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USING CORRELATIVE DATA ANALYSIS TO DEVELOP WEATHER INDEX THAT ESTIMATES THE RISK OF FOREST FIRES IN LEBANON: ASSESSMENT VERSUS PREVALENT METEOROLOGICAL INDICES

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ABSTRACT: *Forest fires are among the most dangerous natural threats that bring calamities to a community and can turn it totally upside down. Lebanon is considered one of the countries that face this natural disaster especially in summer season. Prevention is considered as one of the very essential tools to cope with and overcome such a danger. This is especially true in developing countries where fire suppression cannot be affordable. Early warning fire danger rating systems have been adopted by many developed countries to decrease fire occurrence. In this paper, data analysis is used to find the most affecting parameters on fire ignition during the last six years in north Lebanon using different correlation techniques: statistical regression, Pearson, Spearman and Kendall's Tau correlation. The correlations of these attributes with fire occurrence are studied in order to develop a new fire danger index. The strongly correlated attributes are then derived. The index is a simple linear equation relying on few numbers of weather parameters that are easy to measure and which facilitate its application in developing countries like Lebanon. The outcomes resulting from validation tests of the proposed index show high performance in the Lebanese regions. It is strongly believed that this index will help improve the ability of fire prevention measures in the Mediterranean basin area.*

KEYWORDS: Correlation Techniques, Data Analysis, Fire Danger Index, Forest Fire Prediction

INTRODUCTION

Nowadays, scientific research is oriented towards natural disasters threatening our ecosystems. Natural crises such as earthquakes, tornados, floods and forest fires may cause damage to the shape of the land besides their threat to living things. Forest Fires are considered among the most dangerous. Their frequencies are increasing day after day especially in the prevailing local and global climate changes which make these kind of natural disasters a complex phenomenon to tackle. This is despite the fact that wildfire is an important part of nature. It plays a key role in shaping ecosystems by serving as an agent of renewal and change.

Scientists have been working hard to predict forest fire danger since 1940.Many mathematical models, based on weather data, were implemented to estimate fire danger level. Fire danger rating based on meteorological data is more precise when it is based on weather forecast of the previous evening or previous day (Pyne et al., 1996; Gillet et al., 2004). Calculation methods lead to a numerical index that is translated as a level of alarm which rises with the increase in probability of fire occurrence conditions. Fire regimes have serious consequences on the local environment and boostglobal climate change through emission of long-lived greenhouse gases and physical changes in vegetation structures (Galanter et al., 2000; Winkler et al., 2008). According to a recent study by (VanDerWerf et al, 2010), in the last two decades, forest fires have contributed approximately 15% of the world's total carbon emissions. Although the contribution of global warming in changing fire regimes is still unclear, it's expected that higher temperatures will result in increasing the risk of fire occurrence.

This research focuses on the case of Lebanon which has been facing the threat of fires in the last decades and is considered one of the most affected areas in the Mediterranean region by forest fires. Forests had covered most of Lebanon landscape in the past. According to the Association for Forests Development and Conservation AFDC, only 13% of the Lebanese area is still forested (Knusten, 2014; UNDP, 2005). To conduct this research, North Lebanon is an appropriate place to be studied because 94 fires have been reported during the last 6 years (2009 and 2014).

The main purpose is to have an early warning index that contributes in reducing forest fires occurrence. A simple linear mathematical model is derived from data analysis, and comparison between meteorological data and the occurred fires in North Lebanon. Our real data were collected from the Lebanese Agriculture Research Institute (LARI) during the last 6 years. Our goal from data analysis is to find the appropriate parameters in the given inputs: temperature, soil temperature, relative humidity, wind speed, precipitation and dew point and the occurrence of fire. Then the relationships between the selected attributes are used to develop a fire danger index. The new obtained index is then verified to be conforming to the Lebanese environment and its characteristics.

Overview on widely used weather fire indices

Fire danger rating is a fire management system that integrates the facets of selected fire danger factors into one or more qualitative or numerical indices of current protection needs (Chandler et al, 1983). Fire danger rating systems are used by fire and land management agencies to determine levels of preparedness, to issue public warnings and to provide an appropriate scale for management, research and laws for fire related matters. All these systems integrate weather variables to assess fire danger, calculated as a numerical index.

Keetch Byram Drought Index

(John et al, 1968) created a fire prediction model for the United States Department of Agriculture's Forest Service. The KBDI (Keetch-Byram Drought index) model measured the likelihood of wild fire occurrence based on soil upper layer measurements. Also they put a range of drought (0-800) where a value of 800 represents the extreme dry conditions. The mathematical model of KBDI is defined by the following equations:

$$\mathrm{KBDI_t} = \mathrm{KBDI_{t-1}} + \mathrm{DF} \qquad (1)$$

While the drought factor DF could be calculated using the following:

$$\mathrm{DF} = \frac{[800 - \mathrm{KBDI_{t-1}}]\left[0.968\mathrm{e}^{(0.0875\mathrm{T}+1.5552)} - 8.30\right]\mathrm{dt}}{1 + 10.88\mathrm{e}^{(-0.001736\mathrm{R})}} 10^{-3} \qquad (2)$$

T is the daily maximum temperature (C°), R is the mean annual rainfall (mm), dt is the time increment (days) and KBDIt-1 is the Keetch-Byram Drought index for time t-1. Daily precipitation decreases the KBDI when the total of precipitation measured over 24 hours is greater than 5 mm (0.2 inches).

KBDI fire danger potential scale is divided into 5 danger levels as shown in Table 1.

Table1 KBDIFIRE POTENTIAL SCALE

KBDI Range	General Description	Forest Fire Potential
0 -150	Upper soil and surface litter are wet.	Fire potential is minimal
150 -300	Upper soil and surface litter are moist and does not contribute to fire intensity	Fire behavior is predictable
300 -500	Upper soil and surface litter are dry and may contribute to fire intensity.	Fire behavior is somewhat predictable
500 -700	Upper soil and surface litter are very dry. Surface litter and organic soil material contribute to fire intensity.	Fire suppression is a significant
700 -800	Upper soil and surface litter are extremely dry. Live understory vegetation burns actively and contributes to fire potential.	Fire behavior is unpredictable

(Dolling et al,2005) found a strong relationship between the KBDI and fire activity in the Hawaiian Islands. The strongest relationship between the KBDI and total area burned was found in the islands of Oahu, Maui and Hawaii. The Pearson correlation was also used to investigate the relationship between the KBDI and the monthly number of fires occurring on each Hawaiian island. This test was statistically significant between KBDI and the number of fires. (Ainuddin et al, 2008) In addition, Malaysia adopted KBDI software to predict forest fire risk level during the period of 1990-1995 which resulted in recording optimal results in fire prediction.

