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Case study

Using correlative data analysis to develop weather index that estimates the risk of forest fires in Lebanon & Mediterranean: 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. In this paper, to enable a prevention mechanism, we rely on analytics to build a novel fire danger index model that predicts the risk of a developing fire in north Lebanon. We use correlation methods such as statistical regression, Pearson, Spearman and Kendall's Tau correlation to identify the most affecting parameters on fire ignition during the last six years in north Lebanon. The correlations of these attributes with fire occurrence are studied in order to develop the fire danger index. The strongly correlated attributes are then derived. We rely on linear regression to model the fire index as function of a reduced set of weather parameters that are easy to measure. This is critical as it facilitates the application of such prevention models in developing countries like Lebanon. The outcomes resulting from validation tests of the proposed index show high performance in the Lebanese regions. An assessment versus common widespread weather models is then made and has showed the significance the selected parameters. It is strongly believed that this index will help improve the ability of fire prevention measures in the Mediterranean basin area.

1. 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 kinds of natural disasters a complex phenomenon to tackle.

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 [29,17]. 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

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have serious consequences on the local environment and boosts global climate change through emission of long-lived greenhouse gases and physical changes in vegetation structures [16,44]. According to a recent study by Van der Werf et al. [42], 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 Mediterranean which has been facing the threat of fires in the last decades. Lebanon is considered one of the most affected areas in this 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 [25]. To conduct this research, North Lebanon is an appropriate place to be studied where 94 fires have been reported during the last 6 years (2009 and 2014).

In recent years with climate change, Lebanon has become more susceptible to fires. Previous research applied artificial intelligence based methods. Sakr et al. [33] used two parameters only: relative humidity and cumulative precipitation and showed the ability of support vector machine (SVM) and neural networks (NN) to precisely predict the possibility of fire/no fire. Likewise, a preliminary work on a system of remote sensing was designed by [13] for prediction of forest fires and rapid fire detection. The system consists of sensors, a weather station and a website. The sensors with the weather station are able to discover different environmental conditions and retransm it them on the website where SVM and NN are combined to predict the estimated area of fire. These contributions didn't present a quantitative weather index. This is the first time such a model is developed to analyze forest fire risk in Lebanon.

The main purpose of this paper is to have an early warning index that contributes to reducing forest fires occurrence. An overall outlook has been first made on the most powerful and influential meteorological indices. The area and data under scope are then described. Thereafter data analysis techniques are used to identify the most affecting attributes on fire occurrence and derive the equation of the new Mediterranean index. The performance of the obtained model is tested at last.

2. General literature review

2.1. Overview of widely used weather fire indices

Fire danger rating is a fire management system that incorporates the aspects of selected fire danger attributes into numerical or qualitative indices [8]. Fire danger rating systems are used by fire fighters to determine the risk level of fire occurrence, and thus provide appropriate scale for managing such crisis. These systems are based on historical metrological parameters to assess fire danger, calculated as numerical indices. A list of popular fire management systems is presented: Angstrom, Nesterov, Modified Nesterov, Keetch Byram Drought Index (KBDI), Modified Keetch Byram Drought Index (M-KBDI), Canadian Forest Fire Weather Index, Baumgartner Index, Simple Fire Danger Index and Fire danger index (FD). In what follows, we present an overview on three indices among them that have been adopted in the Mediterranean region.

2.1.1. Modified Keetch Byram drought index

Previous research has indicated that KBDI is not good indicator to predict forest fire in USA—Georgia and Mississippi [10,9,7]. Then it has been necessary for an improvement to be made on this model.

The improvement was proposed [31] for use in the Mediterranean conditions after taking into account the annual rainfall parameter in this region as shown in Eq. (1)

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

Where DF is the drought factor, T is the daily maximum temperature (°C), R is the mean annual rainfall (mm), and KBDIt-1 is the Keetch-Byram Drought index for time t-1. Daily precipitation decreases KBDI when 24-hprecipitation is greater than 5 mm (0.2 in.).

$$Mod\ KBDI = ModKBDI_{t-1} + DF - (R - 3) \tag{2}$$

Where *ModKBDI* represents the modified Keetch-Bayram drought index if and only if there is any rainfall greater than 3 mm.

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 dry condition scale of soil (0–250) [28].

2.1.2. 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 24 h 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 equations of FWI are given below:

$$B = 0.1Rf(d)$$

Where B is the B-scale of FWI readjusted by the factor 0.1, R is the rainfall (mm) and $f(d)$ is the fuel availability (ft^2). The final S-scale FWI is given bellow:

$$\ln(s) = 2.72[0.434\ln B]^{0.647}$$

The fire potential scale of the fire weather index is listed in Table 1.

The Canadian model has been tested and adopted in New Zealand, Fiji, Alaska, Mexico, Chile, Argentina and Europe. The system has many desirable traits. In addition Viegas et al. [43] found that DC of the sub-model of Forest Fire Weather Index can be used to evaluate the moisture content of live fuel during the summer period in Central Portugal and Catalunya (NE Spain). The Drought Code of the system was also selected by Aguado et al. [1] to investigate the spatial relation between meteorological fire risk indices and satellite derived variables in Andalucia, southern Spain.

