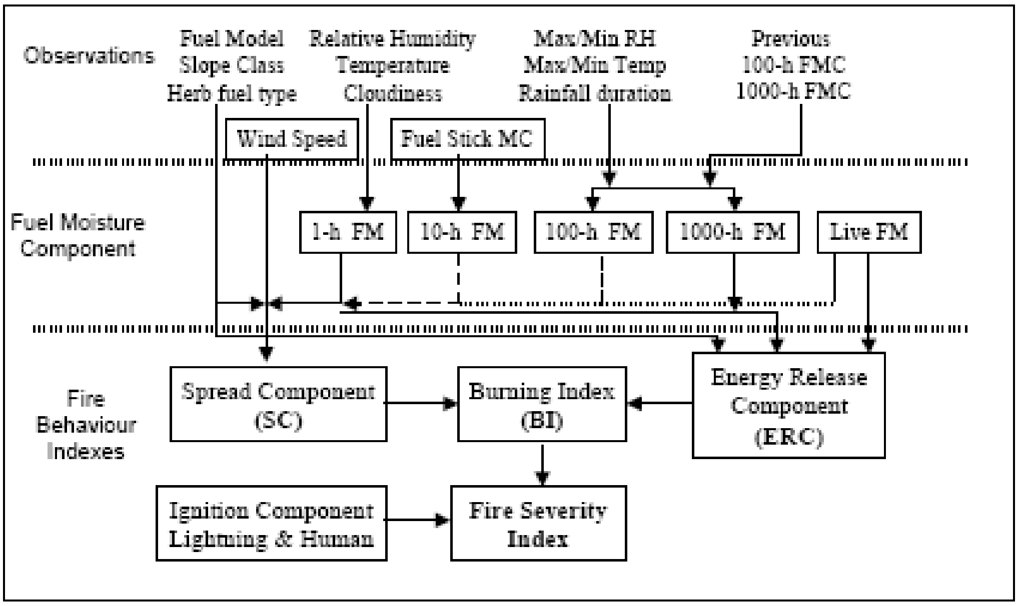


Figure 2.5: Diagram of U.S. NFDRS and its Fuel Moisture components

NFDRS 1 hour sub model of the system is to estimate the fuel moisture content of fine dead fuels. To calculate this index, the following formulas are used (Equation 2.6 - 2.10):

$$mc_1 = mc_0 + (EMC - mc_0)\left[1 - \zeta\left[\exp\left[-\frac{T}{\tau}\right]\right]\right]$$

(2.6)

Where, mc_1 is 1 hour time lag fuel moisture at time *T*, mc_0 is 1 hour time lag fuel moisture at time *T-1*, *EMC* is Equilibrium moisture content (%) at the fuel-atmosphere interface, *T* is simulation (stress) period time step (h), τ is fuel particle time lag (h) and ζ is empirically derived and dimensionless similarity coefficient. Final formulae (Equation 2.7):

$$mc_1 = 1.03 * EMC(\%)$$

(2.7)

It should be noted that this formulae is derived using empirical data from O'Neil experiment reported by Lettau and Davidson (1957) (in Camia et al., 1999) and assuming,

T = 0.5 hours, ζ = 1, and τ = 1

On the other hand, the calculation of NFDRS 10 hour is the same with NFDRS 1hour, but the final step is as the following (Equation 2.8):

$$mc_{10} = 1.28 * EMC(\%)$$

(2.8)

and assuming the value of the parameters are *T* = 4 hours, ζ = 0.87, and τ = 10. Finally, NFDRS 100 hour time lag has the following calculation (Equation 2.9):

$$mc_{100} = mc_{100^0} + (D - mc_{100^0})\left[1 - 0.87\exp\left[-\frac{24}{100}\right]\right]$$

(2.9)

Where D = 24 hour average boundary condition (%) and is expressed in the following (Equation 2.10):

$$D = \frac{\left[(24 - p_d)\,EMC + (0.5p_d + 41)\,p_d\right]}{24} \tag{2.10}$$

2.2.1.5. BEHAVE Fine Fuel Moisture Model

The aim of the BEHAVE model is to estimate fuel moisture content of dead fuels (Rothermel et al. 1986). The model is based on the FFMC component of the Canadian Fire Weather System with some modifications to better express the air temperature and relative humidity. In addition to this, a modification has been done to the rainfall routine in the BEHAVE system. Behave system relies on temperature, relative humidity (r), wind speed and daily rainfall amount. The following formulae expresses the BEHAVE model (Equation 2.11-2.14.)

$$Mr = \min\left\{101;100 - \frac{100 - Mo}{101} f(r) + 0.000110e^{0.1117Mo}\right\} \tag{2.11}$$

Where, *Mr* is denoted by rain-corrected moisture content (%), *Mo* is denoted by moisture content of fine fuels (%) of the previous day. The calculation is based on some conditions, where rainfall is denoted by *r*:

if $0.5 < r \leq 1.45$ then $f(r) = 123.85 - 55.6 \ln(r + 1.016)$

(2.12)

if $1.45 < r \leq 5.75$ then $f(r) = 57.87 - 18.2 \ln(r - 1.016)$

(2.13)

if $5.75 < r$ then $f(r) = 40.69 - 8.25 \ln(r - 1.905)$

(2.14)

2.2.1.6. Keetch Byram Drought Index

The Keetch Byram Drought Index (Keetch and Byram, 1968), which is designed for fire potential assessment and which accounts for the seasonal trend of dryness, representing the cumulative long-term moisture deficiency estimate of organic material in the ground is the last Fire Danger Index included in this study.

This index represents the flammability of organic material in the ground and ranges between 0 and 800:

- 0–200 indicates that soil moisture and large class fuel moisture rates are high and that fire occurrence is not so much expected.
- 200–400 are considered to be typical of late spring or early growing season. Contribution to fire occurrence is expected.
- 400–600 are represented by typical of late summer and early fall. Lower litter and duff layers may lead intensive fire occurrence.
- 600–800 are values referring a severe drought and relatively, expectance of a severe fire occurrence is higher. In addition, live fuels can also be expected to burn actively at these levels.

(URL: http://www.tamu.edu/ticc/kbdi_fact_sheet.pdf)

The Keetch Byram Index relies on maximum temperature, rainfall and average annual rainfall parameters and calculated with the following formulas (Equation 2.15):

$$dQ = \frac{[800 - Q_{t-1}] * \left[0.968\exp\left(0.0486T_{t-1}\right) - 8.30\right] * d\tau}{1 + 10.88\exp\left(-0.0441R\right)} * 10^{-3} \tag{2.15}$$

Where dQ is denoted by drought factor, Q_{t-1} is by drought index of the day before – or the time period before and $d\tau$ is by time increment in days. Finally the Keetch Byram Index is (Equation 2.16 -2.18):

$$Q = dQ + \left(Q_{t-1} - NR_{t-1}\right) \tag{2.16}$$

Where, NR_{t-1} is the net rainfall of previous day and with the condition that if the rainfall of the previous 24h is 0.20 or less, the net rainfall is 0.

$$NR_{t-1} = R_{t-1} - 0.2 \tag{2.17}$$

$$\text{if } NR_{t-1} < 0, \text{ then } NR_{t-1} = 0 \tag{2.18}$$

2.3. Overview of candidate Meteorological Fire Danger Indices

In this section, a brief summary of the candidate Meteorological Fire Danger Indices was provided in terms of their general advantages and disadvantages. In addition, the criteria used for selecting the candidate meteorological fire danger indices for Turkey were presented. A comparison between these fire danger indices was examined. The comparison was made according to the parameters they use and if they satisfied the criteria mentioned in Section 2.2.1.

The Meteorological Fire Danger Indices incorporate mostly the moisture content estimations of dead and living fuels and the drought. (Camia et al, 1999) They use weather parameters and process these parameters to generate some numerical values, which are associated with fire danger by using specific mathematical formulae. However, as discussed before the nature of forest fires have many faces and their dynamics are quite complicated. If one considers about the Fire triangle mentioned before, occurrence of a fire event relies on three fundamental steps – weather, topography and vegetation cover.

The Meteorological Fire Danger Indices account for weather parameters only and do not include topographical and vegetation cover inputs. In this respect, the outcomes should always be associated with these components to have more accurate fire danger estimation.

Despite this fact, since these Meteorological Fire Danger Indices are mathematical expressions, they are easy to implement. Especially with the capabilities of GIS, fire danger can be visualized and put into further process to make further analysis. Moreover, although Meteorological Fire Danger Indices might not be enough alone to assess fire danger and it is necessary to combine this information with topographical and vegetation cover inputs, they are capable of providing daily information about fire danger and or presenting the vulnerable regions in the study area by providing long term meteorological trends.

Having reviewed the advantages and disadvantages, it was useful to summarize here, the features of the selected Meteorological Fire Danger Indices for Turkey. As mentioned before according to Willis et al. (2001), available models can be selected by a set of criteria. The table below sums up the features of the candidate Meteorological Fire Danger Indices for Turkey in terms of the parameters they use and if they meet the criteria as mentioned before (Table 2.1).

It should be noted that among the major Meteorological Fire Danger Indices and including their sub components, only Fire Weather Index (FWI), Initial Spread Index (ISI) and Fine Fuel Moisture Code (FFMC) indices of the Canadian Fire Danger Rating System use all meteorological weather parameters – wind, relative humidity, temperature and rainfall. On the other hand, in terms of ability to comfort the criteria described in Section 2.2.1 all selected Meteorological Fire Danger Indices are quite promising (Table 2.2).

When the candidate meteorological fire danger indices compared, it can be seen that they slightly differ from each other. As a result, among the selected fire danger indices, the Canadian FFDRS has theoretically been found the best index in terms of conforming the requirements.

Besides, it has been found that the U.S. NFDRS has also promising capabilities to be a candidate fire index for Turkey in terms of ability to predict on a daily basis, applicability all over the country and use of currently available data. However, outcomes of the theoretical comparison of the indices should be also confirmed by the results of the performance of the indices.

Mc.Arthur's Mark3 and Mark5 components are not included in the study, because these indices cannot satisfy all the requirements of the criteria listed in Table 2.2. Since, they depend on degree of curing; these indices may not be applicable to all over Turkey. Moreover, their performance in other areas of the world is varying and there is no data available for Turkey about degree of curing.

Another point is that in the study the 1000h time lag component of the U.S. NFDRS has been excluded for the scope of the study. Because this component relies on 7 days of average meteorological conditions, it does not comfort the criteria of ability to predict on a daily basis.

Table 2.1: Comparison of six major Meteorological Fire Danger Indices with regard to input parameters used.

MFDIs	Wind	Moisture		
		Relative Humidity	Temperature	Rainfall
Canadian FFDRS				
FWI	+	+	+	+
BUI	-	+	+	+
ISI	+	+	+	+
FFMC	+	+	+	+
DMC	-	+	+	+
DC	-	-	+	+
US NFDRS				
1hour	-	+	+	-
10hour	-	+	+	-
100hour	-	+	+	+
McArthur 1967	-	+	+	+
McArthur's 1980				
Mark5F	+	+	+	-
Behave	-	+	+	+
Keetch Byram	-	-	+	+

Table 2.2: Comparison of six selected major Meteorological Fire Danger Indices with regard to meeting criteria requirements

MFDIs	ability to predict on a daily basis	applicability all over the country	full range of conditions	use of currently available data	performance in other areas
Canadian FFDRS	+++	+++	++	+++	+++
US NFDRS	+++	+++	++	+++	++
McArthur 1967	+++	+++	+	+++	+
McArthur's Mark5	+++	+++	+	+++	+
Behave	+	+++	++	++	+++
Keetch Byram	++	+++	++	++	++

Therefore, candidate Meteorological Fire Danger Indices are Canadian Forest Fire Danger Rating System, US National Forest Danger Rating System, Mc.Arthur’s 1967 and Mc. Arthur’s Mark5F forest Fire Danger Meter, Behave Fine Fuel Moisture Model and finally Keetch Byram Drought Index.

CHAPTER 3

DATA DESCRIPTION

In this section, required meteorological data for calculating Meteorological Fire Danger Indices were mentioned. Next, the software used for calculating Meteorological Fire Danger Indices was presented. Moreover in this section, the nature of the fire history dataset needed for performance testing and calibration processes were mentioned. Finally, month based outcomes of the Meteorological Fire Danger Indices were presented and explained.

3.1. Retrieving Meteorological Data

The meteorological dataset was obtained from MARS-STAT Database, which has been carried out under the scope of Crop Growth Monitoring System developed by AGRIFISH Unit in Joint Research Center of European Commission. The MARS-STAT database contains meteorological interpolated data from 1975 to 2004. The dataset includes following meteorological data (Table 3.1):

Table 3.1: Parameters contained into the MARS database (URL: http://agrifish.jrc.it/marsstat/datadistribution/)

Parameters	Unit	Description
Minimum Air Temperature	°C	Daily minimum temperature
Maximum Air Temperature	°C	Daily maximum temperature
Precipitation	mm	Cumulated daily rainfall
Mean Wind speed 10m height	m/s	Daily Mean wind speed at 10m
Mean Vapour pressure	hPa	Daily Mean vapour pressure
Calculated Potential Evapotranspiration	mm	Penman potential evapotransp.
Calculated Global Radiation	kJ/m2	Daily global radiation

MARS weather data has been interpolated on a 50 X 50km Grid (Figure 3.1). Daily values in a GRID describe the "spatial-average" conditions prevailing inside the region covered by the GRID for one particular day.

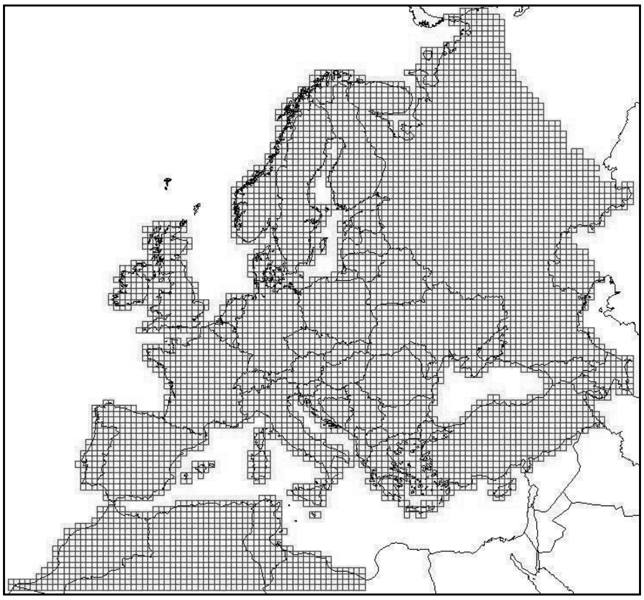


Figure 3 1: MARS database 50X50km GRID

According to the work of Van der Goot, (1997) and Orlandi (2003), interpolation process has been made by selecting appropriate meteorological stations, which broadcast a complete set of data via the Global Telecommunication System in order to determine the representative meteorological conditions for a grid cell. Selection process has been made according to the following criteria:

- Distance,
- Difference in altitude,
- Difference in distance to coast and
- Climatic barrier separation.

After the selection process, a simple average for most of the meteorological parameters was performed and corrected for an altitude difference in the case of temperature and vapor pressure. On the other hand, rainfall parameter was directly taken from the most suitable station. More information about MARS Database can be found in. Van der Goot, (1997) and Orlandi (2003).

Among these meteorological data, daily maximum temperature, minimum temperature, mean daily vapor pressure, mean daily wind speed and mean daily rainfall are the common data inputs for calculating the fire danger indices; thus these data were queried from MARS-STAT database and stored in text file format. The raw meteorological data has been obtained according to each Grid cells extracted for Turkey (Figure 3.4). List of Weather Stations are given in Appendix A.

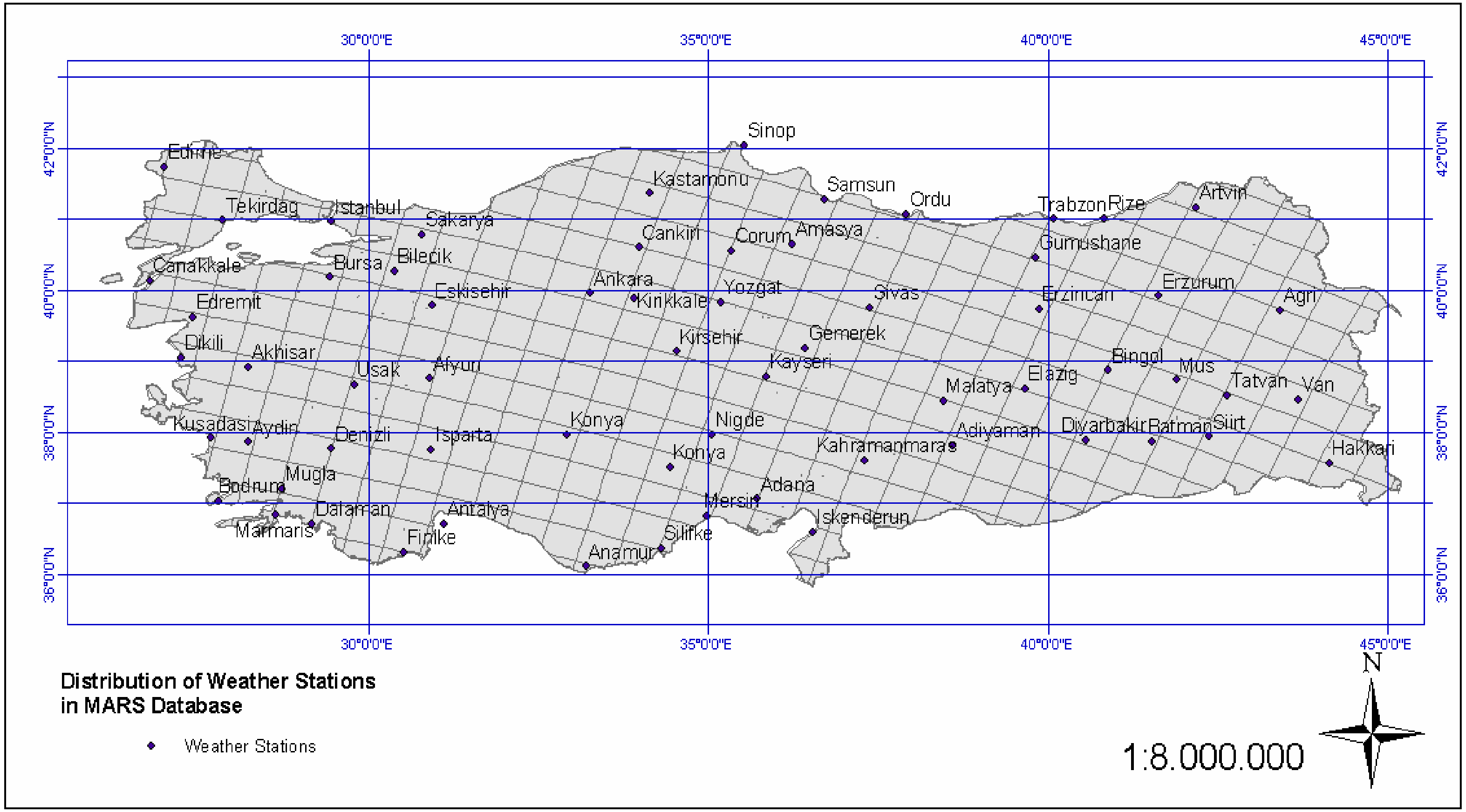


Figure 3 2: Layout of the 50 X 50km Grid cells for Turkey

There are 401 grid cells and for each Grid cell, daily meteorological data averaged from the year 1975 to 2004 including associated geographic longitude coordinates of the grid cells were assigned. It is important to remember here that for the stability of the observations for long period of time, the values of the variables in fire danger studies are often averaged for the temporal scale of interest (Ayanz et al., 2002). In this study, the main attention was given to fire season months in Turkey. For this purpose, meteorological inputs of 29 years were averaged on monthly base.

3.2. Fire History Dataset

The fire history archive is obtained from the unit of Research and Development Department of General Directorate of Forestry in Turkey. The dataset includes daily-recorded fire events in terms of number of fires (NoF) and burned area (BA) in hectares between the years of 2001 and 2005. The locations of the fire events have been recorded in reference with their forestry management boundaries.

To evaluate the performances of the Meteorological Fire Indices in accordance with the fire events recorded in 5-year period of time, a common map unit should be constructed. For this purpose, forest management unit boundaries are merged into 50 X 50km grid cells. In doing so, the original fire statistics have been preserved. Monthly observations of total number of fires and total burned area between the years of 2001 and 2005 are presented in 50 X 50km grid cells.

3.3. Land Cover Data for Turkey

In Turkey, there is not land cover data like CORINE or forestry inventory maps available for GIS community. This is a general problem of many studies and projects for ground truth verification. Despite this fact, currently, there have been several global land cover products available such as Moderate resolution Imaging Spectrometer (MODIS) global land cover and GLOBCOVER product of ENVISAT (Giri et al., 2005). At operational level, all these products are not high quality. Another point to consider about these global land cover products is that they might have important disagreements between them. Yet still they offer valuable information on current situation of the Earth's surface (Jung et al., 2005).

For this study, two candidate global land cover products are selected according to their availability:

- MODIS Terra, 1km resolution, Level 3 Land cover product,
- GLC 2000, 1km resolution, SPOT Vegetation sensor derived Land cover product, recently released by Joint Research Center of European Commission.

There are important differences of these products that might lead different classification results of the area of interest. These differences are described by Giri et al., (2004).

The GLC 2000 is based on SPOT-Vegetation daily 1 km data and Normalized Difference Vegetation Index (NDVI) was also used, whereas for MODIS land cover product, surface reflectance channels, MODIS Vegetation and some other ancillary data were used. For GLC 2000 data, the satellite data was acquired between November of 1999 and December of 2001, whereas for MODIS data, the period January and December of the year 2001 was used.

In terms of classification systems, MODIS land cover adopts supervised classification system using decision tree classifiers, whereas GLC

2000 product adopts flexible classification system depending on the partner institutions. On the other hand, for classification system, GLC 2000 follows Land Cover Classification System developed by Food and Agriculture Organization (FAO) and United Nations Environment Program (UNEP) and MODIS team uses primarily International Geosphere Biospehere Program (IGBP) described by Loveland (1991) in Giri (2005). Another difference between these two products is that MODIS land cover product updates in every 6 months and refinement of GLC 2000 is currently in progress. Also the accuracy assessment of GLC 2000 product is also currently ongoing. The accuracy of MODIS data was evaluated at global, continental and individual class level. Although they are not comparable since they use different land cover classification scheme, the overall sea accuracy for GLC 2000 is 69% and for MODIS, it is 71%.

In terms of advantages, GLC 2000 product has effective geometric correction and relies on daily composites of calibrated spectral bands and NDVI. The product has been manipulated by experts, thus this enables to overcome the problem of eliminating ambiguous land covers. Moreover, it is more sensitive to region-specific characteristics and landscape complexity. MODIS product, on the other hand, enjoys its high-resolution (250/500m) sensors, which have more advanced spectral properties compared to SPOT Vegetation sensor. This means that MODIS has more potential to obtain more additional information through its specific land surface mapping sensors. Its classification algorithm is also superior to GLC 2000 product classification, since it is more objective, reproducible and suitable for change detection.

However in general, according to Giri et al., 2004, GLC 2000 seems most elaborate representation and has most advanced and flexible classification system with standard definition of land classes (Figure 3.3).

For the reasons listed, GLC 2000 land cover product was used for the refinement process of Fire Danger in Turkey. According to GLC 2000 product, there are 15 classes for Turkey. A binary forest/non-forest mask was prepared based on the classes and the fire danger zones were integrated to the areas of the land cover data, where forest existed.

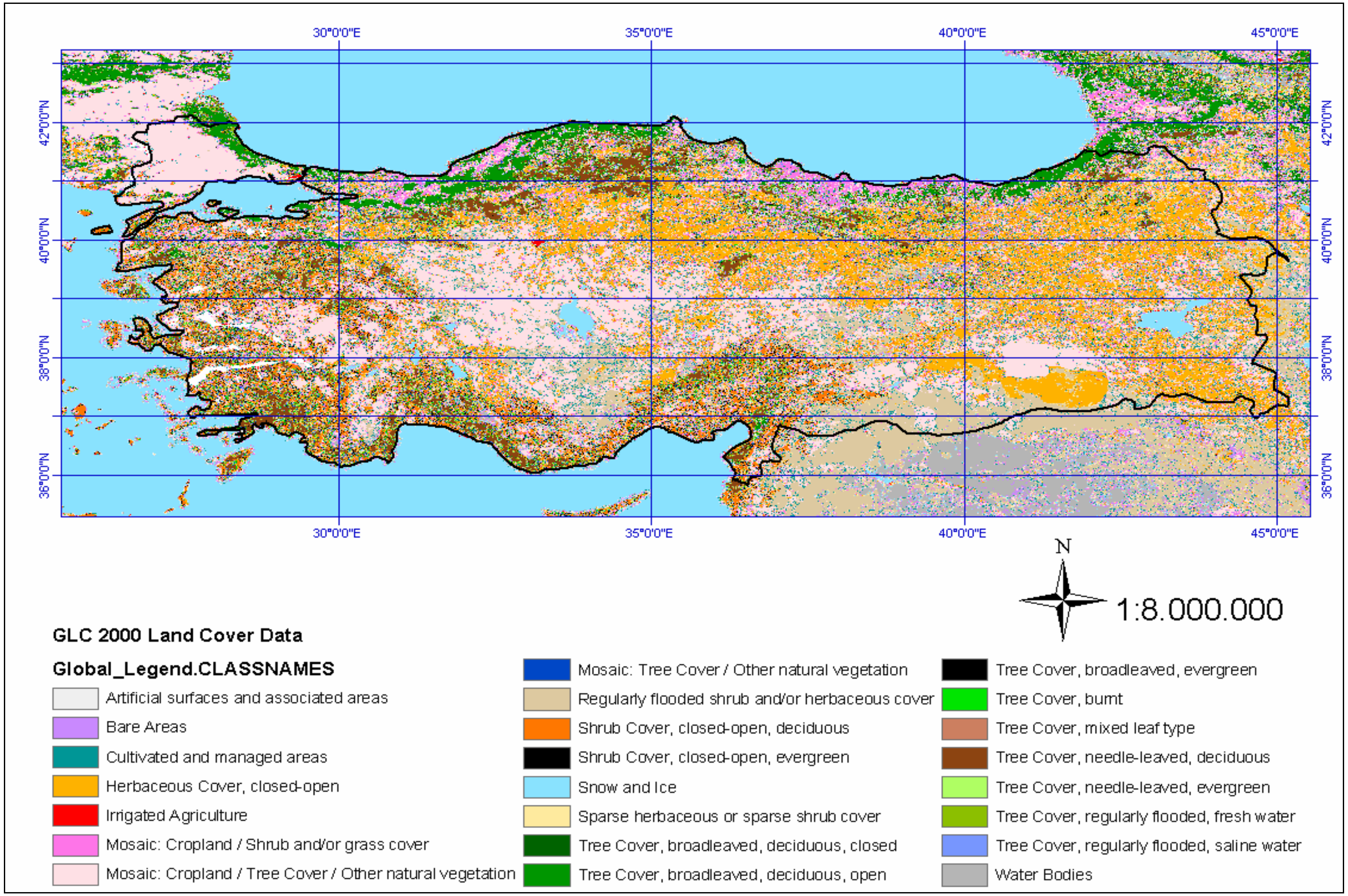


Figure 3.3: GLC 2000 Global Land cover data of JRC in the region of Turkey

CHAPTER 4

CALCULATION OF SELECTED METEOROLOGICAL FIRE DANGER INDICES

Under the MEGAFiRes Project of DG XII of European Commission, INFOREST team in collaboration with the University of Torino developed a software prototype called *Meteorological Fire Danger Indices Processor-MFDIP* (Camia, 1999) based on the formulae of the associated danger indices given in the previous Chapter. This program is capable of calculating most commonly used indices by forest fire and civil protection services in Europe (Ayanz, 2003).

The program MFDIP has been modified in Visual Basic 6, according to the needs of this study and in order to facilitate the calculation of the candidate Meteorological Fire Danger Indices for Turkey (Figure 4.1). The original version of MFDIP relies on parameters Day, Month, Year, Station Number and five weather parameters – daily wind speed, maximum temperature, minimum temperature, vapour pressure, rainfall, potential evaporation and calculated radiation. Instead of Day, Month, Year parameters, the modified version of MFDIP works on the identity of each grid cell, which was pre-defined in the MARS Database.

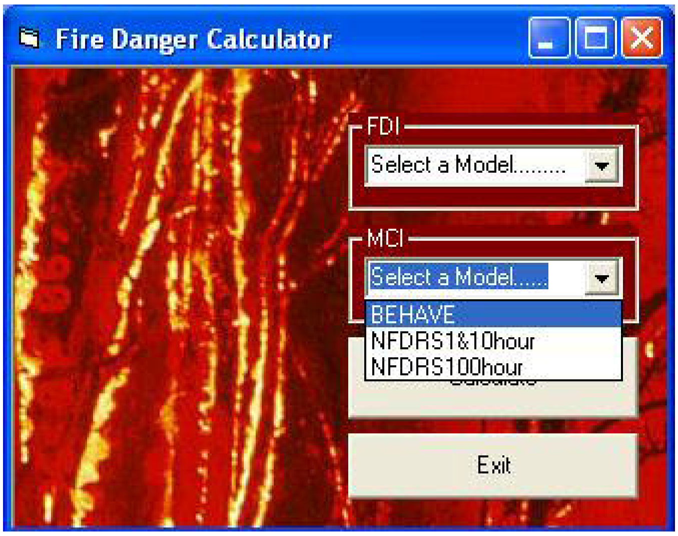


Figure 4.1: Interface of the modified Meteorological Fire Danger Indices Processor

The difference of the modified version from the old version of MFDIP is that new version is not only capable of performing fire danger index calculation for a specific date but also for a specific period of time by providing the averaged parameters to the system.

The candidate Meteorological Fire Danger Indices are grouped into two categories.

1. FDI; Fire Danger Indices: Mc:Arthur 1967, Mc. Arthur's Mark5F component, Canadian Fire Weather Index and Keetch Byram Drought Index
2. MCI: Moisture Content Indices: BEHAVE, US NFDRS 1 and 10 hour time lag, NFDRS 100 hour time lag

The user is in a position to make a choice between to combo lists and select one index at a time. Once the desired index is selected, the Calculate Button should be clicked to execute the program. The program asks the user to provide the meteorological input file in ASCII tab delimited text format and a directory to save the output file. (For further instructions, the contents and the structure of the input data, refer to Appendix B).

