EVALUATION OF FIRE ACTIVITY IN SOME REGIONS OF AEGEAN COASTS OF TURKEY VIA CANADIAN FOREST FIRE WEATHER INDEX SYSTEM (CFFWIS)

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Abstract. Çanakkale, Izmir and Muğla regions, which have much higher number of fires and larger burnt area values than Turkey's mean values, are the regions at 1st rank in terms of forest fire risk. The negative changes in climate conditions in recent years have significantly increased the forest fire risk. One of the most common methods used worldwide in order to rank the weather-related forest fire risk is the Canadian Forest Fire Weather Index System (CFFWIS). In this research, it has been determined for all of 3 regions that the SSR index calculated by using DSR index was statistically significantly successful in explaining the burnt area in forest fires. The success levels of SSR were 37.8% in Çanakkale Region, 49.8% in Izmir region, and 59.6% in Muğla region.
Keywords: *forest fire, fire index, CFFWIS, burnt area*

Introduction

Especially the Aegean and Mediterranean coastal regions of Turkey are at high fire risk due to the plant cover and climate conditions (Altan, 2011; Altan et al., 2011). Meteorological factors such as long summer drought and high temperatures are some of the factors increasing the risk. Maquis and *Pinus brutia*, among the plant cover types that are prone to be burnt, are dominant in these regions. Three of the highest fire activity regions of Turkey are located in Aegean coasts of Turkey; these are the regions investigated in this research. Of 21,137 forest fires that have occurred in Turkey between the years 2001 and 2011, the portion of these three regions is 27.92% in terms of the area (22.30% in terms of the number of fire). In other words, while the annual mean number of fire per regional directorate in Turkey is 73.90, the annual mean area burnt is 308.27 ha in 2001-2011. The same values of these three regions were 482 forest fires per year and 2115.11 ha of mean burnt area, respectively.

Various fire-weather indices have been developed throughout the world in order to rank the fire risk. These systems used under the name of National Fire Danger Rating System (NFDRS) in USA, McArthur Forest Fire Danger Index (FFDI) in Australia and Canadian Forest Fire Weather Index System (CFFWIS) in Canada constitute the Foundation of the Fire Weather Risk Indices that is used commonly in world. During the comparisons of these indices, it has been determined that there are similarities and differences between them. In study of Dowdy et al. (2010), where they compared Canadian and Australian forest fire risk indices, it has been determined that both of the indices are sensitive to wind at most, and then the relative humidity, and temperature,

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respectively. When these indices are compared, it has been determined that, in proportion to FWI (Fire weather index), FFDI is more sensitive to temperature and relative humidity and less sensitive to wind speed and precipitation (Dowdy et al., 2010).

Nowadays, the CFFWIS is the most commonly used index in the world (Natural Resources Canada, 2015). Some of those countries are New Zealand, Fiji, Northeastern China, Alaska, Minnesota, Michigan and Florida from USA and Mexico, Indonesia, Malaysia, and Argentina. Furthermore, since the system is suitable for entire continent, it is used by the research center affiliated to European Commission in order to determine the fire risk in Europe (Taylor and Alexander, 2003; Taylor, 2001; San-Miguel-Ayanz et al., 2012; Willis, 2001).

All these indices have been perfected via the data that have been collected from the numerous natural forest fires and the test fires for many years in the country, where they have been developed. In many countries, in order to rank the forest fire risk, the above-mentioned models are used either by modifying or as is. Various weather elements are utilized in ranking the forest fire risk through both of existing systems and new indices that are derived from them.

CFFWIS, which is the result of the studies carried out for many years in Canada, has been introduced firstly by Van Wagner in year 1968. Then, Van Wagner has published the new improvements for Forest Fire Weather Index in 1970, his studies about the structure of index in 1974, and recent developments in CFFWIS and index's structure in 1987 (Van Wagner, 1970; Van Wagner, 1974; Van Wagner, 1987). In the course of time, CFFWIS has been continuously improved for perfection. This system has been used in Canada officially since 1971 (Turner and Lawson, 1978). CFFWIS has been utilized in many researches to date. In year 2004, FWI and head fire intensities have been calculated in Canada for burnt areas (larger than 2 km^2) in boreal forest lands and taiga ecozones. As a result of calculations made, it has been determined that the effects of climate change are earlier and severer in regions in northern longitudes (Amiro et al., 2004).