2.1.3. Simple fire danger index (F)

Sharples et al. [35] 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:

$$F = \frac{\max(U0, U)}{FMI} \tag{4}$$

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:

$$FMI = 10 - 0.25(T - H) \tag{5}$$

Where FMI is the fuel moisture index, T is the temperature (°C) and H is the relative humidity (%).

Simple Fire Danger Index (F) divided danger scale into 5 danger levels as shown in Table 2.

This index showed a good performance in prediction after testing it in Austria [2]. While it showed a limited performance in Italy [12].

2.2. Current state of play in Lebanon

Further to AFDC, about 1500 ha of Lebanese woodland is affected by fires every year. Severe fires often lead to serious consequences. A shift is required towards more pandemic, inter-sectoral approaches to forest fire management in aspect, implementation, recovering and monitoring. The joint efforts between concerned ministries, donors and NGOs lead to the proposal of a forest fire fighting strategy and a reforestation plan in 2009. The forest fire management strategy has been adopted by the Council of Ministers, but unfortunately lacks necessary funds and resources for valid implementation. Regrettably, institutions of public sector do not have an allocated budget for risk reduction, as Lebanon is under large deficit and deficits are going higher; hence crisis risk reduction is not a governmental priority. Particular initiatives could work in this regard but couldn't solely fill the void. AFDC has launched a project to plant one million trees as a part of the strategy of both Ministry of Environment and Ministry of Agriculture to increase Lebanon's green areas from 13 to 20%, supported by the private sector.

In the last decade, the Civil Defense and through the cooperation of Active NGOs (AFDC) and the National Council for Scientific Research (CNRS)-Remote Sensing conducted various projects for mapping forest fires risk potentiality and building relevant geo-database. The UNDP also supported a national media campaign that aims to raise awareness on forest fires and the significance of taking actions to reduce risks through the Disaster Risk Management Unit. The campaign is a joint partnership with the Ministry of Interior, Ministry of Agriculture, and Ministry of Environment, AFDC, USAID and others.

The Civil defense in corporation with CIMA Research Foundation, founded by the Italian Civil Protection Department, provides municipalities, farmers and related Ministries with a set of tools for fire hazard mapping, fire danger early warning system and diffusion model useful to manage a fire risk. RISICO model has been implemented in Lebanon since 2011 enabling local civil defense to issue a daily bulletin for the prediction and prevention of forest and rural fires. The system RISICO is being updated using near-real time satellite imagery based data in cooperation with the CNRS-Remote Sensing Center [27].

Table 1
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

Table 2
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

The RISICO provides Italian Civil Protection Department (DPC) with daily wildland fire risk forecast maps of the entire Italian territory since 2003. The RISICO system comprises a complex software architecture relying on a framework able to conduct geo-spatial and temporal information like real time weather observations and satellite data. Semi-physical models are implemented within the model taking into account the variability of the fuel moisture content. This factor is the most influential on the ignition of a fire. Relying on this parameter and benefiting from parameters of topography, vegetation and wind, the model generates the rate of spread and linear intensity of a potential fire caused by accidental or intentional ignition. The model outputs are represented in a GIS environment. Some improvements have been made to the model's structure and functionality in 2007. In order to validate the RISICO system, a data set of more than 11,000 wildland fires that took place in Italy in the years 2007–2008 has been considered. The system effectiveness relevant to the capability of identifying the correct danger classes with reference to the extension and duration of the fire has been tested and it is found that the model is able to integrate the main fire danger indexes present in Literature and thus providing an appropriate tool for identifying the different indexes in different territorial and climatic conditions. RISICO serves to be used as an integrated approach to wildland fires management both during the phases of prevention and firefighting.

The RISICO system has been used by Civil Defense in Lebanon to develop the fire risk bulletin that aims to inform involved parties about Likelihood of a fire occurring in a particular area. The fire risk alert is the result of the hard labor and collaboration between the Italian Cooperation, CIMA foundation and local Lebanese partners such as the civil defense, LARI, the Shouf Cedar Nature Reserve and AFDC. The bulletin relies on static and dynamic information to give daily predictions of Likelihood of forest fire occurrence in any given Lebanese locality. Static data includes the land topography, soil type, land cover, elevation, etc. whereas dynamic data includes changing weather patterns such as precipitation, wind speed, temperature, cloud cover, etc. The bulletin started as a general alert system lacking the fine-tuning needed to organize efforts on local-municipal level. Later on, the alert was refined and developed into an easy tool with clear representation of the color legend. The refined version allows each municipality and local Civil Defense center to coordinate efforts in case of high fire risk.

The fire danger index is obtained as the weighted average of FWI where a long and complicated algorithm is followed to estimate the output. Unfortunately, the obtained index was not calibrated by the Italian representatives in Lebanon because of the lack of opportunities to monitor and report fire accidents occurring in Lebanon. For this reason the same thresholds calibrated in Italy were applied. The Italian thresholds were defined on the basis of the fires occurred in Italy in the period 2007–2011. This leads to being overestimated upon application in Lebanon. Thus actually the bulletin cannot be considered as the optimal index for Lebanon.

3. Place of study and data

Lebanon is part of the Middle East, located at approximately 35°N; 35°. The area of the Lebanese Republic is 10,452 Km^2, 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.

Table 3 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.

Table 3
Correlation coefficient of studied parameters with fire occurrence.