4.1. Results of candidate Meteorological Fire Danger Indices

After processing the meteorological data with the MFDIP software, the results of each meteorological index has been obtained in ASCII text file format, along with the associated Grid cells and geographic coordinates. The output of these danger indices has been mapped in ESRI's ArcMAP version 9.1. The results of the calculated monthly- based Meteorological Fire Danger Indices for Turkey are presented in this section (Figure 4.2 – 4.39):

4.1.1. Results of Mc. Arthur's Fire Danger Index (Mc.Arthur 1967)

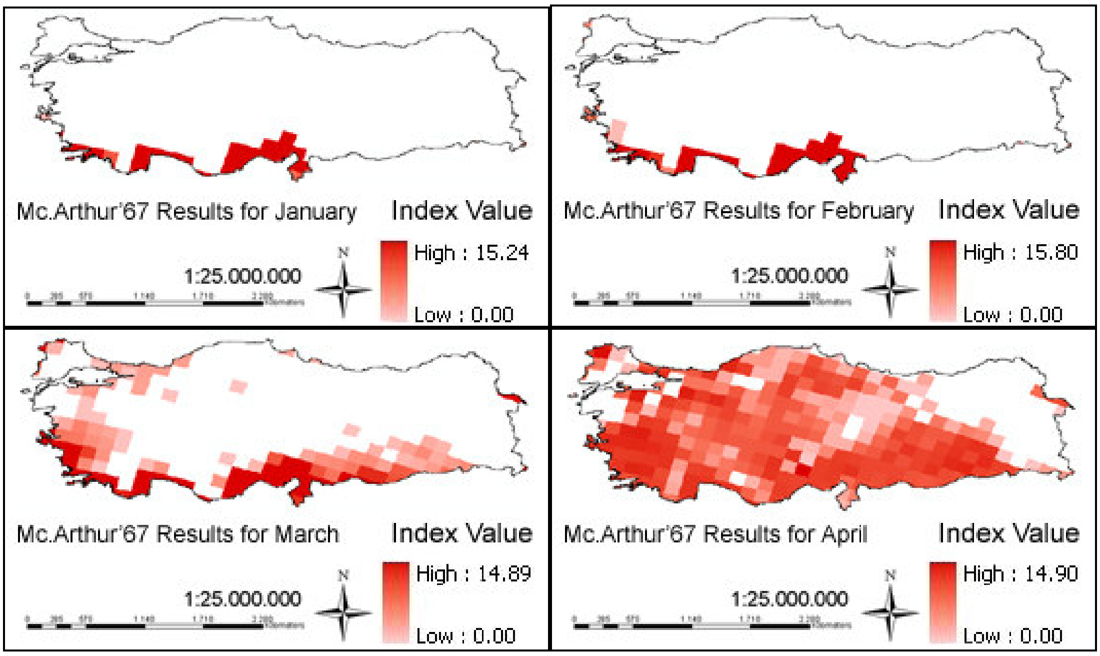


Figure 4.2: Monthly results of Mc.Arthur's Danger Index (1967) from January to April

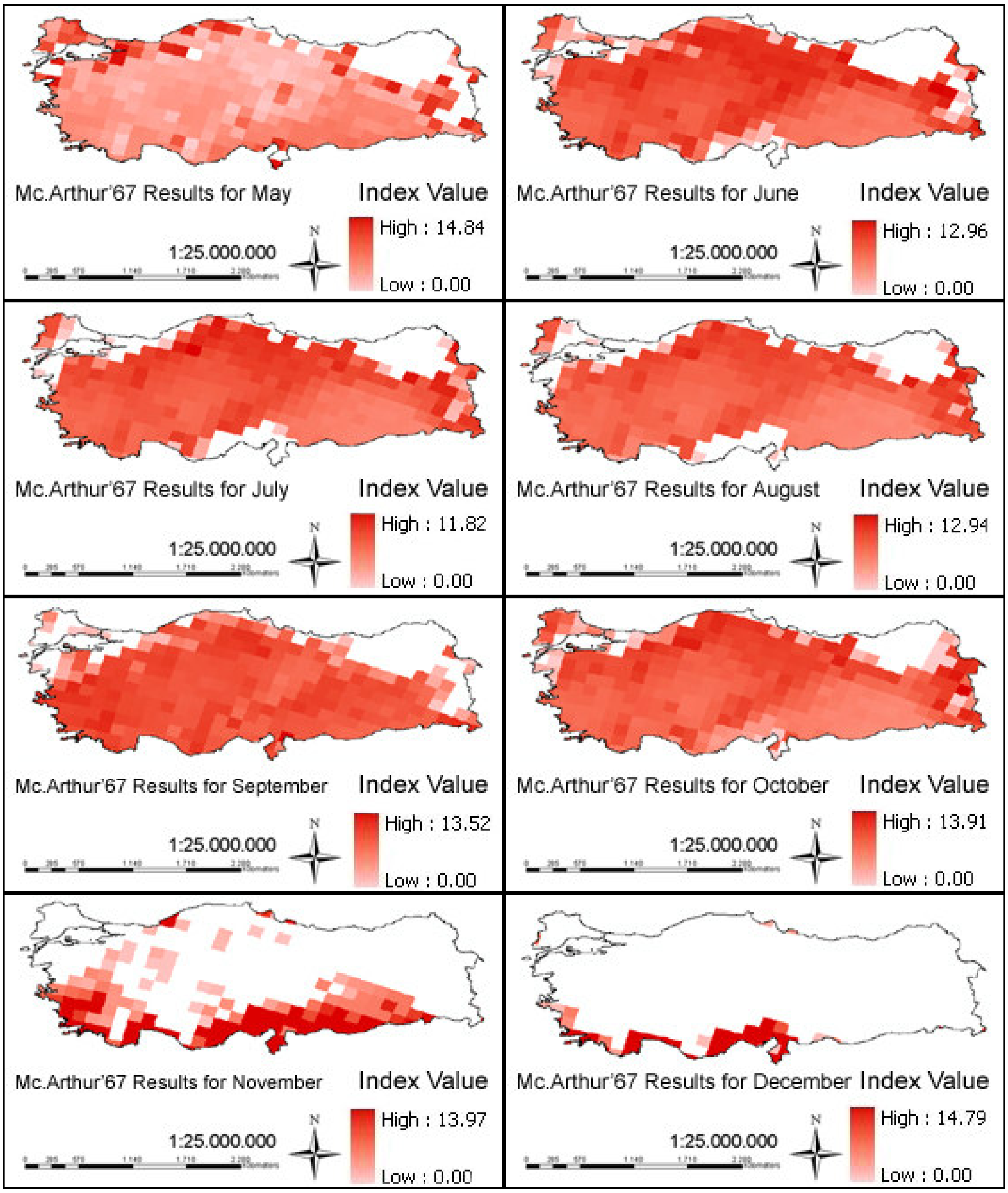


Figure 4.3: Monthly results of Mc.Arthur's Danger Index (1967) from May to December

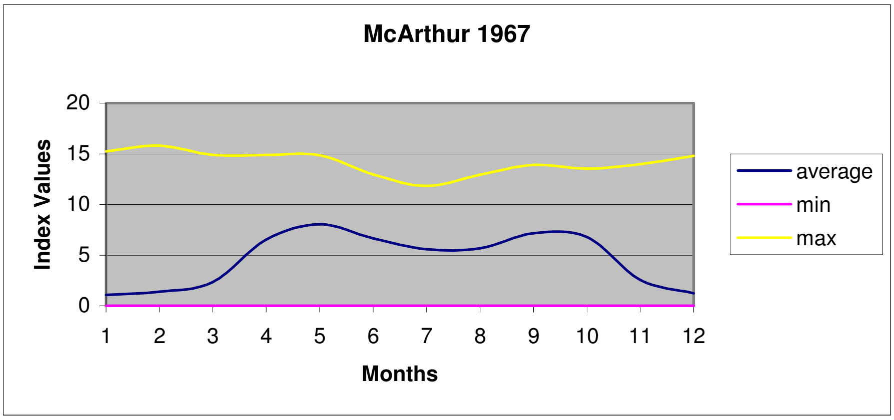


Figure 4.4: Yearly performance of McArthur 1967 index

4.1.2. Results of Mc:Arthur's Forest Fire Danger Meter (Mark5F)

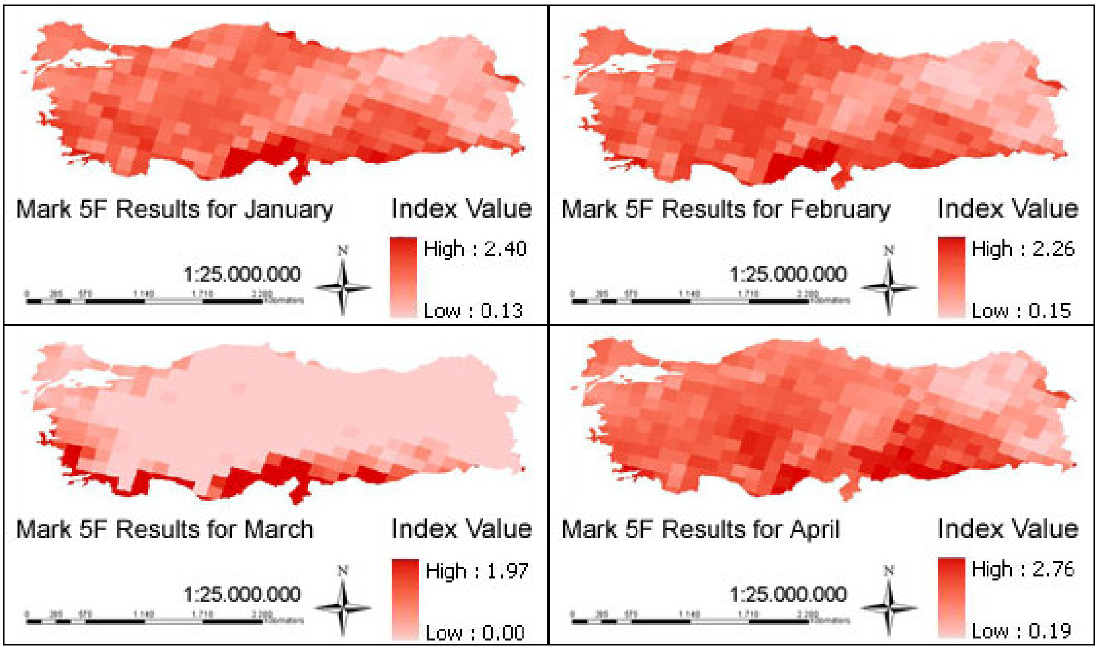


Figure 4.5: Monthly results of Mc.Arthur's Mark5F from January to April

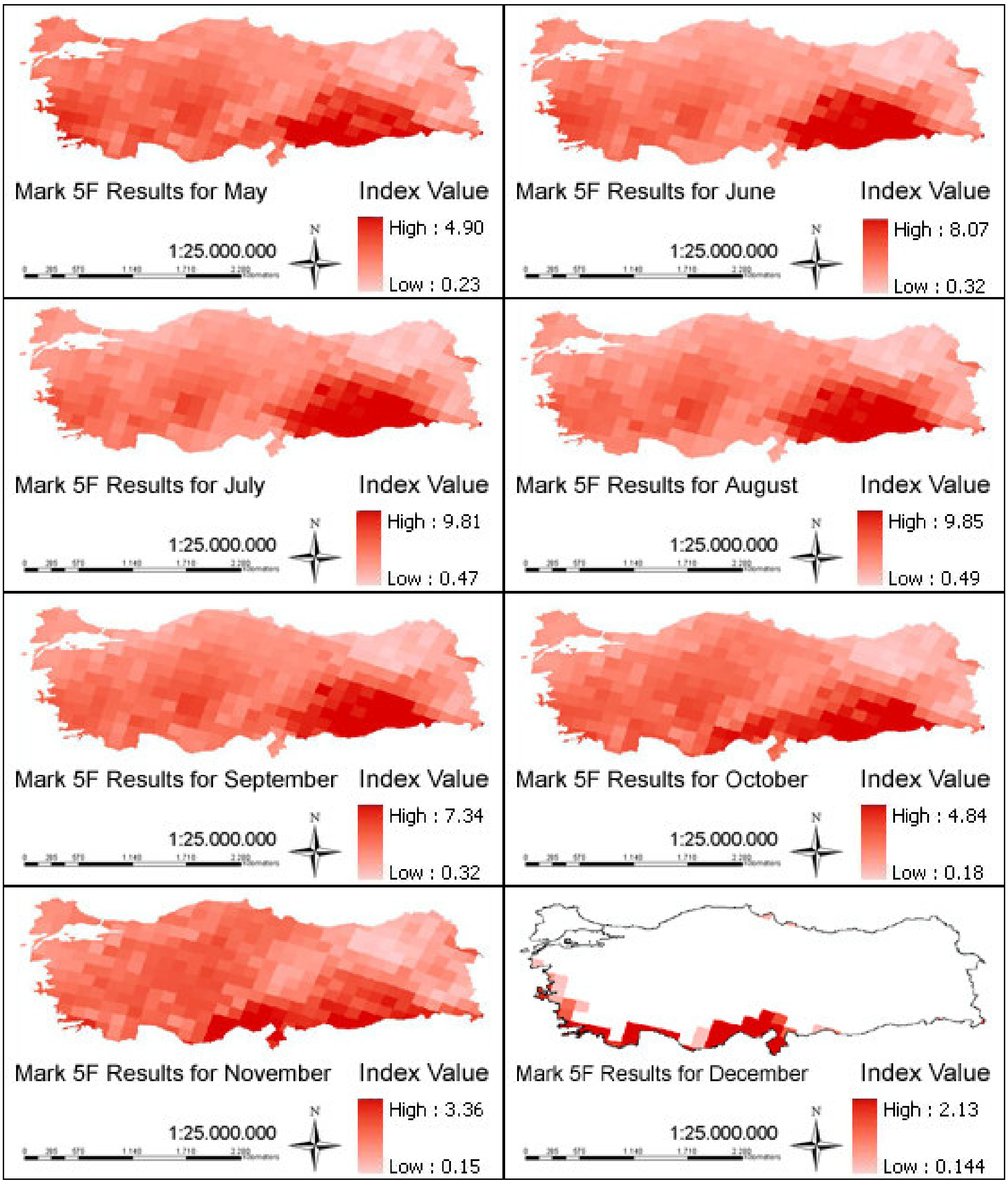


Figure 4.6: Monthly results of Mc.Arthur's Mark5F from May to December

The fire danger prone areas are distributed all over Turkey except from the northeastern part In spring, the higher values are assigned mainly to southeastern part and southwestern part. During summer, the index value is increased significantly around the southeastern and southwestern parts along the Aegean and Mediterranean costs of Turkey.

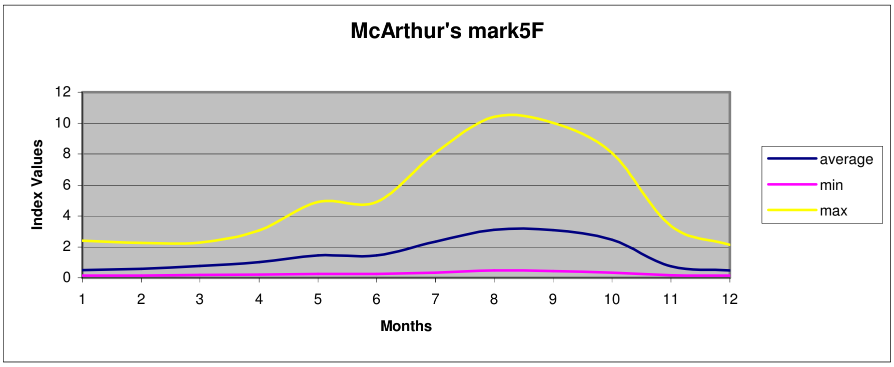


Figure 4.7: Yearly performance of McArthur mark5F component

4.1.3. Results of Canadian Fire Danger Rating System (CFDRS)

4.1.3.1. Fine Fuel Moisture Code (FFMC)

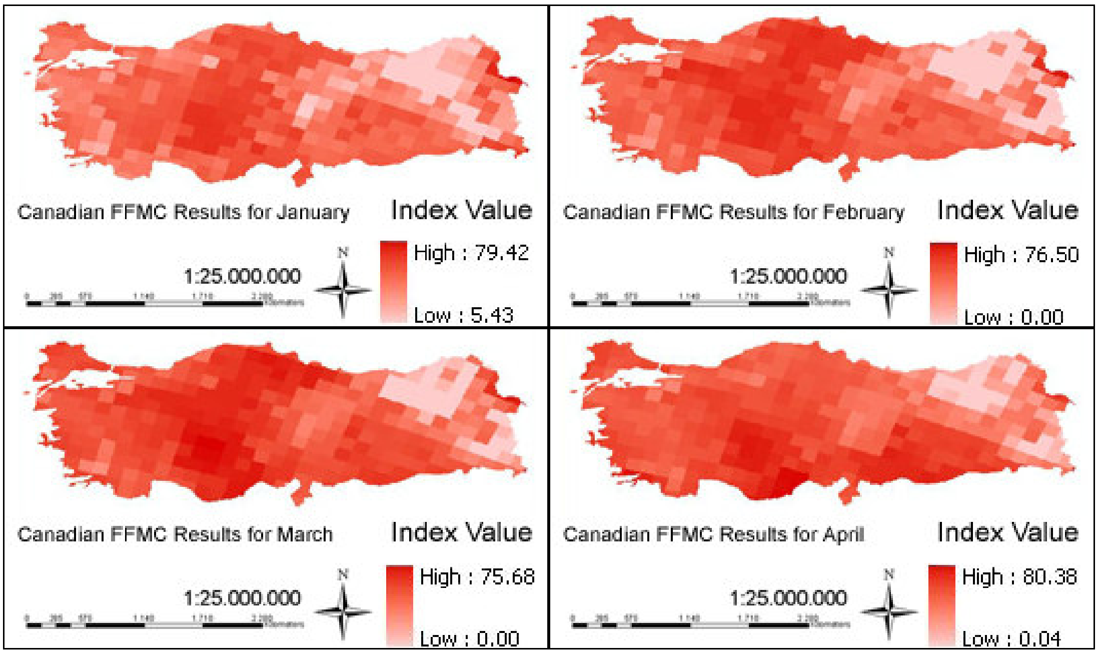


Figure 4.8: Monthly results of Canadian FFMC from January to April

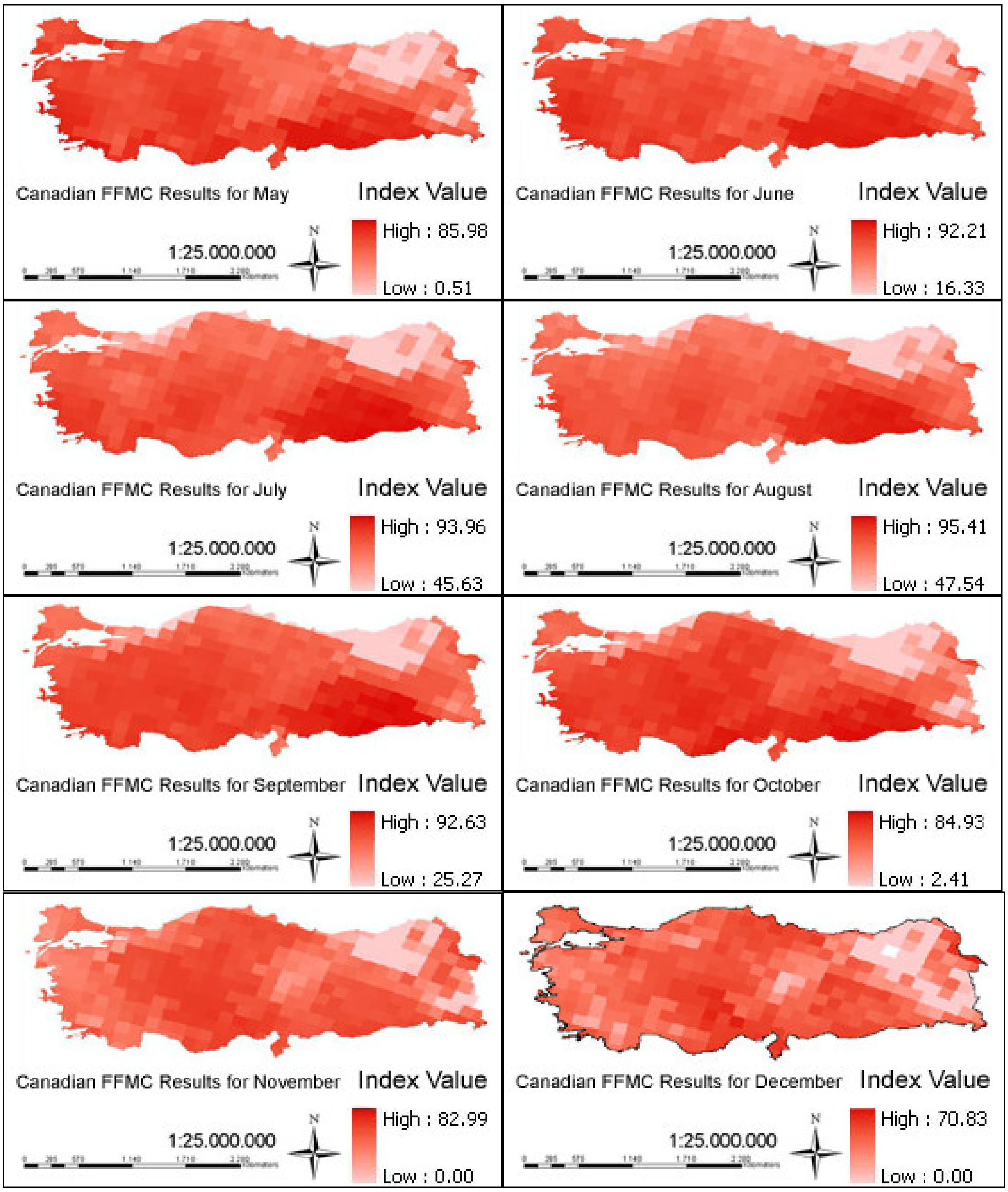


Figure 4.9: Monthly results of Canadian FFMC from May to December

Fine Fuel Moisture Code aims to express the water content of litter and fine dead fuels. Mainly, from winter onwards it can be seen that the index values are increasing towards summer months. According to the result of this index, there are three main focuses In Turkey mainly the southeastern part, southwestern part and a part of central region close to southwest direction.

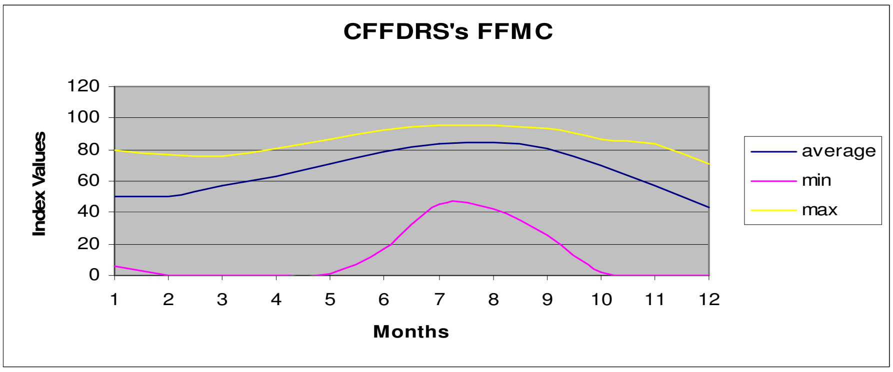


Figure 4.10: Yearly performance of CFFDRS's FFMC

4.1.3.2. Duff Moisture Code (DMC)

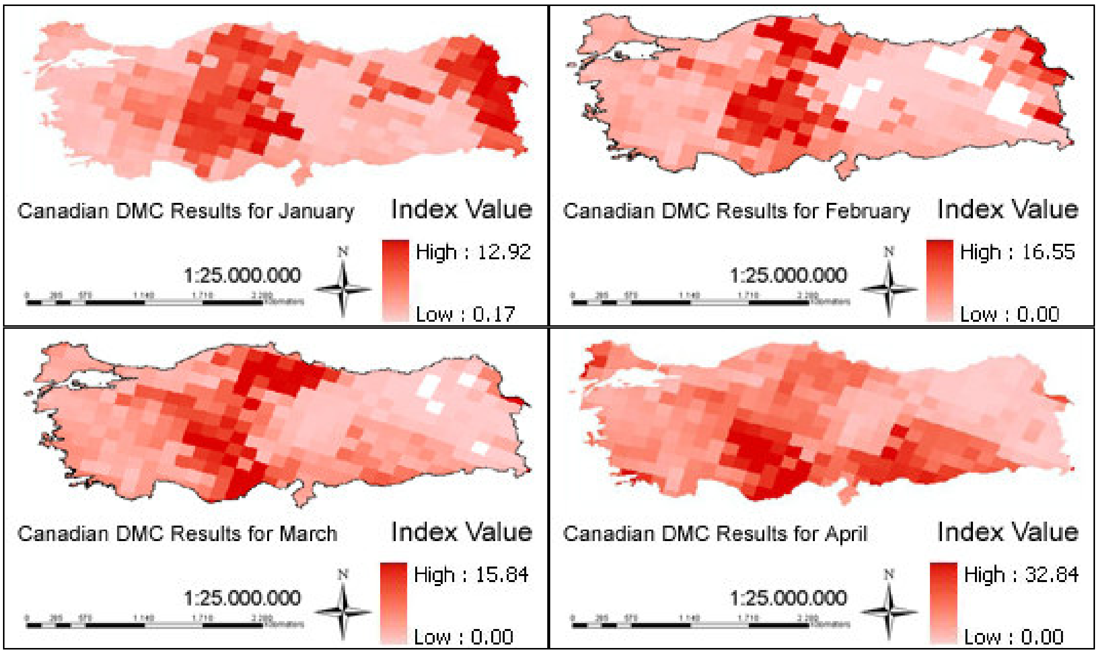


Figure 4.11: Monthly results of Canadian DMC from January to April

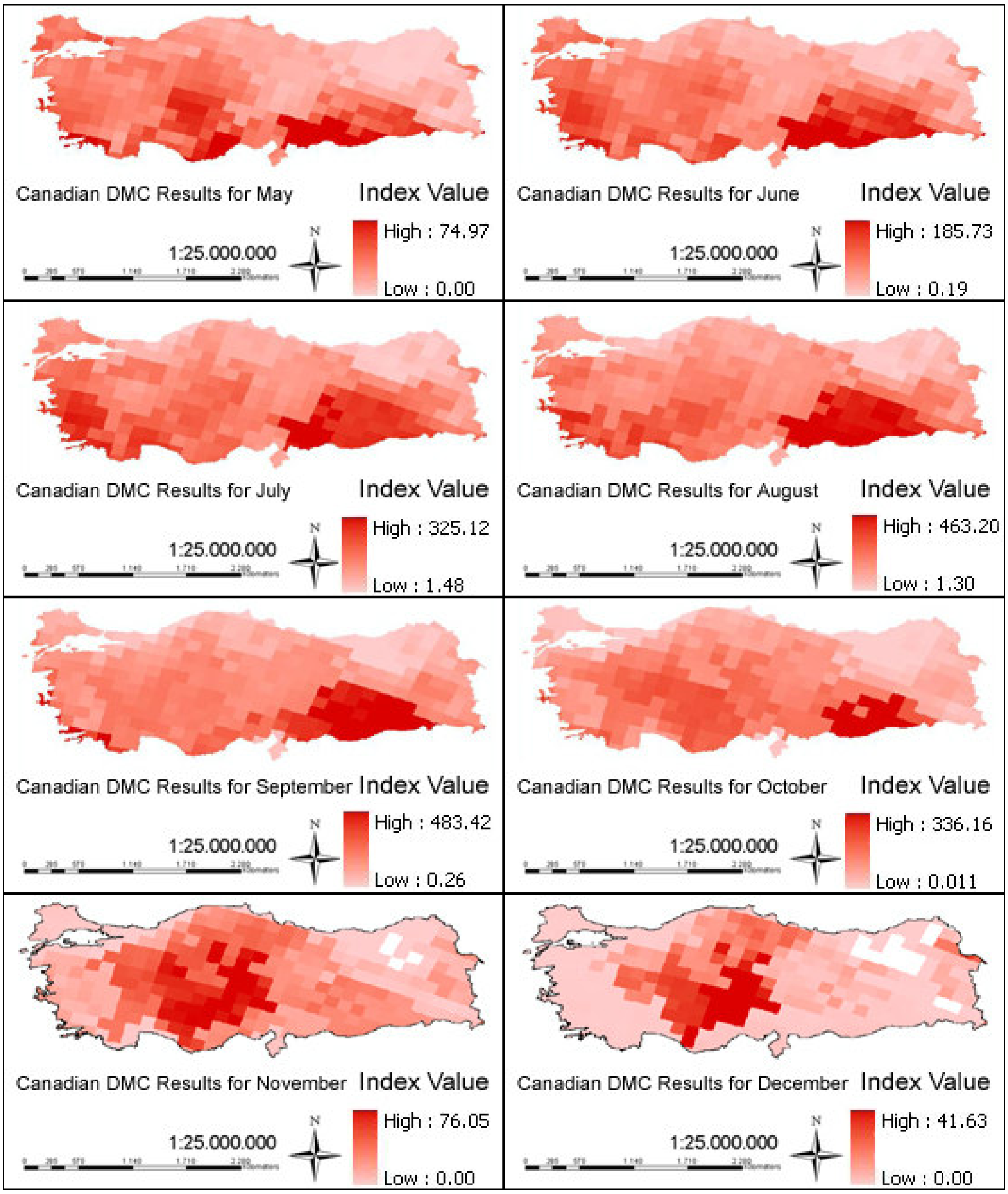


Figure 4.12: Monthly results of Canadian DMC from May to December

Majority of the cells getting highest scores of drought moisture are in southeastern part. In July and August, the highest value of the DMC dramatically increases and decreases in mid autumn period.

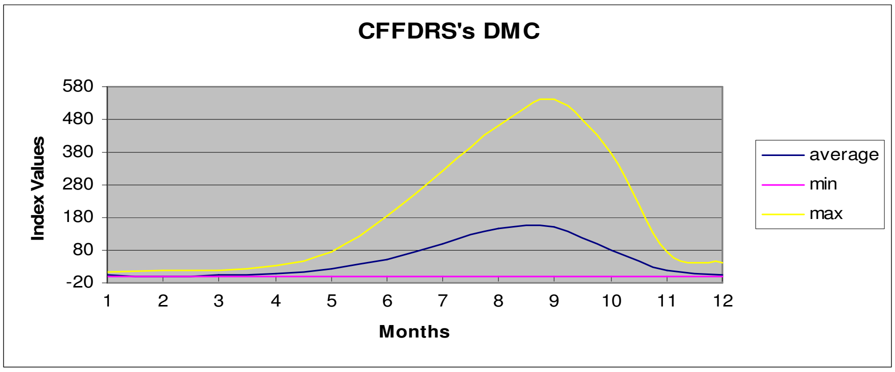


Figure 4.13: Yearly performance of CFFDRS's DMC

4.1.3.3. Results for Drought Code (DC)

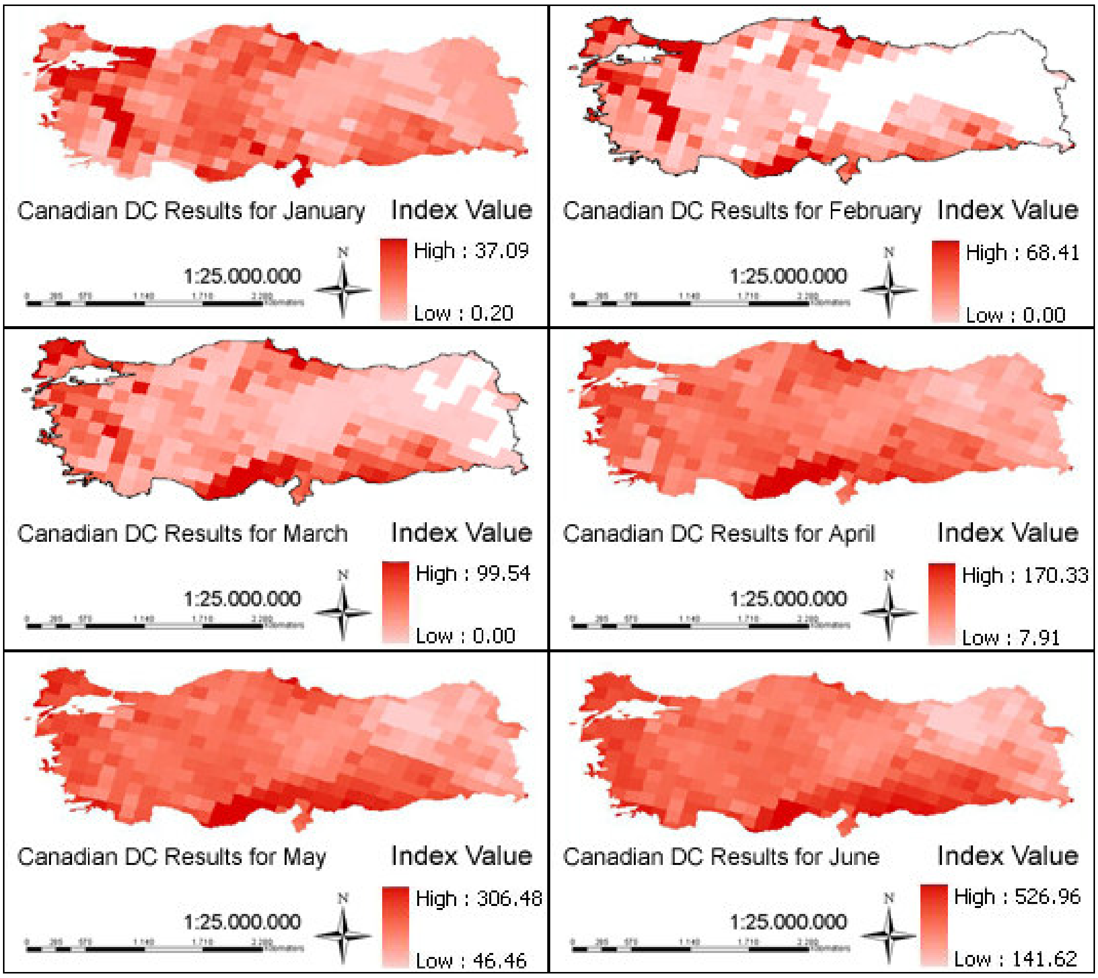


Figure 4.14: Monthly results of Canadian DC from January to June

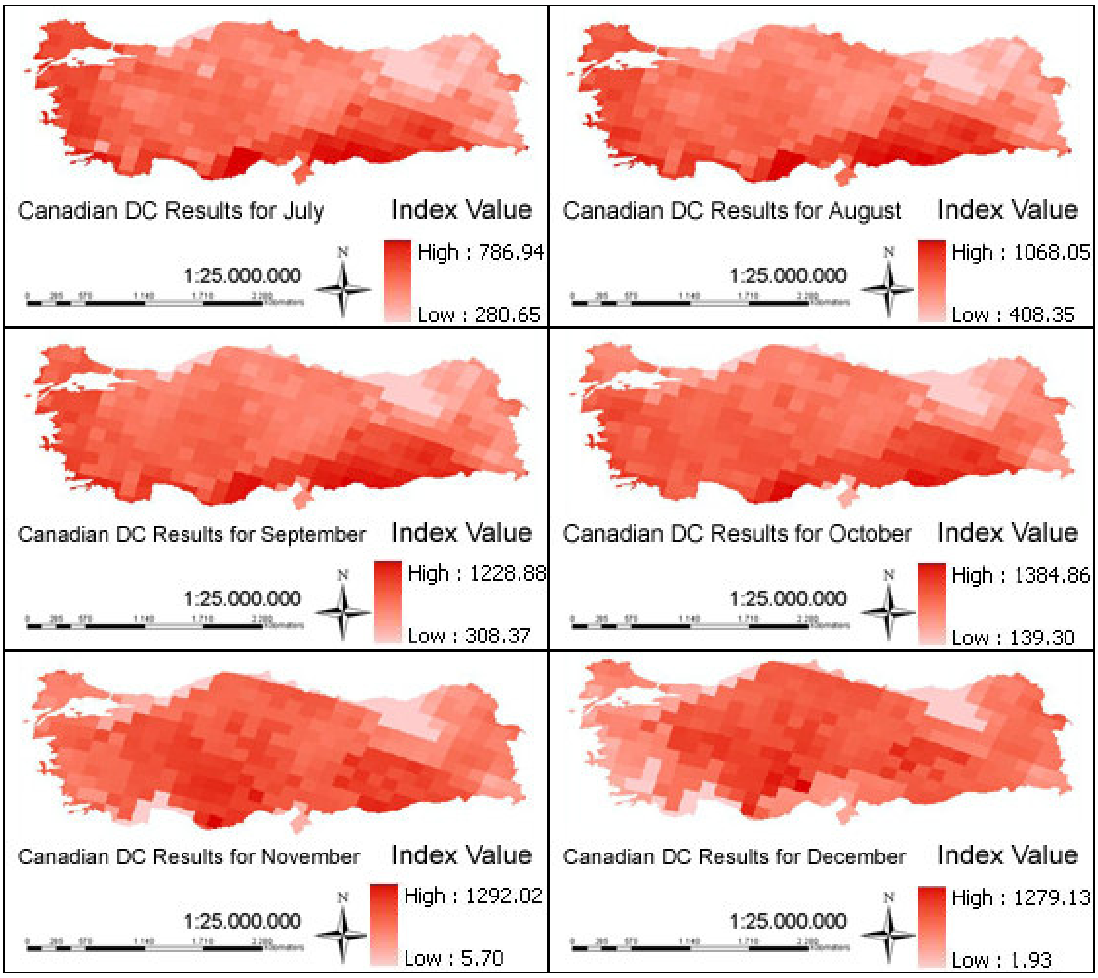


Figure 4.15: Monthly results of Canadian DC from July to December

Drought Code is an indicator of seasonal drought effect on large size fuels. According to the results of this index, the drought starts increasing from summer onwards and reaches its highest value in December. From summer on, the fuel gets drier and may contribute to start a potential fire.

