OGRIGINAL ARTICLE

USING REMOTE SENSING AND GIS TECHNOLOGIES TO MAP FOREST FIRE DANGER IN LATTAKIA GOVERNORATE (SYRIA)

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ABSTRACT

Background: Forest fires play a critical role in landscape degradation, so fire risk estimation is vital to reduce its negative impacts. In Syria, forest fires are one of the greatest risks, and they are one of the dominant disturbances in the forests of Lattakia governorate, therefore a forest fire risk map can be an appropriate process to find solutions. **Objectives:** This study is aimed at mapping Forest Fire Danger Index (FFDI) in Lattakia governorate, by estimating different factors that can contribute significantly to the ignition and spread of a forest fire. **Methods:** to produce Forest Fire Danger Map, all factors affecting forest fire in study area (weather, topography, vegetation fuel, human activities and potential factors) were studied using remote sensing (RS) and geographic information systems (GIS] technologies. The forest fires danger zones were delineated by creating GIS layers that represent all studied factors, assigning subjective weights to all layers according to their sensitivity to fire. **Results**: In this study, the value of FFDI ranged between 16 and 75, when the value of FFDI reached 45, the forest fires danger becomes high and very high. The most dangerous areas are concentrated in north-west and middle-east of study area that is due to high vegetation and topography danger indices while less dangerous areas are located in the south because of low density of forest cover. **Conclusion:** The forest fire danger map obtained forms an important tool for precautionary measures for Lattakia forests protection.

Keywords: *Forest Fire danger, weather danger index, topographic danger index, fuel danger index, potential fire danger index, Lattakia forest.*

1. INTRODUCTION

Forest fires are one of the major natural risks in the Mediterranean basin, creating economic and ecological damages. Each year, several hundred thousand hectares of forests and shrub lands are destroyed by fires in the Mediterranean region [1], it is estimated that about 50,000 fires occur each year that affect more than 600,000 ha [2]. In neighboring countries to Syria as Turkey, the annual areas of forests affected by fires are over 24.000 ha [3], in Lebanon, the Ministry of agriculture reported that a total of 1200 ha of natural forests are burned every year [4].

In Syria, forest fires are still one of the greatest risks, the average of burned area per year is about 1312 ha, which represent 0.31% of the total forest area in Syria [2]. Latakia forests are considered the main forests in Syria, which are about 28.94 % of the total Syrian forests [5]. In the period 1987 – 1998 Lattakia forests were affected by 786 fires (67 fires per year], causing complete or partial damages to 3802.25 ha (316.85 ha per year) [5].

Forest fires play a critical role in landscape transformation, vegetation succession, soil degradation and air quality. Improvements in fire risk estimations are vital to reduce the negative impacts of fires [6]. A solution can only be suitable when a forest fire risk map is obtainable, it helps in identifying the locations where a fire is expected to start, and from where it can easily spread to other areas [7]. Many researchers used remote sensing (RS) and geographic information systems (GIS) to predict the forest fire risk zones [8,9,10,11,12,13]. In these studies, forest fire risk zones were mapped by evaluating factors affecting forest fires as climatic and topography factors, vegetation fuel, human activities, history of fire in the studied region [4-7-14,15,16]. The forest fire risk zones were defined by creating GIS layers that represent these factors in studied region, assigning subjective weights to all layers according to their sensitivity to fire [17].

Fire is one of the dominant disturbances in the forests of Lattakia governorate, so the objective of this work is to develop a fires danger map for Lattakia forests, using (GIS) and (RS) technics, by estimating different factors that can contribute significantly to the ignition and spread of forest fires.

2. MATERIALS AND METHODS

2.1 Study site:

The study was carried out in Lattakia governorate, which is located in northern-west of Syrian Arab Republic on Mediterranean cost, Geographic coordinates are 35° 13′ 12.708″ north and 35° 47′ 21″ east, and its area is about 243636 ha. The study area is subjected to Mediterranean climate, which is characterized by dry summer that encourages forest fires ignition. The precipitation average in study area is about 765 mm/year, but almost is unregulated and concentered on winter, and less in spring and autumn.