In order to rank the forest fire risk in European countries, CFFWIS index is frequently used. Thus, it has been examined by Dimitrakopoulos et al. (2011) in Crete Island under 2 different fire season conditions; one normal precipitation and one extremely drought season. According to the research, DMC (Duff Moisture Code), DC (Drought Code), BUI (Build Up Index) and FWI were highly correlated with the occurrence of the fire. On the other hand, the correlations of these indices with burnt area were at medium level. Moreover, high level of correlation has been found between FFMC (Fine Fuel Moisture Code) and determined L (measured litter layer) and moisture values. Moreover, DC has been found to be lowly correlated with the ground surface moisture (Dimitrakopoulos et al., 2011).

The Fire Protection Department of Croatia, another country having coast to Mediterranean Sea, has been using CFFWIS in coastal regions since 1981. For this purpose, FWI is calculated daily from June to September. For the calculations, the data obtaining from 20 synoptic meteorology stations are used (Vucetic and Vucetic, 2008).

In Europe, it has been adopted that all of the EFFIS-member (The European Forest Fire Information System) countries will use CFFWIS in determining the fire danger rating. In previous studies, it has been found that FWI is useful in fire risk rating in countries having Mediterranean climate such as Greece and Italy (Viegas et al., 1999). In another study carried out in Toscany-Italy and Thessaloniki, Athens and Heraklion (Greece), this method has been utilized in determining the aggravated and protracted fire seasons. In that study, in addition to previous calculations, a non-linear functional

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relationship between the number of fires per day and FWI has been found to be roughly consistent between multiple stations (Good et al., 2008)

In a study of Sturm et al. (2012) carried out in Slovenia, the fire activity between 1995 and 2009 has been examined via the same method in SW Slovenia Sub-Mediterranean Karst forestland. In that study, the usability of CFFWIS under Middle European conditions has been tested (Sturm et al., 2012).

By the forest department in New Zealand, another system named NZFDRS (The New Zealand Fire Danger Rating System) based on CFFDRS (Canadian Forest Fire Danger Rating System) has been developed in 1980 (Fogarty et al., 1998; Anderson, 2005). The main foundation of the NZFDRS is the FWI system, and this index provides numeric proportions about the relative combustion potential and fire behavior by utilizing weather data (Van Wagner, 1987; Anderson, 2005; Pearce and Clifford, 2008).

The above-mentioned method has been utilized by Tian et al. (2011) in Daxing'anling region in northern China in order to examine the fire seasons between 1987 and 2006. Accordingly, according to FWI classification, 81.1% of the total fires have occurred at high, very high, and extremely high fire risk levels. Hence, at the end of the research, it has been determined that the FWI elements are useful indicators for forest fire risk in Daxing region of China (Tian et al., 2011).

The Canadian Forest fire weather index system (CFFWIS-FWI), with The Canadian Forest Fire Behavior Prediction (FBP) System, constitutes the Canadian Forest Fire Danger Rating System (CFFDRS). CFFWIS, one of the elements constituting the fire risk rating system, is based only on meteorological observations (Natural Resources Canada, 2015). Nowadays, as well as the CFFDRS, CFFWIS is still used by fire management agencies in Canada in predicting forest fires, and enlargement and severity of fire (Wotton, 2009). It is widely used for many years as decision-making mechanism in fire occurrence, fire behavior estimations, and other fire management activities (Martell and Sun, 2008).