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

The meteorological data (temperature, soil temperature, relative humidity, wind speed, precipitation and dew point) are provided by Lebanese Agriculture Research Institute, LARI collected from their station located in Kfarchakhna city. The inputs for 6 years (2009–2015) are undertaken for study. Data prior to 2009 are unfortunately not available. Kfarchakhna is a city which lies about 220 m above sea level, 25 km from the Mediterranean Sea and about 80 km north of Beirut. The distribution of fires over the six years taken for our study is shown in Fig. 1.

4. Data analysis to identify the influential parameters

4.1. Linear regression

Meteorological factors 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). As well,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. Here, we tend to use the regression analysis to find the influential meteorological parameters that affects fire occurrence. In this work, we adopted the following key attributes: temperature, humidity, dew point, soil temperature in the upper layer, wind speed, and precipitation as function of fire occurrence during the 6 years (2009–2014) have been adopted to build the model for fire index. 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 3.

4.1.1. Temperature

Temperature is the inner energy of motion presented by the atoms and molecules composing a substance and is important in determining the ease of fuel ignition. It is this heat energy that is crucial in the beginning of the evaporative phase of combustion [22]. So, higher temperatures heat forest fuels and predispose them to ignition once sufficient source of ignition is available.

Fig. 2 shows that as temperature increases, fire danger increases.

4.1.2. 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 underburning varies from 30 to 55% [36]. When relative humidity falls below 30%, prescribed burning becomes dangerous [14].

The effect of relative humidity on fire occurrence is not clearly shown in Fig. 3 where the fire occurrence accidents occurred when relative humidity ranged from 45 to 90%.

4.1.3. Dew point temperature

Dew point is the temperature at which air cannot hold the water vapor which is mixed with it. Moreover, 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 views the dew point in function of fire occurrence. As the dew point rates increase, the danger of fire increases.

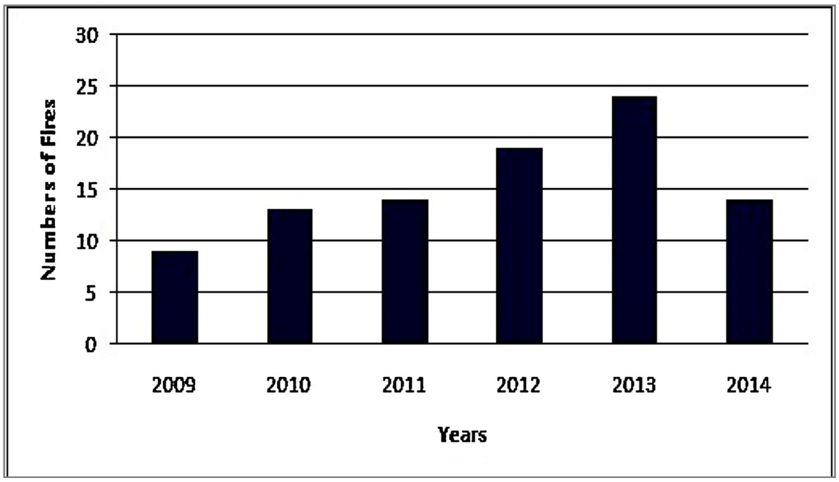

Fig. 1. Numbers of forest fire over the period 2009–2014.

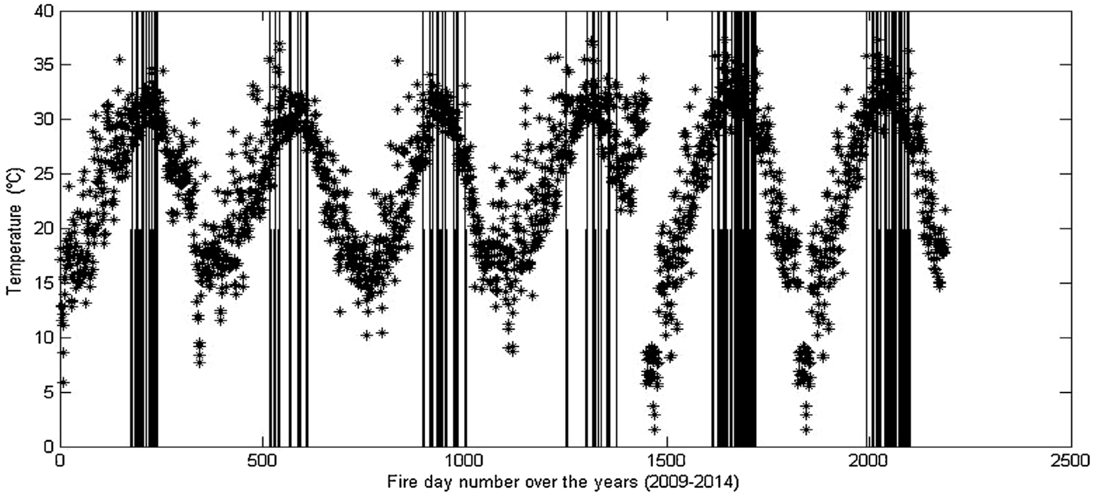

Fig. 2. Temperature (°C) in function of fire occurrence per day over the 6 years.

