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Research article

Satellite-based approach for forest fire prediction: A case study from Lebanon

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Abstract: Forest fires are one of the severe natural hazards that frequently occur in the Mediterranean Region, as a result of the increased temperature from global warming. The damage in the forest area has been exacerbated lately, making it necessary to adopt systematic tools based on scientific techniques. This can be performed by producing vulnerability maps for forest fires. The production of vulnerability maps can be attained by integrating several indices to determine the likelihood of fires. The most applicable indices are the Structural Fire Index (SFI), Fire Risk Index (FRI), and Hybrid Fire Index (HFI). However, the geographical location of the study area (exposed to hot and dry east winds during spring and autumn) requires adopting a new indicator for forest fire prediction, with enhanced methodology according to the temporal and spatial dimensions. In this study, satellite datasets were used to identify inducing factors and then mapping these factors as GIS layers with all required calculations. For this purpose, Sentinel-2 satellite images were processed with the Google Earth Engine (GEE) to compare the Normalized Difference Vegetation Index (NDVI) change, related to the Normalized Burn Ratio (NBR) changes at the same time. A comparison was also made between the years 2015 and 2020 for (NDVI) and (NBR) (Pre, Post). The considered dataset parameters are: elevations, slopes, aspect, NDVI, temperature, humidity, wind direction and distance from residential areas and roads. The extracted geospatial data from satellite images for building GIS layers were manipulated using a Geographic Information System (GIS) which enabled the integration of different indices to end up with the vulnerability map for the forest fire. It represents a supportive tool for decision-makers to adopt the best forest fire prediction and intervention plans.

Keywords: Vegetation cover, Temperature, Forest Fire, Slope, Sentinel-2, Lebanon.

INTRODUCTION

Fire is a tool used by humans since the beginning of life for removing the vegetation cover and to fertilize poor soils with nutrients and germination of pastures for early grazing before winter. On the other hand, fire can be a natural disaster and a dangerous aspect for the environment where it destroys vegetation cover Adab *et al*. (2013). The huge increase in greenhouse gas emissions (GHGs), especially carbon dioxide, affects the global climate Eskandari *et al*. (2020), The fires that reach forests have a double effect because forests are an important source of carbon absorption, so instead of absorbing carbon it will emit it and this will have a great impact on climate change Rowell & Moore (2000).

The origin of the forest fire can be natural, such as lightning, or anthropic, whether by intent or negligence and error (Stolle & Lambin, (2003). The recently increased number and geographic extent of forest fires and the relevant damages urge research and studies to find out the best ways to fight them and reduce their impacts. Strategies and policies of many countries and international organizations have been asked recently for the development of strategies to reduce fires FOA (2005).

Forest fires in the Mediterranean region became one of the main environmental problems even on the national level, with 50,000 fires each year ravaging about 700 to one million hectares of vegetation cover including forests and other properties (Moore & Allard, G.B. (2008). They often occur in the dry months, especially between June and the end of October due to the effects of drought spells and low soil moisture, in addition to active human activity during this period. Hence, 95% of the forest fires in the Mediterranean, are due to human causes FOA (2006).

A typical example is the forest fires that occurred frequently in South Lebanon, especially during the drought periods with high wind velocity. Thus, the region in the spring and autumn seasons is exposed to dry and hot winds called the “Khamaseen winds”. Yet, there are no alert or prediction tools that can be utilized to point out forest fire risk, and this exacerbated the problem and increased the loss and damages. Therefore, the concerned institutional entities in Lebanon are in urgent need to adopt a monitoring and prediction tool. Furthermore, access to a map of forest fire hazards became a must to contribute to the prevention and decreasing the negative effects, which is, in turn, minimizing

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the social and economic losses as much as possible.

The scientific community agrees with the hypothesis that the greater frequency and intensity of forests fires result from the symbiosis between some natural conditions (terrain, climate and state, and type of vegetation) that favour the outbreak and spread of fire and the depth transformations experienced by societies and the rural and/or natural environment in recent decades. These changes have led to the mass desertion of traditional activities in these areas (e.g. farming, livestock raising, and forest utilization), favouring the accumulation of combustibles prone to catching fire.