Materials and Methods

Study Area

In this study, Çanakkale, Izmir and Muğla regions of Turkey (*Figure 1*) have been determined as study areas. Çanakkale region is located in 39^{0}33'39"-42^{0}04'08" northern latitudes and 26^{0}05'32"–27^{0}31'39" eastern longitudes, Izmir region in 39^{0}25'28"-37^{0}52'30" northern latitudes and 26^{0}11'42"–28^{0}52'28" eastern longitudes, and Muğla region in 36^{0}16'26''-38^{0}06'32'' northern latitudes and 27^{0}13'49''-29^{0}46'40'' eastern longitudes (*Figure 1*). Together with the number of fires between 2001 and 2011, also the daily meteorological data of these 3 regions have been used in this study (*Table 1*).

Table 1. *Distribution by month of forest fire in study area.*

	May		June		July		August		September	
	No	**Burnt Area**	**No**	**Burnt Area**	**No**	**Burnt Area**	**No**	**Burnt Area**	**No**	**Burnt Area**
Çanakkale	14	17.36	42	358.81	114	1860.42	88	587.63	69	57.16
İzmir	157	201.95	371	1475.07	479	3454.44	404	3667.92	245	312.27
Muğla	184	596.91	405	304.01	566	2224.69	528	6730.90	424	663.66

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During the study period (2001-2010), of the burnt areas stated above, 1621 ha in Çanakkale and 4111 ha in İzmir and 6343 ha in Muğla have been damaged in large forest fires .

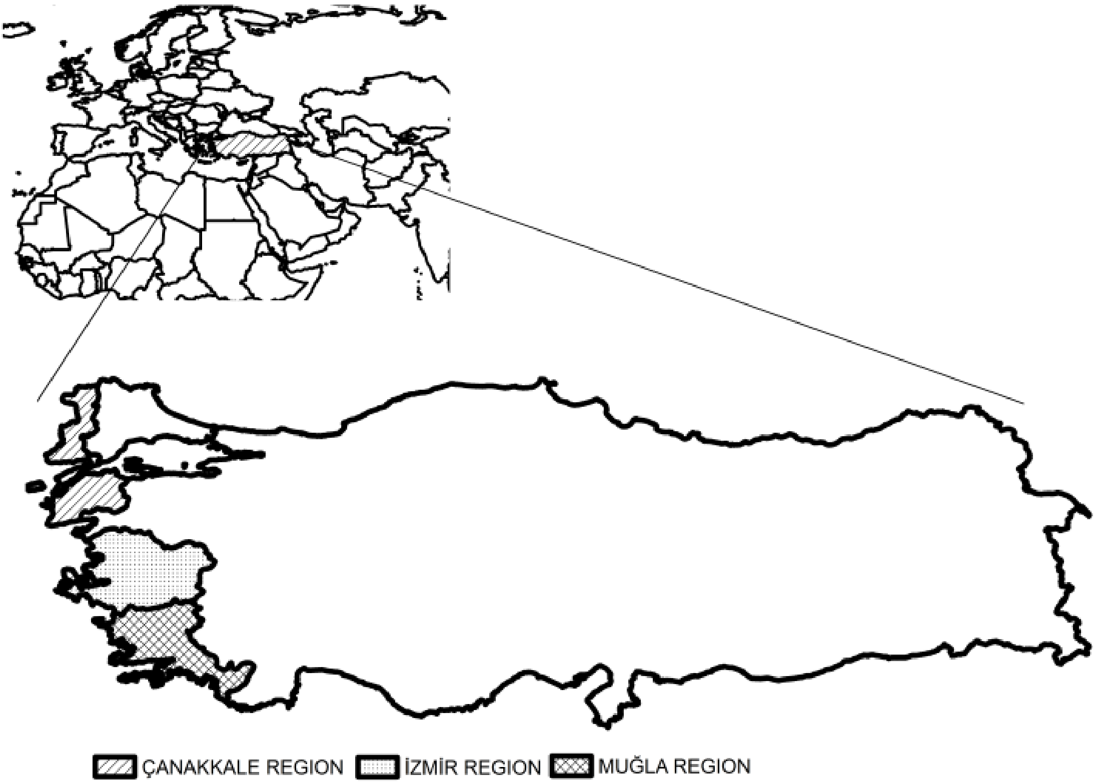

Figure 1. *Locations of Çanakkale, Izmir and Muğla regions constituting the study area*