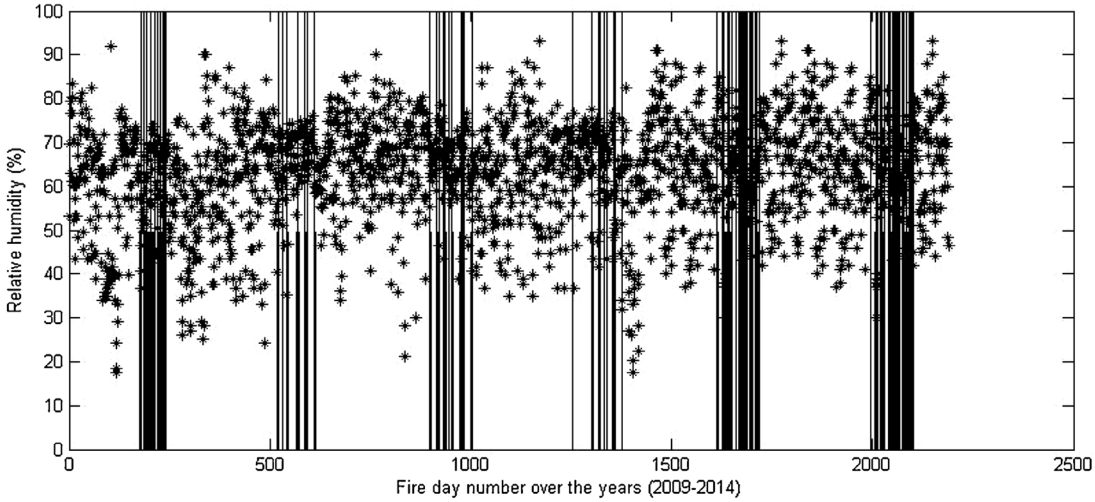

Fig. 3. Relative humidity (%) in function of fire occurrence per day over the 6 years.

4.1.4. Soil temperature

Soil is affected directly by the air temperature and sun radiation absorbed by the micro substances between layers [39]. 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 thus increase the chance of fire occurrence (Hälgren et al., 1991).

Fig. 5 clearly shows the effect of soil temperature on fire occurrence. Fire danger increases with the increase of soil upper layer temperature.

4.1.5. Wind speed

Wind is the most important factor on wildland fire. Fire behavior is strongly affected by windspeed and its direction, which vary in time at the scale on the order of hours, minutes, and seconds [32]. But it has limited effect on burning process (pre- fire) [5,11].

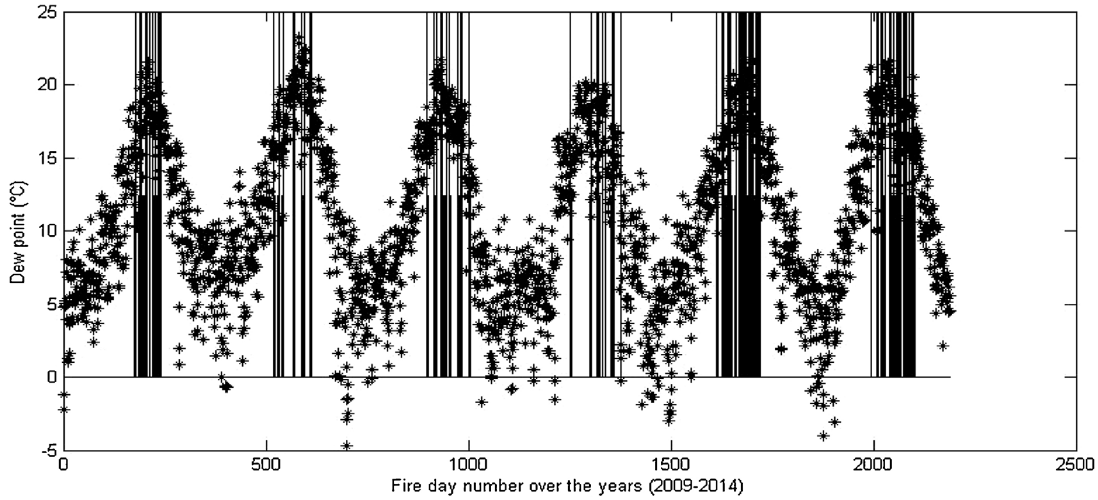

Fig. 4. Dew point in function of fire occurrence per day over the 6 years.