Modified Keetch Byram Drought Index.

Previous research has indicated that KBDI is not good indicator to predict forest fire in USA - Georgia and Mississippi (Cooke et al., 2007; Choi et al., 2009; Chan et al., 2004).Then it has been necessary for an improvement to be made on this model.

The improvement was proposed by (Petros et al, 2011) for use in the Mediterranean conditions after taking into account the annual rainfall parameter in this region as shown in equation (2)

$$DF = \frac{[200-KBDI_{t-1}][1.713e^{(0.0875T+1.5552)}-14.59]dt}{1+10.88e^{(-0.001736R)}} * 10^{-3} \qquad (3)$$

By setting the threshold R to 3 (mm), the modified Keetch-Byram equation is obtained:

$$Mod\ KBDI = ModKBDI_{t-1} + DF - (R-3) \qquad (4)$$

Modified Keetch Bayram can only be used in summer season when the climate is dry. This model was tested and adopted in different places in the Mediterranean. It showed more acceptable results than KBDI in forest fire prediction especially after decreasing the scale of dry condition of soil (0- 250) (Petroset al., 2011; Liao et al., 2012).

Nesterov Index

(Nesterov, 1949) created an empirical drought Index to be used in the former Soviet Union and then to establish a range of discrete fire-risk levels. This index uses synoptic daytime data of temperature, humidity and daily precipitation. Other variables such as wind speed or daily humidity are not taken in consideration in this model. The index is based on a simple mathematical model that is the weighed difference between temperature and dew point, as given in the following equation:

$$N = \sum_{i=1}^{w} Ti(TiDi) \qquad (5)$$

Where N is the Nesterov Index, W is the number of days since last rainfall greater than 3 mm, T is the mid-day temperature (°C) and D is dew point temperature (°C).

Nesterov divided fire danger potential scale into 5 danger levels as shown in Table 2.

Table2 NESTEROV FIRE POTENTIAL SCALE

Nesterov (N)	Risk Of Fire
N<300	No fire risk
301<N<1.000	Low risk
1.001<N<4.000	Medium risk
4.001<N<10.000	High risk
N>10.001	Extremely risk

The Russian Nesterov index has been adopted for use in Portugal (Camia, 2000) and Austria (Arpaciet et al, 2010) after reports of high prediction accuracy (Venevsky et al,2002) They applied Nestrov model to estimate areas burnt on a macro scale (10-100 km) in human-dominated ecosystems in the Iberian Peninsula that proved to produce realistic results, which were well correlated, both spatially and temporally, with the fire statistics. Likewise, Nesterov index was comparatively tested with KBDI in East Kalimantan, Indonesia to predict fire occurrence (Buchholz and Weidemann, 2000). In both cases it was proved applicable and a useful tool for early warning.

Angstrom index.

Angstrom index developed in Sweden in the first half of the twentieth century to predict forest fire before occurrence (Skvarenina et al, 2003). It is based on relative humidity and air temperature only. It provides an indication of the likely number of fires on any given day (Chandler, 1983).The mathematical equation is given below:

$$I = \frac{R}{20} + \frac{27-T}{10} \qquad (6)$$

Where R is the relative humidity (%), T is the air temperature (°C).

Angstrom presented his potential scale divided into 5 danger levels as shown in Table 3.

Table3ANGSTROM FIRE POTENTIAL SCALE

Fire Risk Index (I)	Risk Of Forest Fire
I>4.0	Fire occurrence unlikely
4.0<I<3.0	Occurrence unfavorable
3.0<I<2.5	Fire conditions favorable
2.5<I<2.0	Fire conditions more favorable
I<2.0	Fire occurrence very likely

Angstrom index has been used all over the Scandinavian Peninsula after recording high accuracy in forest fire map prediction; (Willis et al, 2001). (Alves White et al, 2013) found that Angstrom accuracy was 46.6% in Northern Brazil which can be an acceptable result to predict the number of fires.

Canadian Forest Fire Weather Index

The Canadian Forest Fire Weather Index (FWI) was issued in 1970. It uses four meteorological parameters: noon relative humidity; noon temperature; precipitation during 24h and the maximum speed of the average wind; (Van Wanger, 1974). The FWI System is comprised of six components: three fuel moisture codes (Fine fuel moisture code, Duff Moisture code & Drought code) and three fire behavior indexes (Initial spread index, Buildup index & Fire weather index).

The mathematical equation is given below:

$$\ln(s) = 2.72\left[0.434 \ln\left(0.1Rf(D)\right)\right] \text{^}0.647 \qquad (7)$$

If$0.1Rf(D) > 1$

$s = 0.1Rf(D)$

If $0.1Rf(D) \leq 1$

$f(D)$is the duff moisture content and R is the initial spread index. The fire potential scale of the fire weather index is listed in Table 4.

Table4 THE FIRE POTENTIAL SCALE OF FWI

FWI range	Forest Fire Potential
[0, 1.0]	Fire occurrence very low
]1.0 , 4.0]	Fire occurrence unlikely
]4.0 , 8.0]	Fire occurrence unfavorable
]8.0 , 16.0]	Fire conditions favorable
]16.0 , 29.0]	Fire conditions more favorable
<29.0	Fire occurrence very likely

The Canadian model has been tested and adopted in New Zealand, Fiji, Alaska, Mexico, Chile, Argentina and Europe. The system has many desirable traits. Also, it was found by (Viegas et al, 2001) that the Drought Code of the sub-model Forest Fire Weather Index can be used to estimate the moisture content of live fine fuel of shrub type fuels during the summer period in Central Portugal and Catalunya (NE Spain). The Drought Code of the system was also selected by (Aguado et al, 2003) to investigate the spatial correlation between meteorological fire risk indices and satellite derived variables in Andalucia, southern Spain.

Modified Nesterov Index

The Modified Nesterov index was developed in 1952, it is also known as drought index (Groismanet et al, 2005). The index is widely used in the Russian fire rating system together with the Nesterov index by taking the reduction factor (K) into consideration.

The mathematical equation is given as follows:

$$\mathrm{MNI} = \mathrm{K}\sum_{i=1}^{w} \mathrm{Ti}(\mathrm{Ti} - \mathrm{Di}) \qquad (8)$$

Where K, representing an indication of rain quantity takes the values of the Table below, in dependence of the current rainfall; its range is listed in Table 5.