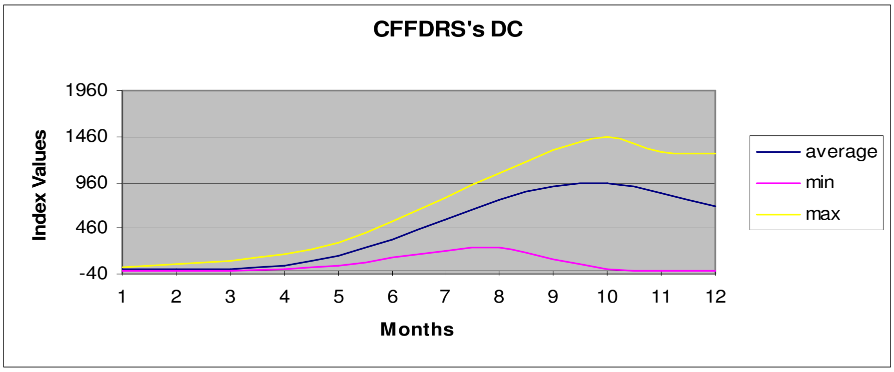


Figure 4.16: Yearly performance of CFFDRS's DC

4.1.3.4. Initial Spread Index (ISI)

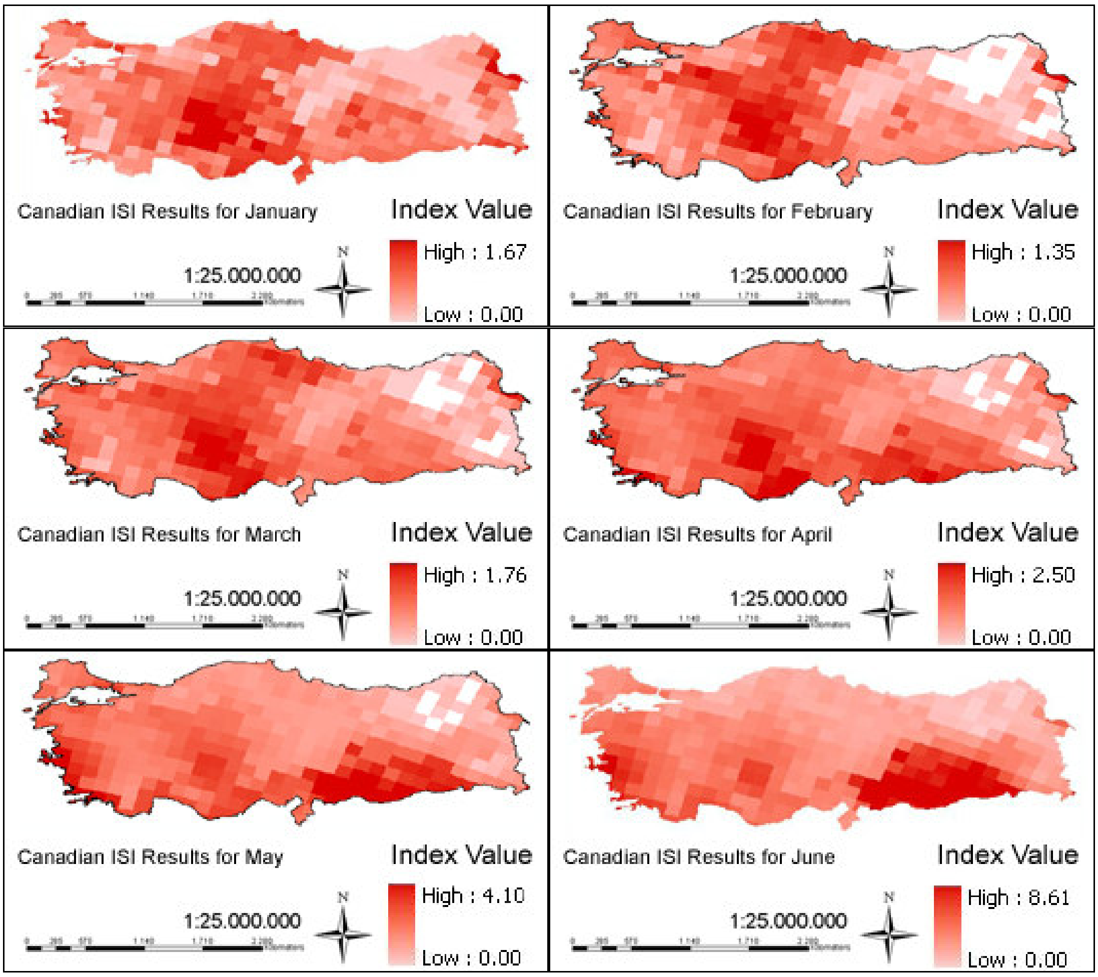


Figure 4.17: Monthly results of Canadian ISI from January toJune

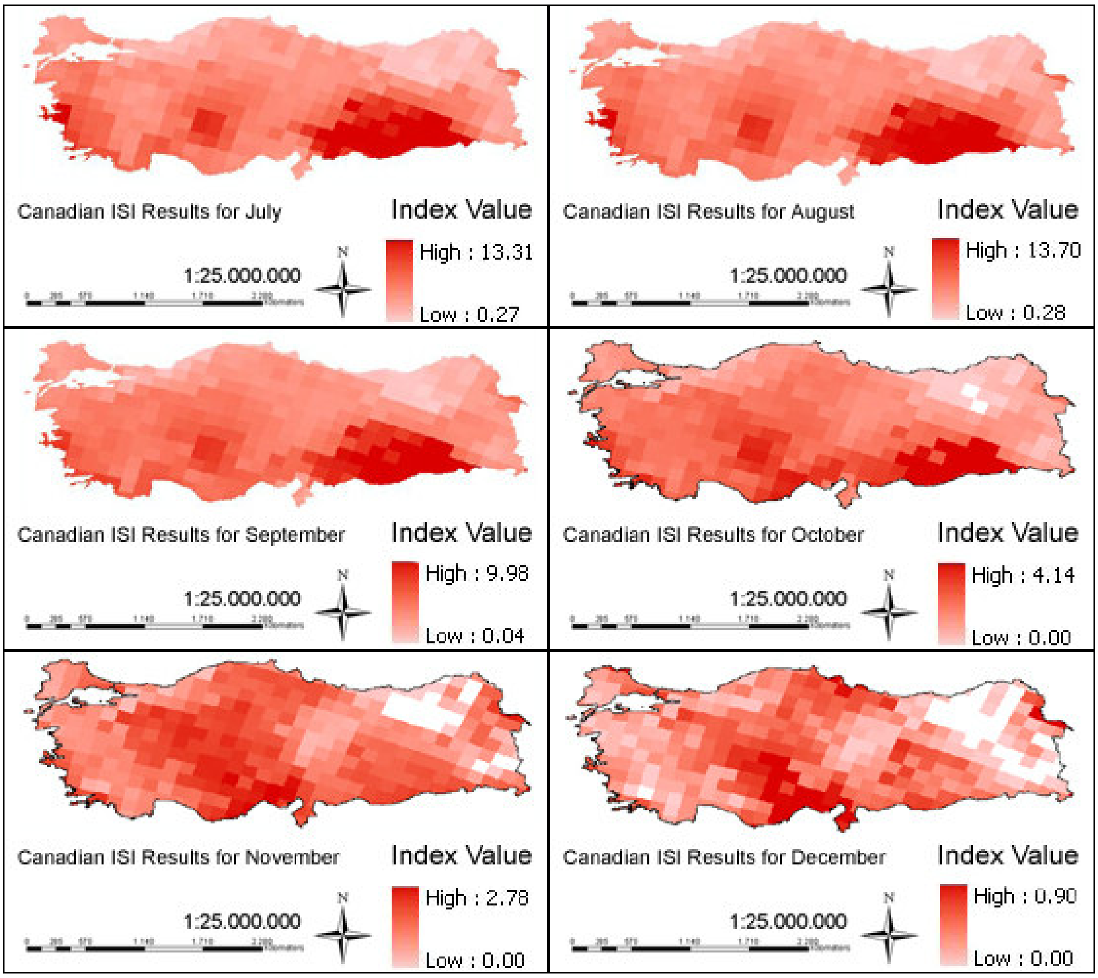


Figure 4.18: Monthly results of Canadian DC from July to December

ISI tries to estimate the flame propagation with the information derived wind parameter and the FFMC component of CFFDRS. During summer, there are three important concentration spots: southeastern part, one around the Mediterranean cost and finally the west and southwestern cost of Turkey.

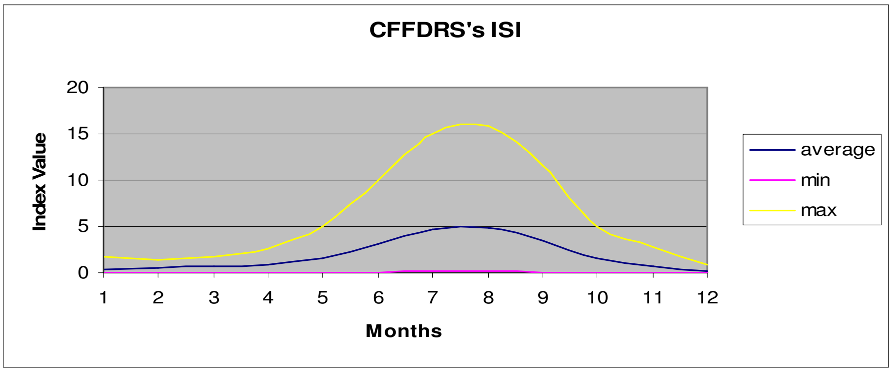


Figure 4.19: Yearly performance of CFFDRS's ISI

4.1.3.5. Build Up Index (BUI)

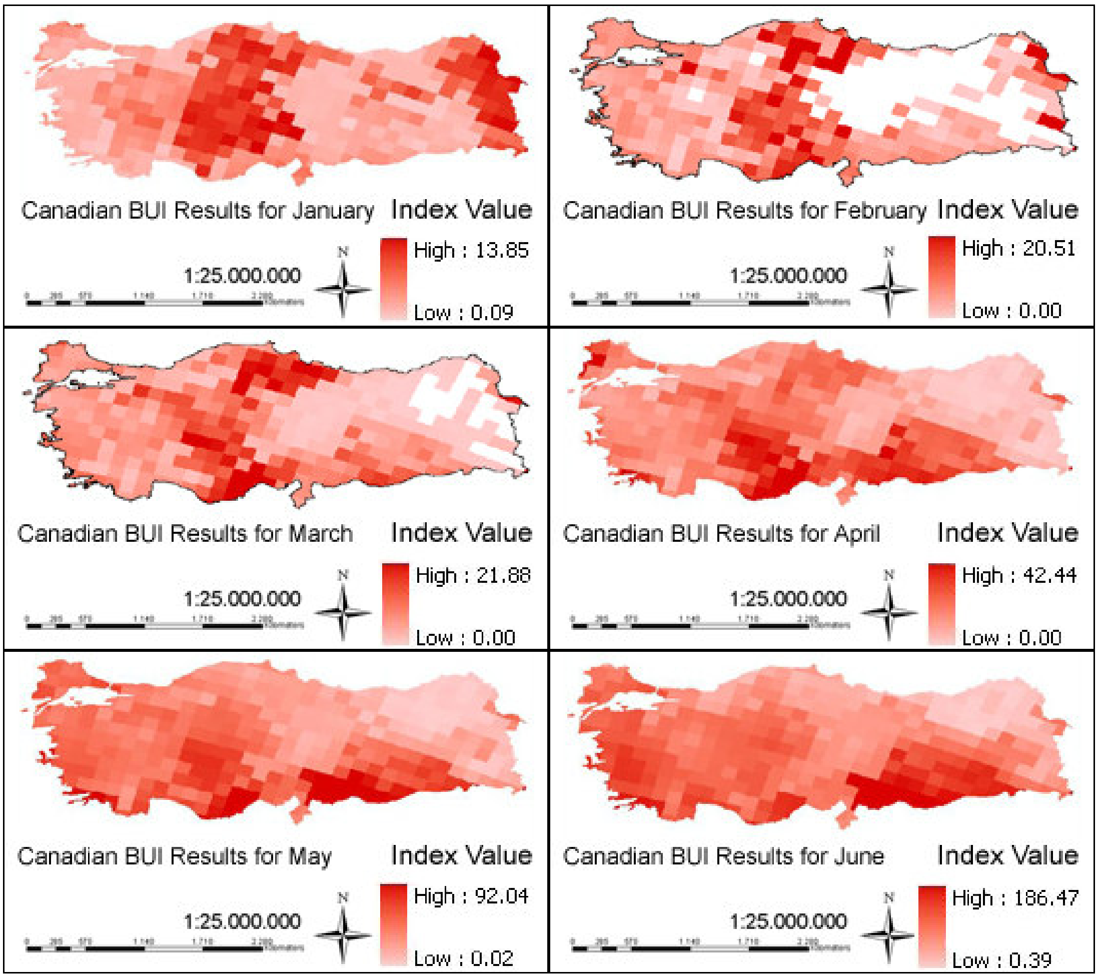


Figure 4.20: Results of Canadian BUI from January to June

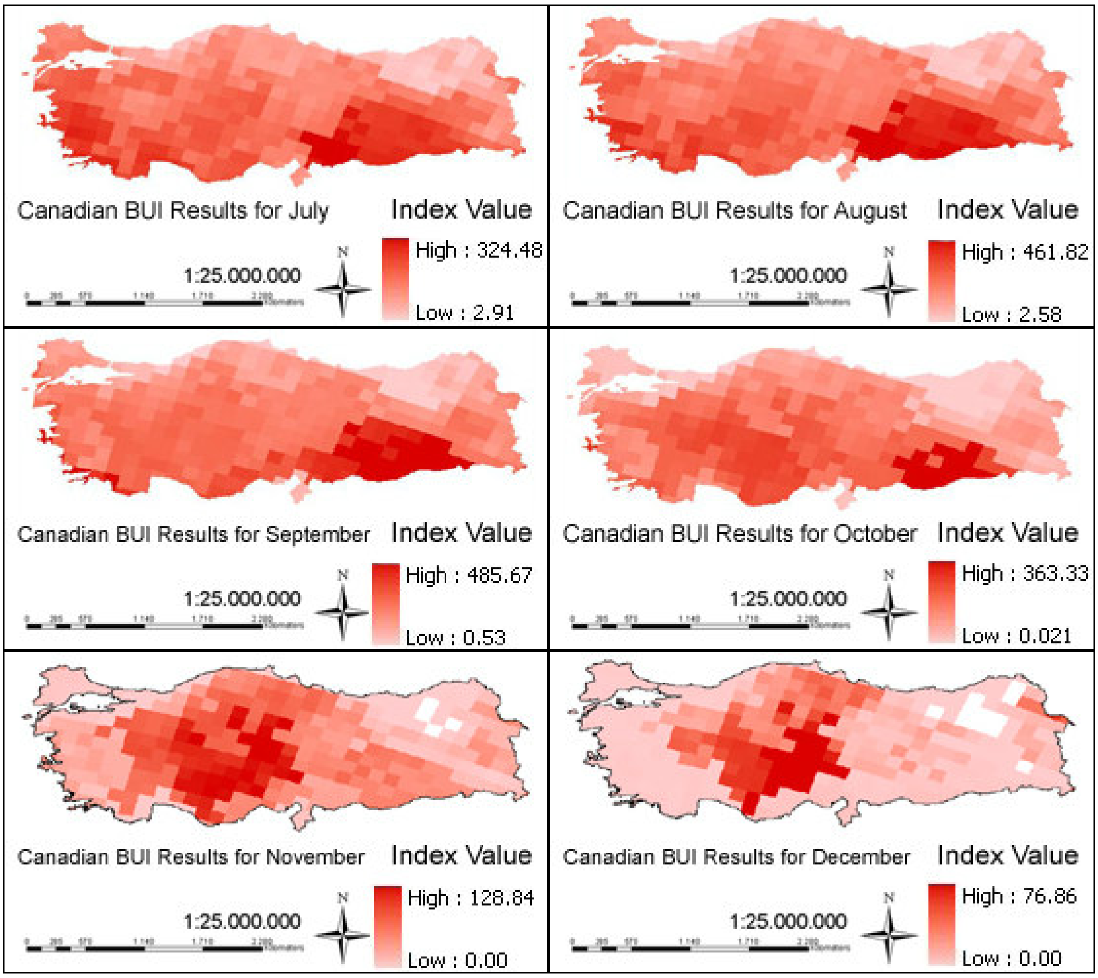


Figure 4.21: Monthly results of Canadian BUI from July to December

Built Up Index represents a rating of the total fuel available for burning. BUI combines the information obtained from DMC and Dc information. As in the case of Initial Spread Index, the results of BUI follow more or less the same pattern of distribution.

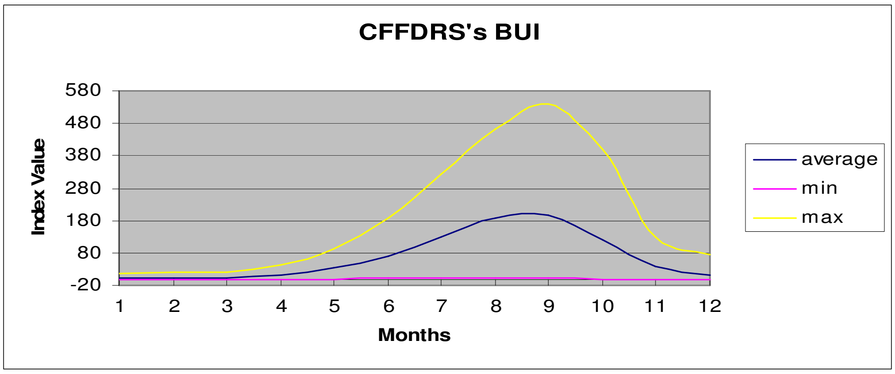


Figure 4.22: Yearly performance of CFFDRS's BUI

4.1.3.6. Fire Weather Index (FWI)

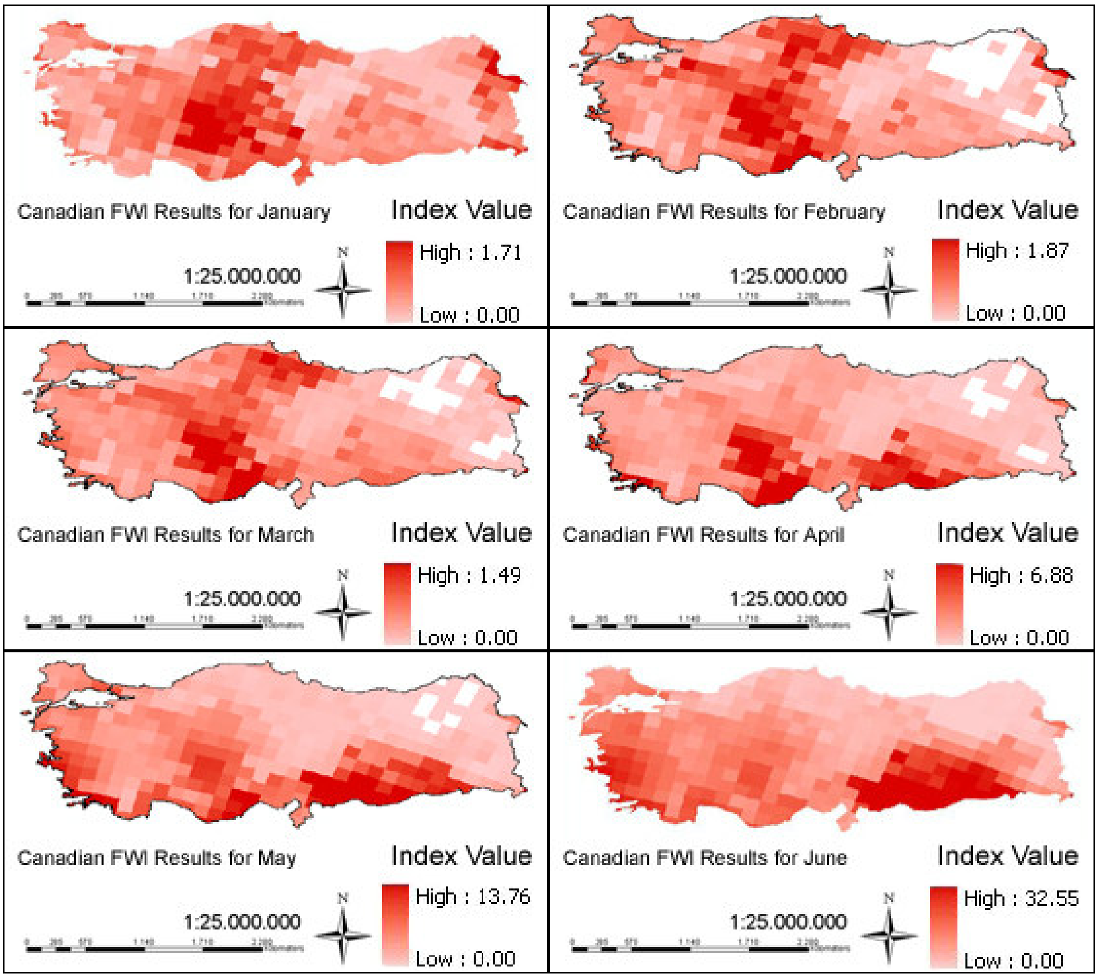


Figure 4.23: Results of Canadian FWI from January to June

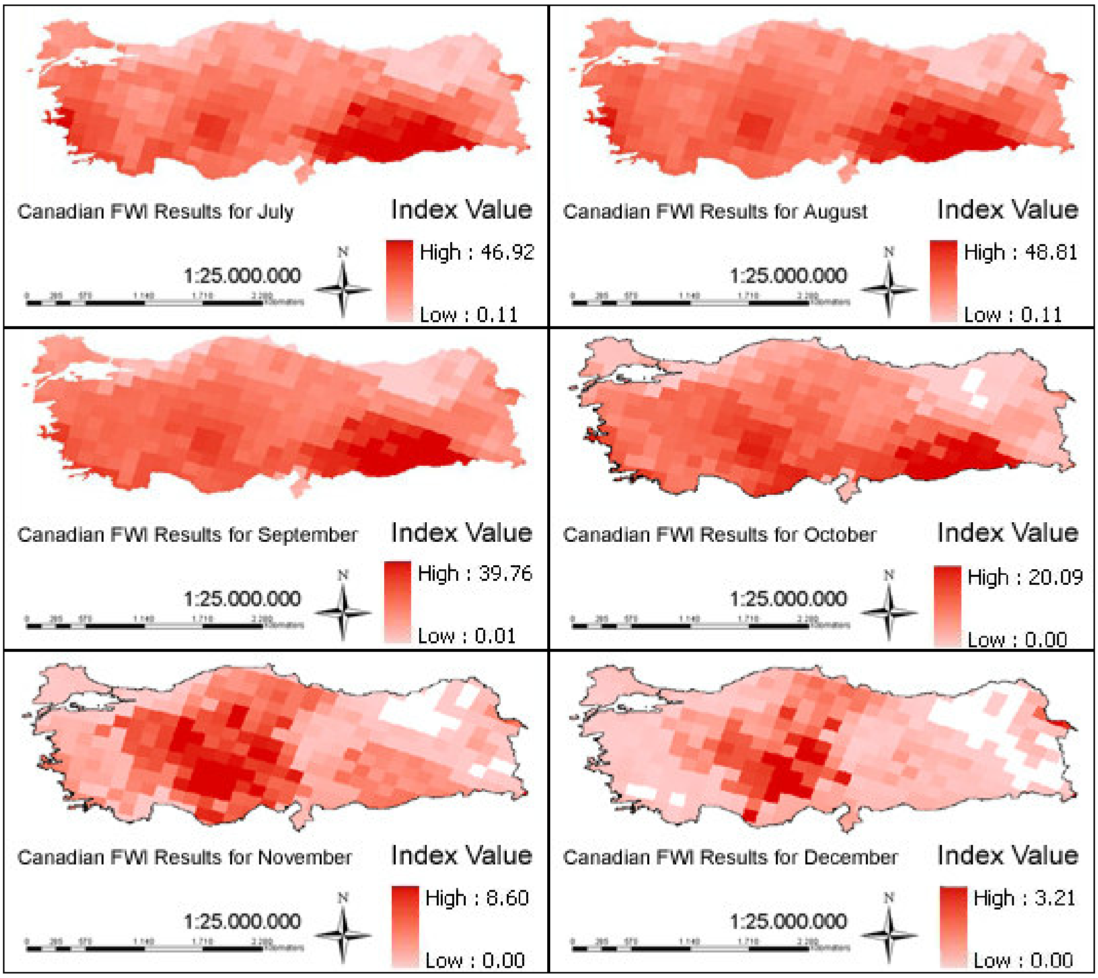


Figure 4.24: Monthly results of Canadian FWI July to December

In terms of its results, FWI indicates similar distribution pattern as BUI and ISI. During the summer months and beginning of the autumn, the index value gets the highest scores. The distribution of the grid cells having highest index values is concentrated along the Aegean and Mediterranean costal zones and predominantly in southeastern part of Turkey.

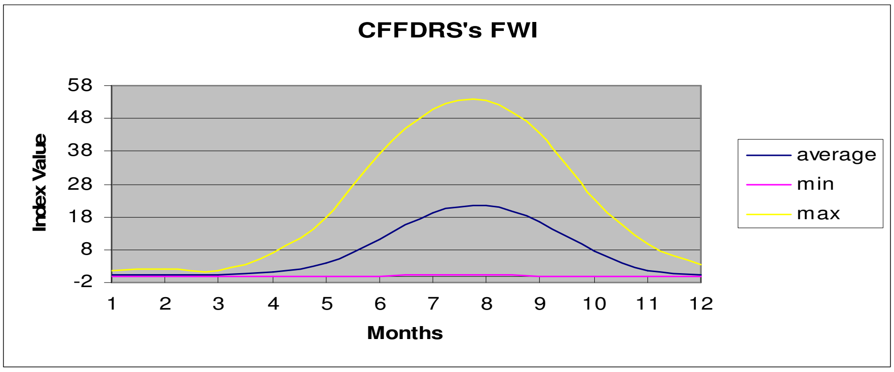


Figure 4.25: Yearly performance of CFFDRS's FWI

4.1.4. The U.S. National Fire Danger Rating System (NFDRS)

It is important to note that for better visual inspection, the legends of the maps are reversed for this fire danger index, since it presents the hourly fuel moisture condition and there is a reverse relationship between fuel moisture and fire danger. Namely, where the fuel moisture is high, there might be relatively lower chance of having a fire ignition and where the fuel moisture is low, there might be a greater chance of having a fire ignition.

4.1.4.1. NFDRS 1hour time lag

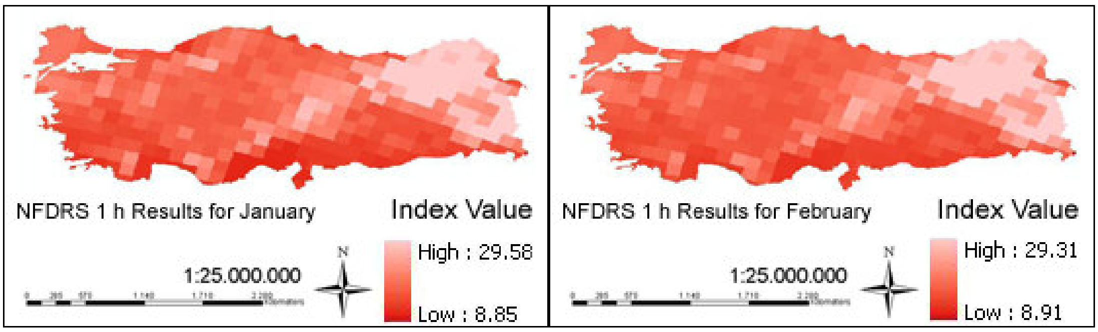


Figure 4.26: Monthly results of NFDRS 1hour from January to February

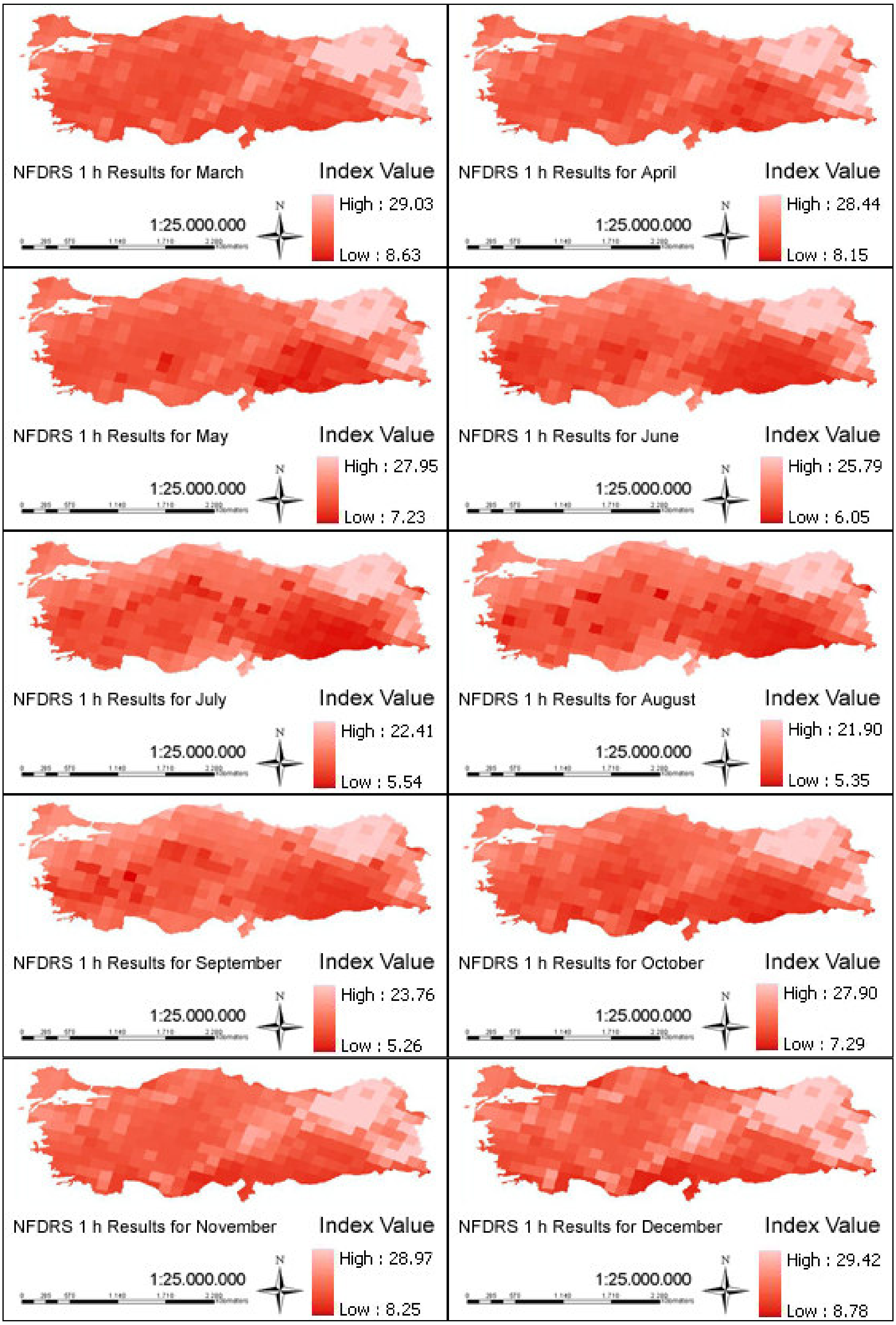


Figure 4.27: Monthly results of NFDRS from March to December

The lowest degree of moisture is concentrated in mainly southeastern zone, in Mediterranean and Aegean costal zones during the summer months.