Method

CFFWIS consists of the components such as FWI, FFMC, ISI (Initial Spread Index), BUI, DMC, DC and DSR (Daily Severity Rating) (*Figure 2*). FFMC, DMC and DC used in calculating the moisture of flammable material. They numerically express the moisture status of litter layer, other fine fuels, decomposed organic matters in medium depth, and deep compact organic matter. High level of the elements indicates the more flammable dry matters (Anderson et al., 2007). The system uses daily meteorological data in order to determine the moisture at 3 different forest layers (Wotton and Beverly, 2005). Among these variables constituting the model, FFMC is related with the moisture of litter and other fine fuels in forest surface. DMC, another variable, represents the moisture content of the decomposed organic matter (5 kg/m^2 dry weight). DC, the final variable about the moisture, represents the deep compact organic material up to 25 kg/m^2 dry weight (Lawson and Armitage, 2008).

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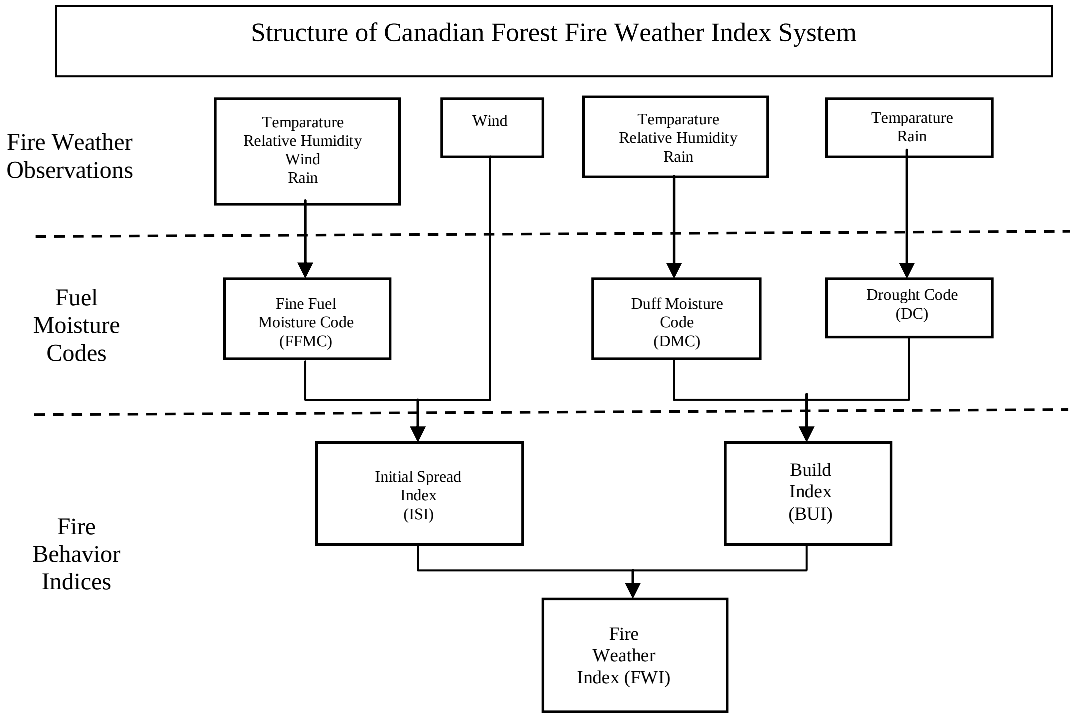

Figure 2. *Structure of the Canadian Forest fire weather index system (De Groot, 1987)*

Different from these 3 variables, the other elements constituting the system are the ISI, BUI and FWI fire behavior indices, and they represent the fire's spreading speed, flammable material ready-to-combust, and pre-severity of the fire. As is in other elements, the higher values of these elements indicate the increasing fire risk. DSR and its mean values are the extensions of FWI system. The DSR is the transformed form of daily FWI value. Seasonal sum of DSR value is the SSR (Seasonal Severity Rating) (Anderson et al., 2007). ISI is also the combination of the spreading speed represented by FFMC and the wind without considering the flammable material effect that is also a variable. BUI is the combination of DMC and DC, the flammable materials representing the spreading of the fire. They are correlated with fuel consumption. FWI is a combination of ISI and BUI representing intensity of the spreading fire that is expressed as energy rate per unit length of fire front, and lonely represents the fire weather in general (Lawson and Armitage, 2008).