Table5 K VALUE IN FUNCTION OF RAIN QUANTITY

R(mm)	0	0.1-0.9	1.0-2.9	3.0-5.9	6.0-14.9	15.0-19.0	>19
K	1	0.8	0.6	0.4	0.2	0.1	0

The Fire Risk level is classified using the following potential scale:

Table6 Modified NESTEROV FIRE POTENTIAL SCALE

Modified Nesterov	Risk Of Fire
100<MN<1000	No fire risk
1001<MN<2500	Low risk
2501<MN<5000	Medium risk
5.001<MN<10.000	High risk
MN>10.000	Extremely risk

Modified Nesterov index showed good results after being applied in Lebanon to predict the forest fire (Karouniet et al,2012). It has been comparatively tested with other indices (Keetch-Byram drought index, and Nesterov northern (Groisman et al, 2007), by testing their values versus forest fire statistics where it appeared well performing as an applicable early warning index.

Baumgartner Index

The Baumgartner Index, developed in 1967, was in use in West Germany until unification (Badeck et al, 2004).It is based on the amount of precipitation and the potential evapotranspiration (Skvarenina et al, 2003).It is calculated as follows:

$$\mathrm{BI} = \mathrm{P} - \mathrm{PE}\ (\text{Sum of 5days}) \qquad (9)$$

Where P is the precipitation (mm) and PE is the potential evapotranspiration (mm). The fire potential scale of Baumgartner index is given in Table7. It is divided into five different classes in order to classify fire risk during five stages in the first eight months.

Table7 BAUMGARTNER FIRE POTENTIAL SCALE

Fire danger clas-ses/Month(mm)	1	2	3	4		5
March	+5>	[+5,-3]	[-3,-9]	[-9,-15]		-15[
April	+3>	[+3,-8]	[-8,-16]	[-16,-27]		-27[
May	-3>	[-3,-16]	[-16,-25]	[-25,-35]		-35[
June	-12>	[-12,-24]	[-24,-32]	[-32,-41]		-41[
July	-12>	[-12,-24]	[-24,-31]	[-31,-40]		-40[
August	-8>	[-8,-20]	[-20,-28]	[-28,-37]		-37[
September	-6>	[-6,-18]	[-18,-26]	[-26,-35]		-35[
October	-6>	[-6,-18]	[-18,-26]	[-26,-35]		-35[

It was comparatively evaluated by (Skvarenina et al, 2003), with two other indices (Nesterov and Angstrom) in the Slovak Paradise National Park during two large forests fire events. In these local conditions, it rarely appeared approaching the highest fire risk levels (class 5). Also Baumgartner index evaluated in Valais (Western Alps) after recording a good result in forest fire prediction (Wastl et al, 2012).

2.7 McArthur Forest Fire Danger Index (FFDI)

Forest fire danger index (FFDI) was developed in the 1970s by A.G. McArthur to measure the degree of danger of fire in Australian forests (Sharples, 2011). The mathematical equations are given as follows:

$$\mathrm{FFDI} = 2\mathrm{e}^{(-0.45+0.978\ln(\mathrm{DF})-0.0345\mathrm{RH}+0.0338\mathrm{T}+0.0234\mathrm{U}\ )} \qquad (10)$$

Where T is the temperature (˚C), U is the wind speed (km/h), RH is the relative humidity (%) and DF is the drought factor.

The Drought factor is a measure of moisture in the fuel which is affected by rains and number of days since last rain.

Drought factor can be calculated from the following equation:

$$DF = \frac{[0.191(I+104)(N+1)^{1.5}]}{3.52(N+1)^{1.5}+R-1]} \qquad (11)$$

Where N is the number of days since last rain fall, R is the total rain in the last 24 hours (mm) and *I*is the amount of rain needed to restore soil moisture to (200mm).

FFDI fire danger potential scale is divided into 6 danger levels as shown in Table8.

Table 8 FFDI FIRE POTENTIAL SCALE

Forest Fire Danger Index(FFDI)	Risk Of Fire
Catastrophic	100+
Extreme	75-99
Severe	50-74
Very High	25-49
high	12-24
Low to Moderate	0-11

This index is the most accurst and usable index to predict forest fire danger rating in Australia (Dowdy et al, 2009), Canada (Abbott,2007), USA (Hardy et al,2007) and Europe, mainly Greece, Italy (Good et al, 2008), Portugal(Fernandes,2001) and Spain (Bisquert et al,2014).

Simple Fire Danger Index (F)

(Sharples et al, 2008) developed Simple fire danger index (F) in Australia. Fire danger rating systems combine meteorological information with estimates of the moisture content of the fuel to produce a fire danger index. This index calculated as follows:

$$F = \frac{max(U0,U)}{FMI} \qquad (12)$$

U denotes wind speed in km/h and U0 is some threshold wind speed introduced to ensure that fire danger rating is greater than zero, even for zero wind speed. *FMI* is the fuel moisture index calculated as follows:

$$FMI = 10 - 0.25(T - H) \qquad (13)$$

Simple Fire Danger Index (*F*) divided danger scale into 5 danger levels as shown in Table 8.

Table9 Simple FIRE DANGER (F) POTENTIAL SCALE

Simple Fire Danger Index(F)	Fire Risk
[0 , 0.7]	Low
[0.7 , 1.5]	Moderate
[1.5 , 2.7]	High
[2.7 , 6.1]	Very High
I>7	Extreme

This index showed a good performance in prediction after testing it in Austria (Alexander et al., 2013; Switzerland Angelis et al., 2015). While it showed a limited performance in Italy (Donatella, 2012).

Fire danger index (FD)

(Martin et al, 2014) proposed a new fire danger index related to Czech Republic to predict forest fire danger. This fire danger index is based on combination between meteorological information and soil moisture.

This index has been activated from 15th of March to 15th of October calculated as follows:

$$FD = \frac{(b1U - b2F)}{(b3T - b4H)} \qquad (14)$$

Where T the air temperature in (°C), H the air humidity (%), U is the wind speed in m/s, F is the soil moisture(%), and b1, b2, b3, b4 are coefficients to be estimated.

The fire danger potential scale of Simple Fire Danger Index (*FD*) is divided into 6 danger levels as shown in Table 10.

Table 10 FD FIRE POTENTIAL SCALE

***FD* Range**	**Fire Danger Classes**
Very Low	< 0.9
Low	0.9 – 1.7
Moderate	1.7 – 3.0
High	3.0 – 6.0
Very High	≥ 6.0

FD was adopted in Germany and Sweden and recorded good results in predicting forest fires,(Martin et al, 2015).