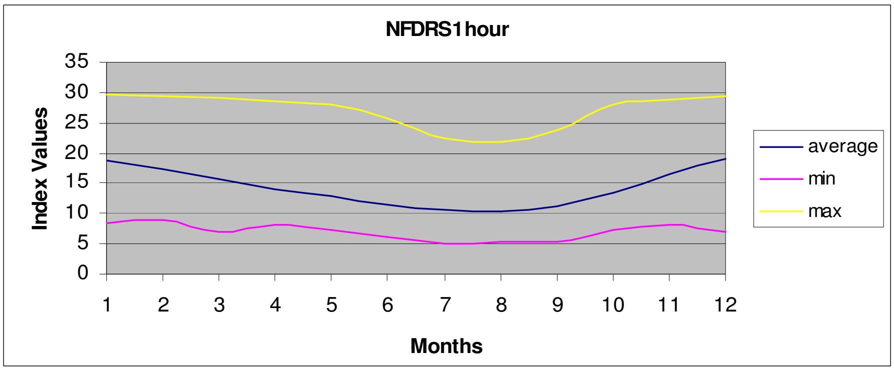


Figure 4.28: Yearly performance of US NFDRS's 1 hour

4.1.4.2. NFDRS 10hour time lag

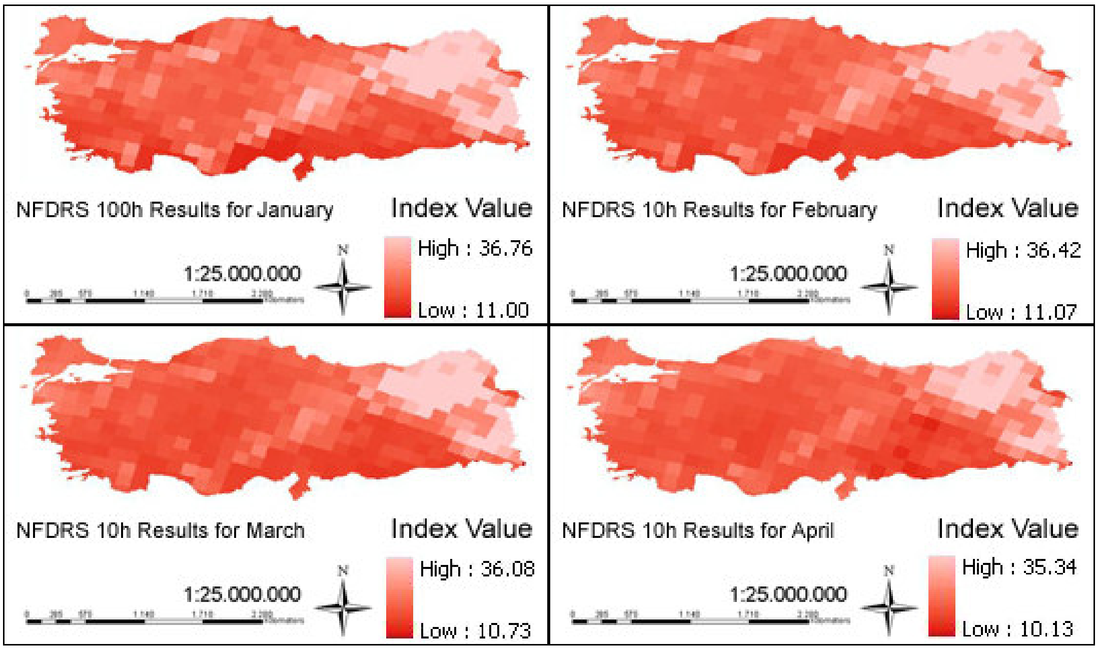


Figure 4.29: Monthly results of NFDRS 10 hour from January to April

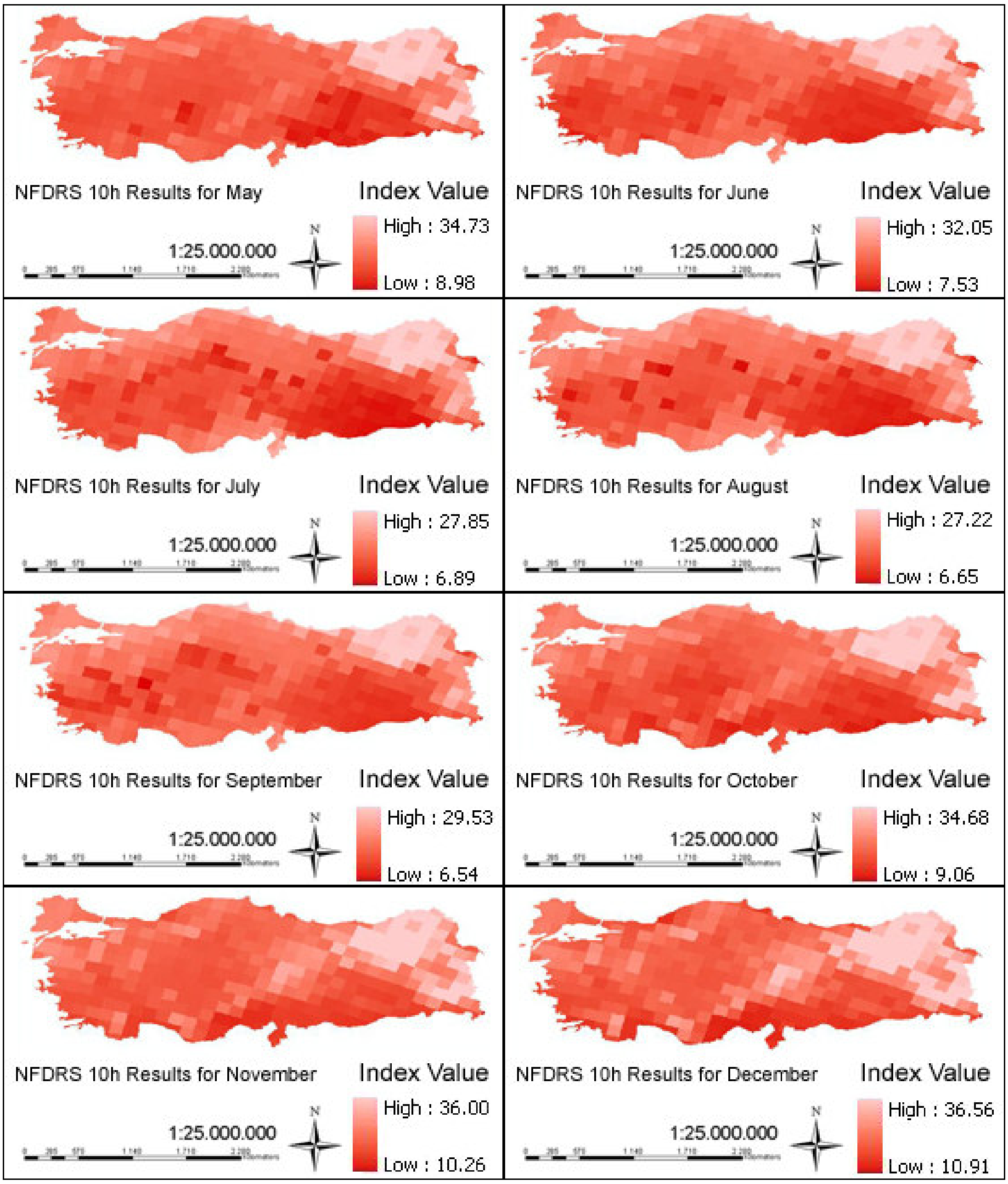


Figure 4.30: Monthly results of NFDRS 10 hour from May to December

NFDRS's 10 hour shows exactly the same characteristics as 1 hour. The values generated by the index for each month are very close to each other and the spatial distribution of cells having low fuel moisture values is concentrated mainly around southern and southwestern part of Turkey, although except from the northeastern part, the inner parts get also lower fuel moisture values, which deserve attention.

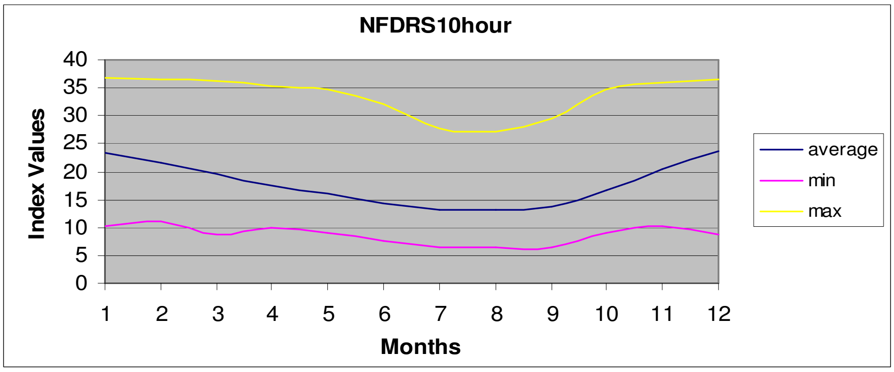


Figure 4.31: Yearly performance of US NFDRS’s 10 hour

4.1.4.3. NFDRS 100hour time lag

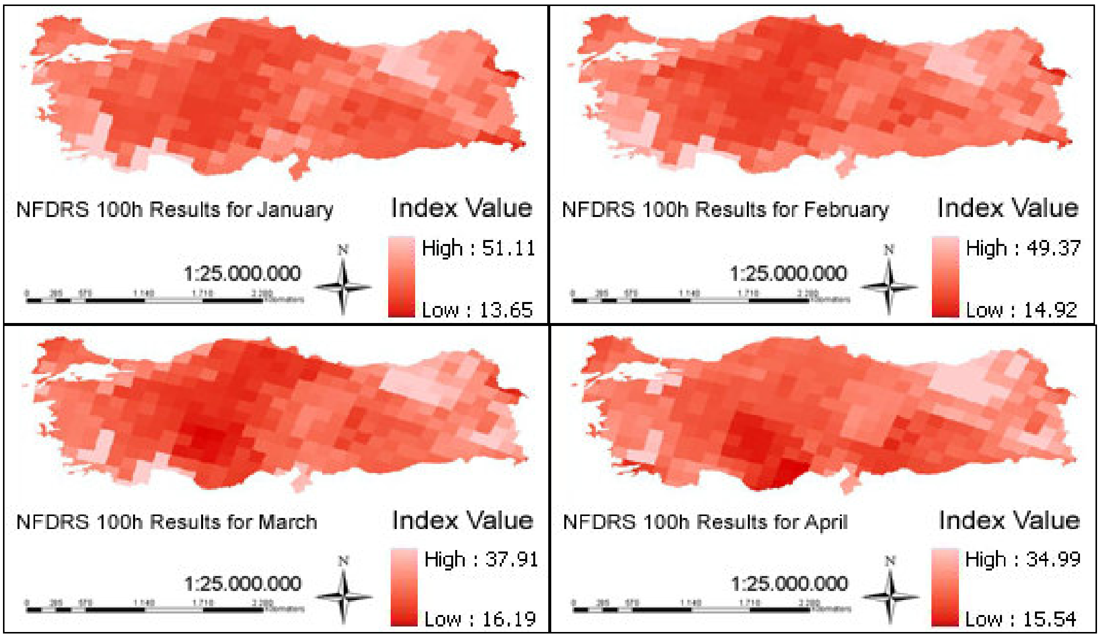


Figure 4.32: Monthly results of NFDRS 100 hour from January to April

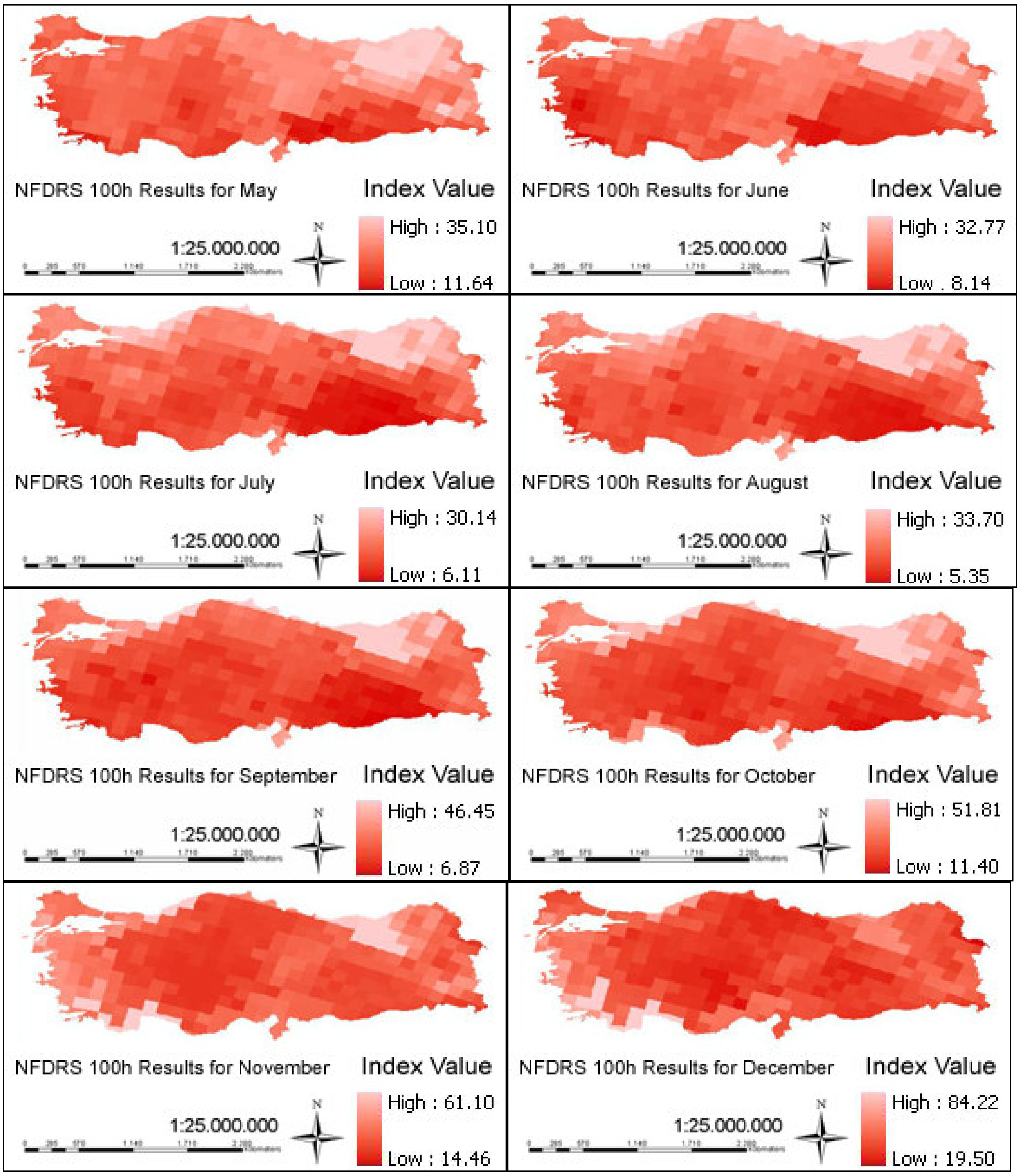


Figure 4.33: Monthly results of NFDRS 100hour from May to December

The results of 100hour index agree on previous NFDRS 1 and 10 hour results. The lowest index values are assigned to southeastern, Aegean and Mediterranean costal zones. Differently, southwestern part and partially the Black sea zone gets higher fuel moisture values during winter months. The lowest index values are observed during late spring, summer and early autumn months.

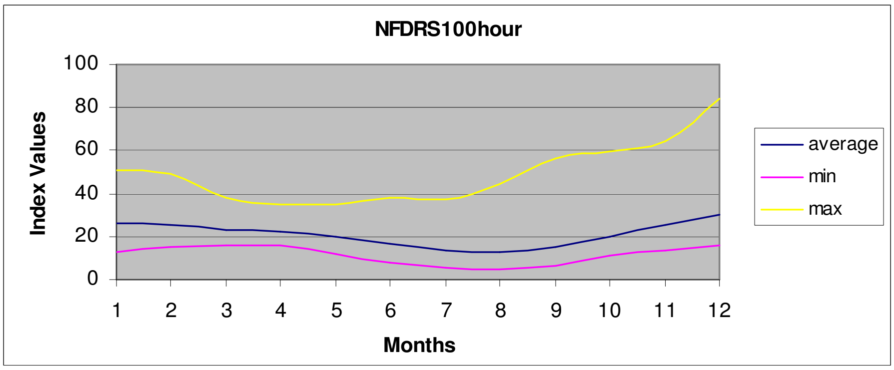


Figure 4.34: Yearly performance of US NFDRS's 100 hour

4.1.5. BEHAVE Fine Fuel Moisture Model

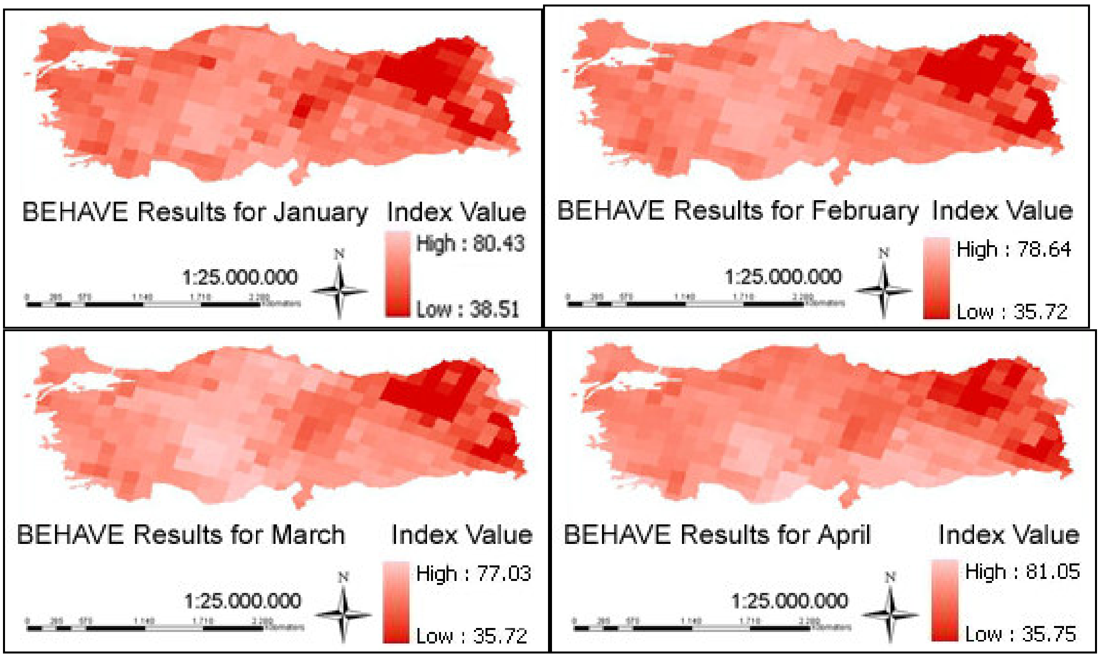


Figure 4.35: Monthly results of BEHAVE from January to April

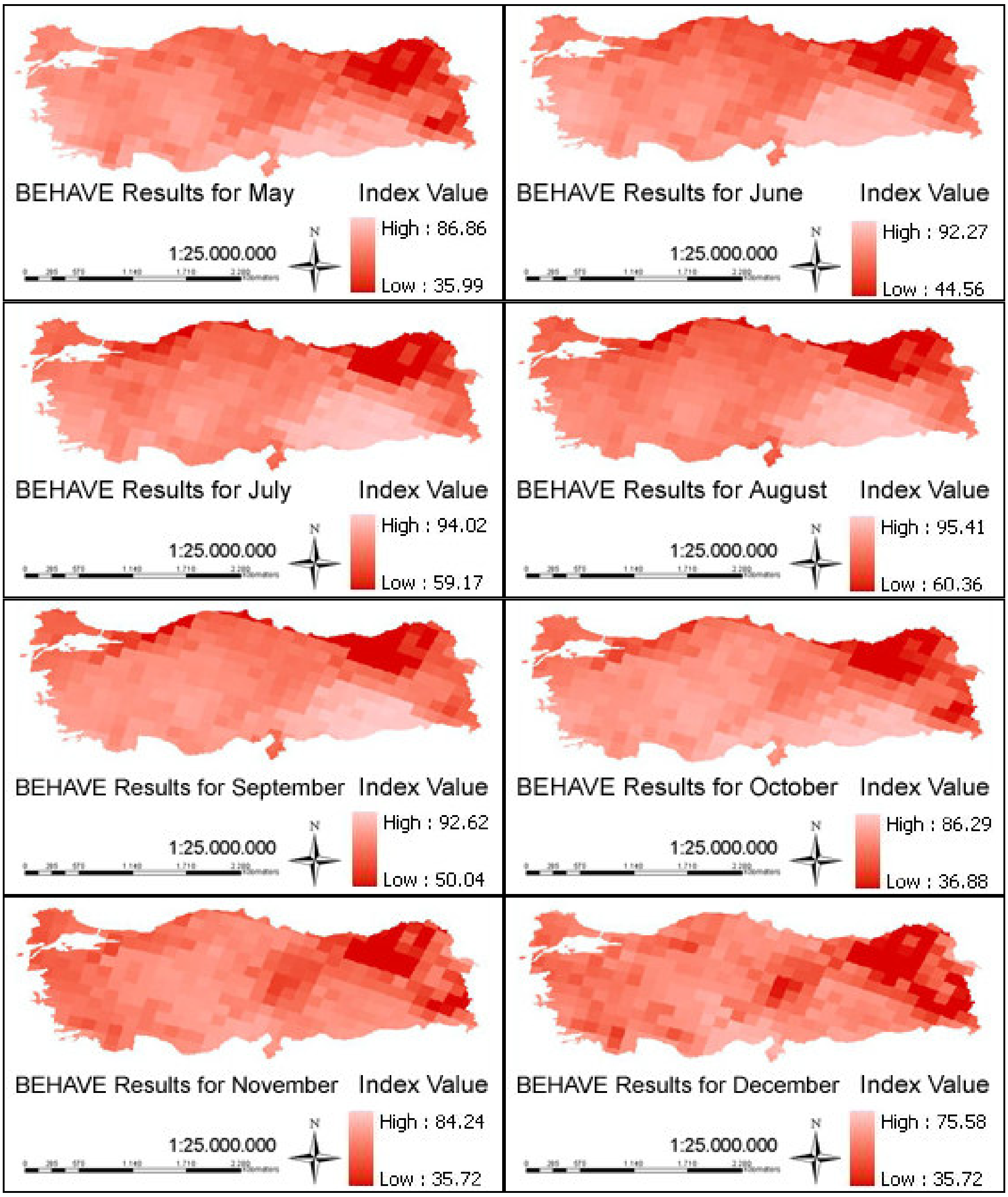


Figure 4.36: Monthly results of BEHAVE hour from May to December

The index BEHAVE points out the fine fuel moisture. As in the case of U.S. NFDRS components, to ease the visual interpretation, the legends of the maps above are inverted due to the inverse relationship between fuel moisture content and fire danger.

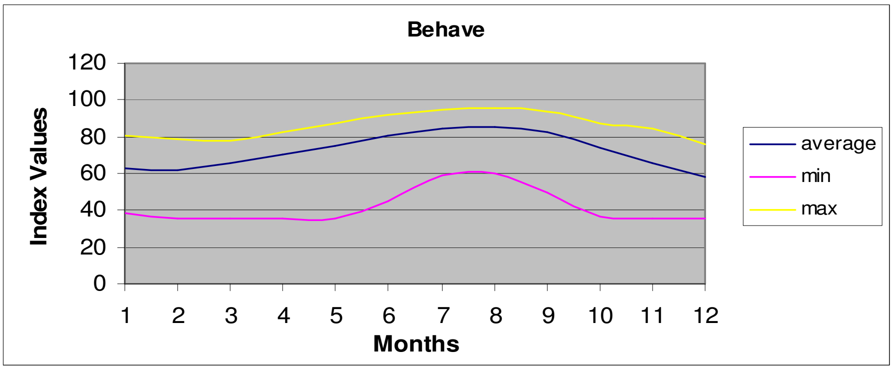


Figure 4.37: Yearly performance of BEHAVE

4.1.6. Keetch Byram Drought Index

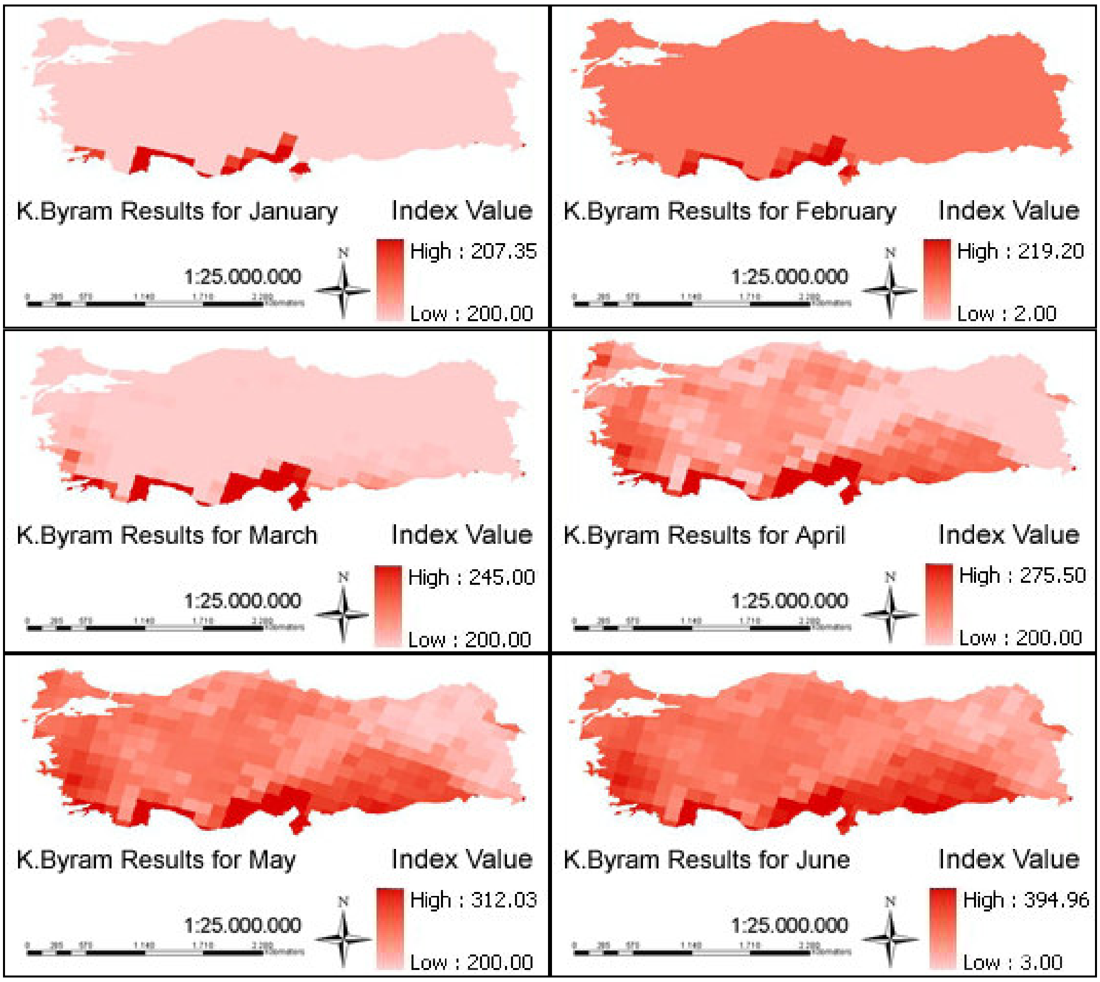


Figure 4.38: Monthly results of BEHAVE from January to June

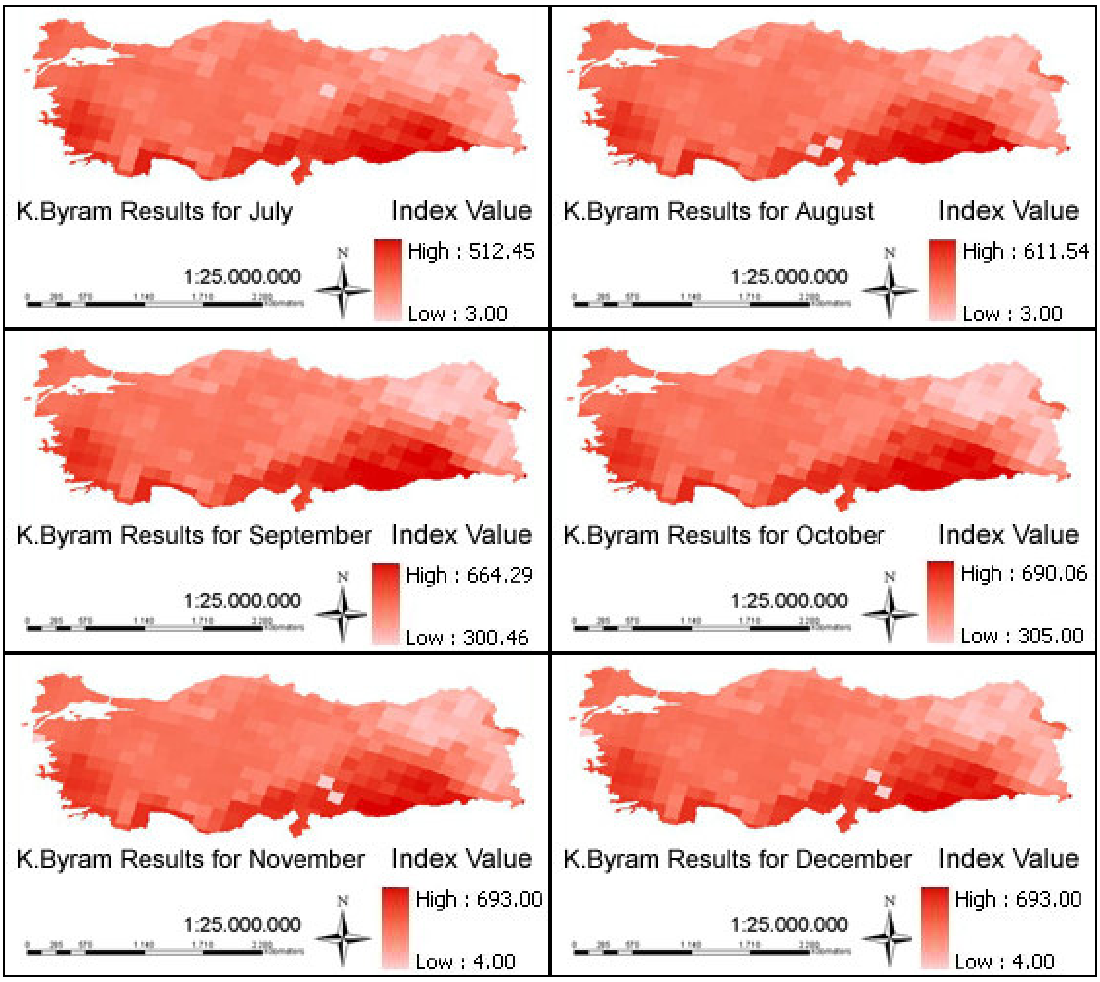


Figure 4.39: Monthly results of BEHAVE hour from July to December

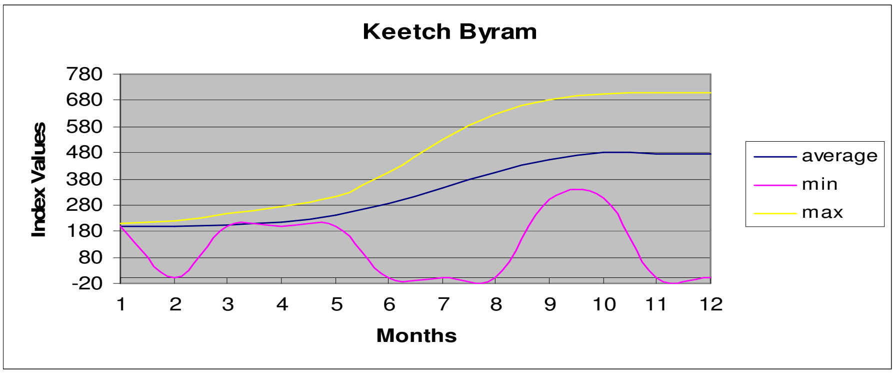


Figure 4.40: Yearly performance of Keetch Byram

Keetch Byram index is a drought index and has been component of other indices. According to the results of Keetch Byram index, the grid cells getting highest index values are concentrated in southeastern and southwestern parts including Mediterranean and Aegean costal zones of Turkey throughout the year, as other previous danger indices suggested. Differently, the highest index values are observed during summer and especially during autumn months.