The forests covered about 98000 ha (in 2010), which represents 43 % of Lattakia surface (Figure 1). The conifer species especially Brutia pine (*Pinus brutia* Ten.) are the dominants species in Lattakia forests, these species as known is very sensitive to fire because of it's resinous content.

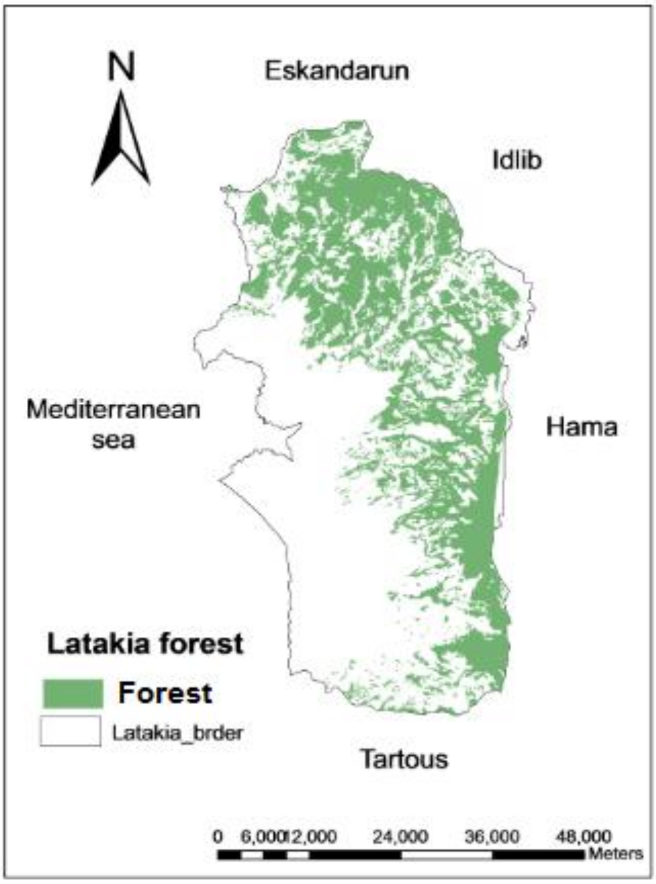

Figure 1: The figure presents the forest lands in Lattakia governorate, Syria (Source: GORS, 2005).

2.2 Weather Danger Index (WDI): Temperature and relative humidity influence the vegetation moisture, and influence the flammability of forest vegetations. The wind speed and direction influence the spreading of fires. In this study, temperature and relative humidity data were collected from 11 stations for the period (2008-2011), Wind speed and direction data were not available. The mean maximum temperature and mean maximum relative humidity were used to compute the WDI using a simple model as shown in Eq. (1) [18]:

$$WDI = (TMax/ RHMax)*100 \quad (1)$$

Where:

TMax is the mean maximum temperature for one month.

RHMax is the mean maximum relative humidity for one month.

WDI was calculated for fire season in the 11 stations. Fire season was defined in Lattakia by months of July, August, September and October. Lattakia Weather is dry in summer because rain interruption and this drought increases accumulatively until October, so we give weight for October more important than other fire season months as following:

$$WDI = 0.46WDI7 + 0.52WDI8 + 0.9WDI9 + 1.1WDI10 \quad (2)$$

Where:

WDI7 , WDI8, WDI9, WDI10: Weather Danger Index in July, August, September, and October, respectively.

WDI maps of studied region was generated in ArcGIS 10.3 using WDI data of studied stations.

2.3 Topographic Danger Index (TDI): Elevation and aspect influence vegetation composition and moisture, slope determines fire behavior; therefore, TDI was computed using these parameters. Elevation, slope, and aspect data were extracted from the Digital Elevation Model (DEM) of studied region, the TDI was calculated using the Eq. (3). In our study site, the slope has an impact more important on forest fire than elevation and aspect.

$$TDI = Slope\ (\%) + 0.6 * Aspect + 0.4 * Elevation\ (m) \quad (3)$$

TDI map of study region was produced using the slope, aspect and elevation layers in ArcGIS 10.3.