Place of Study

Lebanon is part of the Middle East, located at approximately 35˚N; 35˚. The area of the Lebanese Republic is 10452 Km2, divided into five regional administrative districts: Beirut, North Lebanon, South Lebanon, The Beqaa and Nabatiyeh. Its weather is generally mild. In winter, it is cool and wet, while in summer it is hot and dry. During the last several decades, green and forest areas declined rapidly in the country. This created an urgent need for intervention which requires strict governmental policies and support of non-governmental organizations as well.

Table11 shows a summary of the collected data, the obtained maximum and minimum values and the correlation of each parameter with fire occurrence. The effect of each weather attribute on the occurrence of fire is shown in the following graphs. North Lebanon Governorate is the most affected place by fires in the country.

The meteorological data are provided by LARI station located in Kfarchakhna city. Kfarchakhna is a city which lies about 220 meters above sea level, 25 kilometers from the Mediterranean Sea and about 80 kilometers north of Beirut. The distribution of fires over the six years taken for our study is shown in Fig.1.

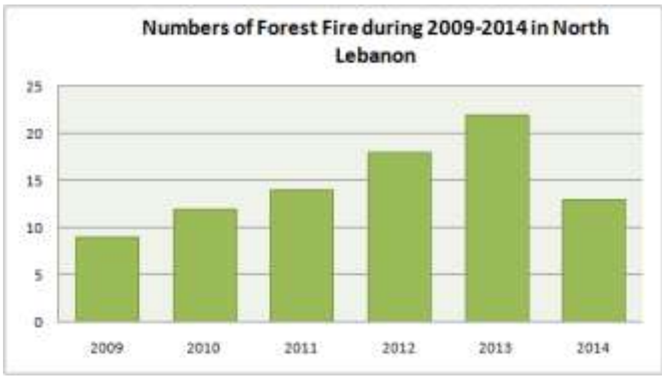

Fig. 1. Numbers of Forest Fire over the period 2009-2014.

Data Analysis to Identify the Influential Parameters

Meteorological factor such as dew point, soil temperature, air temperature, humidity, precipitation and wind speed have a major impact on the occurrence of forest fires as these climatic factors change with time and space rapidly (Liu et al, 2015), we can't ignore the effect of the relationships among the involved parameters.

To predict a forest fire, we should find the effective parameters that facilitate fire occurrence. In our study we use the regression analysis to find the influential meteorological parameters that affects fire occurrence.

In this work, attributes such as temperature, Humidity, dew point, soil temperature in the upper layer, wind speed ,and precipitation in function of fire occurrence during the 6 years (2009-2014) have been analyzed. During the last 6 years, there were 2095 days with No fire and 94 days with fire. To balance the data, we multiplied the number of days with fire by 22 to have 2068 days with fire and 2095 days with no fire as shown in Table 11.

Table11 Correlation Coefficient of Studied Parameters with Fire Occurrence

Parameters	Total Number of Days	Days with No Fire	Days With Fire	Correlation Coefficient	Maximum	Minimum
Temperature (°C)	4163	2095	2068(94days presented 22 times)	0.72	37.36	0.75
Relative Humidity (%)	4163	2095	2068(94days presented 22 times	0.02	93	34
Dew Point (°C)	4163	2095	2068(94days presented 22 times	0.61	23.25	-5.7
Precipitation (mm)	4163	2095	2068(94days presented 22 times	0.19	53.2	0
Soil Temperature (°C)	4163	2095	2068(94days presented 22 times	0.65	54	8.18
Wind Speed (m/S)	4163	2095	2068(94days presented 22 times	0.21	29.9	0.9

Temperature

Temperature is the average kinetic energy of motion exhibited by the atoms and molecules composing a substance and is important in determining the ease of combustion of wildland fuels. It is this heat energy that is crucial in beginning the evaporative phase of combustion (Johnson et al, 2001). Therefore, higher temperatures heat forest fuels and predispose them to ignition provided that an adequate ignition source becomes readily available.

In Fig.2, we normalize the following data (0-1) to show the effect of temperature on forest fire occurrence. It shows that as temperature increases fire danger increases (during the six years). This reveals that there is a high positive correlation of 0.72 between temperature and fire occurrence.

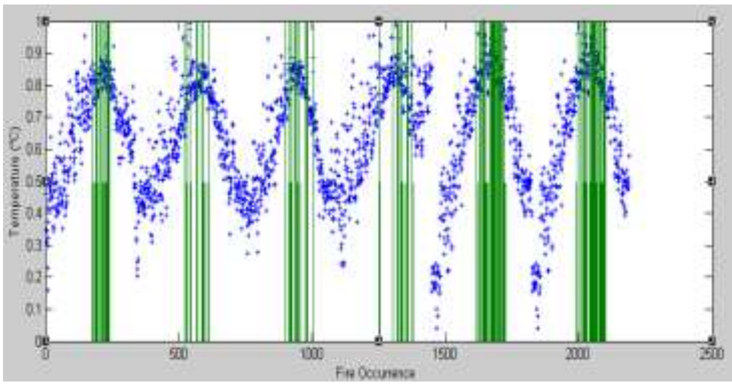

Fig.2. Temperature (°C) in function of Fire Occurrence .

Relative Humidity

Relative humidity is an expression of the amount of moisture the air is capable to hold at that temperature and pressure. Preferred relative humidity for prescribed under burning varies from 30 to 55 percent (Sosebee et al, 2007).When relative humidity falls below 30 percent, prescribed burning becomes dangerous (Eric et al, 2009).

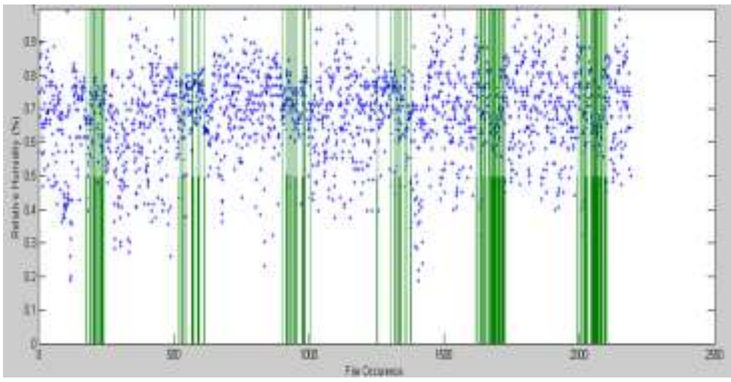

Fig.3. Relative Humidity (%) in Function of Fire Occurrence **.**

The effect of relative humidity on fire occurrence is not clearly shown in Fig.3 where the fire occurrence accidents occurred where relative humidity ranged from 45 to 90 %.Fig.3 shows allow correlation of 0.02 between relative humidity and fire occurrence.