CHAPTER 5

PERFORMANCE TESTING OF THE CANDIDATE METEOROLOGICAL FIRE DANGER INDICES

In this section performances of the calculated Meteorological Fire Danger Indices against several scenarios were evaluated and the best explanatory fire danger index was identified. The meaning of the best performing index is stated versus the defined conditions with the application of Mandallaz and Ye performance Scores method (Mandallaz and Ye, 1996), which can describe the index capability of discriminating the value of a binomial variable (Francesetti et al., 2004).

5.1. Defining various scenarios based on Number of Fires (NoF) and Burned Area (BA)

Defining various scenarios based on number of fires and burned area values enabled to observe the discriminating power of each fire danger indices. The conventional scenarios that have been set for this process are as the following:

Scenarios for NoF:

NoF between 0.5 and 1 per grid cell in a given month	1> NoF >= 0.5
NoF between 1 and 1.5 per grid cell in a given month	1.5> NoF >= 1
NoF between 1.5 and 2 per grid cell in a given month	2> NoF >= 1.5
NoF between 2 and 2.5 per grid cell in a given month	2.5> NoF >= 2
NoF between 2.5 and 3 per grid cell in a given month	3> NoF >= 2.5
NoF between 3 and 3.5 per grid cell in a given month	3.5> NoF >= 3
NoF between 3.5 and 4 per grid cell in a given month	4> NoF >= 3.5
NoF between 4 and 4.5 per grid cell in a given month	4.5> NoF >= 4
NoF between 4.5 and 5 per grid cell in a given month	5> NoF >= 4.5
NoF between 5 and 5.5 per grid cell in a given month	5.5> NoF >= 5
NoF between 5.5 and 6 per grid cell in a given month	6> NoF >= 5.5
NoF between 6 and 6.5 per grid cell in a given month	6.5> NoF >= 6
NoF between 6.5 and 7 per grid cell in a given month	7> NoF >= 6.5
NoF between 7 and 7.5 per grid cell in a given month	7.5> NoF >= 7
NoF between 7.5 and 8 per grid cell in a given month	8> NoF >= 7.5
NoF between 8 and 8.5 per grid cell in a given month	8.5> NoF >= 8
NoF between 8.5 and 9 per grid cell in a given month	9> NoF >= 8.5
NoF between 9 and 9.5 per grid cell in a given month	9.5> NoF >= 9
NoF between 9.5 and 10 per grid cell in a given month	10> NoF >= 9.5
NoF greater than 10 per grid cell in a given month	NoF >= 10

Scenarios for BA:

BA between 5 and 10 per grid cell in a given month	10> BA >= 5
BA between 15 and 20 per grid cell in a given month	15> BA >= 10
BA between 20 and 25 per grid cell in a given month	20> BA >= 15
BA between 25 and 30 per grid cell in a given month	25> BA >= 20
BA between 30 and 35 per grid cell in a given month	30> BA >= 25
BA between 35 and 40 per grid cell in a given month	35> BA >= 30

BA between 40 and 45 per grid cell in a given month   40> BA >= 35

BA between 45 and 50 per grid cell in a given month   45> BA >= 40

BA greater than 50 per grid cell in a given month   50> BA >= 45

For each of the above given scenario a binary variable was assigned value 1 if the condition was satisfied in the grid cell and 0 otherwise (Table 5.1).

Table 5.1: Example for binary values generation for a given grid cell regarding the conditions in each scenario. Here the conditions for the number of fire events equal or greater than 0.5 and less than 1 and burned areas equal or greater than 5 ha and less than 10 ha are shown.

Binary variable Per grid cell	**Type**	**True/False**	**Value**
Fire event (NoF)	1>x>=0.5	no	0
	1>x>=0.5	yes	1
Burned area (BA)	10>x>=5	no	0
	10>x>=5	yes	1

Mandallaz and Ye performance Scores method can be done with the following three indices:

I_{index}, I_{max} and I_{random}

These indices are constructed based on binary values resulted from evaluation of scenario conditions and number of grids considered. According to the definition, the following steps are followed to test the performances.

Once the binary values - denoted by I_i - obtained from the specific scenario condition, the index values of interest are ranked in ascending order, which is denoted by Z_i – the rank value of i^{th} grid. Next step is to multiply each Z_i value with associated binary value I_i. Namely, binary values I_i having value of 0 neutralize their associated rank value Z_i and only binary values having value of 1 get their corresponding rank value. Next, I_{index} value is the sum of these values (Equation 5.1):

$$I_{index} = \sum_{i=1}^{N} rank(z_i) I_i \tag{5.1}$$

It is expected that the highest values of the index should refer to the days in which the events mostly occurred. Next (Equation 5.2),

$$I_{max} = \frac{d(2N + 1 - d)}{2} \tag{5.2}$$

Where *d* is the sum of occurred events (1 values of the binary variable) and *N* is total number of considered days for index calculation. On the other hand, I_{random} is calculated as the following (Equation 5.3):

$$I_{random} = \frac{d(N + 1)}{2} \tag{5.3}$$

Based on these three indices two score parameters were created – Score 1 and Score 2. By definition Score 1 and Score 2 are obtained as the following (5.4):

$$Score\ 1 = \frac{I_{index}}{I_{max}} \qquad Score\ 2 = \frac{I_{index}}{I_{raadom}} \tag{5.4}$$

“Score 1 represents the performance of a certain index with reference to a certain event (binary variable) related to a deterministic rating in which all the events occurred are forecasted with absolute confidence. The value of this score is 1 when the index is performing well.

Score 2 corresponds to the ratio between the index and an absolutely casual rating. If this score is lower than 1 it means that the random rating performs better that the index, vice versa if the scores values are more than 1 the index has good performance"' (Francesetti A. et al., 2004).

Having described the Mandallaz and Ye performance Scores method, the results and the evaluation of the performances were presented. The discriminating power and/or sensitivity of candidate meteorological fire danger indices in terms of both number of fires and burned area variables are graphed in accordance with different scenarios. The comparison between indices can be visualized and the best performing index can be chosen.

5.2. Outcomes of Performance Testing Process

The performance testing was made with both Number of fires (NoF) and Burned Area (BA) parameters.

5.2.1. Performance Testing with Number of Fires Variable

As can be seen (Figure 5.1 and 5.2.), among the selected indices the result of the Canadian Forest Fire Danger System's Fire Weather Index, Built Up Index, Initial Spread Index and BEHAVE indices are promising. The performance values of these indices over various scenarios were quite optimum. When compared not all these indices were following almost the same trend, especially Initial Spread Index was slightly more successful to discriminate the number of fires greater than 7. FWI, BEHAVE; FFMC, BUI and DMC components were following up ISI. On the other hand, the performances of NFDRS 1hour, 10hour and 100hour, BEHAVE; Mark5F, McArthur 1967 and Keetch Byram indices were very close to be chance or random.

For Score 2, in this case the attention was drawn to indices, which had values above 1. The results of Score 1 for scenarios with number of fires were verified. In overall evaluation, ISI, FWI, BEHAVE, FFMC, BUI and DMC indices showed good performances (Figure 5.1). As a result, the performances of both scores for ISI, FWI, BEHAVE, FFMC, BUI and DMC indices are promising in terms of discriminating number of fires; however this conclusion should be verified by scores generated for burned area parameter, as well (Figure 5.2).

5.2.2. Performance Testing with the Burned Areas Variable

According to the results of Score 1, BUI, DMC, FWI, ISI, BEHAVE and FFMC indices had clear superiority over other indices and had good results. Again, the results of NFDRS 1hour, 10hour and 100hour, BEHAVE, Mark5F, McArthur 1967 and Keetch Byram could be explained as random or chance, since these indices had relatively low score values.

The results of Score 2 indicated also BUI, DMC, FWI, ISI, BEHAVE and FFMC indices as best performing indices (Figure 5.4).

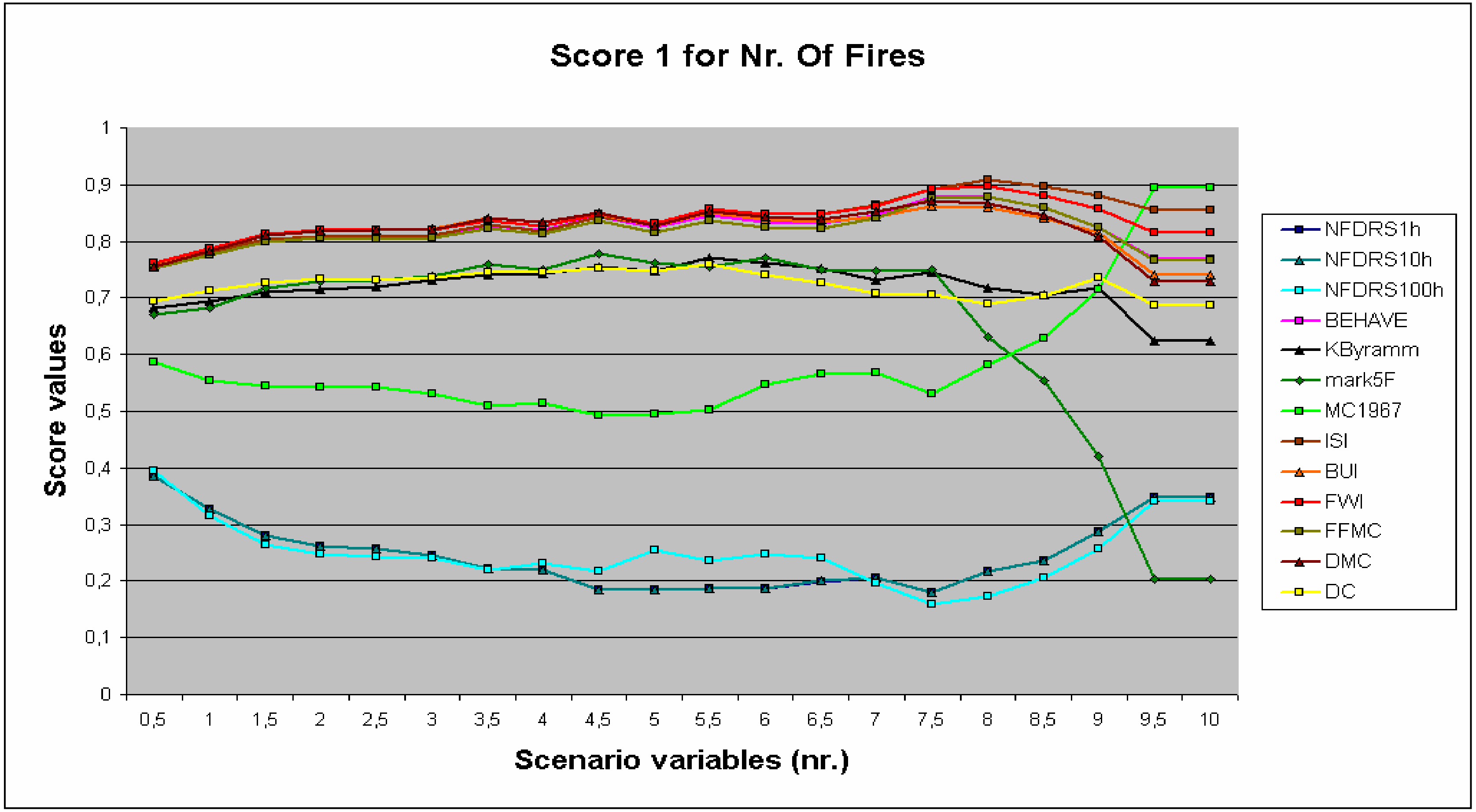


Figure 5.1: core 1 for various selected indices over different scenarios related with Number of Fires

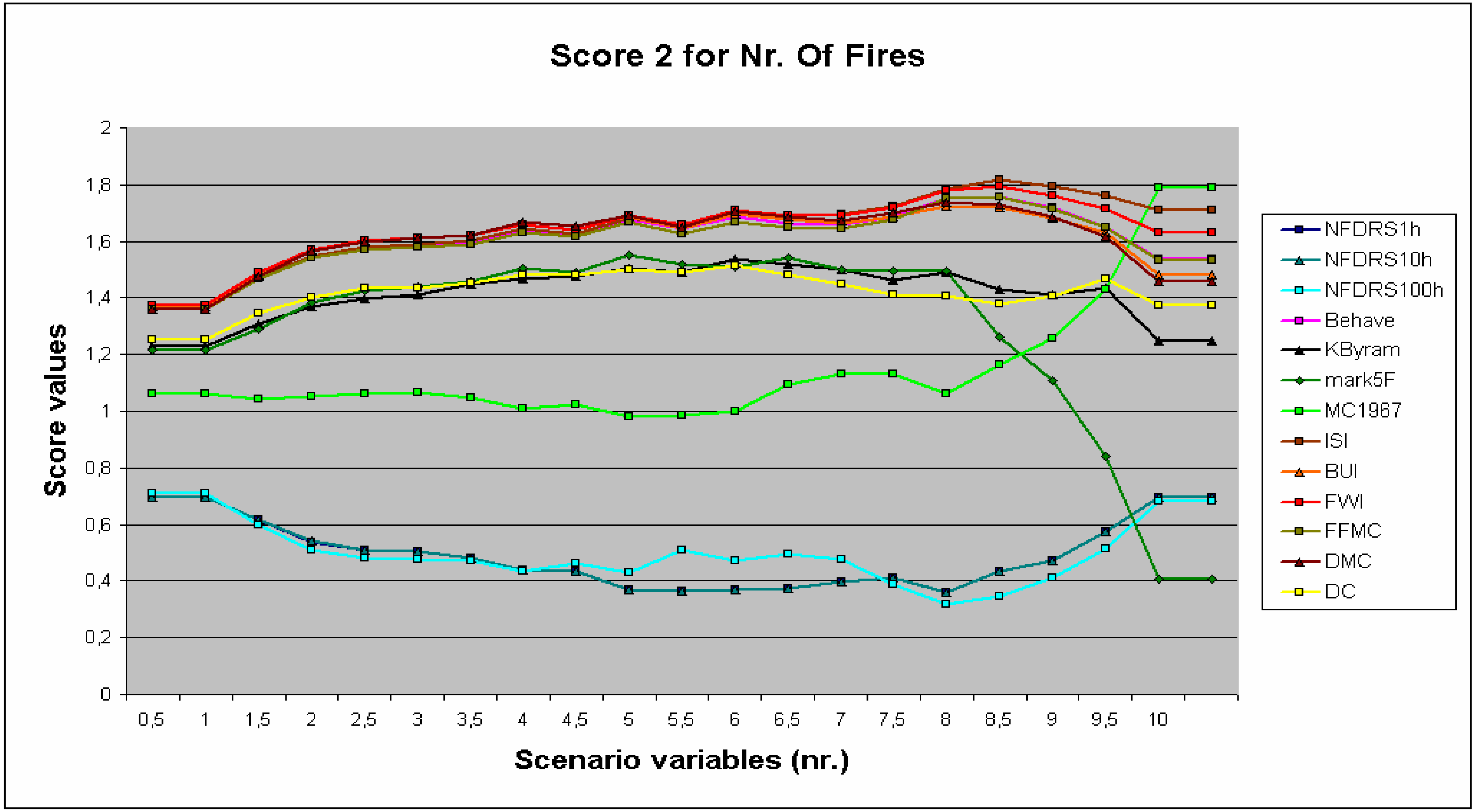


Figure 5.2: Score 2 for various selected indices over different scenarios related with Number of Fires

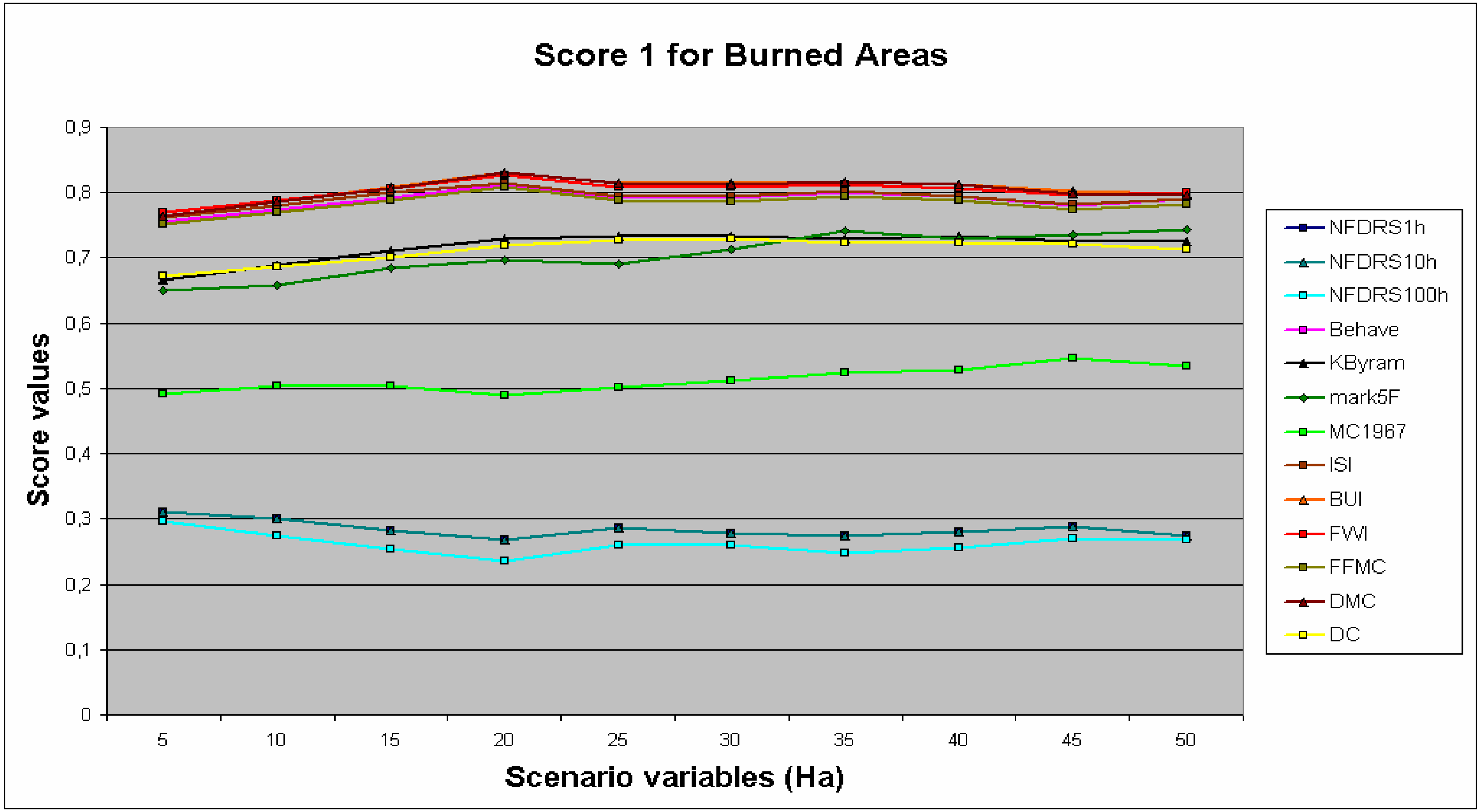


Figure 5.3: Score 1 for various selected indices over different scenarios related with Burned Areas

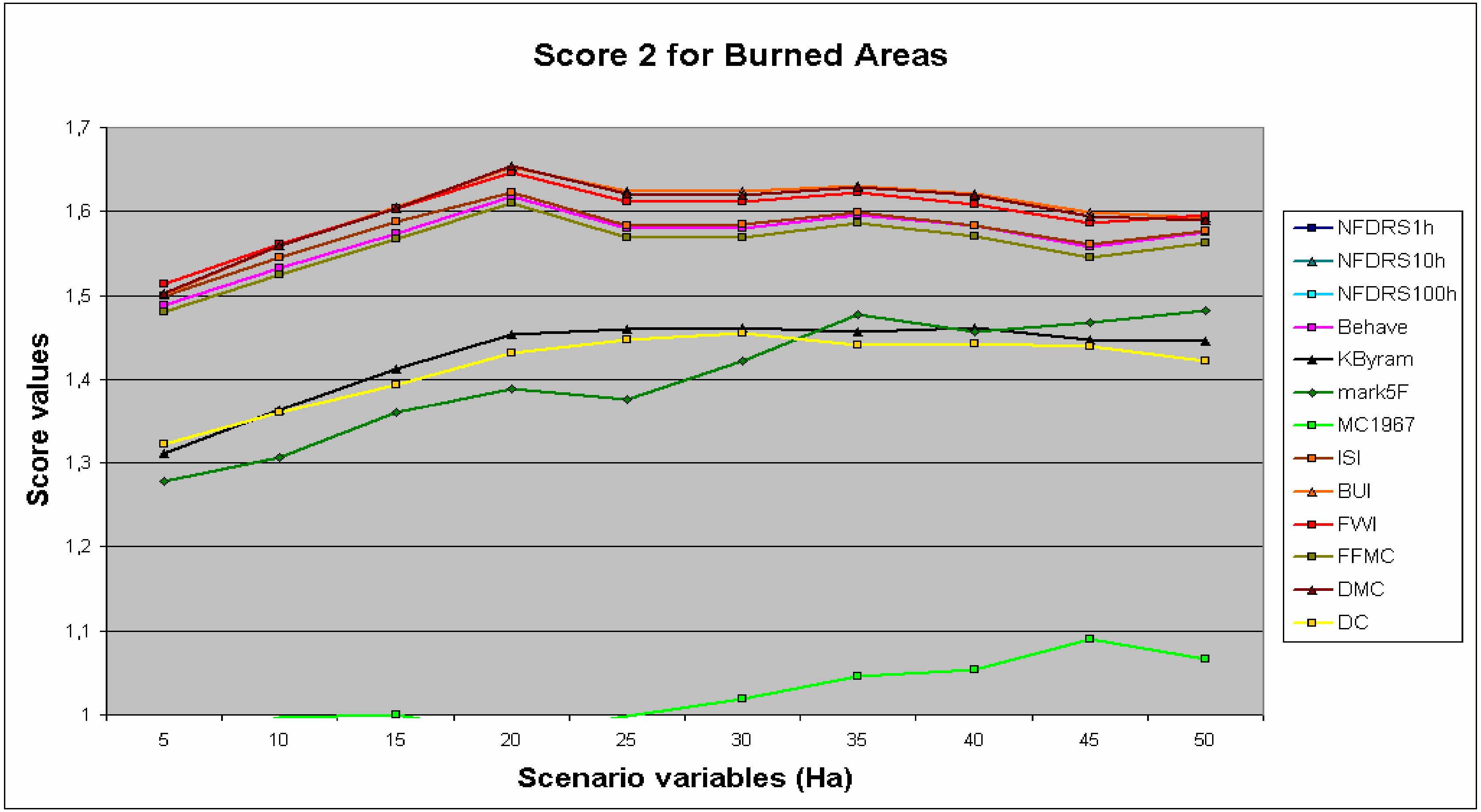


Figure 5.4: Score 2 for various selected indices over different scenarios related with Burned Areas

5.3. Overview of the Outcomes of Performance Testing Process

Having presented the results of the performance testing of the selected meteorological fire danger indices, a brief overview is useful before calibration of the best performing indices. To illustrate one fire event per grid and 5ha of burned area per grid were selected in order to express how well the selected meteorological fire danger indices could be sensitive against the smallest unit of scenario values (Table 5.2).

Table 5.2: Classification of best performing Meteorological Fire Danger Indices in terms of discriminating one fire event per grid

Indices	Score 1	Score 2
FWI	0.788007	1.488361
BUI	0.785225	1.483106
DMC	0.782319	1.477619
ISI	0.78073	1.474618
BEHAVE	0.780027	1.473288
FFMC	0.77659	1.466797
DC	0.711764	1.344356
Keetch Byram	0.693515	1.309887
Mark5f	0.682238	1.288588
McArthur	0.552624	1.043777
NFDRS-10h	0.326795	0.617239
NFDRS-1h	0.326772	0.617196
NFDRS-100h	0.316	0.596851

In this table the results of score 1 and 2 for grid cells having one fire event were ranked in descending order. The highest values were observed by FWI, BUI, DMC, ISI, BEHAVE and FFMC indices.

The results of Score 1 and 2 for number of Fires variable were verified also with burned area component. The best performing indices were FWI, BUI, DMC, ISI, BEHAVE and FFMC indices (Table 5.3).

Table 5.3: Classification of best performing Meteorological Fire Danger Indices in terms of discriminating 5ha of burned area per grid

Indices	Score 1	Score 2
FWI	0.76948	1.51308
DMC	0.763811	1.501932
BUI	0.76343	1.501183
ISI	0.762331	1.499022
BEHAVE	0.756765	1.488077
FFMC	0.752586	1.47986
DC	0.672144	1.321681
KeetchByram	0.666613	1.310806
Mark5f	0.649918	1.277976
McArthur	0.492295	0.968032
NFDRS-10h	0.311822	0.613157
NFDRS-1h	0.311812	0.613136
NFDRS-100h	0.296573	0.58317

As a result, it can be concluded that generally the results of Canadian Forest Fire Danger System's sub components and alternatively BEHAVE are quite promising. It is also important to note that for the number of fires parameter ISI, FFMC and FWI indices were more explanatory than the other best performing indices, whereas for burned areas parameter BUI, DMC and FWI components were more explanatory. Thus; it is interesting to noted that the number of fires can be explained more with the indices of Canadian Forest Fire Danger System, which take wind component into account and are related with fire propagation, on the other hand, the burned areas parameter can be explained more with the indices, which concerns more about drought or moisture content.

For both cases FWI component was also reliable and had promising results. Therefore FWI of Canadian Forest Fire Danger System was selected as a best performing index, not only it had reliable results for both number of fire and burned areas parameters, but also it contains more information when compared to its sub-components and any other index of interest.

Here, it is also suitable to mention about two recent works in literature. The studies of Gonçalez (2006) in Portugal and Nolasco (2006) in Spain have indicated that Canadian Fire Weather Index had quite promising results for fire danger estimation, when compared with national meteorological fire danger indices in these mentioned countries. The success the Canadian Fire Weather Index in Fire Danger Estimation in these two Mediterranean Countries indicates that FWI might be a good candidate danger index for investigating the fire phenomenon in Turkey as well.

CHAPTER 6

CALIBRATION OF FIRE WEATHER INDEX

Having selected FWI as the best performing index, it was useful to examine this index in detail, before proceeding to calibration phase. Since fire event has also seasonal dimension, it was useful to build a scenario based on fire season to observe the response of FWI to different seasonal conditions. This month-based scenario was expected to highlight the performance of FWI more, since most of the fire events occur during fire seasons.

However it should be clarified that the fire season may not necessarily refer to conventional summer months. For this reason, the stratification of monthly-based scenario should be based on fire season, which was derived from 5-year fire history data.

6.1. FWI Performance testing based on fire season

The following graphs were plotted to find out the months of fire season in the given 5 year period dataset (Figure 6.1 - 6.3).

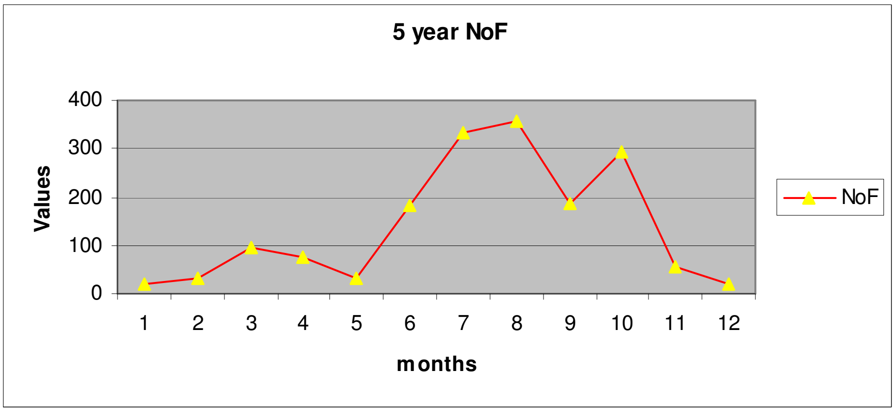


Figure 6.1: Monthly distribution of number of fires in past five years

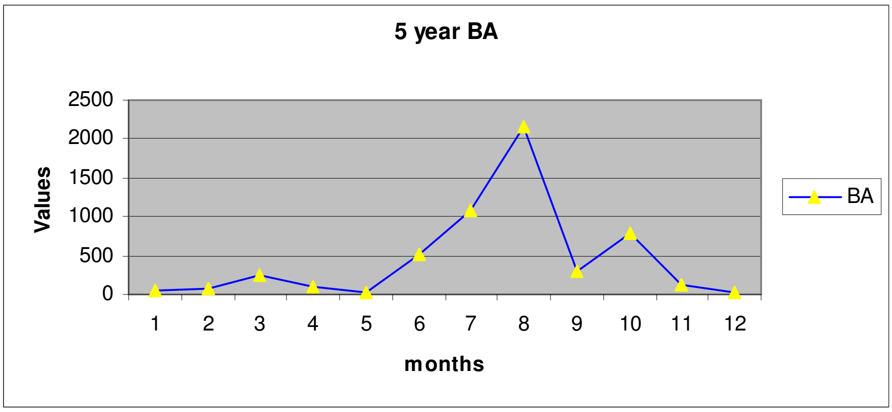


Figure 6.2: Monthly distribution of burned areas in past five years

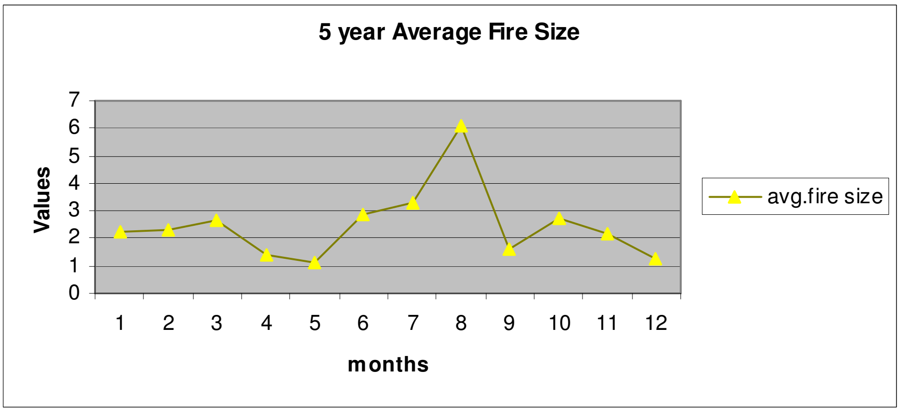


Figure 6.3: Monthly distribution of averaged fire size (Number of Fires per Burned Area) in past five years

As far as the number of fires, burned areas and average fire size (defined as Number of Fires per Burned Area) were considered all together, it was concluded that the fire season based on 5-year dataset should include June (6), July (7), August (8), September (9) and finally October (10). Although there is a sharp decrease in all graphs after August, a slight inclination can be observed in October. Therefore, the fire season included the months from August onwards to October and was considered as summer scenario and the months remaining outside of this range will be considered as winter scenario.