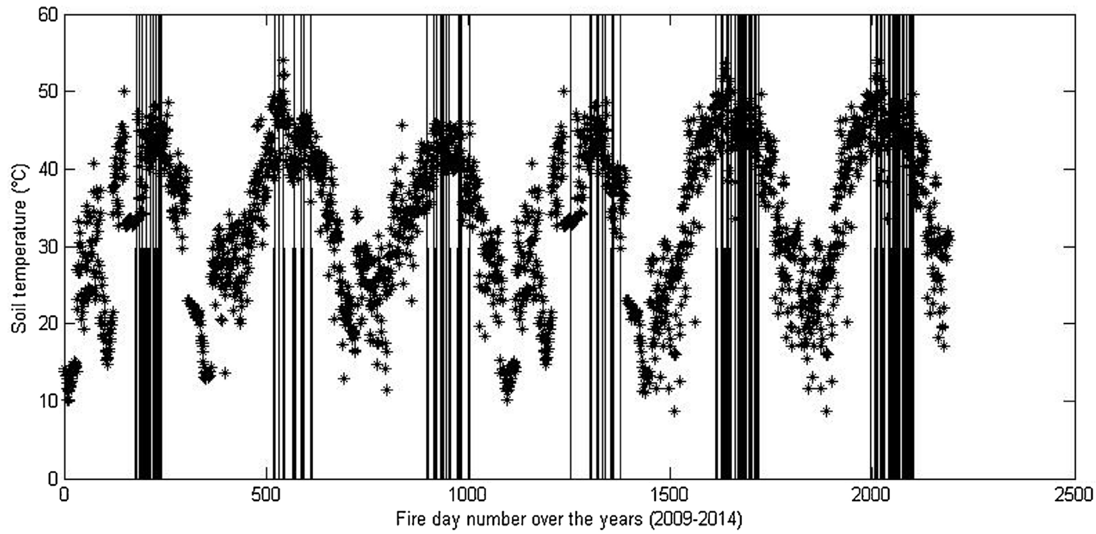

Fig. 5. Soil temperature in function of fire occurrence per day over the 6 years.

4.1.6. Precipitation

Precipitation includes all of the moisture that falls from the atmosphere and reaches the earth's surface. But it has 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 (>1 mm) of seasonal precipitation [41,15].

Upon analyzing Fig. 7, 80% of fire occurrence was reported when the precipitation was less than the threshold but overlapping and scattering shown in the figure makes such parameter a weak indicator for fire prediction.

4.2. Pearson, Spearman and Kendall correlative data analysis

Several correlation coefficients based on different statistical hypothesis are popular today. They are Pearson correlation coefficient, Spearman rank correlation coefficient and Kendall rank correlation coefficient [4].

Pearson's correlation is a parametric test used to measure the degree of relationship between the two linear related commodities [21] 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 [20]. 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 [30] while Spearman and Kendall rank correlation coefficient are the next most commonly utilized approaches in practice [18]. However, the relative performance of these different methods needs to be explored further.

5. Results

The Figs. 3, 6 & 7 show that relative humidity, wind speed and precipitation have weak correlation with fire occurrence. They have recorded correlation coefficients of 0.02, 0.21 and 0.19 respectively upon adopting linear regression (Table 4). This reveals that there is no real impact of these parameters on the number of fire occurrences.

On the other side, Figs. 2, 4 & 5 demonstrate that temperature, dew point, upper layer soil, temperature are strongly correlated with fire occurrence. The obtained correlation coefficients are 0.72, 0.61 and 0.65 respectively (Table 4). Thus these three attributes can be selected to build the desired early warning model.

The techniques of Pearson, Spearman and Kendall are also 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 4, it can be noticed that all obtained p-values are less than the chosen significance level $\alpha = 0.05$ 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.

6. Finding the relationships among affective parameters to derive Lebanese Index (LI)

Before going through elaborating the index, it is necessary to find the mutual 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 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 = 0.69). As shown in the figure, a linear equation with positive slope describes the relation-ship between both attributes.

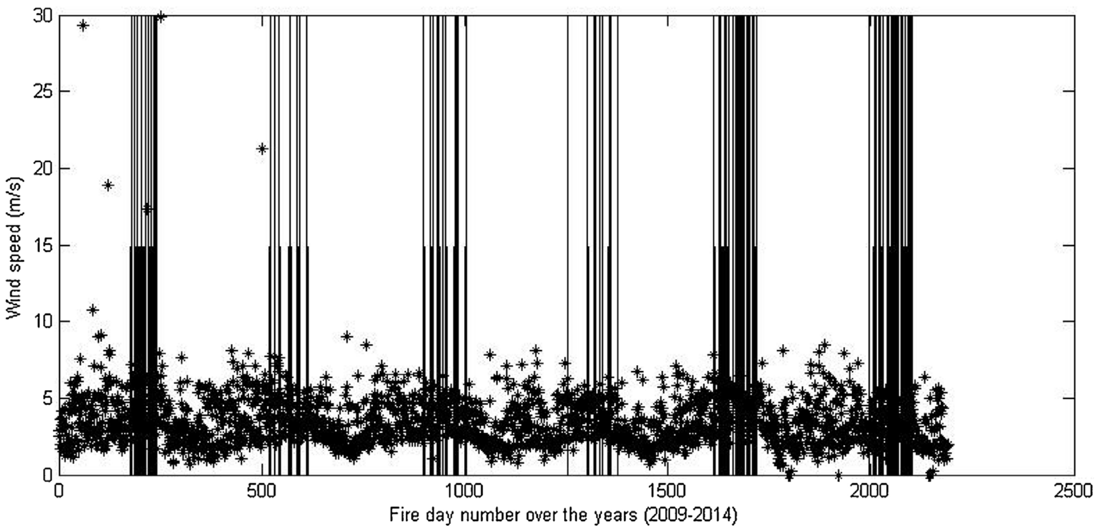

Fig. 6. Wind speed (m/s) in function of fire occurrence per day over the 6 years.