Dew Point Temperature

The dew point temperature is the temperature at which the air can no longer hold all of the water vapor which is mixed with it, and some of the water vapor must condense into liquid water. The dew point is always lower than (or equal to) the air temperature (Kenneth et al, 1999).

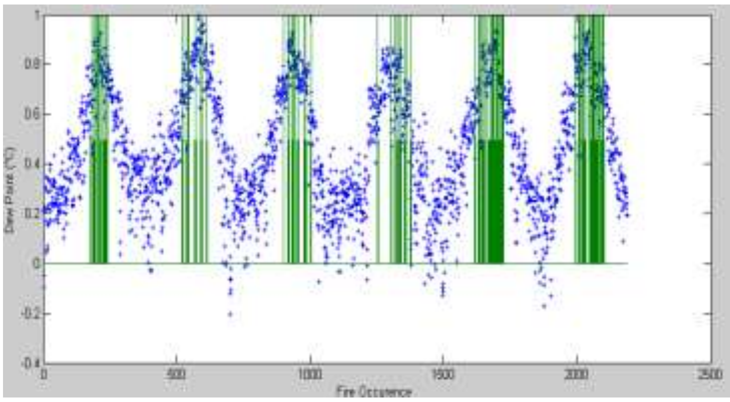

Fig. 4. Dew Point in function of Fire occurrence .

Fig.4 views the dew point in function of fire occurrence. As the dew point rates increase, the danger of fire increases drawing a high correlation coefficient of 0.61.

Soil Temperature

Soil is affected directly by the air temperature and sun radiation absorbed by the micro substances between layers (Theresa et al, 2008).It has been assumed that high temperatures affect seedlings, first, by increasing evaporative demand, and second, by direct tissue damage where seedlings are in contact with hot surfaces which increase the drought in soil and increase the chance of fire occurrence (Hälgren et al, 1991).

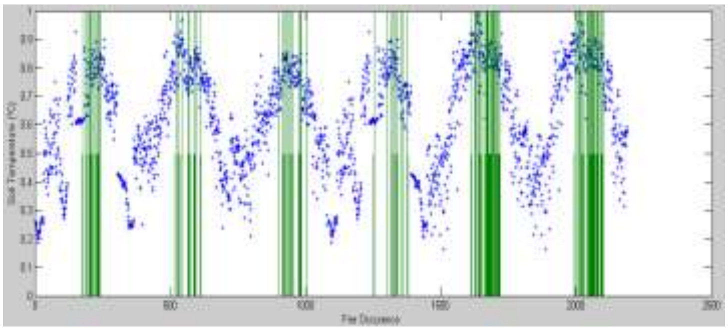

Fig.5. Soil Temperature in function of Fire Occurrence .

Fig.5clearly shows the effect of soil temperature on fire occurrence. Fire danger increases with the increase of soil upper layer temperature. The high correlation recorded is 0.65.

Wind Speed

Wind is among the most important influences on wild land fire. Fire behavior is strongly affected by wind speed and direction, which vary in time at the scale on the order of hours, minutes, and even seconds (Rothermel,1972).But it has limited effect on burning process (pre-fire) (Avis Bar et al., 2011;Dennison et al., 2008).

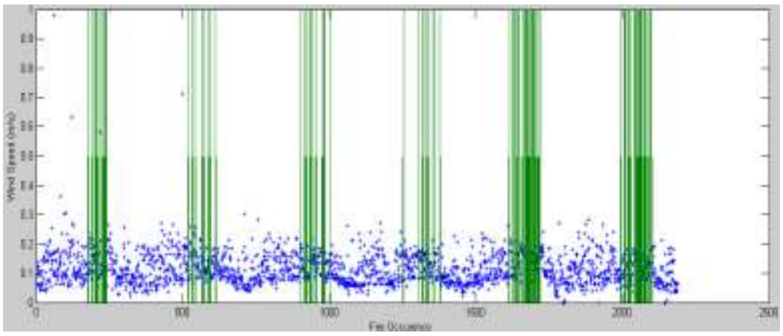

Fig. 6. Wind Speed (m/ s) in function of Fire Occurrence.

Fig.6 shows weak correlation between fire occurrence and wind speed (low correlation of 0.21)

Precipitation

Precipitation includes all of the moisture that falls from the atmosphere and reaches the earth's surface. It can have a negative effect on fire occurrence. Several previous studies have focused on the highly non linear nature of precipitation and fire occurrence in the region; severe fire happens only below a threshold (>1mm) of seasonal precipitation (Field et al., 2004, 2009; Van Werf et al, 2008; Field et al , 2008).

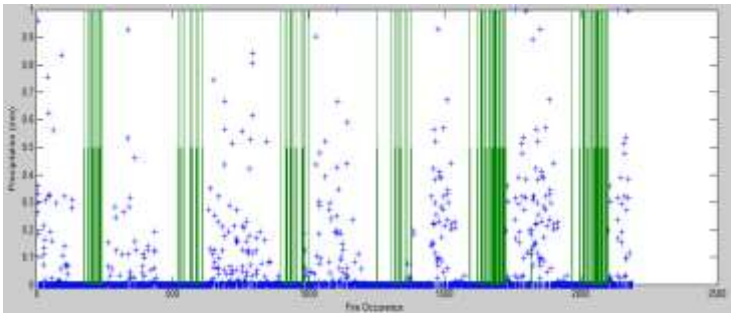

Fig.*7. Precipitation (mm) in function of Fire Occurrence*

After analyzing Fig 7, 80% of fire occurrence was reported when the precipitation was less than the threshold but as a theory the correlation recorded 0.19 which means that there is low correlation. Based on the obtained correlation coefficients, it is demonstrated that temperature, dew point, upper layer soil, temperature are strongly correlated with fire occurrence, and thus they are selected to build the desired early warning model.

APPLYING other correlative data analysis

Several correlation coefficients based on different statistical hypothesis are known and are most frequently used today. They are Pearson correlation coefficient, Spearman rank correlation coefficient and Kendall rank correlation coefficient (Atila et al, 2011).