This time Mandallaz and Ye performance testing method was applied separately for both winter and summer scenarios. To make a comparison between these two scenarios, score 2 values was sufficient (Figure 6.4- 6.5).

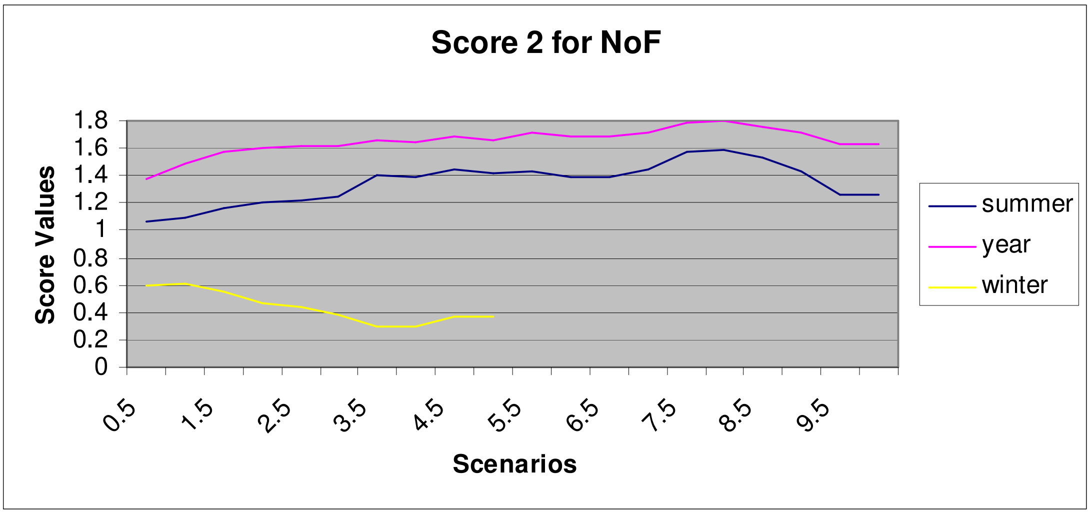


Figure 6.4: Score 2 values over different scenarios of number of fires in accordance with the winter and summer scenarios

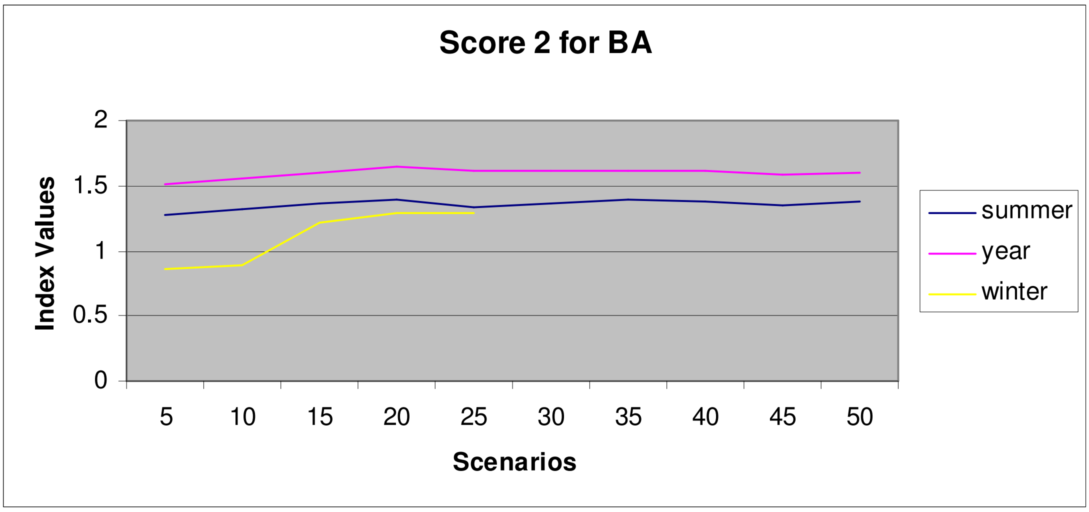


Figure 6.5: Score 2 values over different scenarios of burned areas in accordance with the winter and summer scenarios

Both graphs indicate that FWI has better results in summer scenario over winter scenario and yearly approach predominantly has better results than winter and summer scenarios.

Moreover, for number of fire parameter, winter scenario values were quite close to be chance or random for all scenario ranges about number of fire variable and for some scenario ranges about burned areas.

This detailed overview leads some conclusions. First of all, since the dataset of fire history is limited to 5 years, stratification of scenarios based on fire season months had misleading results especially for winter case. To have more reliable results, the years included in the dataset of fire history should be increased. Another point to consider about was that it was found that limiting the performance testing to summer scenario would highlight performance of FWI was not valid. Yearly performances were more reliable than summer performances. However, another conclusion that could possibly be made is that it is a better idea to calibrate the results of FWI in accordance with the whole year scenario without making a separation between months, but inevitably, the calibration of the results of FWI should be made by taking different characteristics of the months into account.

6.2. Calibration of FWI results for fire season months

Calibration refers to the empirical correlations of system components with statistics of fire occurrence and fire size, rather than the prediction of individual fire behavior. This is done by introducing appropriate danger classes into the system and by reclassifying accordingly. Although in Canada, this danger class categorization is uniform for all over Canada, it is important to find out these danger classes and assigning ranges based on the FWI outcomes found in each system uniquely (Van Wagner, 1987).

6.3. Determining appropriate FWI Danger Classes

According to definition, to develop a rational class breakdown there are four steps to follow:

- Step 1 To compile a historical sample of FWIs over a number of seasons
- Step 2 To decide how many extreme days should be allowed each season on the average and to set the lower limit of the extreme class
- Step 3 To arrange the other classes on a geometric progression in terms of I-scale, using a constant ratio of I-scale value from class to class
- Step 4 To convert I-scale values back to S-scale values using exponential and logarithmic algorithms described in literature.

I-Scale and S-scale here refers to empirical logarithmic functions that were derived from fire behavior or frontal fire intensity (kW/m) of several experimental fire events performed in different zones of Canada. More information on this subject is cited by Van Wagner (1987).

Before proceeding to compile FWI values over each month, a table was constructed, showing number of fires for each month based on the scenarios described early (Table 6.1). However the scenarios in the table were limited, since the information about the number of fire contained by the scenarios.

Table 6.1: The information about number of fire contained by the scenarios

Scenarios	0,5	1	1,5	2	2,5	3	3,5	4
Percentage	**19,3%**	**11,1%**	**7,0%**	**4,7%**	**3,3%**	**2,4%**	**1,6%**	**1,2%**

Scenarios	4,5	5	5,5	6	6,5	7	7,5	8	8,5	9	9,5	10
Percentage	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

The scenarios included in the procedure were limited up to 4 fire events, since the other scenarios started containing grids having less than 1% of the total fire events in the concerned period of time (Table 6.2).

Following the steps, the values of FWI on a month basis were ranked in accordance with their associated percentiles. Here, a separation between summer scenario months and winter scenario months was made and the winter scenario was treated differently than the summer months. In this study five ordinal classes were assumed to present the fire danger map:

Very Low, Low, Medium, High and Extreme classes

Table 6.2: Number of days having at least one-fire events per month with summer scenario highlighted

	SCENARIO										nr. of days with at least one fire event
MONTH	0	0-0.5	0,5	1	1,5	2	2,5	3	3,5	4	
1	288	83	8	0	0	0	0	0	0	0	8
2	243	118	16	2	0	0	0	0	0	0	18
3	195	117	38	19	4	2	1	1	0	2	67
4	186	144	32	10	3	2	1	1	0	0	49
5	259	99	15	5	1	0	0	0	0	0	21
6	101	169	45	25	19	5	7	2	2	4	109
7	71	153	45	26	28	12	11	11	8	14	155
8	70	151	49	30	14	20	10	6	10	19	158
9	103	171	41	28	12	9	4	4	2	5	105
10	65	169	49	31	21	12	10	7	2	13	145
11	202	137	28	9	3	0	0	0	0	0	40
12	283	88	8	0	0	0	0	0	0	0	8

However for the winter scenario months, there were three danger classes, since no extreme danger was expected during this period: Low, Medium and High.

According to Step 2, the lower limit of extreme class was defined according the days with extreme danger. In the table below, for the summer season months the grid cells having at least 1 fire event is presented. Next, % of days with extreme danger was estimated by dividing the grid cells having at least fire event by total number of grid cells. For June, 28.8 % of the total grids have at least 1 fire case and for July this is 39.8 %, for August it is 41.7 %, for September it is 27.7 % and finally for October it is 38.3 %. Based on this calculation, the lower limits of extreme danger class were assigned. Here, it was assumed that for every 4 days in fire season, there was a chance to have an extreme fire case. So the lower limit of the extreme danger class was within the ¼ of the percentile of the days with extreme danger (Table 6.3).

Table 6.3: Definition of extreme class lower boundary

	JUN	JUL	AUG	SEP	OCT
Grid cells having at least 1 Fire	109	151	158	105	145
Total Grid cells per month	379	379	379	379	379
% days with extreme danger	28,8%	39,8%	41,7%	27,7%	38,3%
lower limit of Extreme Danger Class	**7%**	**10%**	**10%**	**7%**	**10%**

Having obtained percentile of the days with extreme danger, the lower limit of the extreme danger class was the corresponding FWI value for this percentile. The FWI values highlighted in Table 6.3 are the corresponding percentiles found in the results of Table 6.4. Next step was to arrange other classes by applying a constant ratio of I-scale and then converting these values back to S-scale FWIs (Van Wagner, 1987). It should be noted that for winter scenario months, the biggest value of FWI, which is in March, was selected due to the reason explained earlier in this section.

The constants were found out 6.49, 8.26, 8.43, 7.04 and 4.27 for June, July, August, September and October respectively (Table 6.6). These constant values were used to derive other boundaries for danger classes. To illustrate the lower boundary value of the high danger class was generated by dividing the lower boundary value of extreme class (Table 6.7). Respectively, this process was performed for each danger classes: Moderate, low and very low danger classes.

Table 6.4: Monthly FWI values ranked in respect to associated percentiles

%	JAN	FEB	MAR	APR	MAY	JAN	JUL	AUG	SEP	OCT	NOV	DEC
10	0,0267	0,0021	0,0799	0,0931	0,2334	0,9701	3,1358	4,8478	3,2902	0,2781	0,0535	0,0006
20	0,0510	0,0342	0,3261	0,2028	0,6021	2,8413	8,9071	12,2755	8,6551	1,4734	0,1742	0,0161
30	0,0733	0,0614	0,7772	0,3309	1,0008	4,8311	12,4293	16,2228	11,6426	3,7336	0,2884	0,0342
40	0,0966	0,0868	1,3490	0,4882	1,6888	7,1180	15,4525	18,9989	14,4352	5,4815	0,5579	0,0558
50	0,1213	0,1124	1,8010	0,5997	2,5819	9,4577	17,8329	20,7429	16,2913	7,0197	0,9770	0,0755
60	0,1432	0,1378	2,1921	0,7526	3,4063	11,2209	20,4160	22,9933	18,1213	8,7581	1,6899	0,1151
65	0,1626	0,1520	2,4054	0,8108	3,8319	12,7557	21,7495	23,9817	19,0633	9,3110	2,0415	0,1482
66	0,1638	0,1586	2,4259	0,8263	3,8771	13,0182	22,0466	24,0950	19,2344	9,4414	2,0790	0,1557
70	0,1817	0,1706	2,7111	0,9117	4,4878	13,7919	23,4698	24,8828	20,2082	9,9548	2,2897	0,1812
74	0,1986	0,1916	3,0689	1,0040	5,2701	15,0808	25,2484	26,5007	21,6787	10,6160	2,5352	0,2186
75	0,2037	0,1974	3,1632	1,0338	5,4569	15,9663	25,5942	26,7208	21,9570	10,7460	2,6207	0,2305
80	0,2274	0,2160	3,7850	1,2328	6,2870	17,9069	28,1021	28,2409	23,3619	11,8826	3,0570	0,3117
82	0,2358	0,2322	4,1778	1,3989	6,5668	19,1147	29,3997	29,3951	24,1081	12,2095	3,2039	0,3723
85	0,2493	0,2595	4,6025	1,8536	7,5514	21,2173	32,7395	34,4870	26,8846	12,8806	3,4385	0,4493
87	0,2572	0,2770	4,9594	2,1094	7,9940	23,6987	34,8804	36,2930	27,5653	13,6862	3,6776	0,5415
90	0,2781	0,3017	5,5034	2,3807	9,1637	25,4987	37,8868	38,8594	28,6511	14,9425	4,2717	0,6527
91	0,2890	0,3137	5,6681	2,4850	9,5578	26,1560	38,6027	40,1793	29,6619	15,4629	4,4667	0,7164
92	0,2966	0,3292	5,9655	2,6168	10,3497	27,0894	40,4237	40,5596	30,1568	15,5900	4,5937	0,7331
93	0,3059	0,3370	6,1975	2,7850	11,0045	27,4353	40,8017	41,8829	30,6551	16,0357	4,7538	0,8178
94	0,3440	0,3528	6,4419	3,0484	11,4266	27,9917	41,4703	43,2513	32,9351	16,3488	5,0658	0,8781
95	0,3695	0,3645	6,8708	3,2653	11,8100	28,6634	41,6636	43,6903	35,5312	16,7441	5,2341	0,9381
96	0,3962	0,3857	7,0856	3,3738	12,1411	29,0310	43,0377	44,6310	36,1501	16,9779	5,4351	1,0174
97	0,4184	0,4260	8,9964	3,5897	12,3200	30,2922	43,7522	45,9432	36,7208	17,4312	5,6131	1,2187
98	0,4535	0,4600	11,0221	4,9189	12,7797	31,5166	44,7349	46,9993	37,8282	18,4046	5,8239	1,4670
99	0,6741	0,4977	12,9693	5,2738	13,3219	31,7822	45,7558	47,8077	38,5785	19,5813	6,3013	2,4300
100	1,7116	1,8772	21,8813	6,8898	17,9200	37,4193	49,9726	50,9168	43,0633	23,3452	9,9100	3,2197

Table 6.5: Converting FWI values to I-scale and finding the constant ratio

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
FWI S	21,88	21,88	21,88	21,88	21,88	23,70	28,10	28,24	26,88	11,88	21,88	21,88
lnS	3,09	3,09	3,09	3,09	3,09	3,17	3,34	3,34	3,29	2,48	3,09	3,09
lnS^1,546	5,71	5,71	5,71	5,71	5,71	5,94	6,44	6,45	6,31	4,06	5,71	5,71
ln(0,289I)	5,59	5,59	5,59	5,59	5,59	5,82	6,31	6,33	6,18	3,98	5,59	5,59
I	930,49	930,49	930,49	930,49	930,49	1165,52	1905,29	1932,95	1674,57	184,89	930,49	930,49
Constant	9,76	9,76	9,76	9,76	5,52	5,84	6,61	6,63	6,40	3,69	5,52	5,52

Table 6.6: The lower boundaries of each danger class

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
extreme	930,49	930,49	930,49	930,49	930,49	1165,52	1905,29	1932,95	1674,57	184,89	930,49	930,49
high	95,31	95,31	95,31	95,31	168,47	199,48	288,38	291,52	261,77	50,14	168,47	168,47
moderate	9,76	9,76	9,76	9,76	30,50	34,14	43,65	43,97	40,92	13,60	30,50	30,50
low	1,00	1,00	1,00	1,00	5,52	5,84	6,61	6,63	6,40	3,69	5,52	5,52
very low	0,10	0,10	0,10	0,10	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

The next step was to convert these I-scale values into original FWI values by applying the following exponential function (6.1):

$$EXP(1.013*(LN(0.289 * \text{I-Scale Value}))^{\wedge}0.647) \tag{6.1}$$

Finally the danger classes for winter and summer scenario months are represented in Table 6.7 and Table 6.8 respectively.

Table 6.7: Classification of danger classes for summer scenario months

	JUN	JUL	AUG	SEP	OCT
extreme	>=23.7	>=28.1	>=28.3	>=26.9	>=11.9
high	>=12.3 ; <23.7	>=14.2 ; <28.1	>=14.2 ; <28.3	>=13.6 ; <26.9	>=6.8 ; <11.9
moderate	>=5.6 ; <12.3	>=6.4 ; <14.2	>=6.4 ; <14.2	>=6.2 ; <13.6	>=3.5 ; <6.8
low	>=1.9 ; <5.6	>=2.1 ; <6.4	>=2.2 ; <6.4	>=2.1 ; <6.2	>1.2 ; <3.5
very low	>=0 ; <1.9	>=0 ; <2.1	>=0 ; <2.2	>=0 ; <2.1	>0 ; <1.2

Table 6.8: Classification of danger classes for winter scenario months

	JAN	FEB	MAR	APR	MAY	NOV	DEC
high	>=9 ; <21.9	>=9 ; <21.9	>=9 ; <21.9	>=9 ; <21.9	>=11.4 ; <21.9	>=11.4 ; <21.9	>=11.4 ; <21.9
moderate	>=2.8 ; <9	>=2.8 ; <9	>=2.8 ; <9	>=2.8 ; <9	>=5.3 ; <11.4	>=5.3 ; <11.4	>=5.3 ; <11.4
low	>=0 ; <2.8	>=0 ; <2.8	>=0 ; <2.8	>=0 ; <2.8	>=0 ; <5.3	>=0 ; <5.3	>=0 ; <5.3

6.4. Maps of Calibrated FWI

The following maps show danger classes and associated FWI values. Moreover, grid cells having at least one fire event are presented by dot density. 1 dot represents a fire size of 1. The results of winter scenario maps of FWI are presented in Figures 6.6 – 6.12.

In January, FWI values estimated low danger for all over Turkey and grids having at least one fire event are concentrated mainly around Black Sea cost (Figure 6.6).

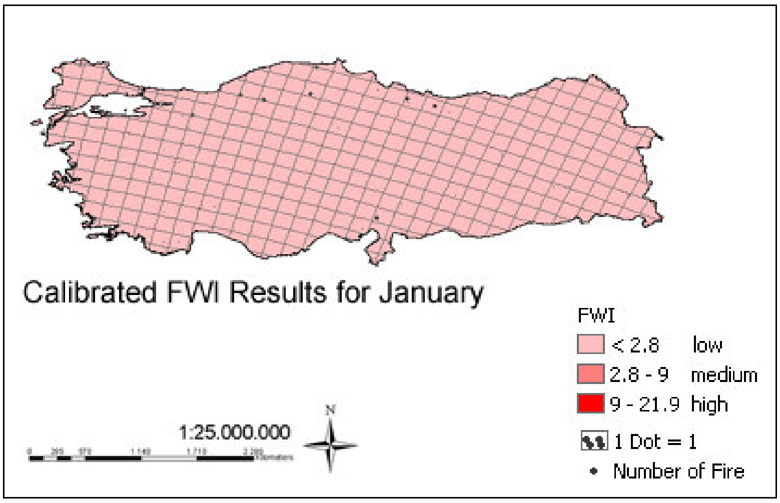


Figure 6.6: Calibrated FWI for January

In February, according to FWI results there was low danger throughout the country, on the other hand there were some fire events observed along Black Sea and sparsely around Mediterranean cost of Turkey (Figure 6.7).

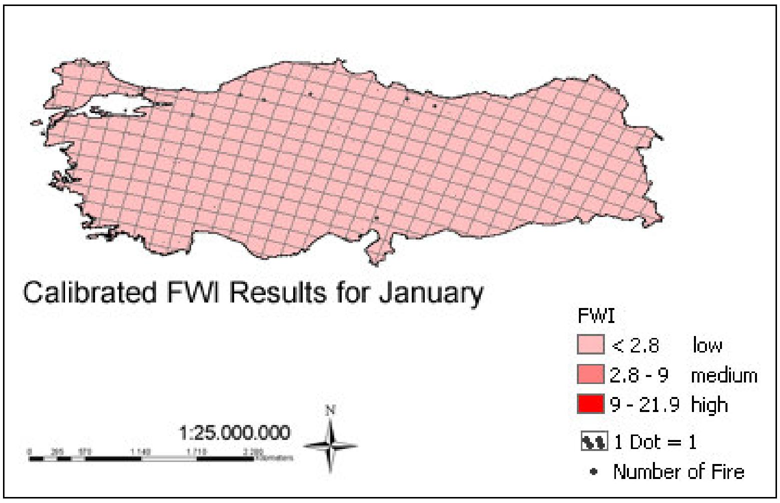


Figure 6.7: Calibrated FWI for February

On the other hand in March, relatively more fire events were observed around Black Sea and predominantly on Aegean costal zone of Turkey. FWI still indicated low danger of fire (Figure 6.8).

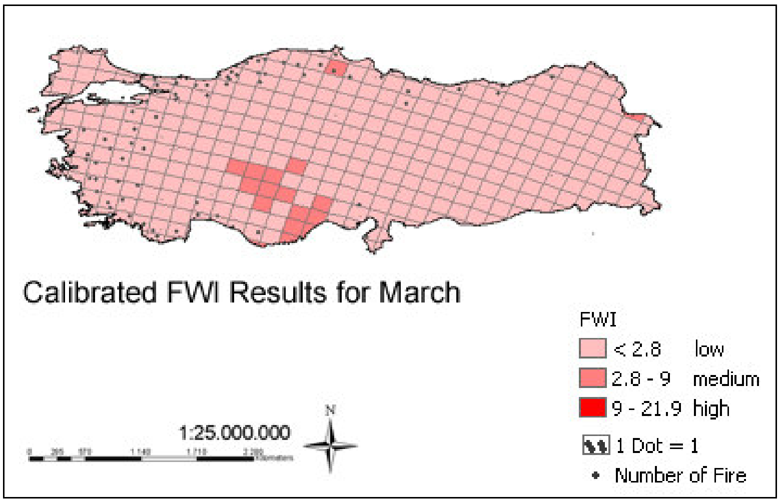


Figure 6.8: Calibrated FWI for March

April was the month that FWI indicated medium level of fire danger.

Medium level of danger was around Marmaris, southwestern part and a part of Mediterranean cost following the sparse distribution of fire events in these regions, but on the contrary, there were also some fire events recorded in Marmara northwestern region of Turkey. In April, 92.9 % of the grid cells were assigned to moderate fire danger class, and 7.1 % grid cells to for the low danger class (Figure 6.9).

In May, there was high level of fire danger in southeastern part of Turkey close to Mediterranean region. The southwestern part, Marmaris region had also high level of fire danger, the Mediterranean and inner parts, Aegean costs and the part around the city of Istanbul had respectively medium level of fire danger. In contrast, the fire events were recorded on the northwest and western axis of Turkey. In this month, 74.4 % of the grid cells were assigned to high danger class, 19.3 % to the medium danger class and 6.3 % to the low danger class (Figure 6.10).

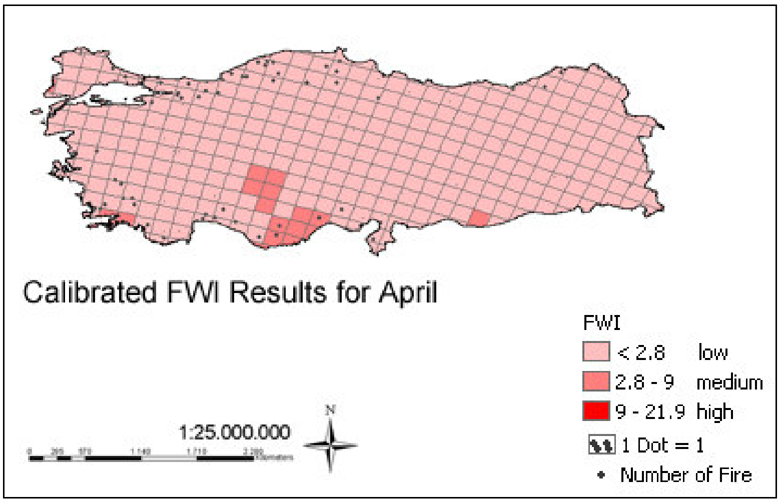


Figure 6.9: Calibrated FWI for April

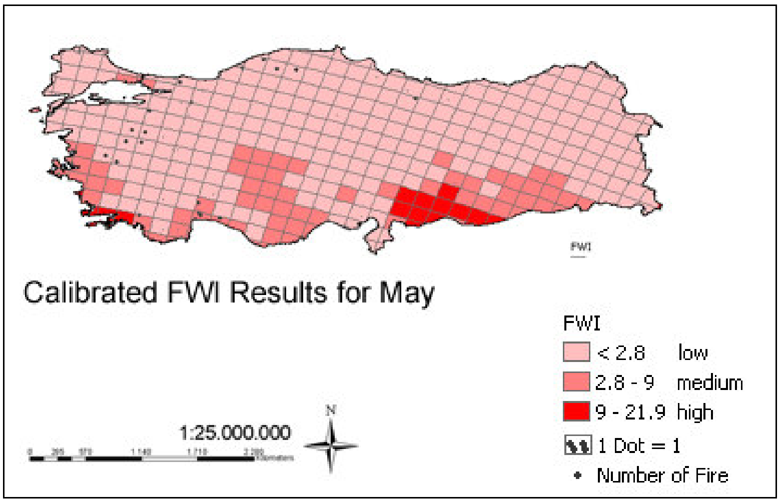


Figure 6.10: Calibrated FWI for May

For November, the fire danger was low and medium for some parts. Fire events were concentrated on southwestern and Mediterranean cost of Turkey mainly and it seems the FWI values remains controversial to estimate the fire prone areas. Medium level fire danger class includes the 4.2% and low-level fire danger class includes the 95.8% of the grid cells (Figure 6.11).

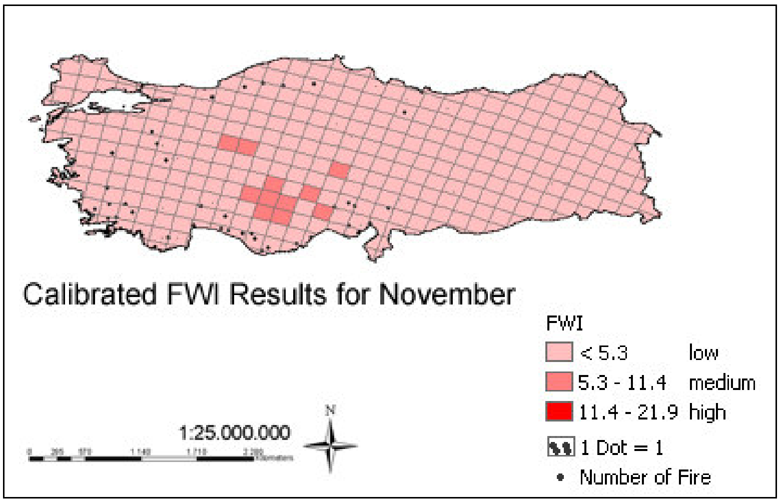


Figure 6.11: Calibrated FWI for November

In December, both number of number of fires, fire size and the fire danger of FWI indicates were low. The cases were concentrated along Mediterranean cost. All grid cells were assigned to the low fire danger class (Figure 6.12).

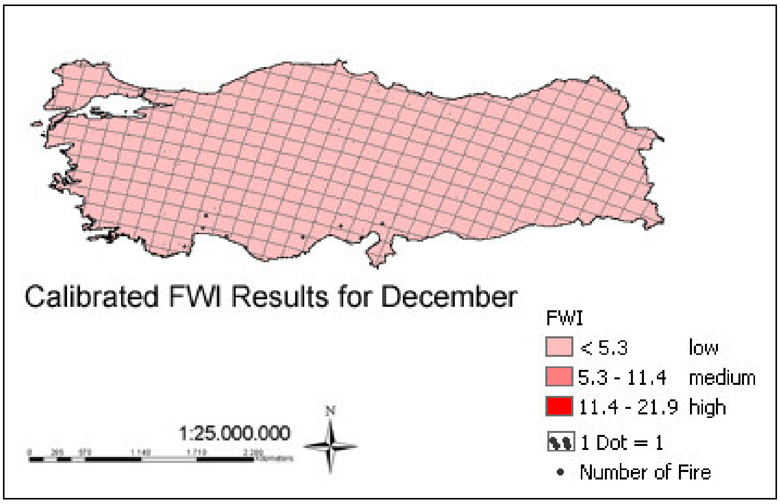


Figure 6.12: Calibrated FWI for December

The results of summer scenario maps of FWI are given in Figures 6.8-6.12:

In June, the extreme fire danger areas were located in the southeastern part of Turkey, where very few fire cases were observed. The Aegean and Mediterranean costal areas were inside the high danger zone and not only the number but also the fire size were relatively bigger compared to the other areas. In this month, 13.2 % of the grid cells were assigned to extreme danger class, 23.2 % to high danger class, 30.1% to medium danger, 18.7% to low danger and 14.8% to very low fire danger class (Figure 6.13).

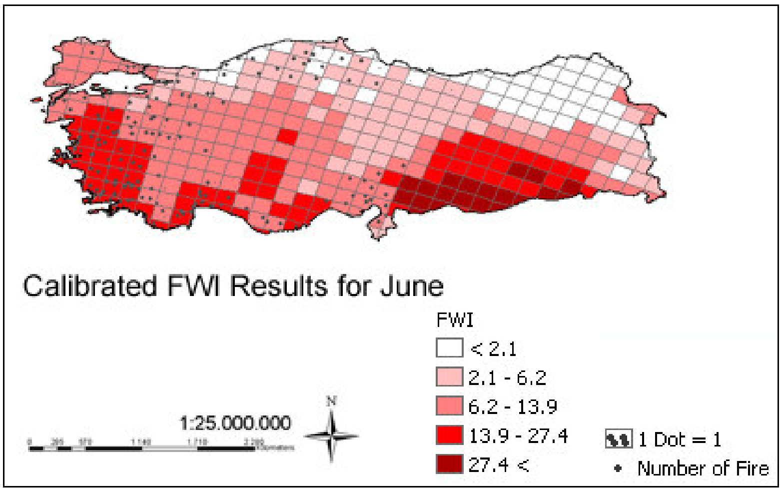


Figure 6.13: Calibrated FWI for June in ascending order from very low to extreme danger

In July, 20.1% of the grid cells were assigned to extreme danger class, 43.3% to high danger class, 21.4% to medium danger class, 7.1% to low danger class and finally 8.2% to very low danger class and the highest FWI value was observed (Figure 6.14).

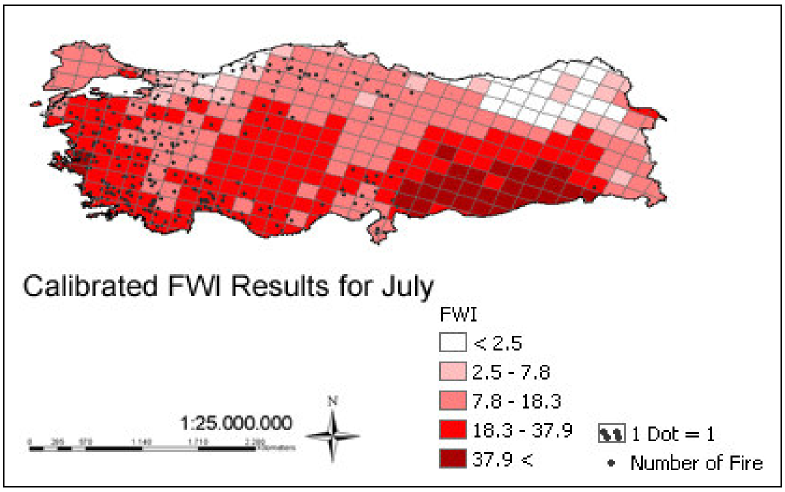


Figure 6.14: Calibrated FWI for July in ascending order from very low to extreme danger

In August, extremely fire prone areas were in the southeast and the region around Izmir. It can be observed that also the whole Aegean part and bigger part of the continental parts of Turkey are under the high-danger area.

20.1% of the cells were assigned to extreme danger class, 55.1% to high danger class, 12.4% to medium danger class, 5.0 % to low danger class and finally 7.4% to the very low danger class (Figure 6.15).