Therefore, the importance of studying such risks lies in the serious consequences, not just environmental (e.g. ecosystem degradation and loss of natural heritage) but also economic (costs derived from prevention, extinction, protection of the urban area and human and post-fire regeneration) and social (e.g. loss of state and private belongings and maybe, life), caused by a fire.

The current technology applied in monitoring these natural events has three categories: prediction, prevention, and monitoring. Therefore, forest fire risk mapping is essential for urban planning and future strategies to conserve the human and environment as well. It has, therefore, become necessary to generate maps that identify and categorize areas more likely to be affected by an eventual fire in forests.

Recently, the development of new technology, mainly based on remote sensing and geographic information systems, substantially assisted in performing vulnerable maps for all types of natural hazards including forest fires. The development of the Google Earth Engine (GEE) also made a revolution in geospatial data retrieval and analysis. Estimates are considered quantitative and qualitative of burn-area are decisive to analyze the impact of fire on forests. The medium-resolution optical-satellite imagery of Landsat-8 and Sentinel-2 is employed covering large areas for forest fire patch identification on GEE Bar *et al*. (2020).

In this context, the estimated 1.8°C mean temperature increase in Lebanon, exposes this area to a greater extent of forest fire phenomenon.

The main goal of this study is to create a detailed vulnerability map for forest fires using Sentinel-2 and Google Earth Engine (GEE) satellites. It is therefore aiming to categorize the produced vulnerability map into four risk classes. Such a map will be a very useful tool for decision-makers and many concerned stakeholders to facilitate making the right management plans and policies for environmental protection.

MATERIALS AND METHODS

The study area is located in the southern part of Lebanon, which is a mountainous zone adjacent to the Mediterranean Sea (Fig. 1). It encompasses many forest mountains which are sometimes dense. The region of the study has a surface area of about 2012 km^2, where it is situated between the following geographic coordinates: 33° 00' N; 33° 45' E and 35° 00' N; 35° 45°E. the area of study consists of several geomorphologic units including mainly coastal plains, valleys, and plateaus where the average altitude is about 680 m.

The majority of used materials in this study include the remotely sensed datasets acquired from satellite images, as well as the climatic records. In addition, field surveys have been carried out to verify the reliability of the extracted data from satellite images. In this regard, GIS was also an essential tool for data manipulation.

Data Availability

The used datasets can be summarized as follows:

1. SRTM (Shuttle Radar Topography Mission) to generate Digital Elevation Model (DEM), with 30 m pixel size, and it was downloaded from the USGS website, from which the elevation, slope, and aspect will be inferred.
2. Satellite image Sentienl-2 in October, cell size is 30 meters from the USGS website, through which NDVI is extracted.
3. Wind maps (direction and speed) from the USGS website.
4. Climatic time series from the Lebanese Agronomy Research Institute (LARI) for the period between 2012 and 2021.
5. The network of roads and buildings from Open Street Map in ArcMap.

The methodology is based mainly on the identification of the influencing factors that contribute to the outbreak of forest fires. These are elevation, slope, aspect, vegetation, man-made interference, and wind. The maps were created through the selected indices. Thus, each factor was mapped, constituting a GIS layer, according to its impact on the probability of a fire occurring and its geographic spread. Consequently, the vulnerability to forest fires map was produced by systematically merging the GIS layers and then analyzing and displaying the results.

The selection of methodology and indices was based on data availability and natural and anthropogenic conditions. Therefore, two paths were considered as follows:

1. Temporal path (T) where climate-related parameters (e.g. temperature, relative humidity, and direction of the

wind) were used to determine the most suitable period for ignition.

2. Spatial path (S) using elevation, slope, destination, vegetation cover, and wind speed in addition to the distance and proximity to roads and population centres.

To determine the localities that are most vulnerable to forest fire risk in the period specified, a map was created for each index with the classification of the indicator into categories with numerical values ranging from 1 to 7, according to the effect of each one of them on the possibility of the occurrence and spread of fire as follows:

1 = Very low, 2 = Low, 3= Moderate, 4 = High, 5-7 = Very high

In this respect, the following concept must be considered:

- Arbitrary fire: This is caused by humans making ignition to remove the vegetation cover.
- Unintentional fire: This is also caused by humans but not on purpose such as throwing cigarettes and burning waste on the sides of roads.
- Natural fire: It is happened spontaneously by nature.