Pearson’s correlation is a parametric test used to measure the degree of relationship between the two linear related commodities (Jan et al, 2011)assuming that data is normally distributed about the regression line while Spearman and Kendall rank correlations are non-parametric tests used to measure the degree of association and strength between two variables (Jacqueline, 2013). Spearman and Kendall are computed on ranks and so depict monotonic relationships. In our case, we have a lot of numerically equal observations. The fire occurrence column is represented by zeros and ones only, then an arithmetic average of the rank numbers associated with the ties are assigned to the values of the variables. The two rank correlation techniques have alternative formulas to deal with ties.

Various studies have conducted Spearman-Rank, Kendall Tau, and Pearson correlation coefficients. Pearson correlation showed a limited and non-satisfactory correlation in different studies (Wilcox.,2001;Rasmussen.,1989;Dunlup et al 1995)while Spearman and Kendall rank correlation coefficient are the next most commonly utilized approaches in practice(Good,2009;Jacqueline,2001). However, the relative performance of these different methods needs to be explored further.

Table 12 Pearson, Spearman & Kendall Correlation coefficients between fire occurrence & weather Parameters

Parameters	Minimum	Maxim-um	Days With Fire	Days With No Fire	Total Number of Days	p-value	Pearson Correlation Coefficient	Spearman's Correlation Coefficient	Kendalltau Coefficient Correlation
Temperature (˚C)	0.75	37.6	2095	2068(94days presented 22 times)	4163	~0	0.639	0.6748	0.7093
Relative Humidity (%)	34	93	2095	2068(94days presented 22 times)	4163	1.29625x 10^-39	-0.2021	-0.2031	0.0199
Dew Point (˚C)	-5.7	23.25	2095	2068(94days presented 22 times)	4163	~0	0.5767	0.5517	0.6007
Precipitation (mm)	0	53.2	2095	2068(94days presented 22 times)	4163	2.15909x 10^-41	-0.2067	-0.2574	-0.2655
Soil Temperature (˚C)	8.18	54	2095	2068(94days presented 22 times)	4163	~0	0.6071	0.6231	0.6951

The three methods are applied to examine the relationship between fire occurrence and each meteorological parameter and the strength of such association. Pearson's correlation is the most widely used and common measure of correlation, but the fact that it requires some assumptions and uses the actual values instead of ranks which restricts its applicability and efficiency as well. According to Cohen's standard, coefficients above 0.5 represent a large association. After analyzing Table 12, it can be noticed that all obtained p-values are less than the chosen significance level α=0.05 which means that desired outcome from statistical correlations attain statistical significance, thereby rejecting the null hypothesis. It can be seen that Pearson's and

Spearman's correlation coefficients are close to each other. The slight predominance of Spearman coefficients over those of Pearson shows that the relationship is monotonic more than it is linear. Knowing that Kendall's Tau correlation is more resistant to tied data, Kendall's Tau-b is used and it retrieves better coefficients than the other statistical techniques.

The three methods relatively show good correlations between fire occurrence and Soil temperature, Dew point and Temperature respectively while the other parameters (Humidity, precipitation and wind speed) record limited weak association. These findings go along with the results obtained by regression technique.

Finding the relationships among affective parameters to derive Lebanese Index

Before going through elaborating the index, it is necessary to find the relationships between the vital parameters, which are temperature (°C), soil temperature (°C) and dew point (°C) using the same datasets coming from 2189 days .

Our data were normalized between 0 and 1 to reduce redundancies.

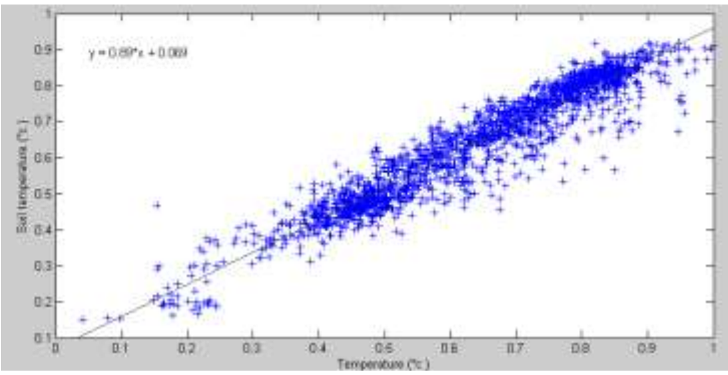

Fig.8. The relationship between Temperature (°C) and

Soil Temperature on the upper layer (°C).

Fig.8 shows the strong relationship between temperature (°C) and soil temperature (°C) over the 2198 days after recording a high positive correlation between the two parameters (correlation=0.961). As shown in the figure, a linear equation with positive slope describes the relation-ship between both attributes.

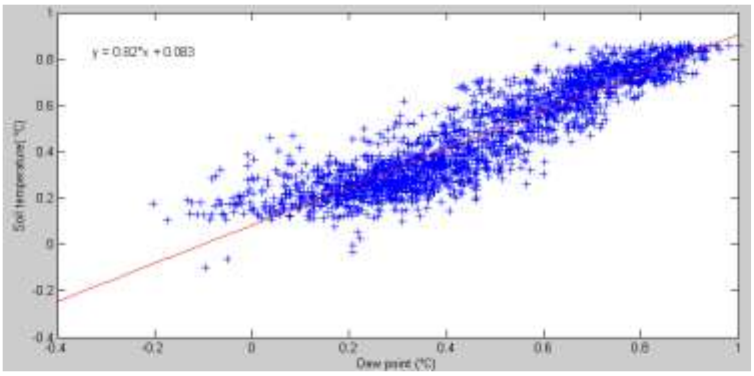

Fig.9.The relationship between Dew Point (°C) and

Soil Upper Layer Temperature (°C).

Fig.9. shows the relationship between dew point (°C) and upper layer soil temperature (°C) over the six years. We can notice that as dew point varies, the soil temperature varies in the same direction deriving a high positive of 0.894.

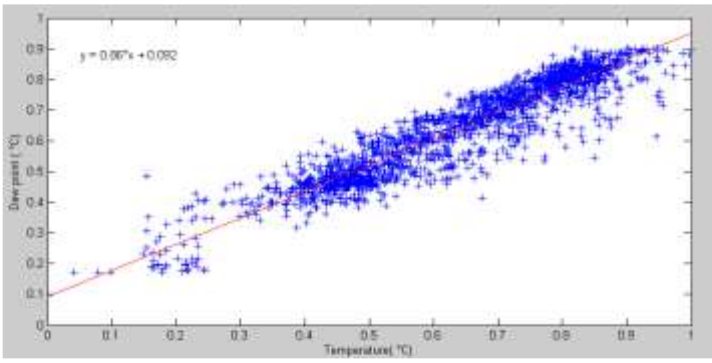

Fig.10. The relationship between Temperature (°C) and Dew Point (°C).