DSR that can be considered as controllability difficulty of a fire is the power function of FWI (Amiro et al., 2004). In cases where the mean of many stations or a certain time period, the use of FWI is not appropriate at all. In such cases, the use of DSR will be more appropriate. The mean value of the DSR during entire fire season is named SSR. This value is used in evaluating the fire weather conditions for regions or seasons (Lawson and Armitage, 2008).

Using the meteorological data of the regions selected as study area, the average values of 5 months (May, June, July, August, and September) selected as fire season have been calculated for 10 years. By using Mann-Whitney U Test, it has been determined if there is any difference between CFFWIS elements determined for 3 regions. Then, Spearman's Rank Order Correlation has been utilized in order to

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calculate the degree of relationship between the number of fires and the burnt area. In order to mathematically explain the relationship between the elements of CFFWIS, of which relationship with number of fires and burnt area has been determined as a result of Spearman's Rank Order Correlation Test, the basic linear regression analysis has been performed. The statistical analyses used in this study have been performed through R 3.0.2 software (R Software, 2014).

Results

The CFFWIS indices have been calculated for these 3 regions in Aegean region of Turkey. The relationships of the calculated indices with the number of fires in study area and the burnt area have been investigated. The index values calculated for Çanakkale, Izmir and Muğla regions and the relationships of these values with the number of fires and the burnt area are presented in *Figure 3*. Since the data of burnt area doesn't exhibit normal distribution, the natural algorithm of these data has been used in order to better-express the values.

As a result of MANN-Whitney U test performed between 6 index values (FFMC, FWI, DC, BUI, ISI, SSR), it has been determined that there was no statistical difference in Çanakkale region between BUI and FFMC (p=0.140), in Izmir region between SSR and ISI values (p=0.974), and in Muğla region between SSR and ISI (p=0.947) and BUI and FFMC (p=0.948). p value of 0.0000 in all of the variations other than these indicate that the indices are different from each other. Since the index values calculated in 3 regions showed significant variation, Spearman analysis has been performed for all the index values. The results of Spearman analysis are presented in *Table 2*.

Table 2. *Spearman RHO coefficients by indices for Çanakkale, Izmir, and Muğla regions*

REGION		**Spearman rho coef. for FFMC**	**Spearman rho coef. for FWI**	**Spearman rho coef. for DC**	**Spearman rho coef. for BUI**	**Spearman rho coef. for ISI**	**Spearman rho coef. for SSR**
ÇANAKKALE	NOF	0.418	0.181	0.463	0.454	0.218	0.209
	Log BA	0.481	0.809*	0.491	0.754*	0.791*	0.736*
İZMİR	NOF	0.572	0.554	-0.009	0.254	0.618	0.254
	Log BA	0.491	0.509	0.263	0.581	0.527	0.709*
MUĞLA	NOF	0.481	0.572	0.054	0.409	0.61	0.572
	Log BA	0.463	0.645	0.363	0.618	0.60	0.745*

NOF: Number of fires, Log BA: Natural log of burnt area, *Statistically significant relationship at confidence level of 95%

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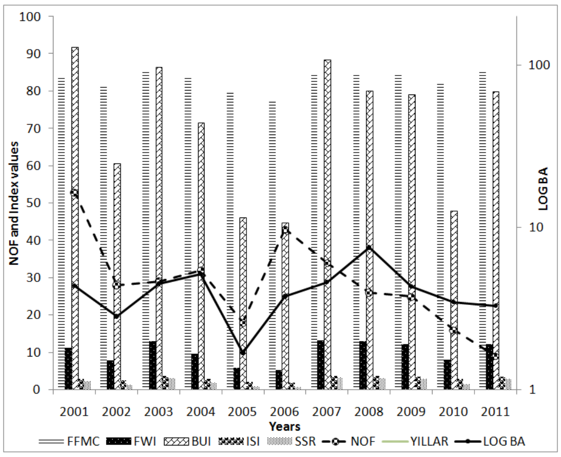