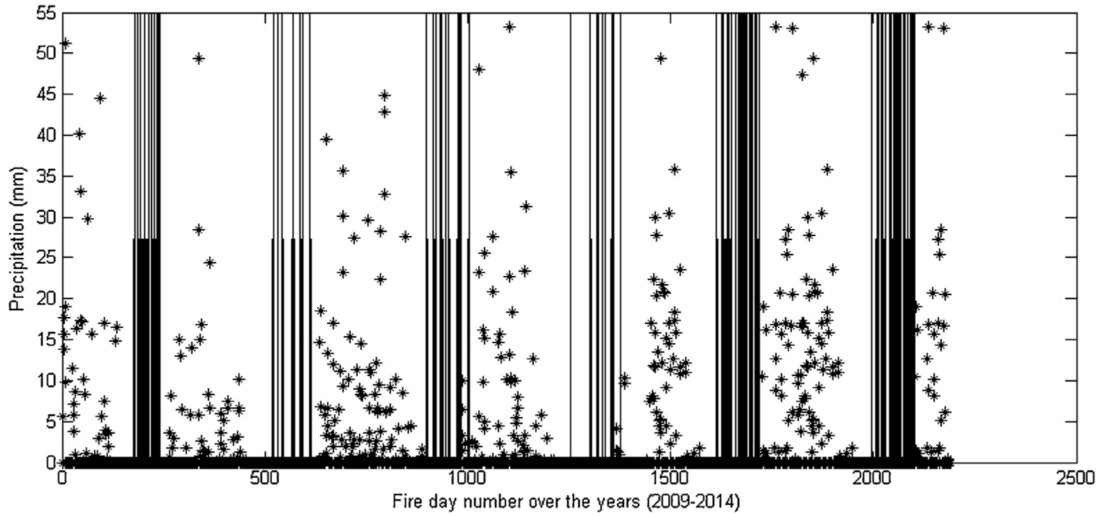

Fig. 7. Precipitation (mm) in function of fire occurrence per day over the 6 years.

Table 4
Linear Regression, Pearson, Spearman & Kendall correlation coefficients between fire occurrence and weather parameters.

Parameters	Total Number of Days	Days With Fire	Linear Regression Correlation Coefficient	p-value	Pearson Correlation Coefficient	Spearman's Correlation Coefficient	Kendal's Tau Coefficient Correlation
Temperature (°C)	4163	2068 (94 days presented 22 times)	0.72	~0	0.639	0.6748	0.7093
Relative Humidity (%)	4163	2068 (94 days presented 22 times)	0.02	$1.2965 * 10^{-39}$	−0.2021	−0.2031	0.0199
Dew Point (°C)	4163	2068 (94 days presented 22 times)	0.61	~0	0.5767	0.5517	0.6007
Soil Temperature (°C)	4163	2068 (94 days presented 22 times)	0.65	~0	0.6071	0.6231	0.6951
Wind Speed (m/S)	4163	2068 (94 days presented 22 times)	0.21	$1.63716 * 10^{-26}$	0.1641	0.2288	0.3068
Precipitation (mm)	4163	2068 (94 days presented 22 times)	0.19	$2.159 * 10^{-14}$	−0.2067	−0.2574	−0.2655

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 0.67.

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 (Table 5).

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 Eqs. (6) and (7) [34]:

$$B = \frac{\ln\left(\frac{RH}{100}\right) + \frac{17.27*T}{237.3+T}}{17.27} \tag{6}$$

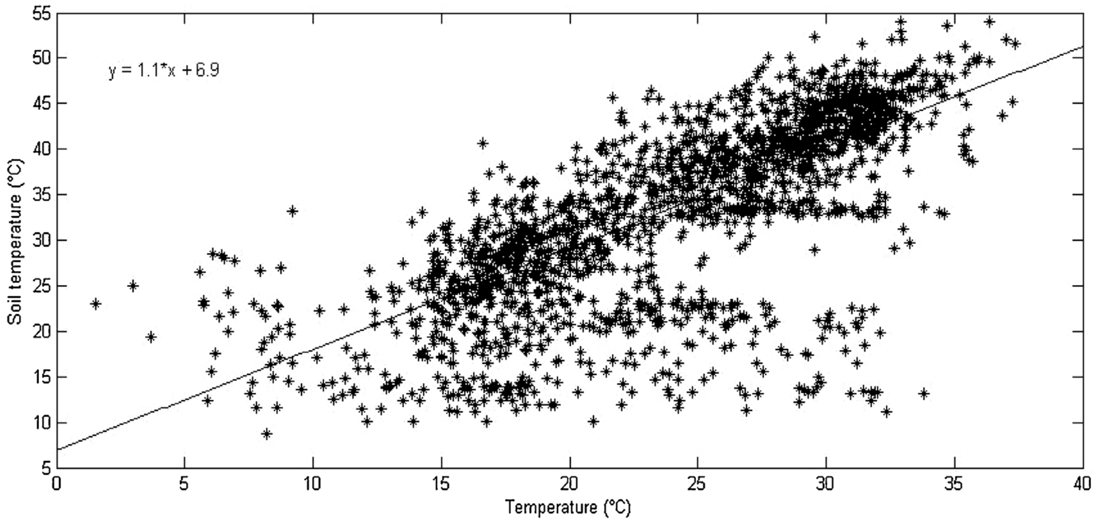

Fig. 8. The relationship between temperature (°C) and soil temperature on the upper layer (°C).