2.4 Fuel Danger Index (FDI): The Fuel Danger Index depends on vegetation moisture, forest type and density. The vegetation moisture influences the spreading of the fire [19], it was evaluated using the Normalized Difference Moisture Index (NDMI) which is defined by the Eq. (4) [20].

$$NDMI = \frac{(NIR - MIR)}{(NIR + MIR)} \quad (4)$$

Where: NIR is the near infrared spectral wavelength, and MIR is mid infrared spectral wavelength.

Some species are more inflammable than others; therefore, forest type was determined from landsat8 images, resolution of 30m, taken on February and July 2016, applying supervised classification algorithm. The higher vegetation density increases the fire risk [21]. It was estimated using the Normalized Difference Vegetation Index (NDVI) which is computed by the Eq. (5)

$$NDVI = \frac{NIR - R}{NIR + R} \quad (5)$$

Where: NIR is the near infrared spectral wavelength, and R is the red spectral wavelength.

In this study, the vegetation type has been given the first highest "weightage of five "keeping in view the fact that forest fires cannot occur unless inflammable material is present [22], so the Fuel Danger Index is presented by the Eq. (6)

$$FDI = 2.5FDIvt + 1.5FDId + 1FDIm \quad (6)$$

Where:

FDIvt: Fuel Danger Index Vegetation type .
FDId: Fuel Danger Index Density.
FDIm: Fuel Danger Index Moisture content.

FDI map of study region was created using the NDVI, NDMI and forest type layers in ArcGIS 10.3.

2.5 Human Activity Danger Index (ADI): Forest fire danger is more important when forest regions are located near to settlements and roads. Because habitants who reside within the forest cause accidental fires when practicing different doings such as grazing or burning the agriculture residues, Cooking and tourism activities, which are capable to forest fire ignition. Also roads allow local people, grazers, and tourists to go into the forest and cause fire [7-9]. So the distance from roads and settlements were taken in account in human activities danger index as shown in Eq. (7). To identify danger areas where a high level of human activity might occur, a multiple buffer was created with intervals of 100 m, 200m and 300 m for roads. A similar analysis was executed for settlements, a multiple buffer was created starting with intervals of 500 m, 1000m and 1500 m.

$$ADI = 2ADIr + 2ADIs \quad (7)$$

Where:

ADIr: Activity Danger Index Roads
ADIs: Activity Danger Index settlements

2.6 Potential Danger Index (PDI): The study of previous fires behavior in interest region, in terms of fires recurrence and burned areas, gives an idea about the potentiality of a fire ignition and spread. So it is vital to consider this factor when elaborating forest fire danger model. The burned areas in our case are more representative for the spread of fire, thus it has been given the highest weightage. The Potential Danger Index is computed as following:

$$PDI= 0.3PDIn + 0.7PDIa \quad (8)$$

Where:

PDIn: Potential Danger Index refers to fire number.
PDIa: Potential Danger Index refers to fire area.

The Fires recurrence and burned areas layers of study site were used to produce the potential danger map.

2.6 Forest Fire Danger Index (FFDI): Based on indices that have been mentioned previously: (WDI, TDI, FDI, ADI, PDI), which represent the factors affecting the fire starting and propagation in study site. We weighted factors and sub factors according to their importance in forest fires in local conditions (Table 1). Different maps represent all studied factors have been obtained, each factor map was reclassified by changing the original values to new values according to fire sensitivity (Table 1). The forest fire danger index refers of study site is described by following relation:

$$FFDI =5\ FDI + 4\ ADI + 3\ WDI + 2\ TDI + PDI \quad (9)$$

Table 1: Table presents the factors and sub factors with their weights in determination of forest fire danger.