Similarly, Fig.10 displays the linear interpolation showing the strong relationship between temperature (°C) and dew point (°C) over the 2189 days. As temperature increases, the dew point increases. The reported correlation coefficient is 0.937. Based on the above; the three elected parameters show strong mutual correlations among them-selves (Table13).

Table13 Mutual Correlations among Elected Parameters

Parameters	Correlation	Linear Equation
Temperature & Soil Temperature(°C)	0.961	Y = 0.89X + 0.069
Temperature & Dew Point(°C)	0.937	Y = 0.86X + 0.092
Dew Point& Soil Temperature(°C)	0.914	Y = 0.82X + 0.083

The entire interpretation results show that fire occurrence is mainly affected by three attributes (temperature, dew point and soil upper layer temperature) among the familiar six attributes that we used in our study. Out of these factors, temperature is the easiest to measure using simple apparatus. Dew point can be obtained in the same manner but with a little bit more advanced tools which commensurate with the situation of Lebanon and other developing countries.

Dew point temperature can be calculated using Equations15& 16 (Snyder et al, 1984):

$$B = \frac{\ln(\frac{RH}{100}) + \frac{17.27*T}{237.3+T}}{17.27} \qquad (15)$$

$$D = \frac{237.3*B}{1-B} \qquad (16)$$

Where T is the air temperature (Dry Bulb) (°C), RH is the relative humidity (%), B is an intermediate value (no unit) and D is the dew point (°C) .

On the other hand, soil temperature (w/m2) depends on heat flux and heat conduction for soil upper layer. Its equation is shown in Equation 17(Thomas et al, 2005).

$$Rn - G = LE + H \qquad (17)$$

Where Rnis the net radiation, G is the soil heat flux density at the soil surface, and LE and H are the latent and sensible heat flux densities, respectively (All in w/m2).

The new simplified model that fits developing countries and their affordability is then the summation of the three picked out parameters (T, D, and S) taking into account the strength of correlation of each parameter with the desired output; as shown in equation 18.

$$\mathrm{I} = 1.18\mathrm{T} + 1.07S + \mathrm{D} \qquad (18)$$

Where I is the fire danger index, D is the dew point (°C), T is the temperature (°C) and S is the soil temperature (°C).

RESULTS AND INTERPRETATIONS

The Index was applied on the year of 2015 at Kfarchakna city which was used in our study. The sum of the three parameters is calculated over the 365 days to examine the performance of the new Lebanese index against the 15 fires which occurred during this period.

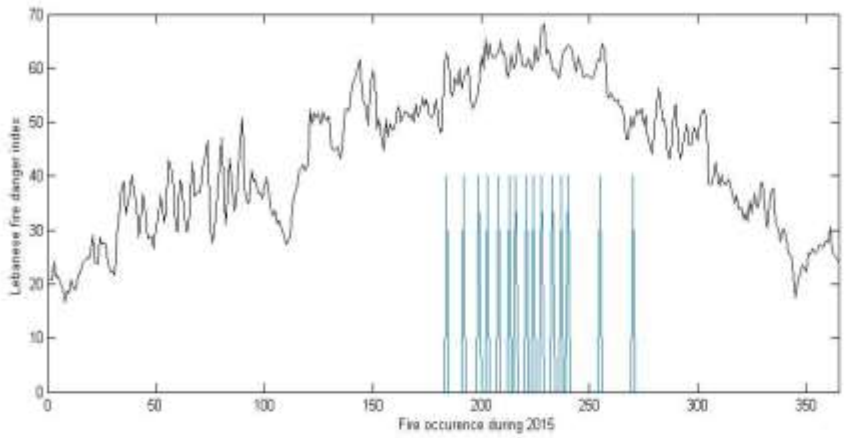

Fig.11. Validation of Fire Danger Index in function of Fire Occurrence

Fig.11 displays the Lebanese index in function of the number of fires. We can notice that when the Lebanese index increases, the fire risk increases especially in summer season when the outlet of Lebanese index is greater than 45. Contrary, there is no risk when index is less than 15.

Here we can state the risk range of our proposed index as shown in Table14.

Table14New Index Potential Scale

Index	Fire Risk
0<I<15	No Fire
15<I<30	Low Risk
30<I<45	Medium Risk
45<I<60	High Risk
I>60	Extremely High Risk

After stating its potential scale, we test the Lebanese index over the 365 days of the year 2015 at Kfarchakna city. In order to reach our goal of validation, our index is assumed to predict the occurrence of fire when values corresponding to high and extremely high fire risks are achieved. Certain measures are used for testing and evaluation. The values of True Positive (TP), False Positive (FP), True Negative (TN) and False Negative (FN) are computed to calculate Precision, Accuracy, Specificity, Sensitivity and AUC; Area under the curve of receiver operating characteristic (ROC) as shown in Table 15.

Table15 Measurements of Precision, Accuracy, Specificity, SENSITIVITY, KAPPA and Auc for Lebanese Index

TP	TN	FN	FP	Precision (%)	Accuracy (%)	Specificity (%)	Sensi-tivity (%)	Kappa (%)	AUC (%)
12	328	0	25	25	93	93	100	92	93

In the field of forest fire prediction, TP and FN tend to be the most important parameters that would affect negatively on the index decision, while FP and TN are less significant. Human beings lives, their properties and the environment are much more valuable than the costs that could be spent on preventive measures in case of false alarms. Thus in our case study, AUC and Sensitivity found to be the most critical measurements for an adequate evaluation, as both formulas depend on TP and FN (Karouni et al, 2014). The computed sensitivity (100%) , AUC (93%) and Kappa (92%) are very high while the precision is low (25%). The low precision is caused by small dataset used for testing (only 15 fires out of 365 days) (Anuj et al, 2012).

To better examine the performance of our index, the mean square error MSE is calculated using Equation 19:

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(Y_i - y_i)^2) \qquad (19)$$

Yi and misrepresent the predicted value of the new index and real value of the day *i* respectively. Yi and yi can take the values 0 when no fire is detected and 1 in case of fire.

The obtained MSE for the year 2015 equals 0.087, which is very good while dealing with the discrete values 0 and 1 only.