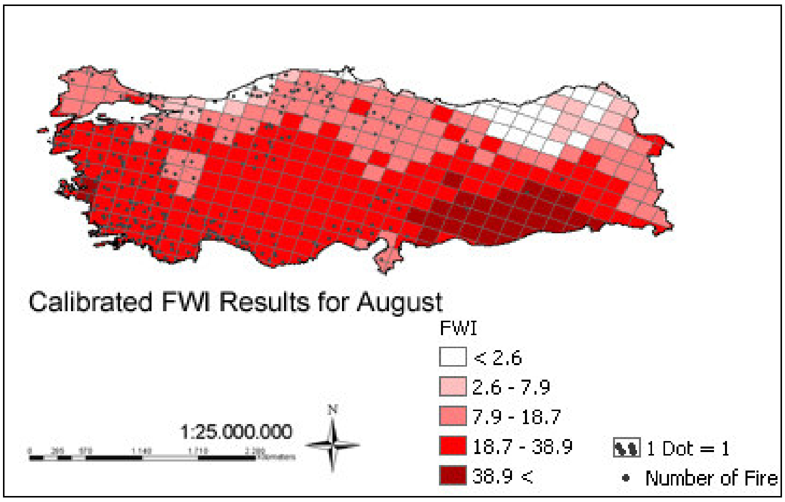


Figure 6.15: Calibrated FWI for August in ascending order from very low to extreme danger

In September, extreme fire danger was concentrated mostly in southeastern part of Turkey. Remarkably, the western, southwestern, southern parts, where the majority of the fire events occurred in this month and also inner parts of the main land are labeled as high danger. According to the results, 15 % of the grid cells were assigned to extreme danger class, 48.8 % to high danger class, 22.2 % to moderate danger class, 5.0 % to low danger class and 9.0 % to very low danger class (Figure 6.16).

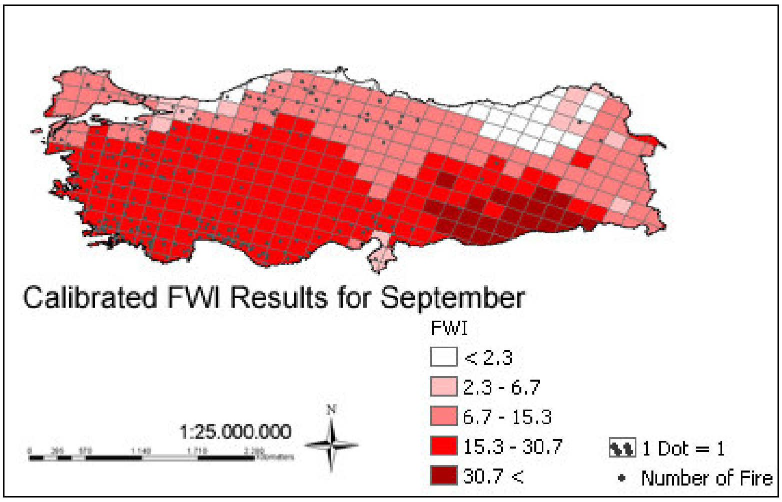


Figure 6.16: Calibrated FWI for September in ascending order from very low to very high danger

October was the last month of the determined fire season. Extreme danger class still includes the southeastern part but also a small part of Mediterranean cost and the inner part of this region. Fire events are mainly located around Aegean costal zone and its inner part, western part of Mediterranean Region. Some cases were recorded also along Black Sea Region as well. 20.1% of the grid cells are assigned to high danger class, 32.2% to high danger class, 18.7% to medium danger class, 10.8% to low danger class and 18.2% to very low danger class (Figure 6.17).

Having presented the results of the calibrated FWI and the distribution of number of fires in 5-year dataset, some evaluations especially regarding to the determined fire season should be made (Figure 6.13-6.17). For this, it was interesting to map for each cell the relative frequency of each danger class for the season from June to October. This facilitated to conceptualize the fire prone regions of Turkey in accordance with their ordinal severity level during the determined fire season – namely June (6), July (7), August (8), September (9) and October (10).

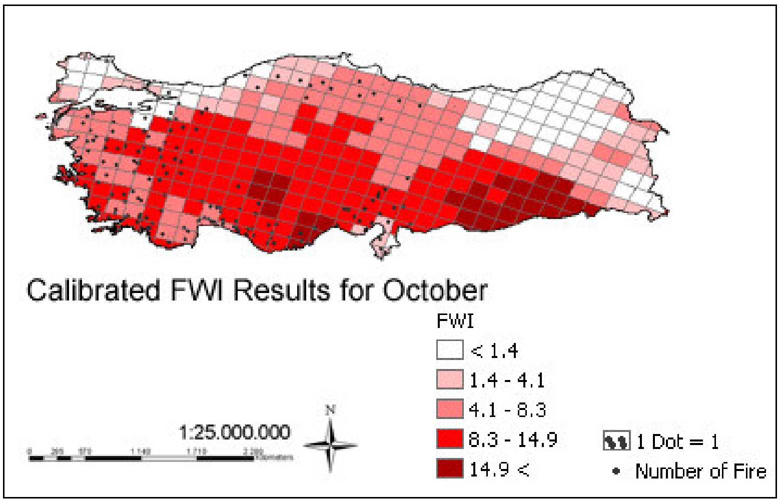


Figure 6.17: Calibrated FWI for October in ascending order from very low to very high danger

Grid cells having extreme degree of fire danger almost during the whole fire season were concentrated in the southeast Anatolian part of Turkey, the region close to the city of İzmir, Marmaris Peninsula and the inner part of Mediterranean Region (Figure 6.18).

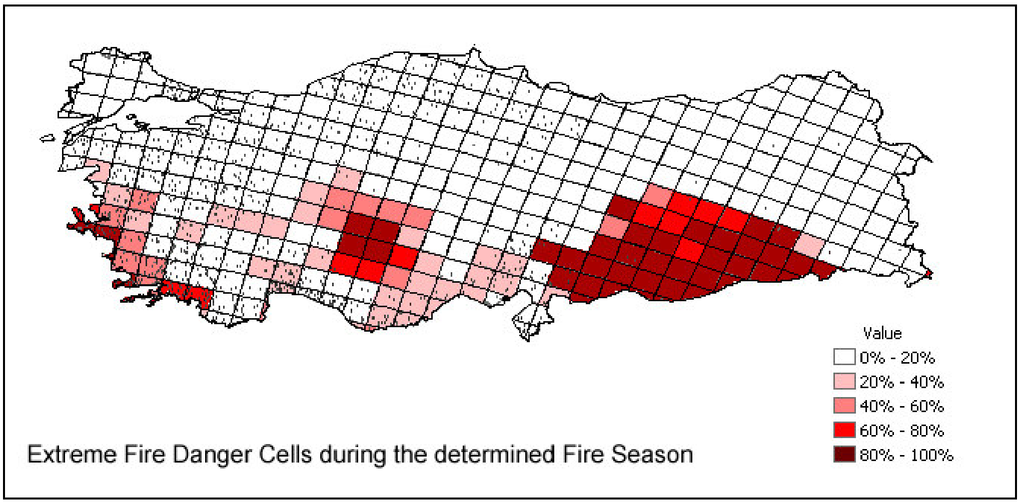


Figure 6.18: Extreme Fire Danger Class from June to October in ascending order from very low to very high danger

According to the results, areas prone to high level of fire danger were determined include southern part of Marmara Region, Mediterranean Region, Aegean Region and inner parts of Anatolia (Figure 6.19).

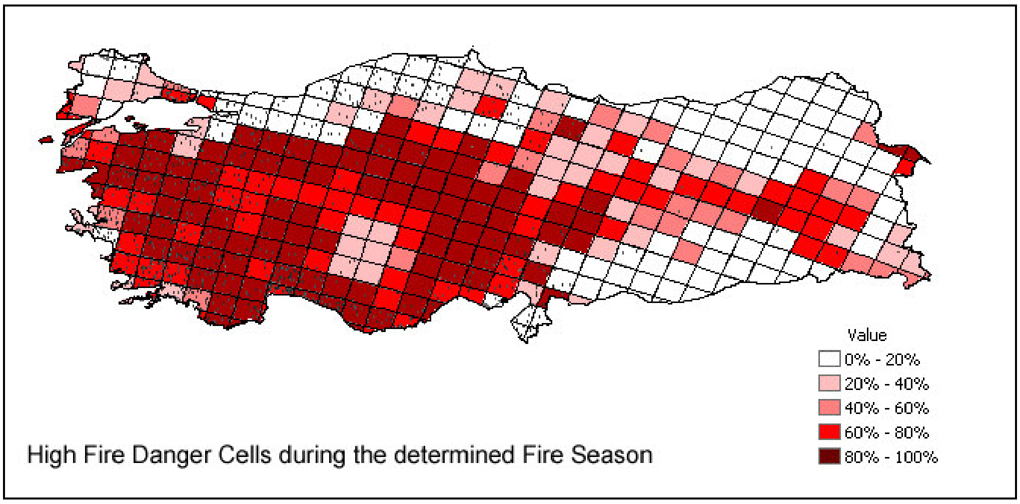


Figure 6.19: High Fire Danger Class from June to October in ascending order from very low to very high danger

Grid cells representing Northwestern Marmara Region, inner parts of western and middle Black Sea Region and region close to the city of Hatay were labeled mostly as Moderate level (Figure 6.20).

Low danger grid cells were distributed along the Black Sea Region, east part of Inner Middle Anatolia and part of and Northeastern Anatolia mainly (Figure 6.21).

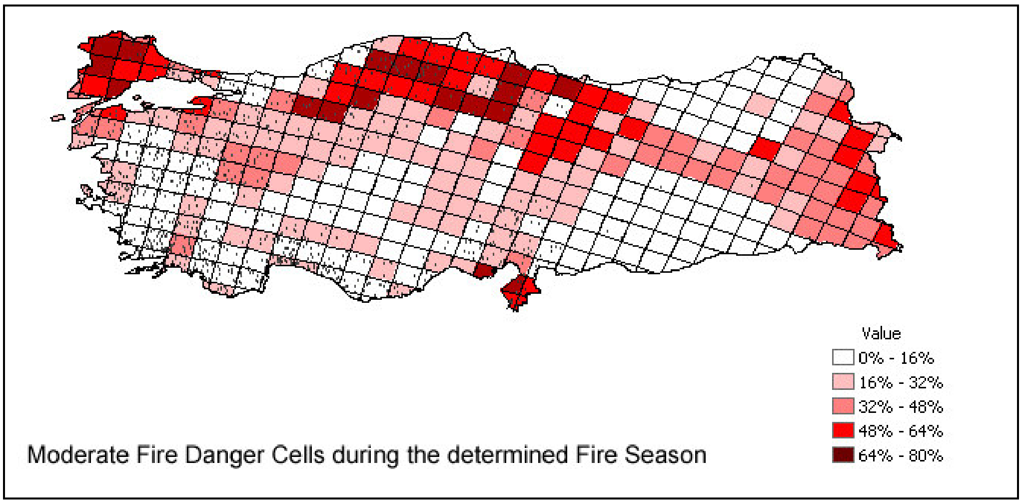


Figure 6.20: Moderate Fire Danger Class from June to October in ascending order from very low to very high danger

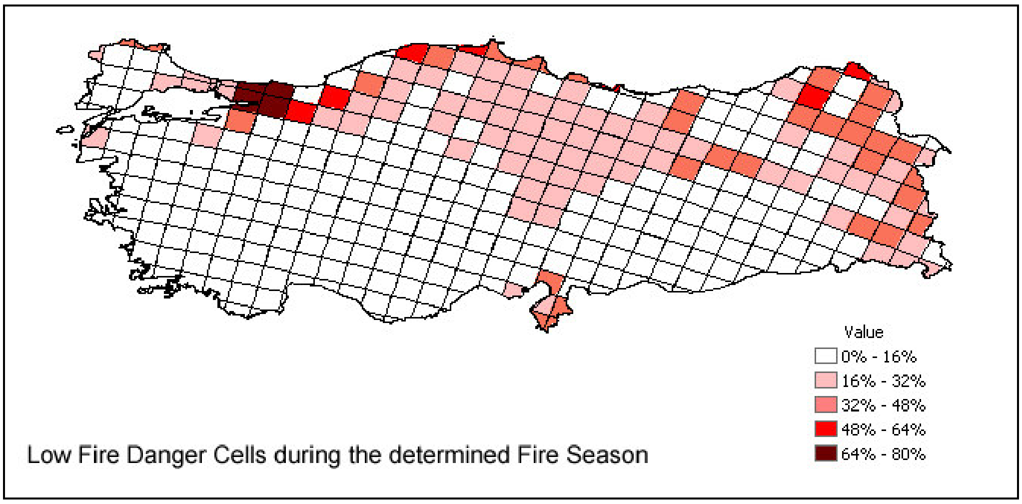


Figure 6.21: Low Fire Danger Class from June to October in ascending order from very low to very high danger

Grid cells representing the costal zone of Black Sea and northeastern part of Turkey were assigned to Very Low category during the whole fire season (Figure 6.22).

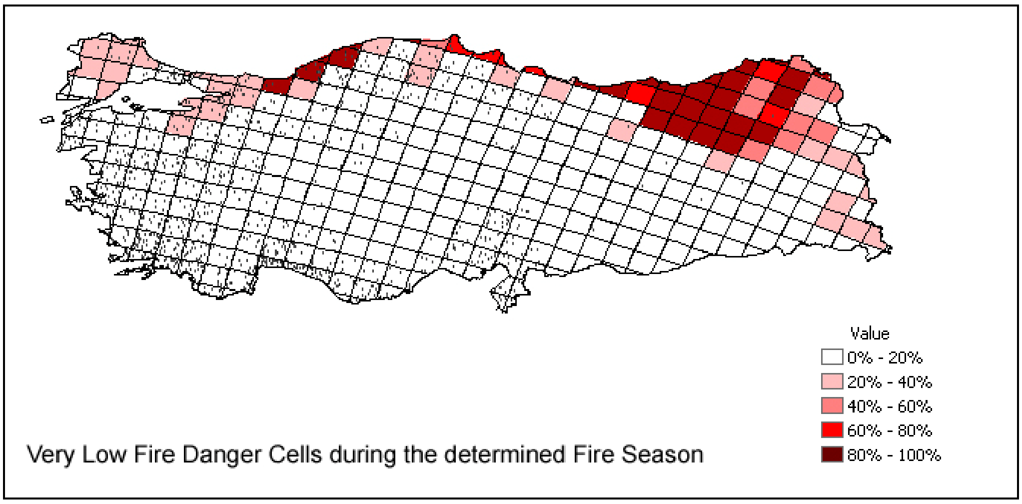


Figure 6.22: Very Low Fire Danger Class from June to October in ascending order from very low to very high danger

6.5. Refinement of Fire Danger Results with Land Cover Data

In this section, the results of monthly Fire Danger maps were integrated with land cover information for Turkey. The land cover map was to use for creating forest/non-forest mask.

The land cover classes were presented in Table 6.9. According to this, Class nr. 2, Tree Cover: Broadleaved Deciduous, closed; Class nr.4, Tree Cover, Needle Leave, evergreen and Class nr.6, Tree Cover: Mixed Leaf type classes are re-assigned to Forest class having the value of 1, and the rest was re-assigned to Non-Forest class having the value of 0.

The Forest/ non Forest Mask derived from GLC 2000 land cover data is presented in Figure 6.18. Integration of this map with calibrated results of FWI indicates the fire prone areas of Turkey on monthly base.

Table 6.9: Re-classification of Land cover classes to derive forest / non-Forest mask

CLASS_NUMBERS	LAND COVER CLASSES IN TURKEY	MASK VALUE
2	**Tree Cover, broadleaved, deciduous, closed**	**1**
4	**Tree Cover, needle-leaved, evergreen**	**1**
6	**Tree Cover, mixed leaf type**	**1**
11	Shrub Cover, closed-open, evergreen	0
12	Shrub Cover, closed-open, deciduous	0
13	Herbaceous Cover, closed-open	0
14	Sparse herbaceous or sparse shrub cover	0
15	Regularly flooded shrub and/or herbaceous cover	0
16	Cultivated and managed areas	0
17	Mosaic: Cropland / Tree Cover / Other natural vegetation	0
18	Mosaic: Cropland / Shrub and/or grass cover	0
19	Bare Areas	0
20	Water Bodies	0
22	Artificial surfaces and associated areas	0
23	Irrigated Agriculture	0

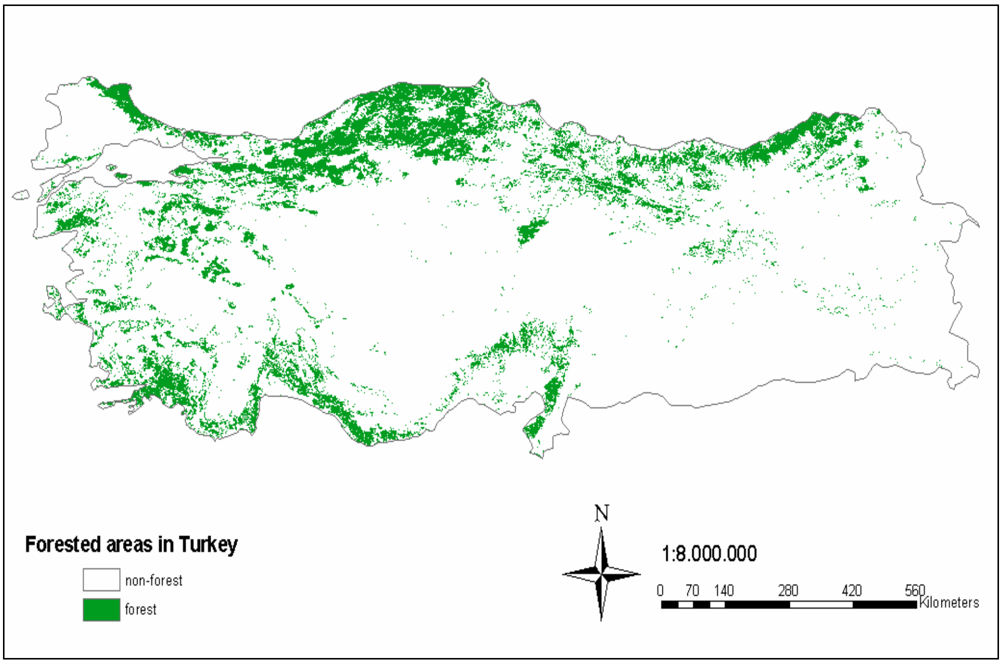


Figure 6.23: Binary Forest/non Forest Map derived from GLC 2000 land cover data.

As far as weather parameters were concerned, the general trend was that Aegean and Mediterranean coastal zones of Turkey have highest fire danger potential. Especially, the concentration was mainly around the province of İzmir and Marmaris – Reşadiye Peninsula for the month June. On the other hand, along the Black Sea zone, the fire danger potential was relatively low (Figure 6.24).

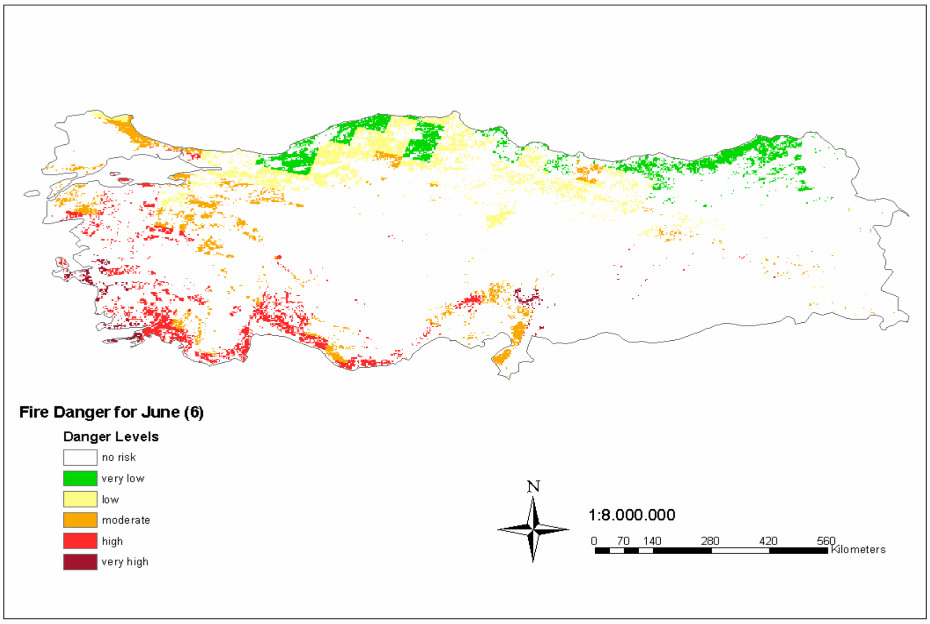


Figure 6.24: Fire Danger Levels for June in Turkey

Compared with the results of June, in July the fire danger extended geographically to Marmara Region and mid- Black Sea Region. The highest danger was still around the southwestern part of Turkey (Figure 6.25).

Both in August (Figure 6.26) and September (Figure 6.27), nearly all-existing forested area in South; Southwestern and Western part of Turkey was under fire danger. Remarkably, mid-section of the Black Sea Region, inner parts of Eastern Anatolia and north of Marmara Region deserves a special attention during August.

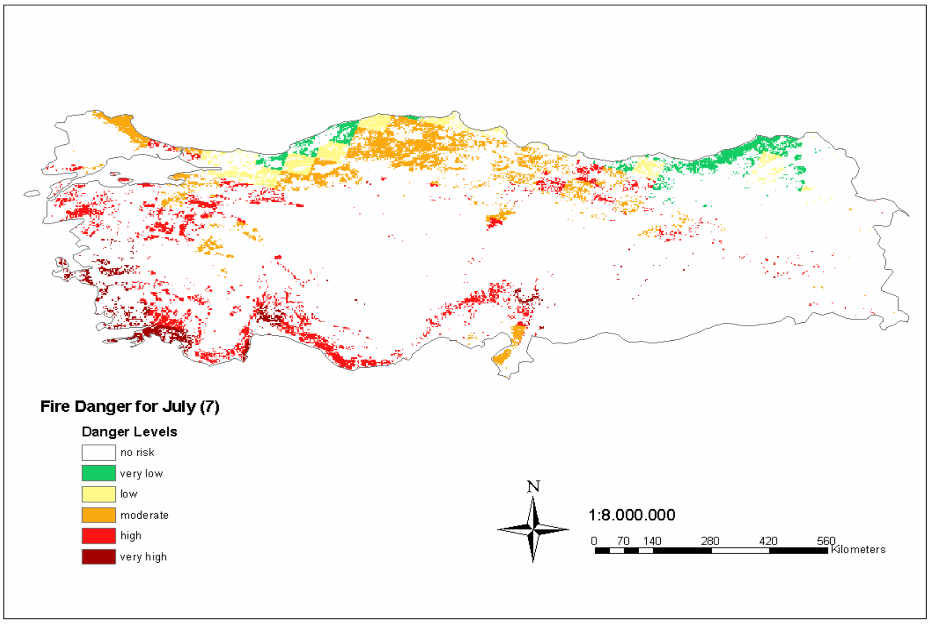


Figure 6.25: Fire Danger Levels for July in Turkey

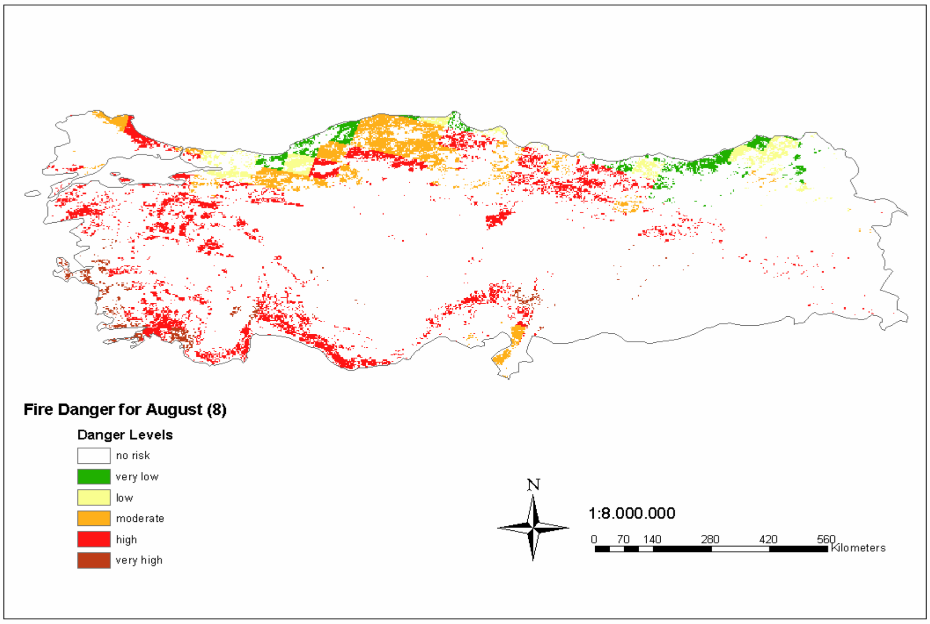


Figure 6.26: Fire Danger Levels for August in Turkey

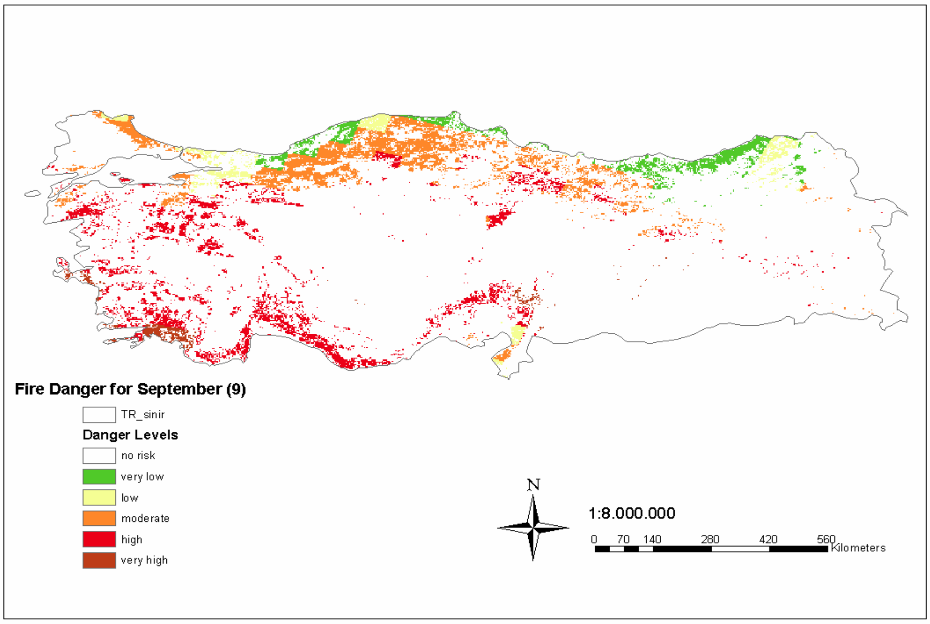


Figure 6.27: Fire Danger Levels for September in Turkey

In October, the geographical extents of very high and high fire danger classes intended to shrink back to its earliest position. 4 spots of high danger concentration was observed in the region close to province of İzmir, Marmaris- Reşadiye Peninsula, mid-section of Mediterranean Zone and inner parts of Hatay Region (Figure 6.28).

To conclude, during the whole fire season (from June to October), the highest fire danger was located around two regions: Close region of the İzmir and Region around Marmaris – Reşadiye Peninsula.

On the other hand, during all months of fire season, in the northeastern and northwestern part of Black Sea Region, the potential of a fire occurrence in terms of meteorological conditions was very low. Having indicated fire danger status of the areas in Turkey during the fire season, the danger levels that were associated with each forest type will be also interesting. The fire danger levels assigned for each forest type- Broad Leaved, Deciduous Forest Type; Mixed Leaf Forest Type and Needle Leaved Evergreen Forest Type in Turkey - during the fire season months are presented in percentages:

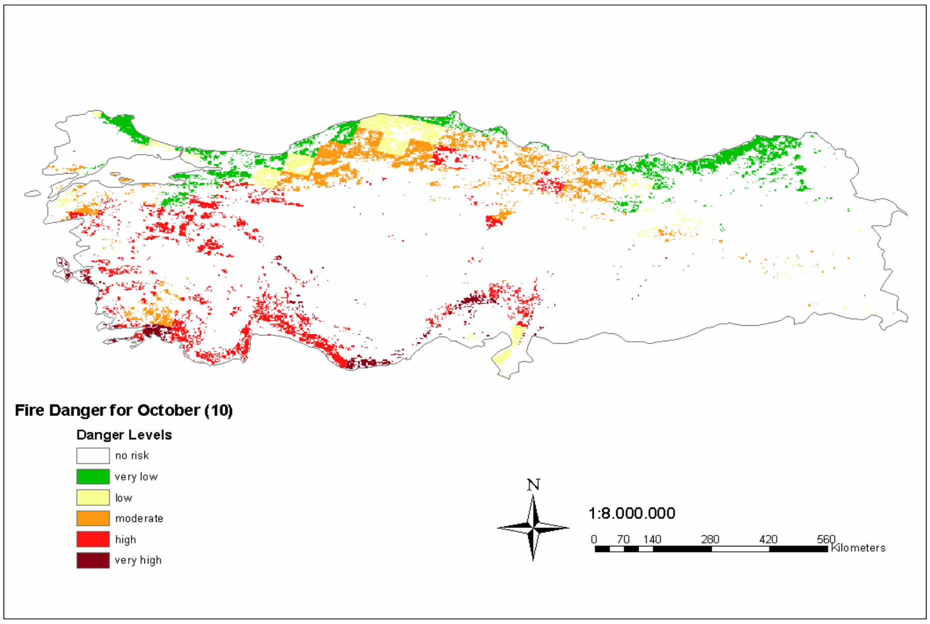
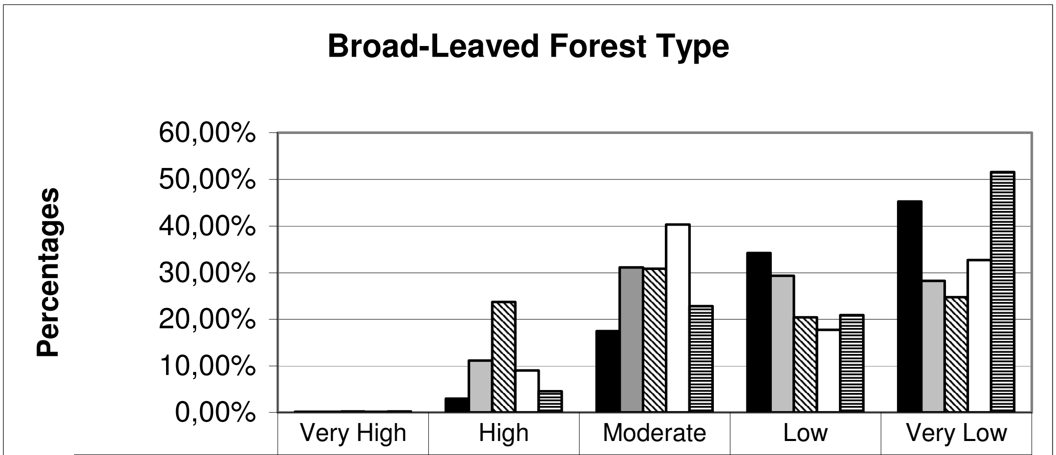


Figure 6.28: Fire Danger Levels for October in Turkey

For Broad Leaved Forest Type, the fire danger was high especially for August. On the general, this forest type was not under the high fire danger. For example In June, 80% of the Broad Leaved Forest in Turkey had very low or low fire danger. On the other hand in August, nearly 24% was under the high or very high fire danger (Figure 6.29).

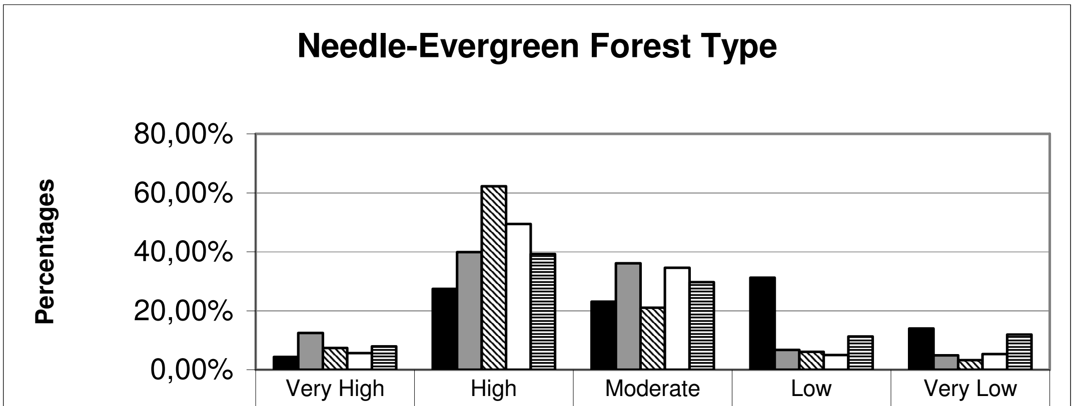
The danger level for Needle-Leaved Forest Type was very high compared to Broad Leaved Forest Type. Especially for August, nearly 70% of the total Needle-Evergreen Forest in Turkey was under high or very high danger. The lowest fire danger was observed in June (Figure 6.30).