Factor	Weight	Sub-factor	Weight	Divisions	class	Fire Risk Relating classes
Fuel (FDI)	5	Vegetation type	2.5	Conifer	5	Very High Risk
				Mix	3	medium Risk
				Broad	2	Low Risk
		Density (NDVI)	1.5	0.40 - 0.60	5	Very High Risk
				0.33 - 0.40	4	High Risk
				0.25 - 0.33	3	Medium Risk
				0.12 - 0.25	2	Low Risk
				0.15 - 0.12	1	Very Low Risk
		Moisture content (NDMI**)**	1	-0.12 - 0.01	5	Very High Risk
				0.01 - 0.1	4	High Risk
				0.1 - 0.16	3	Medium Risk
				0.16 - 0.23	2	Low Risk
				.23 -0.42	1	Very Low Risk
Human Activity (ADI)	4	Distance from roads (m)	2	< 100	5	Very High Risk
				100m - 200	3	Medium Risk
				> 200	2	Low Risk
		Distance from settlements (m)	2	< 500	5	Very High Risk
				500m – 1500	3	Medium Risk
				> 1500	2	Low Risk
Weather (WDI)	3	WDI7	0.46	102.63 – 109.38	5	Very High Risk
		WDI8	0.52	99.55 - 102.63	4	High Risk
		WDI9	0.92	96.65 – 99.55	3	Medium Risk
		WDI10	1.1	92.22 - 96.65	2	Low Risk
				84.7 – 92.22	1	Very Low Risk
Topography (TDI)	2	Altitude (m)	0.4	1 - 300	5	Very High Risk
				300 - 750	4	High Risk
				750 - 1200	3	Medium Risk
				1200 - 1536	1	Very Low Risk
		Slope (%)	1	> 35 %	5	Very High Risk
				25 - 35 %	4	High Risk
				10 - 25 %	3	Medium Risk
				5 - 10 %	2	Low Risk
				0 - 5 %	1	Very Low Risk
		Aspect	0.6	South	4	High Risk
				West	3	Medium Risk
				East	3	Medium Risk
				North	1	Very Low Risk
Potential fire (PDI)	1	Fire recurrence (times)	0.3	31 – 50	5	Very High Risk
				23 – 31	4	High Risk
				16 – 23	3	Medium Risk
				9 - 16	2	Low Risk
				1 - 9	1	Very Low Risk
		Burned area (ha)	0.7	100-1923.21	5	Very High Risk
				10-100	4	High Risk
				1-10	3	Medium Risk
				0.5-1	2	Low Risk
				>0.5	1	Very Low Risk

3. RESULTS AND DISCCUSION

Weather Danger Index (WDI):

The drier the climate is in a particular region, the more fire prone the site will be [7]. The calculated value of weather danger index (WDI) ranged between 3.5 and 15, which are classified into five ranks of danger as shown in table 2. The high and very high dangers form about 35% of the forest areas, which are observed in the north-west and middle of the study area (Figure 2A). These forests suffer from hydric stress between June and October (fire season), which could cause increase the ratio of dead biomass, especially the fine fuel representative by herbs and understory. As well as the drought that occurs in this period causes drying of forest litter that would in turn increases the amount of fuels available to ignite fire. It should be noted that the sensitivity of this index to weather influences remains less effective because it did not take into account the direction and speed of the wind.

Topographic Danger Index (TDI):

Fire travels most rapidly up slopes and the least rapidly down slopes [3]. In our topographic conditions, slope plays the greatest role in fire spread while aspect and altitude do not form real risk. Most forests in the study area spreads on sloped areas that increases risk of fire propagation. The value of topographic danger index (TDI) ranged between 2 and 9.4, which is classified, as in the WDI index, into five classes of danger (Table 2). The high and very high topographic dangers are distributed on 27.2 % of the total of forest area, especially in north (Figure 2B) where approximately more than 70% of Lattakia forest exists.

Fuel Danger Index (FDI):

The vegetation type has the most effects on forest fires as compared by other factors, so it has been given in this study the strongest weight. Forests in study area consist of conifers, broad-leaved and mixes of the two. The conifer forests are very sensitive for fires due to their resinous contents, while broad-leaved forests are less sensitive due to their high content of water and absence resinous in their tissues. For density, it was posing a high and very high dangers when the NDVI value is more than 0.33, while the vegetation moisture presented a high and very high dangers when the NDMI value is less than 0.1. The fuel danger index (FDI) value is between 7 and 25 (Table 2). The figure 2C showed that the high and very high dangers, which present about 60.6% of total forest area, are distributed in the forest of north, where the brutia pine (*Pinus brutia*) forests, which is considered the specie more sensitive for fire in study area, occupy large surface of Lattakia forests. As mentioned figure 2C showed also the increasing of fuel danger index value in the east due to the high density of the vegetation.