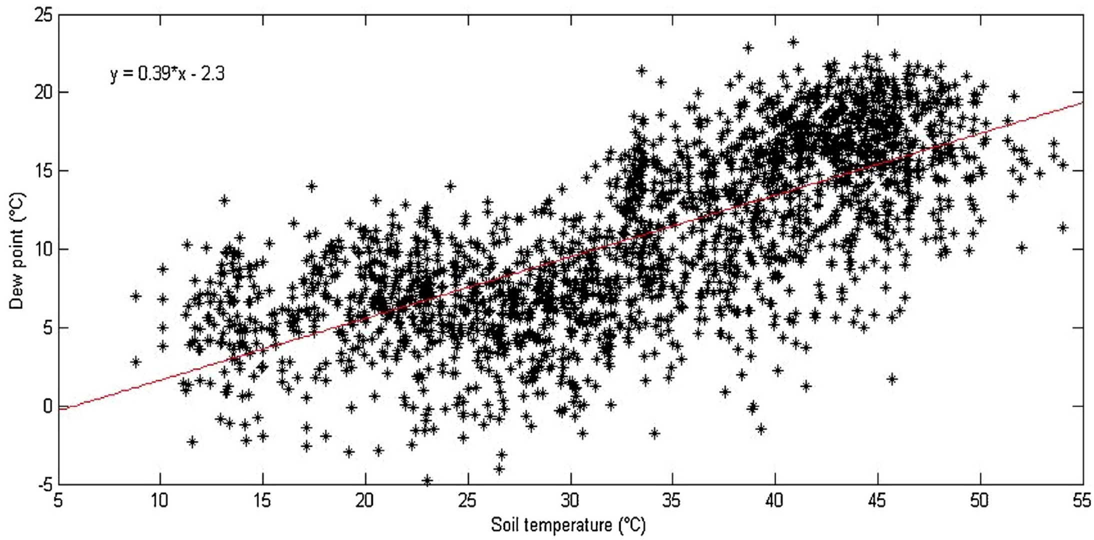

Fig. 9. The relationship between dew point (°C) and soil upper layer temperature (°C).

$$D = \frac{237.3 * B}{1 - B} \tag{7}$$

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/m^2) depends on heat flux and heat conduction for soil upper layer. Its equation is shown in Eq. (8) [40].

$$Rn - G = LE + H \tag{8}$$

Where Rn is 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/m^2).

The new simplified model that fits developing countries in the Mediterranean 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

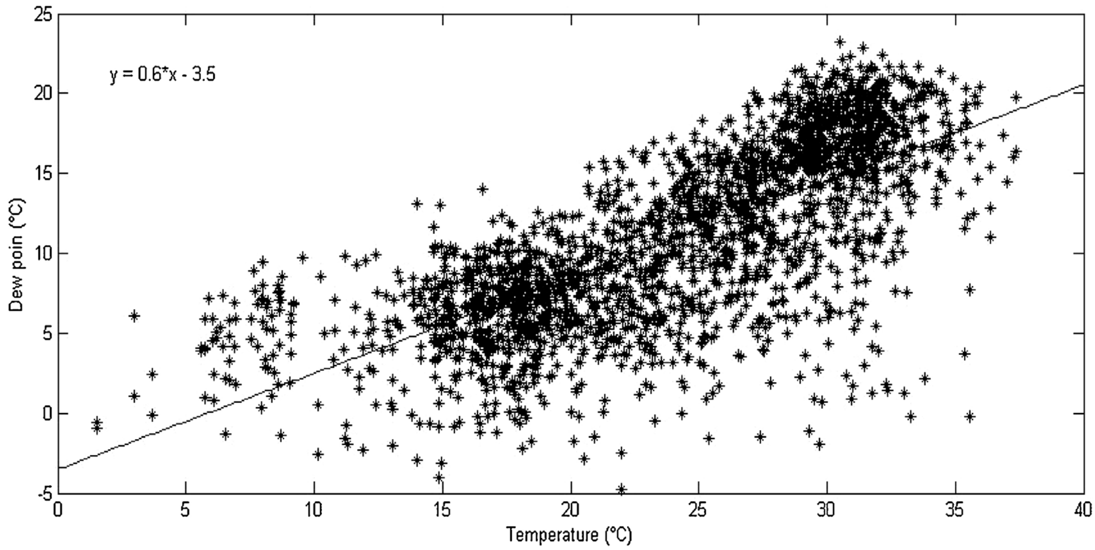

Fig. 10. The relationship between temperature (°C) and dew point (°C).

with the desired output; as shown in Eq. (9).

$$LI = 1.18T + 1.07S + D \tag{9}$$

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

Table 5
Mutual correlations among selected parameters.