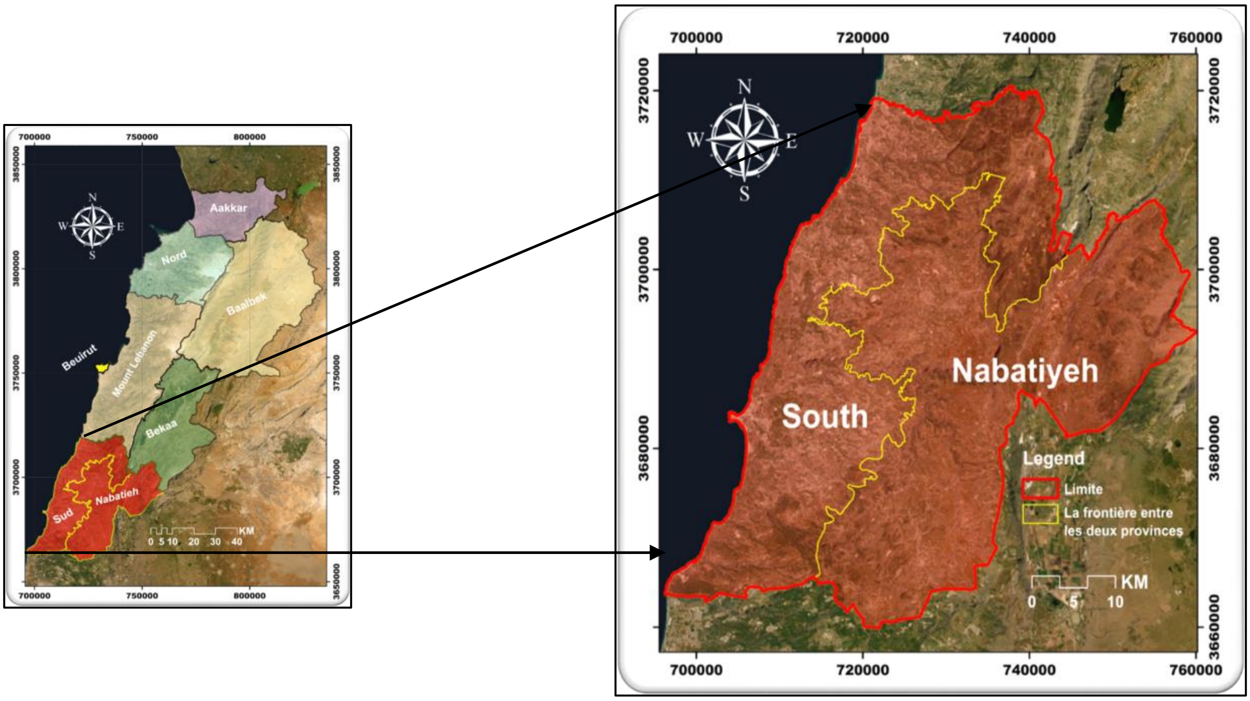


Figure 1. Location map of the study area.

Temporal path

This path determines the most appropriate time period for the ignition and spread of the fire. The outbreak and spread of fire are directly related to the weather condition of the region. Temperature, relative humidity, and the direction of wind were used. In this regard, the correlation between temperature and relative humidity, high temperature, and relative and low humidity increases the possibility of fire (Fig. 2).