Human Activity Danger Index (ADI):

Roads deployed capaciously in study area forests, so it facilitates on men going to forests for many purposes as tourism, grazing, hunting, cutting firewood, that causes fires throw cigarettes, fire cooking, accidents, gunshots..etc There is no forest, in study area, devoid from settlements but it is in different ratios; therefore, most of forests suffer from high pressure, which is representative by infringement on forest land for convert it to agricultural land. The calculated value of human activity danger index (ADI) is ranged between 8 and 20 that classified as shown in Table 2. Figure (2D) showed that the high and very high dangers are distributed over the entire forest study area, with a surface of 12% of the total forest area. . It can be said that the human activity danger index would have been better if the impact of tourism activities was taken into consideration, but it has been difficult to identify the popular tourist sites that are most influential on fires.

Potential Danger Index (PDI):

The PDI was determined at parcel scale, taking in account that burnt area affects fire danger more than fire number. The accuracy of this index would have increased if it could also represent the causes of the fires, but there was no accuracy in recording the real reasons of forest fires in study area, so it was not adopted. The PDI value is ranged between 1 and 5 (Table 2), it indicated that high and very high dangers (which represent about 46 % of forest area) are concerted in northern study area (Figure 2E) where the main forest exist, and where the fires destroyed large surfaces when it occurred.