Fire Danger Indices	Place Of Study	Year Of Study	Characteristics Of Place Of Study	Parameters Used	Model Characteristics	Tested and Adopted Places
Angstrom	Sweden	1949	Polar Climate, high precipitation and humidity	Temperature and Humidity	Daily Empirical Index, Easy to measure.	Sweden, Germany
Nesterov	Russia	1967	Polar Climate, high humidity	Dew Point and Temperature	Cumulative index, easy to measure.	Slovakia, Germany
M-Nesterov	Russia	1968	Polar Climate, high humidity	Dew Point and Temperature	Cumulative index, easy to measure.	Russia and Canada
KBDI	Southern United States	1968	Hot and dry weather in summer with high humidity	Temperature and mean annual rain fall	Cumulative index, Hard to measure.	United States, Australia, Indonesia
Baumgartner	Germany	1967	High precipitation cold and cloudy weather in winter	Precipitation and evapotranspiration	Cumulative index, easy to measure.	Germany
M-KBDI	Greece	2011	Mediterranean weather (Mild)	Temperature and mean annual rain fall	Cumulative index, Hard to measure.	Greece, Indonesia, Malaysia
FWI	Canada	1970	Wet and high precipitation in summer , very cold in winter	Temperature , relative humidity and precipitation	Cumulative index, Hard to measure.	Canada, Chine, Chile, Fiji, Indonesia, Malaysia ,Mexico, New Zealand, Portugal, South Africa, Spain, Sweden, Thailand, United Kingdom, Argentina
FFDI	Australia	1970	High precipitation and high humidity in summer	Precipitation, relative humidity, temperature and wind speed	Cumulative index, Hard to measure.	Australia, Italy, Spain , USA , Portugal , Greece and Canada
Simple Fire Danger(F)	Australia	2008	High precipitation and high humidity in summer	Temperature and relative humidity	Cumulative index, easy to measure.	Australia and Switzerland

FD	Czech Republic	2014	Warm and dry in summer , cold in winter with high wind speed	Relative humidity , temperature, wind speed and soil moisture	Cumulative index, easy to measure.	Czech Republic , Germany and Sweden
Lebanese Fire Danger	Lebanese Republic	2016	Mediterranean weather (Mild)	Temperature ,Dew point and soil temperature	Cumulative index, easy to measure.	Lebanon

Table 16 Fire danger indices Characteristics

Upon analyzing Table 16, we can deduce that Air temperature, relative humidity and wind speed have been used as inputs in several fire risk systems to estimate meteorological risks. While the potential evapotranspiration parameter (Baumgartner index), soil temperature (Lebanese index) and soil moisture (FD) were ignored in most fire indices.

All the above indices mentioned the effect of climate indirectly on drought using precipitation, evapotranspiration, soil temperature, soil moisture and rainfall due to complexity of drought (Heim, 2002). Hence, the Lebanese index claims to take into consideration the influence of drought.

In addition, each index is built on the available climate that is related to its own place of study, which affect directly on fire occurrence. Cold places have high rainfall and humidity over the year (Kevin, 2005), while the Mediterranean and hot places have high temperature and dry summers.

As it is known, fire danger indices are divided into two categories; cumulative and daily indices. Most of the indices are cumulative and follow a similar pattern in their evolution over time; they increase steadily in the absence of rain and go back to zero when rain occurs. A cumulative index, due to its cumulative concept, presents especially high values during the end of September like KBDI (Spano et al, 2005), whereas fire activity is normally reduced, due to atmospheric conditions. This limitation doesn't exist in the daily Lebanese Index.

Baumgartner and simple fire danger index have limitations on forest fire prediction over the year (9 months) as their potential scales have maximal end to reach and beyond they are unable to predict, while the other indices involving the Lebanese Index have no upper limit to predict.

The Nesterov Index, by definition, falls down to zero if we have more than 3 mm precipitation which makes it a weak index (Buchholz et al. 2000). As precipitation is ignored by the Lebanese Index, then this condition is not attributable and the corresponding weakness is avoided.

While the Canadian fire weather index (FWI) and the Australian weather index (FFDI) are the most usable indices in the world (Andrew et al., 2008; Stuart, 2008; Lianli et al., 2014) due to their high accuracy and absence of constraints in forest fire prediction decision, the Lebanese index claims the absence of constraints in its application.

Among the studied indices, only two have been developed in the Mediterranean region: M-KBDI (Greece) and our Lebanese Index. Factors including field capacity (200mm) and R-threshold (3mm) were changed in the modified version of M-KBDI to adapt to the Mediterranean conditions. It has been tested and accepted in many countries (Greece, Italy and Spain).

It has proven its efficiency in Lebanon as well (Karouni et al, 2014). The Lebanese Index, in turn, derived its equation from the correlations between weather data taken from the Mediterranean country.

CONCLUSION AND FUTURE WORK

Lebanon's green areas are in a critical situation because it is close to losing up to 90% of it. For this reason, this study focuses on the effects of six meteorological data on fire ignition during the last 6 years in North Lebanon. The study found out that three parameters (Temperature, Soil Temperature and Dew point) are the most influential ones that induce fire occurrences. These parameters show a good correlation with fire occurrence, while the other parameters (Humidity, precipitation and wind speed) demonstrate limited weak correlations with fire occurrence. In order to find a new index that could fit Lebanon's situation, we have studied the mutual association among the weather data themselves. The research has found linear regression relationships between the selected vital parameters and the number of fires. Based on this finding, the new index is created. Other widely used correlation techniques were applied (Pearson, Spearman and Kendall), and the results show compliance with those obtained by regression.

Validation of the Lebanese Index shows conformity between the index predictions and the real fire occurrences after testing over the year 2015.Good results were recorded upon finding mean square error (0.087), sensitivity (100%), AUC (93%) and Kappa (93%). Accordingly, we can implement this new early warning index which is based on three meteorological parameters and can be simplified into two parameters that are easy to collect in the developing countries of the Mediterranean. The purpose of this index is to support the Lebanese republic to fight against fire occurrences.

The new index can be easily adopted by the Lebanese government and other parties concerned in forest management to define the forests; most prone to fires; and declare them as natural reserves. The next step that should be taken is to apply the index on daily basis through reporting and recording the observations. This will allow placing these susceptible areas under controlled surveillance especially after determining the proactive measures to deal with different expected fire scenarios. These preliminary actions constitute a danger-level specific policy and a first action necessary to foresee and thus tackle significant fire activity.

Further and additional work should be done in order to raise awareness about the relationships between meteorological and man-made fires along with showing stronger signals between them. Although the case study presents some important findings with respect to such relationships, it would be appropriate to collect more data on fire incidents, including other factors of topography, such as elevations, and those of vegetation, such as soil moisture content and fuel load. This would facilitate more robust findings that would help to improve the function of fire danger index.

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