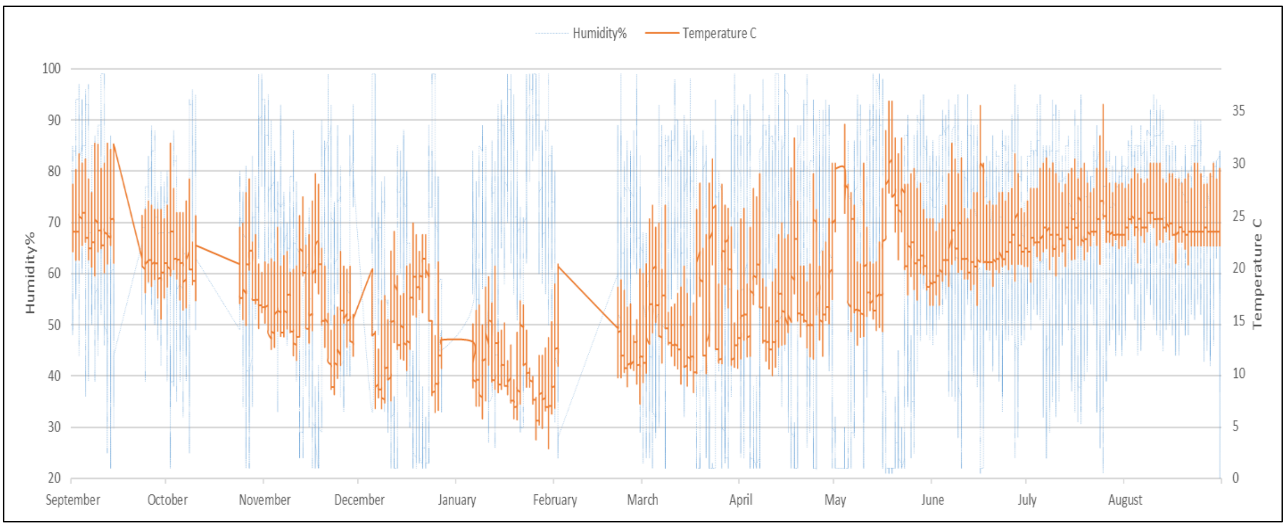


Figure 2. Monthly variation of temperature and humidity.

Figure 2 shows that June, July, and August have high temperatures, but since the relative humidity is also high, it cannot be considered that this period is the most suitable for the ignition of fires. While in September, October, and November where the temperature degrees in some periods are very high and the relative humidity is low due to the Khamaseen winds coming from the desert; and therefore, this period is the most suitable for the ignition of the forest fires.

Moreover, the direction of the wind has been added because it has a significant role in the fire risk within the study area; especially there are many valleys representing wind corridors, which increases the probability of a fire outbreak, and it will be most dangerous in case of south and southeast winds (*i.e.* Khamaseen winds) as shown in (Fig. 3).

The graph highlight is that the winds with a south and southeast direction are active in September, October, and November, during which the relative humidity is very low and the temperatures are high and this contributes to the occurrence of fires in the study area. Consequently, wind speed indicators in these three months as shown in figure 4.

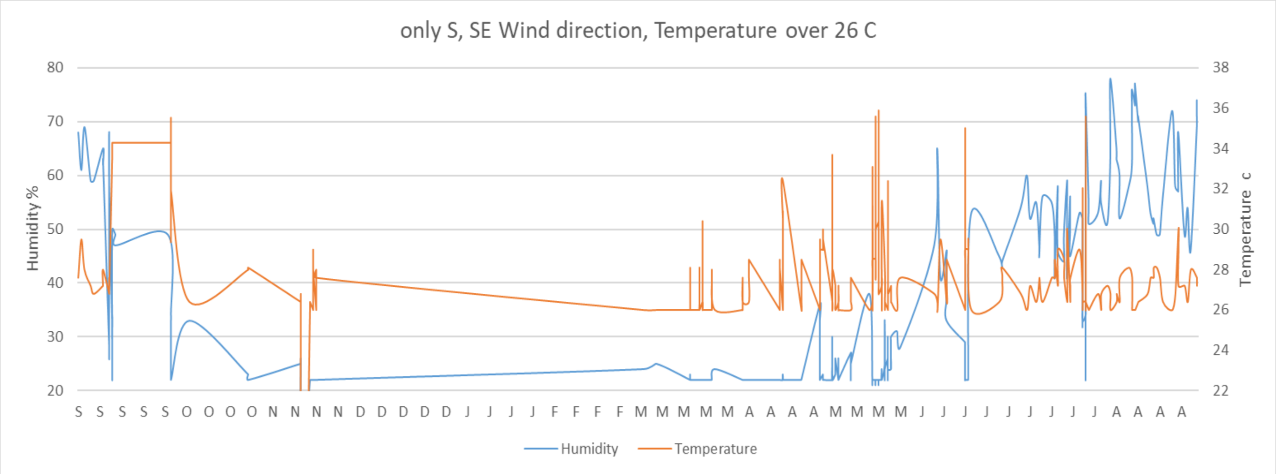


Figure 3. Temperatures variation and humidity with wind direction (south and southeast) as time function.