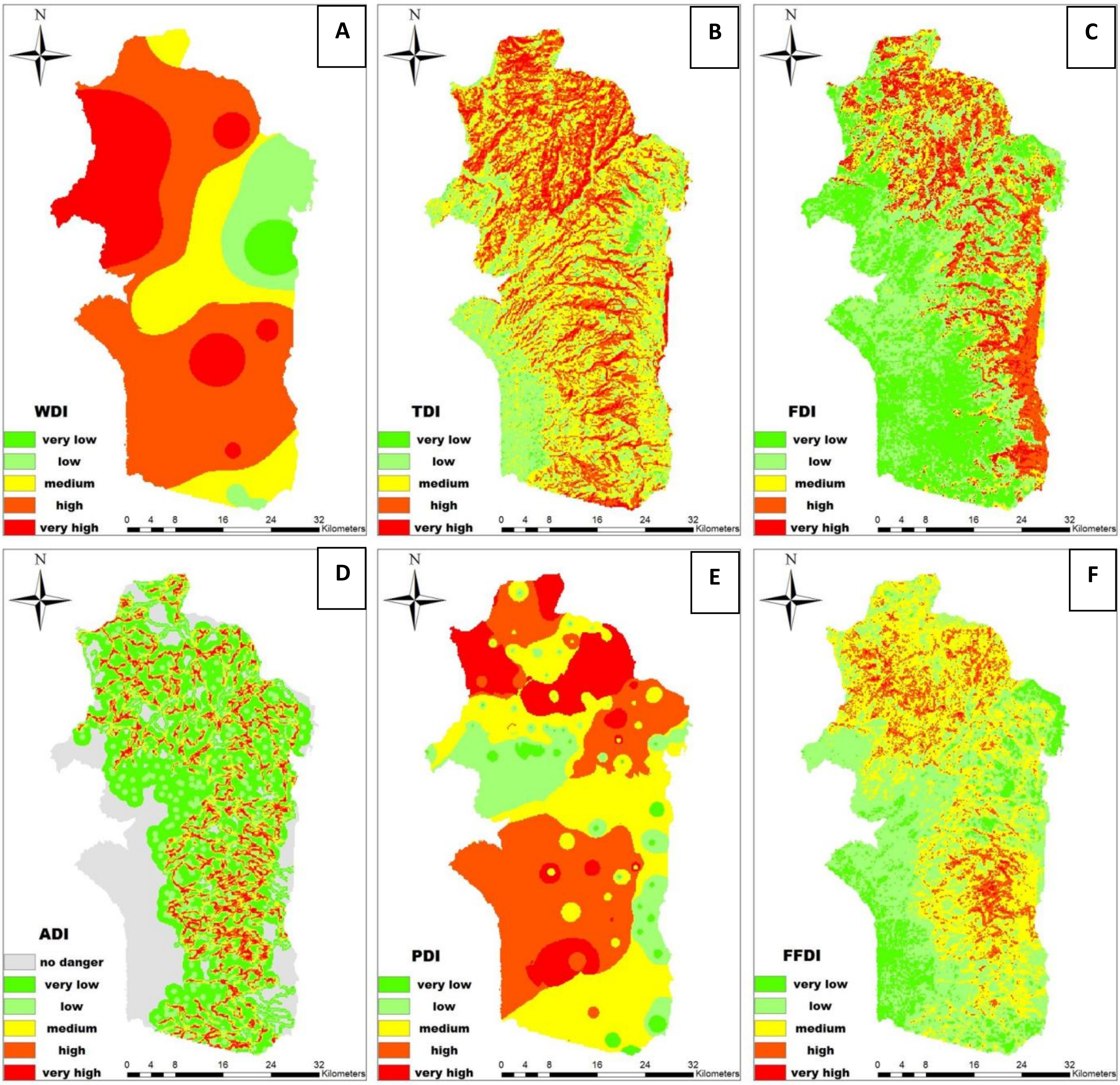

Figure 2: The graph present the studied indices calculated to study area: **A:** Weather Danger Index (WDI), **B:** Topographic Danger Index (TDI), **C:** Fuel Danger Index (FDI), **D:** Human Activity Danger Index (ADI), **E:** Potential Danger Index (PDI), **F:** Forest Fire Danger Index of study area.

Fire Forest Danger Index (FFDI): As explained in the study method, the FFDI is computed based on the five indices mentioned above. The FFDI value is ranged between 16 and 75, we classified FFDI map into five classes (very low, low, medium, high, and very high), with classes values respectively (16-27.8, 27.8-39.6, 39.6 – 51.4, 51.4 - 63.2, 63.2-75). The figure (2F) showed the distribution of the fire danger in the study area, the most dangerous areas are concentrated in north where the five indices indicate to high and very high dangers. We also observed that middle-east of study area is menaced by high and very high dangers of fire. The result showed also that the high and very high dangers were found where the brutia pine forests are distributed especially in the sloped region, when the density is very high.

Table 2: Table presents the indices values with relating classes.

WDI	TDI	FDI	ADI	PDI	FFDI	Class	Fire danger Relating classes
3.5-5.5	2 - 3.4	7.5 - 14	8	1-1.7	16-27.8	1	Very Low Risk
5.5-8	3.4 - 4.6	14-16	8-10	1.7-2.7	27.8-39.6	2	Low Risk
8-10.7	4.6 - 5.6	16-18.5	10-14	2.7-3.4	39.6-51.4	3	Medium
10.7-12.6	5.6 - 6.6	18.5-21.5	14-16	3.4-4.1	51.4-63.2	4	High Risk
12.6-15	6.6 - 9.4	21.5-25	16-20	4.1-5	63.2-75	5	Very High Risk

4. CONCLUSION

This study was an attempt to determine fire danger classes and places of Lattakia forests, which is very essential to forest fire management. The forest fire danger map, which was the purpose of this paper, forms an important tool for precautionary measures for forest protection. The objective map was created using remote sensing and GIS techniques, based on estimation of weather, topography and vegetation conditions, in addition to taking in consideration the human activity, and the potential danger in studied forests, so WDI, TDI, FDI, ADI and PDI were used to compute FFDI. Suitable weight variables were selected for each variable according to the role of each factor and its impact in the ignition and progress of the fire. The result showed that the high and very high dangers were found where the brutia pine forests are distributed especially in the sloped sites, where the density is very high. It can therefore be concluded that FDI and TDI are significant inputs to the production of the FFDI map. The contribution of others index are less significant in this study since most of the fires occurred.

The map can be further more accurate by using wind data (speed and direction), and it can be more reliable if the vegetation water content changes over fire season is taking into account. All in all, we can use same weights and same variables to determine the danger of fires in other regions of the Syrian coast, because the forests of the Syrian coast have very similar characteristics, but in order to be used elsewhere, the indices should be modified over areas with different environmental conditions.

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