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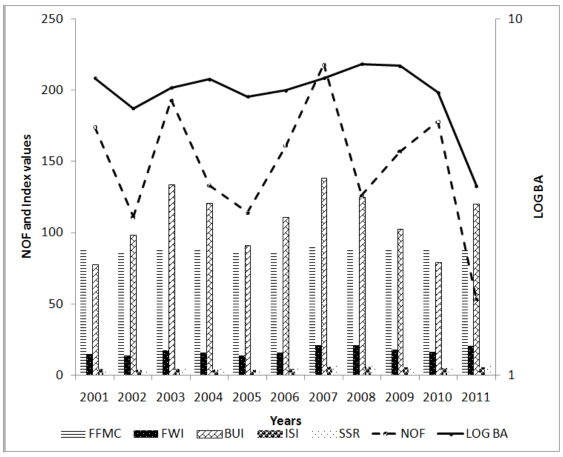

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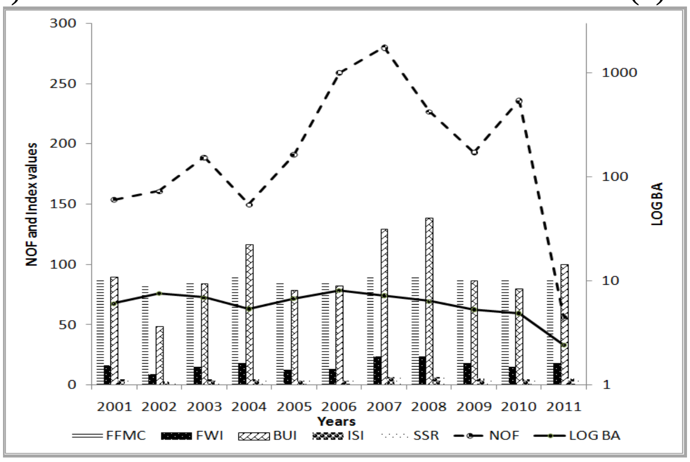

(c)

Figure 3. *The relationship of the number of fire and the burnt area in Çanakkale (a), Izmir (b) and Muğla (c) regions with CFFWIS elements (NOF: Number of fires, Log BA: Natural log of burnt area)*

In *Figure 3*, it can be seen that there was no similar trend between the index components and the number of fires in all of three regions. But, it has also been determined that the higher index values indicated higher risk of fire. Moreover, it has been determined that higher number of fires has occurred in those days, when the high index values were observed (*Figure 4*). It has been found for all three regions that there was a relation between different index components and the area burnt (*Figure 3*).

For all these 3 regions, no statistically significant relationship could be detected between the number of fires and the indices. But, a strong relationship has been detected between natural algorithms of the data about the burnt area in Çanakkale region and FWI, ISI, BUI and SSR values. The p values obtained for mentioned indices are 0.0039, 0.00549, 0.00984, and 0.0127, respectively. When the relationship between the burnt area and indices are examined for Izmir and Muğla regions, it has been seen that there was a strong relationship only between natural algorithm of the data of burnt area and SSR, and the p values of the relations determined for Izmir and Muğla were 0.018 and 0.011, respectively. The results of regression analysis performed in order to determine the mathematical relationship

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between the indices and the data of burnt area are presented in *Table 3*. Regression analysis has been performed because the significant relationships have been identified as a result of Spearman analysis.

Table 3. *Regression analysis results for Çanakkale region*

	R square	F statistics	t	Sig.
ISI-LOGBA	0.350	4.870	2.207	0.055
FWI-LOGBA	0.382	5.555	2.357	0.043*
BUI-LOGBA	0.301	3.897	1.967	0.081
SSR-LOGBA	0.378	5.459	2.336	0.044*

Log BA: Natural log of burnt area

Given the values in *Table 3,* it is seen that the relationship of ISI and BUI indices with the area bunt was not statistically significant. FWI and SSR values explain the 38.2% and 37.8% of the burnt area, respectively. According to the parameter estimations obtained as a result of regression analyses, it has been determined that 1 unit increase in SSR index leads to 0.959 fold increase in burnt area and 1 unit increase in FWI index leads to 0.312 fold increase in burnt area. Since the t values of these coefficients were found to be significant, the coefficients of SSR and FWI variables were found to be statistically significant.