	Very High	High	Moderate	Low	Very Low
June -06	0,11%	2,95%	17,50%	34,19%	45,25%
July -07	0,17%	11,20%	31,12%	29,32%	28,22%
August -08	0,22%	23,75%	30,83%	20,43%	24,77%
September -09	0,17%	9,03%	40,30%	17,78%	32,72%
October -10	0,20%	4,51%	22,82%	20,93%	51,54%

Fire Danger Levels

Figure 6.29: Danger Classes for Broad-Leaved, Deciduous Forest Type in Turkey



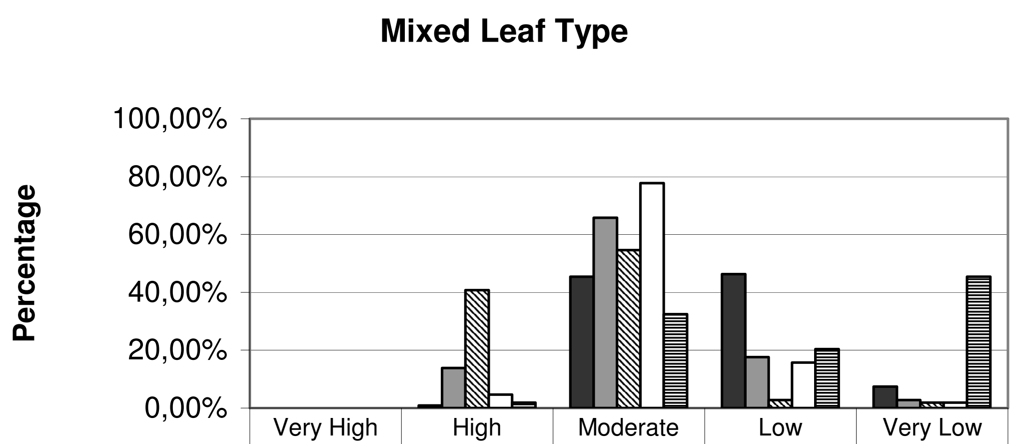
	Very High	High	Moderate	Low	Very Low
June -06	4,30%	27,40%	23,10%	31,26%	13,94%
July -07	12,42%	39,93%	36,06%	6,68%	4,90%
August -08	7,38%	62,26%	21,00%	6,07%	3,29%
September -09	5,68%	49,48%	34,56%	5,01%	5,27%
October -10	7,90%	39,20%	29,67%	11,29%	11,94%

Fire Danger Levels

Figure 6.30: Danger Classes for Needle-Leaved, Evergreen Forest Type in Turkey

This can be explained by the geographical distribution of the forest type. In Turkey, the Needle-Evergreen Forest Type is mainly located along the Mediterranean and Aegean coast, where the temperature is high and rainfall is very low. Not surprisingly, most of the fire cases each year occur in this region of Turkey. On the other hand, Broad-Leaved Forest Type is mainly located along the Black Sea cost, where relative humidity and rainfall is high.

The fire danger for Mixed Leaf Forest Type is very low compared to Broad-Leaved and Needle-Evergreen Forest Types. The highest danger can be observed in August (Figure 6.31).



	Very High	High	Moderate	Low	Very Low
June -06	0,00%	0,93%	45,37%	46,30%	7,41%
July -07	0,00%	13,89%	65,76%	17,60%	2,78%
August -08	0,00%	40,74%	54,63%	2,78%	1,85%
September -09	0,00%	4,63%	77,78%	15,74%	1,85%
October -10	0,00%	1,85%	32,41%	20,37%	45,37%

Figure 6.31: Danger Classes for Needle-Leaved, Evergreen Forest Type in Turkey

6.6. Daily Performance of Calibrated Canadian Fire Weather Index

For this part of the study, three consecutive days for the year 2006 were selected. The days were determined as 19th, 20th and 21st of August, because according to Turkish national newspapers like Sabah, Hürriyet and Milliyet, 2097 fire events occurred in 2006 and 90 of them occurred only in these days (http://arsiv.sabah.com.tr/2006/08/22/gnd115.html).

To calculate the daily FWI values, the required meteorological data for these days were obtained from Turkish State Meteorological Service. By using the MFDIP, the daily values were calculated and by applying the thresholds resulted from calibration process, FWI values for these three days were reclassified separately, as very low, low, moderate, high and extreme danger. Since the geo-location of fire events for the year 2006 has not been available, the calibrated results of FWI were compared with the information compiled from newspaper archives. The nearest settlement unit was assumed as the location of the fire event. Although newspaper archives include only information about major fire events, a coarse fire map was produced. In the following (Figure 6.32-6.34), calibrated FWI results for the days of 19th, 20th and 21st of August against major fire events were indicated.

According to the results for 19th of August (Figure 6.32) in Bodrum and Reşadiye Peninsula, also in the close region of the Province Muğla, high forest fire danger was expected. Moderate fire danger was observed mainly along the Aegean Region. 34 fire events for this day were found in the archives. Large fire events for this day were near Kaş, Kemer, Finike, Manavgat in Antalya Region, Akçaova, Milas, Turgutreis in Muğla Region, Germencik in Aydın, Foça, Yeni Foça in İzmir Region and in Karabük Region (http://hurarsiv.hurriyet.com.tr/ goster/haberler.aspx?id= &tarih=2006-08-19).

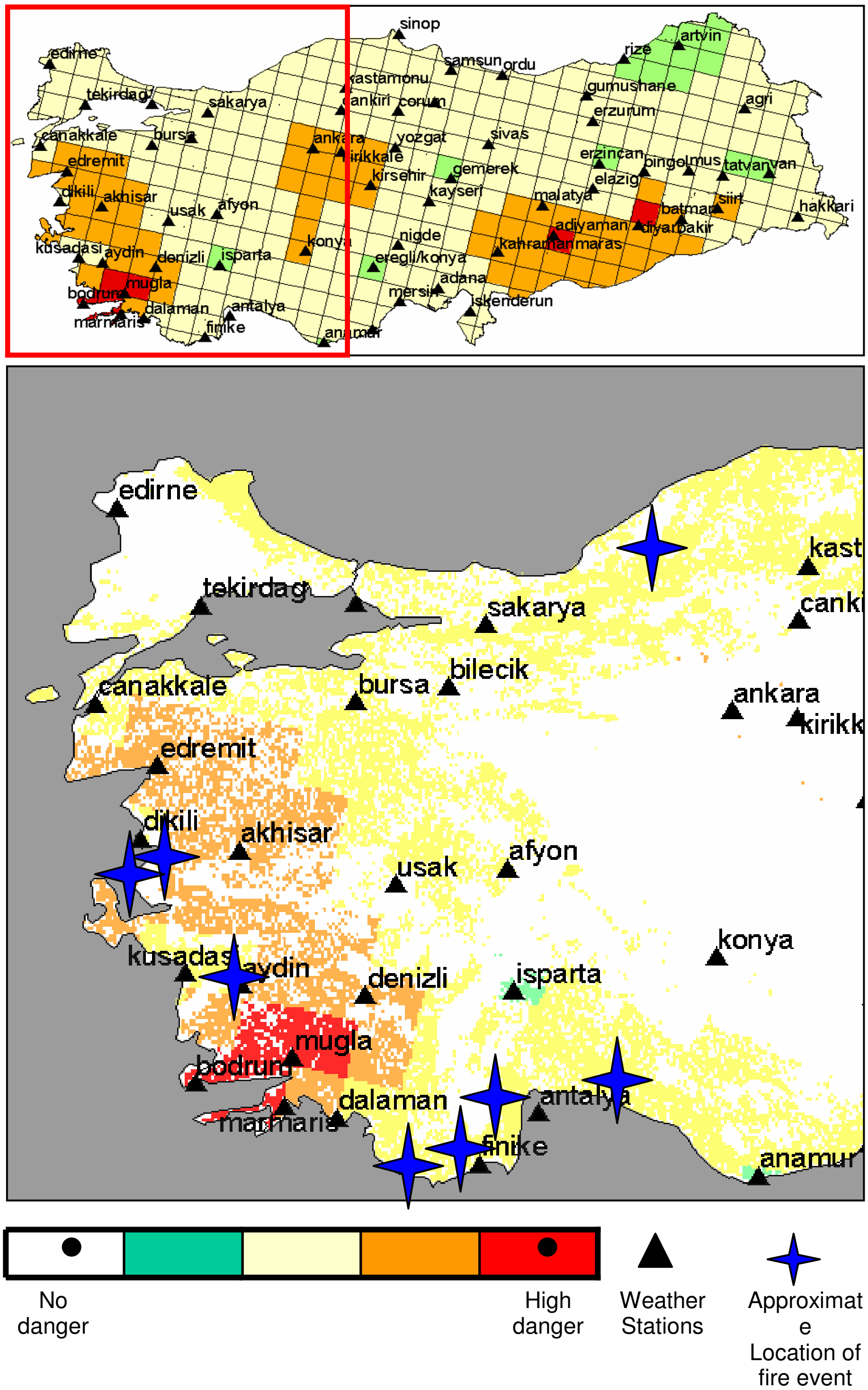


Figure 6.32: Calibrated FWI results for 19th of August 2006 and approximate fire locations

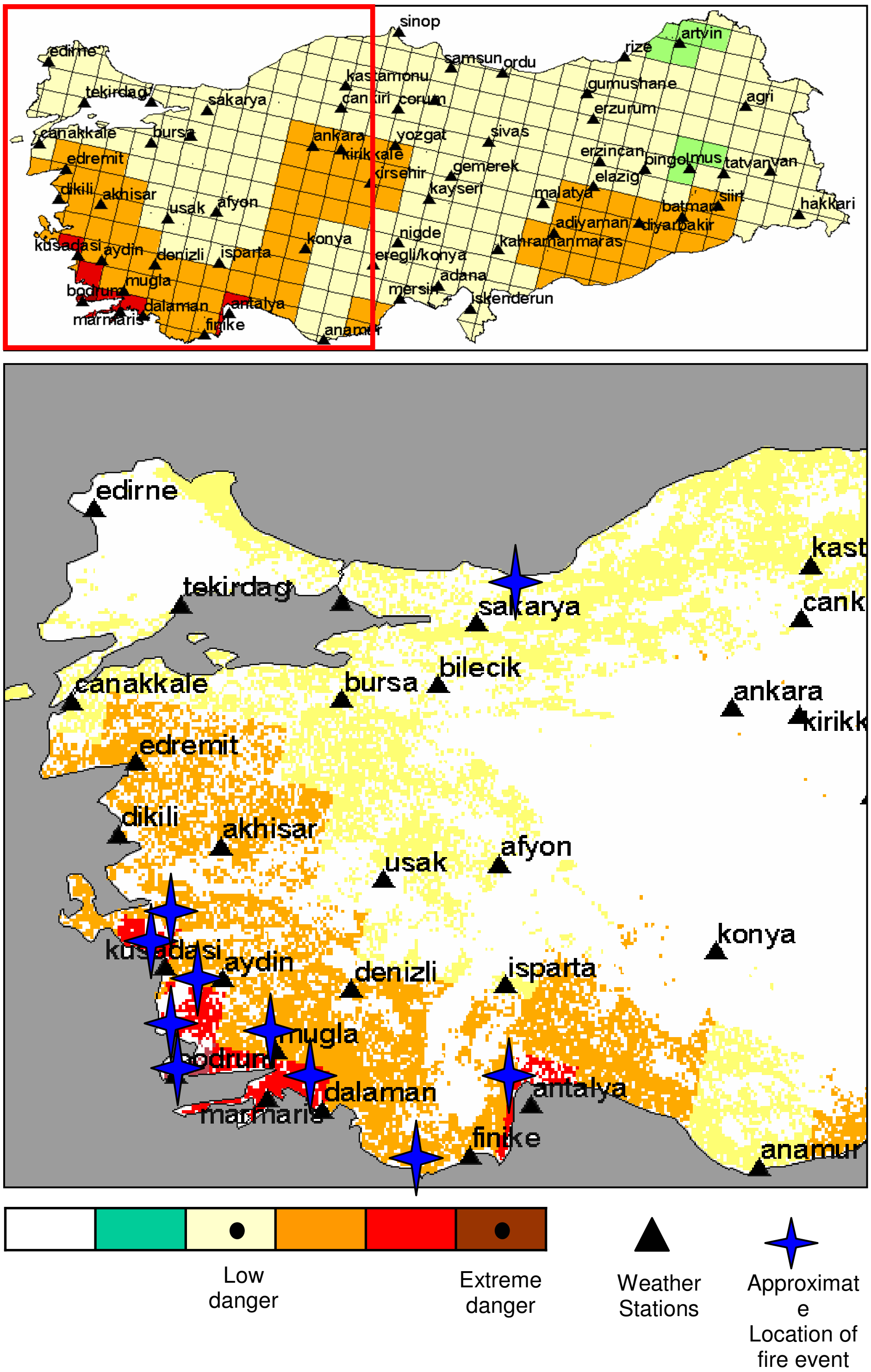


Figure 6.33: Calibrated FWI results for 20th of August 2006 and approximate fire locations

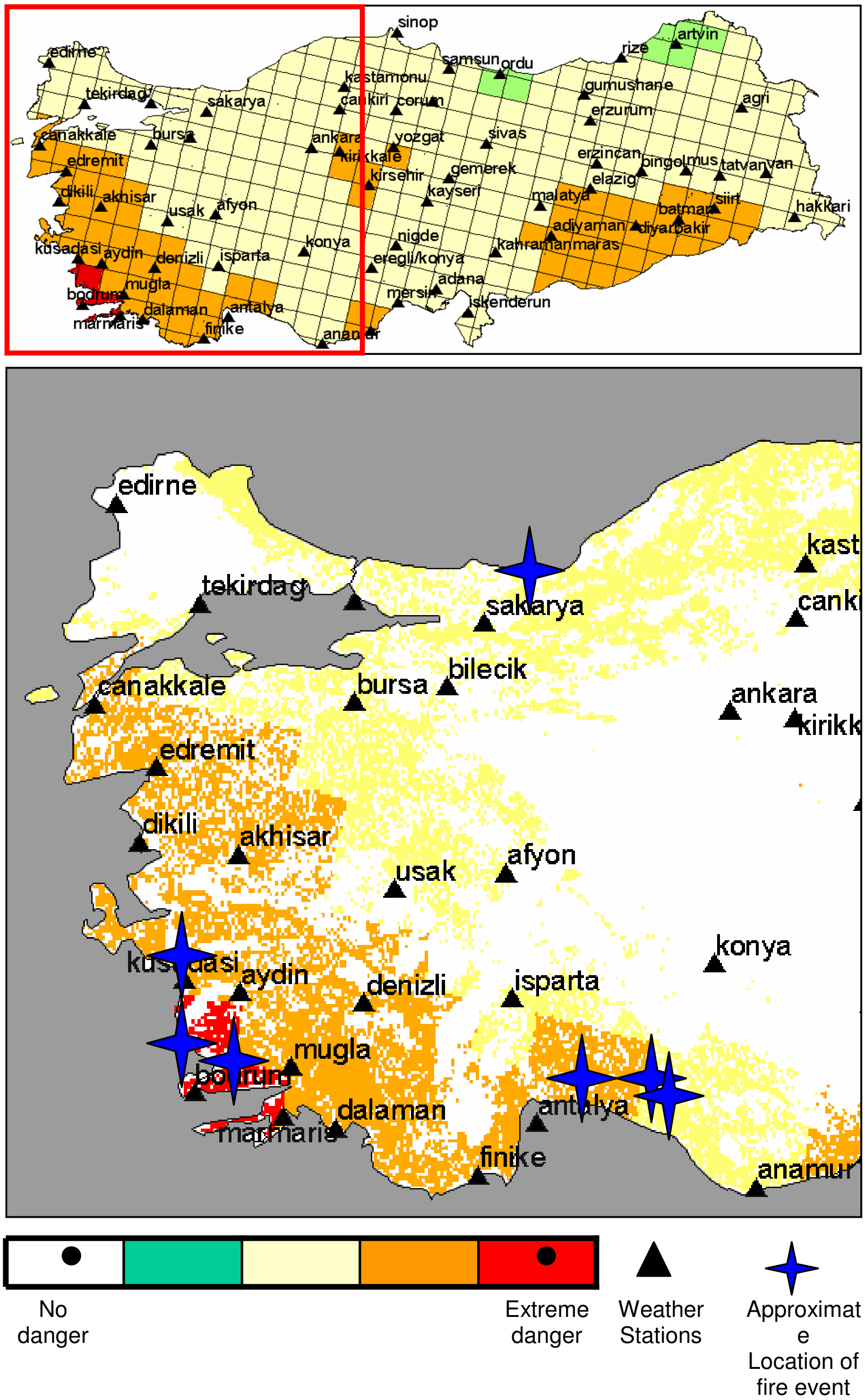


Figure 6.34: Calibrated FWI results for 21st of August 2006 and approximate fire locations

On the 20th of August, 43 fire cases were mentioned in the newspaper archives and these were Kaş, Kemer in Antalya Region, Akçaova, Milas, Turgutreis in Muğla Region, Kuşadası, Selçuk, Didim, Germencik in Aydın Region and in Yığılca Düzce (Figure 6.33). The performance of calibrated FWI values had promising results, when compared to the results for 19th of August. For this day, extreme fire danger was noted around the Bodrum Peninsula. Grid cells assigned to high danger fire class were near Kuşadası, Aydın, Marmaris, Finike and Antalya. The concentration of high danger and extreme danger classes followed mainly the fire distribution for this day (http://hurarsiv.hurriyet.com.tr/ goster/haberler.aspx?id=1&tarih= 2006-08-20).

Finally, on 21st of August, 13 fire events exist in the newspaper archives. These were Manavgat, Serik in Antalya Region, Bodrum in Muğla Region, Didim, Kuşadası in Aydın Region and Yığılca in Düzce. According to the FWI results, areas where high danger was observed were in Marmaris Peninsula, Bodrum Peninsula and Aydın Region (Figure 6.34) (http://hurarsiv.hurriyet.com.tr/ goster/haberler.aspx?id=1&tarih=2006-08-21).

The daily performance of calibrated FWI results for these three selected days highlighted the need for the data of geo-located fire records for August 2006, since some fire events were underestimated according to the outcomes and in some cases, the approximate region of the fire events could be predicted properly. Another point is that the nature of the meteorological data used. It is known that the weather parameters generally are obtained from meteorological stations located within the urban areas. To have more accurate danger estimation results, this effect should be concerned.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

In this study, the main attention was drawn to Meteorological Fire Danger Indices and the main aim was to define the fire prone regions of Turkey in accordance with the meteorological parameters.

According to the calibrated FWI results, during June (6) to October (10), mainly Southeastern Anatolian Region, Aegean and Mediterranean Areas of Turkey were under extreme fire danger and inner part of Anatolian Region was under high fire danger; whereas costal zones of Black Sea Region and northeastern part of Turkey had very low and low level of fire danger.

When compared with the distribution of fire events, the calibrated FWI results seemed overestimate the fire danger especially in Southeastern Anatolian Region. In June 36.4%, in July 63.4%, in August 75.2%, in September 63.8% and 52.3% of the grid cells indicated high and extreme fire danger in Turkey (Table 7.1). There was also an underestimation of fire danger along the Black Sea Region including the zone of the city of İstanbul.

This overestimation in Southeastern Anatolia in Turkey can be explained by the need of other parameters for fire danger estimation. The meteorological fire danger indices are based on the meteorological parameters and they do not take the complex and multi-faced nature of fire phenomena into account.

Table 7.1: Percentage of days for each danger class in the fire season

% days	JUN	JUL	AUG	SEP	OCT
extreme	13.2%	20.1%	20.1%	15.0%	20.1%
high	23.2%	43.3%	55.1%	48.8%	32.2%
moderate	30.1%	21.4%	12.4%	22.2%	18.7%
low	18.7%	7.1%	5.0%	5.0%	10.8%
very low	14.8%	8.2%	7.4%	9.0%	18.2%

For this purpose in this study, global land cover product of GLC 2000 was used. This product was used to build a binary forest / non- forest mask. The forest classes were merged into a single layer called forest layer having the value of 1 and all other non – forest classes were merged into non-forest layer, having the value of 0. In this respect, accuracy of each single layer of these kind of global land cover products may not be so significant and relevant. Today, the capabilities of remote sensing techniques to extract vegetation existence over a period of time is quite promising, therefore a forest/non forest map for Turkey was derived from GLC 2000 land cover data and was used to refine the results of Canadian Fire Weather Index for Turkey.

More importantly, the point to discuss is that the validation of the final output after refinement process. In this study the most recent and updated data were used. For fire history data, the fires recorded from the year 2001 and 2005 and for the observation of daily performance of FWI, meteorological parameters for the month August in 2006 were used. The validation of the calibrated results for each day was made by the information compiled from newspaper archives, where the geographic information about the fires was not available. Moreover, the fire history data were not available for the year 2006. Therefore, it is strongly emphasized that the results of the calibrated Canadian Fire Weather Index for Turkey after refinement with GLC 2000 global land cover data, should be validated with the geo-located fire records for the year 2006.

However, it should be noted that based on the available data, the Canadian Fire Weather Index can be accepted as the most explanatory index for the fire phenomenon in Turkey. Furthermore, either high or low, the accuracy of the index outputs may not play a big role here. The success of the index should be evaluated whenever the complimentary variables – vegetation and topography are included. This issue is a matter of commission (over prediction) or omission error (under prediction), which will not change the fact that the Canadian Fire Weather Index is the best explanatory index for fire phenomenon in Turkey.

Another point to concern is the problem of the scale. The minimum map unit for this study was 50 X 50 km grid cells. This limitation was originated from the nature of MARS database for the meteorological input data. An alternative study with various minimum map units could lead different results, since the performance testing relies on the number of fire events that is contained by each grid cells.

A classification of the fire records according to the causative agents will also have improving effects on this study. Since the study primarily focuses on the fire prone areas of Turkey by analyzing the meteorological factors, the fire events that are purely originated from meteorological factors should be taken into account. This procedure is expected also to improve the results for better fire danger assessment.

Finally, the problem of data acquirement and the nature of the obtained data are worth to mention as a conclusion. Especially, land cover information data like CORINE and Forest inventory maps for Turkey, would be important inputs for this study. Unfortunately, both data were not available even for the scientific purposes.

The structure of fire history data is another issue to consider. The records of fire events should be recorded digitally with their associated geographic location in order to execute accuracy assessment process. Apart from its geographical importance, the fire archive dataset should include the past years as much as possible to obtain better calibration process. Since the calibration has been performed based on the fire history data, boundary determination for each danger class will depend on the data amount acquired. More information on number of fire will enhance the results by determining more realistic boundary limits for associated danger classes.

Mostly the necessary data for this study - meteorological data, GLC 2000 land cover data and the Meteorological Fire Danger Index Processor - were obtained from Joint Research Center of European Commission in Ispra, Italy. The five-year fire records based on forest management boundaries were obtained from the General Directorate of Forestry in Ankara, Turkey. Due to bureaucratic processes, to have an access to available data was time consuming and sometimes discouraging. As a note, unless the available data is open to GIS community for scientific purposes, these bureaucratic processes will always be an obstacle for further research and development activities.

This study was an attempt to produce a general overview for Turkey in terms of fire danger assessment at national scale. Therefore, it is important for the future wild fire related studies. Based on this study, it is possible to work on further fire analysis for Turkey such as Fire Risk Assessment and Fire Cost Analysis. The content of this study will also facilitate the mitigation efforts. As the fire fighting resources are scarce, location based solutions for mitigation is crucial.

7.2. Recommendations

Another advantage of meteorological fire danger indices is that they can elaborate with the information available through weather forecast so that they enable also for making forest fire danger forecasts. Thus, future work can be directed in this way to establish a national fire danger forecast system, which can be served through Internet as well. To illustrate, currently, some organization serve near real time accessibility of Fire Danger Rating Information through user-friendly Web pages (Allgöwer et al., 2003):

- The Canadian Wildland Fire Information System provides daily fire danger assessment for Canada.
  (URL:http://fms.nofc.cfs.nrcan.gc.ca/)

- Oklahoma Fire Danger Model serves hourly weather data, weekly satellite imagery for live fuel moisture and load calculations through a network of 1km dense weather station network. (URL: http://agweather.mesonet.org/models/fire/)

- Another example is EFFIS of Joint Research Center with its user-friendly web page, serving to member states of European Union and Candidate Countries. With meteorological fire danger indices and fire statistics database for the region.
  (URL: http://effis.jrc.it/wmi/viewer.html)

It is worthy to mention here the work of Joint Research Center of European Commission called EFFIS – European Forest Fire Information System. Users of this web-interface are able to choose between four modules (Figure 7.1):

(1) Risk Forecast System, where several meteorological Fire Indices can be selected according to a given data or time period;

(2), (3) Damage Assessment System and Rapid Assessment System, where Burned Areas bigger than 50ha between the years 2000 and 2006,

(4) and finally EU Fire Database, where a query can be made in accordance with number of fire, burned area and average fire size.

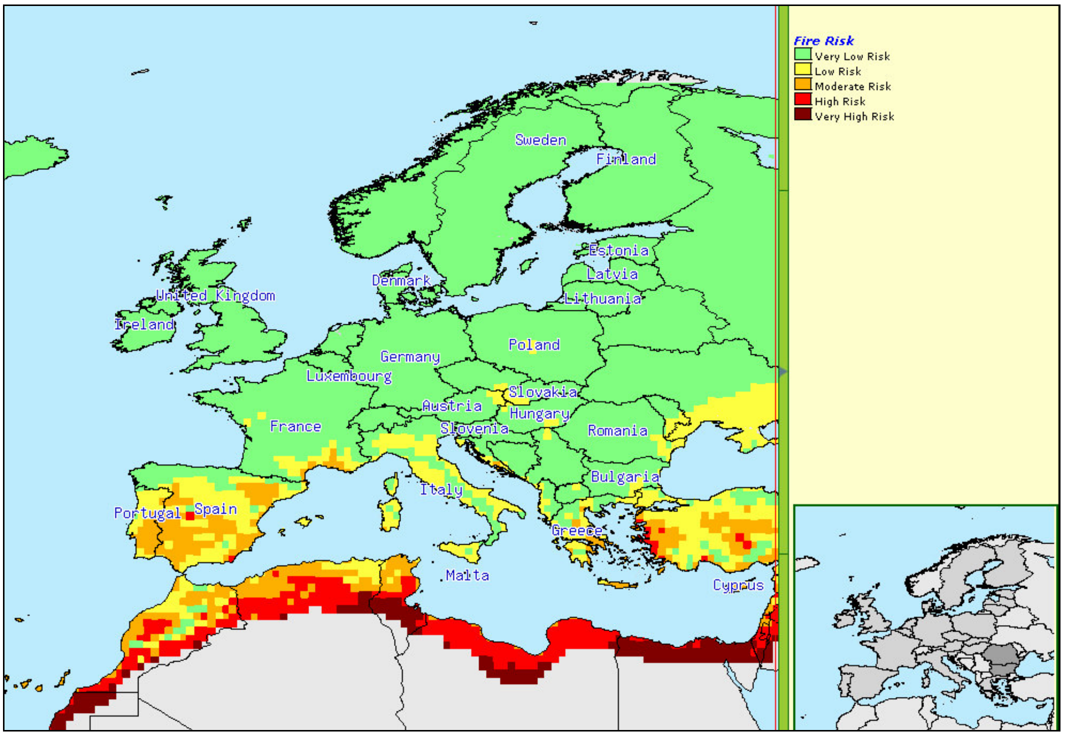


Figure 7.1: EFFIS web-interface showing the averaged fire danger levels during the fire season (from June to October) in 2006, when Canadian Fire Weather Index was selected.

In the future, based on the work here, a web interface might be constructed for the service of Forest Administrations in Turkey (and also researchers interested in this field) in order to establish a reliable early warning system and to overcome the allocation problem of the scarce fire fighting resources.

Another suggestion can be to create a new meteorological fire danger index specific to Turkey. By formularization empirical analyses of the past fire events or assumptions regarding to the factors leading to fire events in Turkey, a national fire danger index can be structured. Instead of creating a new meteorological fire danger index, modification or adjustment of existing fire danger indices in literature, for Turkey is another alternative to consider. Especially in Mediterranean Countries of Europe, some national meteorological indices were mainly developed by modifying existing indices. For example, Italian Fire Danger Index (Palmieri et al., 1993 in Ayanz et al., 2003) was derived from Mc. Arthur's model and moisture content parameterization of Spanish ICONA method (ICONA, 1993 in Ayanz et al., 2003) is the modified version of the BEHAVE model. Therefore, for Turkey, some modifications can be performed for the existing meteorological fire danger indices in literature, especially by consulting fire research experts.

Another important contribution can be made by introducing climatic stratification for Turkey, when applying meteorological fire danger indices. In Turkey, there are mainly 3 climatic zones (General Directorate of Forestry, 2006):

Continental Climatic Zone,
Mediterranean Climatic Zone,
Black Sea Climatic Zone.

Based on this information, each climatic zone can be treated differently in terms of applying meteorological fire danger indices. This might be also helpful to overcome the problem of overestimation in some areas.

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APPENDIX A

METEOROLOGICAL STATIONS IN TURKEY USED FOR INTERPOLATION FOR MARS DATABASE

STATION NAME	LAT	LON
Adana	37.0	35.35
Adiyaman	37.8	38.23
Afyon	38.7	30.53
Agri	39.7	43.05
Akhisar	38.9	27.85
Amasya	40.6	35.85
Anamur	36.1	32.83
Ankara/Central	39.9	32.88
Antalya	36.7	30.73
Artvin	41.1	41.81
Aydin	37.8	27.85
Batman	37.8	41.16
Bilecik	40.2	30
Bingol	38.8	40.5
Bodrum	37.0	27.41
Bursa	40.1	29.06
Canakkale	40.1	26.4
Cankiri	40.6	33.61
Corum	40.5	34.96
Dalaman	36.7	28.78
Denizli	37.7	29.08
Dikili	39.0	26.86
Diyarbakir	37.8	40.18
Edirne	41.7	26.61
Edremit	39.6	27.03
Elazig	38.6	39.28
Erzincan	39.7	39.5
Erzurum	39.9	41.26
Eskisehir	39.7	30.56
Finike	36.3	30.15
Gemerek	39.1	36.05
Gumushane	40.4	39.45

Hakkari	37.5	43.76
Iskenderun	36.5	36.16
Isparta	37.7	30.55
Istanbul/Goztepe	40.9	29.08
Kahramanmaras	37.6	36.93
Kastamonu	41.3	33.76
Kayseri/Erkilet	38.7	35.48
Kirikkale	39.8	33.53
Kirsehir	39.1	34.16
Konya	37.9	32.55
Konya/Eregli	37.5	34.06
Kusadasi	37.9	27.3
Malatya/Erhac	38.4	38.08
Marmaris	36.8	28.26
Mersin	36.8	34.6
Mugla	37.2	28.35
Mus	38.7	41.51
Nigde	37.9	34.68
Ordu	41.0	37.53
Rize	41.0	40.46
Sakarya	40.7	30.41
Samsun	41.2	36.33
Siirt	37.9	42
Silifke	36.3	33.93
Sinop	42.0	35.16
Sivas	39.7	37.01
Tatvan	38.5	42.26
Tekirdag	40.9	27.48
Trabzon	41	39.71
Usak	38.6	29.41
Van	38.4	43.31
Yozgat	39.8	34.81

APPENDIX B

METEOROLOGICAL FIRE DANGER INDEX PROCESSOR (MFDI) MANUAL

1. Introduction

MFDIP was developed within the scope of the EC-DGXII Project MEGAFiReS and it is an Annex of the Project final report delivered to the European Commission.

It was then build for internal use, to accomplish the meteorological fire danger-rating task of the Short-term fire risk mapping Workpackage of MEGAFiReS Project.

2. How MFDI works

Meteorological data are assumed to come from a number of weather stations with a daily temporal resolution. MFDIP reads 1 ASCII files with input data and generates 1 output ASCII file with the calculated requested danger indices. The names of input and output files are requested by the software when running.

3. File Format

The input files must be in ASCII format with a comma as field separator. Field names in the first lines must be omitted.

3.1. Input Data Format

Weather data file has 1 record for each day. The fields must be in the following order and with the following units:

Grid number (GNO)	ID (code) grid cell
Maximum temperature (of the day)	℃
Minimum temperature (of the day)	℃
Vapour pressure	hPa
Windspeed	m/s
Rainfall	mm

Even though not all fire danger indices require all weather data to be used for their computation, the program requires that ALL THE FIELDS MUST BE PRESENT in the input files. In case, replace the missing, non used, parameters with dummy variables.

4. Output Data Format

The name of the output data file is provided by the user. The output file is an ASCII file with 1 record for each day and a first line with fields names. The other fields depend on the previously requested danger indices.