Parameters	Correlation	Linear Equation
Temperature & Soil Temperature (°C)	0.73	$Y = 1.1X + 6.9$
Temperature & Dew Point (°C)	0.69	$Y = 0.39X - 2.3$
Dew Point & Soil Temperature (°C)	0.67	$Y = 0.6X - 3.5$

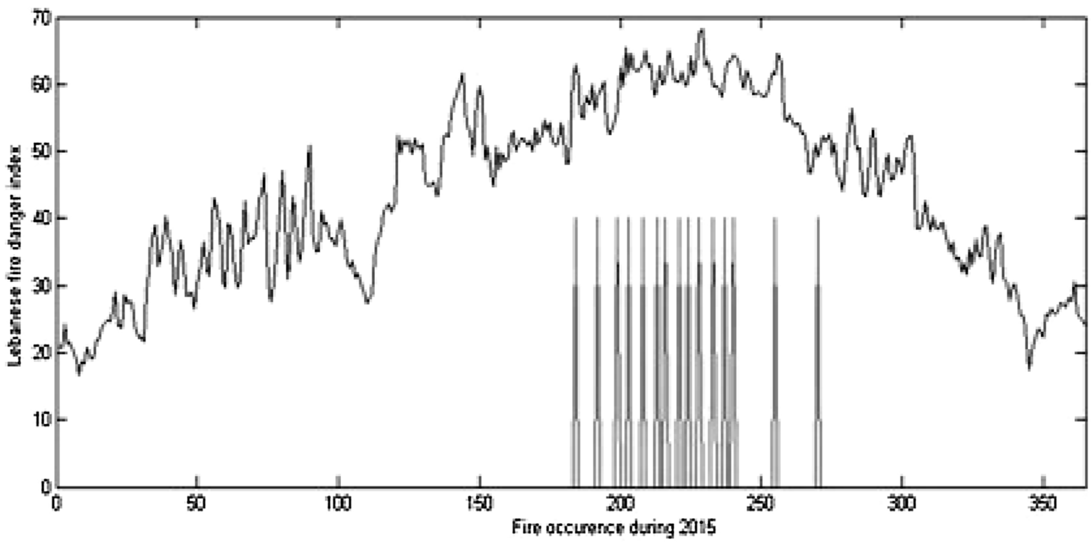

Fig. 11. Validation of fire danger index in function of fire occurrence.

Table 6
New 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

Table 7
Measurements of Precision, Accuracy, Specificity, Sensitivity, Kappa and AUC for LI.

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

7. Validation of LI

The Index has been 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 LI against the 15 fires which occurred during this period.

Table 8
Fire danger indices characteristics.

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 evapotransipiration	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
LI	Lebanese Republic	2016	Mediterranean weather (Mild)	Temperature, Dew point and soil temperature	Cumulative index, easy to measure.	Lebanon

Fig. 11 displays LI in function of the number of fires. We can notice that when LI increases, the fire risk increases especially in summer season when the outlet of LI 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 Table 6.

After stating its potential scale, we test LI 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 7.

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 [23]. The computed sensitivity (100%), AUC (93%) and Kappa (92%) are very high while precision is low (25%). The low precision is caused by small dataset used for testing (only 15 fires out of 365 days).

To better examine the performance of our index, the mean square error MSE is calculated using Eq. (10):

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(Y_i - y_i)^2 \tag{10}$$

Yi represents the predicted value of the new index and real value of the day irrespectively. Yi and yi can take the values 0 when no fire is detected and 1 in case of fire. The obtained mean squared error (MSE) for the year 2015 equals 0.087, which is very good while dealing with the discrete values 0 and 1 only.

8. Assessment of LI versus prevalent meteorological indices

The vital features of the currently adopted weather models are stated in Table 8 allowing having a reasonable assessment of the novel index. The chosen indices for this mission are as follows: Angstrom, Nesterov, Modified Nesterov, KBDI, Baugartner, Modified KBDI, Canadian FWI, FFDI, Simple Fire Danger Index and FD.

Upon analyzing Table 8, 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 (LI) 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 [19]. Hence, LI 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 rain full over the year Parent and Ilinca [24], 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 [37], whereas fire activity is normally reduced, due to atmospheric conditions. This limitation doesn't exist in the daily LI.

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 LI 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 [6]. As precipitation is ignored by LI, 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 [3,38,26] due to their high accuracy and absence of constraints in forest fire prediction decision, LI 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 LI. Factors including field capacity (200 mm) and R-threshold (3 mm) 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 [23]. It seems interesting to present a comparison between M-KBDI and our proposed index. While M-KBDI is a cumulative drought index that, because of the cumulative conception, could wrongly forecast high levels in fire danger rating; LI is a daily index, where the daily conception may affect its precision as the weather information of the previous day are ignored. On the other side, the equations of both indices imposed some simplifications and estimations upon derivation: the drought factor incorporated in M-KBDI, expressing the water loss in the system and expressed by potential evapotranspiration PET, is estimated as PET is difficult to obtain accurately, and the same is considered in the litter moisture content; on the other side, the equations used in LI are estimated based on regression equations and corresponding correlation coefficients. Here, in the point of estimations, appears the advantage of LI over M-KBDI as the LI's incorporated estimations are limited to one trend which is not the case in M-KBDI. Regarding the inclusion of drought factor in M-KBDI, it is good to point-out that LI also considers this factor indirectly by the inclusion of soil temperature. High soil temperatures lead to increasing evaporative demand and thus increase the drought in soil. Other advantage is recorded to LI is its ignorance of precipitation as previously mentioned. Conversely, another disadvantage is recorded to M-KBDI represented in the index initialization based on assumptions and suggestions, for example, the index starts up when the mean daily temperature is 6 °C for three consecutive days, as the Canadian FWI suggests. Initialization is not needed in LI at all.

9. 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 LI 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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