While the linear equation for FWI is

$$y=0.968+0.312x, \quad \text{(Eq.1)}$$

The linear equation for SSR is

$$y=2.063+0.959x \quad \text{(Eq.2)}$$

For Izmir and Muğla regions, since only the relationship between SSR values and the data of burnt area has been found to be significant in Spearman analysis, the regression analysis has been performed only between these data groups. As a result of these analyses, the F statistics of the variance analysis has been found to be significant (p=0.023). This value indicates that our model, where we try to explain the data of burnt area via SSR index, is a significant model. While SSR value is capable of explaining 49.8% of the data of burnt area, the 1 unit increase in SSR value leads to 0.031 fold increase in the data of burnt area.

The linear equation obtained for SSR is

$$y=6.269+0.031x \quad \text{(Eq.3)}$$

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As a result of variance analysis in Muğla region, the F statistics has been found to be significant (p=0.042). This value indicates that our model, where we try to explain the data of burnt area via SSR index, is a significant model. While SSR value is capable of explaining 59.6% of the data of burnt area, the 1 unit increase in SSR value leads to 0.762 fold increase in the data of burnt area.

The linear equation obtained for SSR is

$$y=3.640+0.762x \tag{Eq.4}$$

Discussion and conclusion

62.85% of the forest fires occurring in Turkey are caused from human activities (GDF, 2009; GDF, 2013). Despite that, it cannot be disclaimed that the climate factors have an important effect on forest fires worldwide (Pinol et al., 1998; Crimmins, 2006; Liu et al., 2010; McKenzie et al., 2004; Westerling et al., 2003; Flannigan and Wotton, 2001).

Thus, in recent years, it has been reported in scientific studies that the summer temperature and droughts of especially the Aegean and Mediterranean regions of Turkey have shown increase (Turkes and Altan, 2013; Demir et al., 2008; Erlat and Turkes, 2013).

In this study, the fire activity in 3 regions of Aegean region of Turkey that are risky in terms of forest fires have been interpreted via CFFWIS elements. For instance; as a result of the study of Carvalho et al.(2008), it has been determined that almost 81% of the variation of the burnt area in Portugal has been explained with relative humidity and DC and monthly max. FWI, the elements of CFFWIS. The variation determined about the number of fire is lower, and is 63% (Carvalho et al., 2008). In the study of San-Miguel-Ayanz et al. (2013) large forest fires that have occurred in 3 South African countries have been examined. As a result of that research, it has been determined that all the mega-fires have occurred in high FWI and DMC periods (San-Miguel-Ayanz, 2013). Differently from South Europe, in a study of Arpaci et al. (2013) for determining the forest fire in Austria that is a middle European country, it has been determined that BUI, one of the CFFWIS elements, is one of the most useful indices for ranking the actual forest fire risk in summer season (Arpaci et al., 2013).

As a result of the study, it has been determined for the relationship of annual number of fire and burnt area with calculated indices that different indices were successful for different regions, and that SSR was successful in determining the fire activity in all 3 regions. Besides that, no relationship like the one expected could be determined between the indices and the number of fire; the days, in which the multiple fires occurred in the region, overlap with the high index values. Moreover, strong relationships have been determined between indices and the areas burnt in all 3 regions. Among these regions, it has been determined that the burnt area has strong relation with FWI, ISI, BUI and SSR in Çanakkale region, and with SSR in Izmir and Muğla region. It has also been observed that the above-mentioned indices were significantly successful in indicating the large fires (>300 ha) that occurred in various dates (*Figure 4*).

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(a)
(b)
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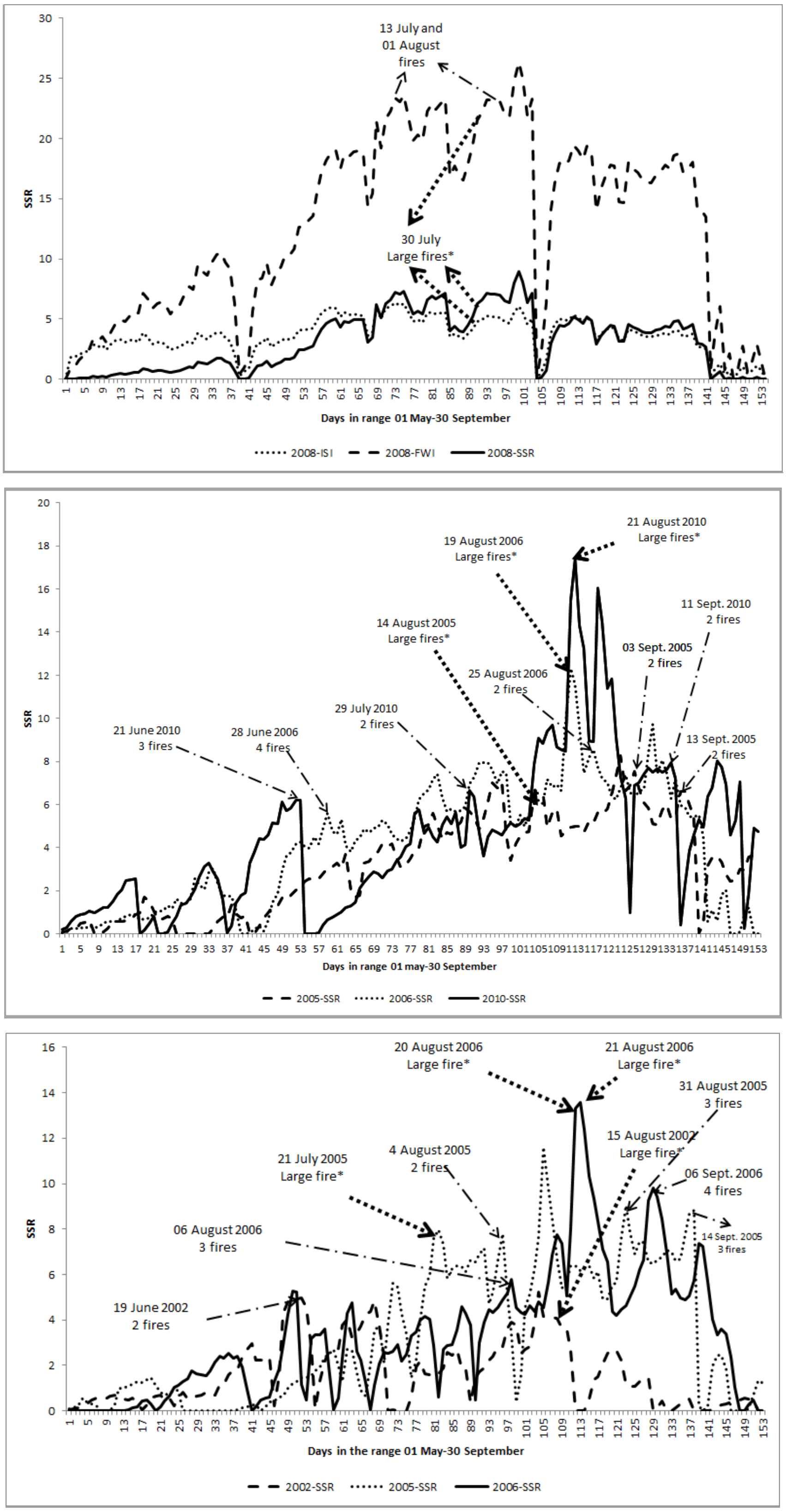

***Figure 4**. The fires in 3 regions and SSR values for 5-month period (May-Sept) (a-Çanakkale region, b-Izmir region, c-Muğla region)*

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