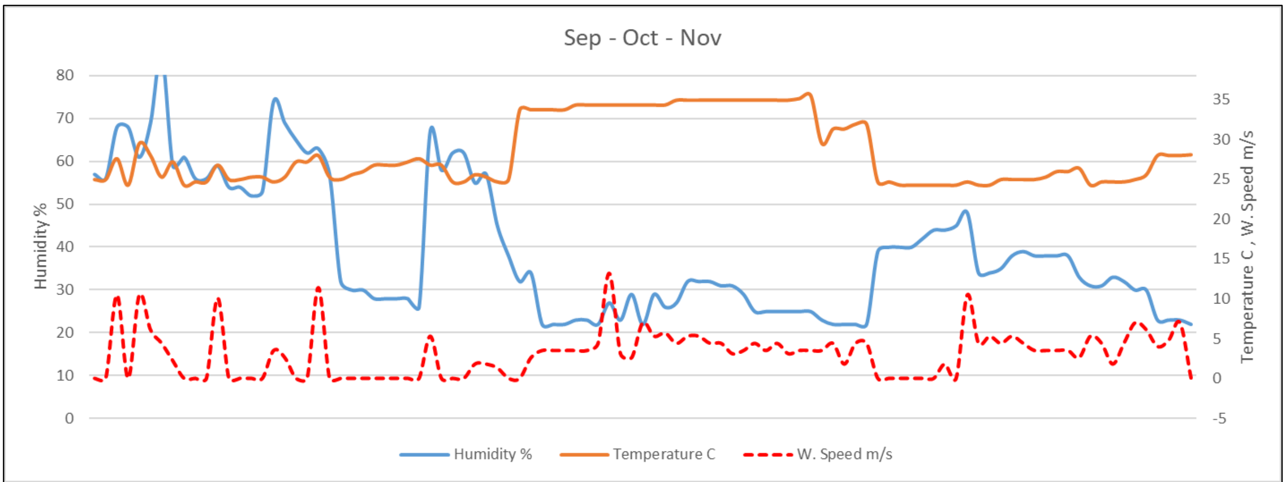


Figure 4. Temperatures variation and humidity with wind speed depend on the three determined months (Sep.-Oct.-Nov.).

The spread of fire is closely related to wind speed, and through this graph, it was found that October is the period when temperatures rise above 32°C; and the relative humidity drops to less than 25%. Thus, the speed of the wind increases to closely reach 15 m s^{-1} then the possibility of fire and its spread becomes very high.

The time path contributed to determining the date of the satellite image from which the vegetation cover will be derived, it will be in October, and also it contributed to the dispensation of maps for many indices such as temperature, relative humidity, as well as land surface temperature (LST). In addition, this temporal factor will be represented spatially by the destination (Aspect).

Spatial path

In this path, sites are most exposed to the possibility of fires occurring and spreading at the time that has been determined through the timeline. To perform this, it is necessary to select the appropriate spatial indices that have been mentioned. These indices provide reliable results in determining these target locations, as follows:

- Landforms related indications (*i.e.* slope, aspect, elevation)

- Indices related to vegetation cover (NDVI)
- Indices related to distance and proximity to roads and residential areas

Therefore, the use of the GIS system, using Arc-GIS, enabled producing the following maps:

Elevation map

Elevations have a significant role in the probability of fires occurring at a specific time because the fire is related to temperature and relative humidity which are controlled by elevation. Therefore, the following climatic elements are related to the altitude factor:

- Temperature in the study area decreases by 6°C whenever elevation rises 1000 meters above sea levels (Farhat 2018).
- The study area is affected by spring and autumn climate, namely the Pentecostal winds coming from the Egyptian or Arabian Peninsula deserts. In this case, the elevated localities become warm and dry, unlike coastal areas that maintain moderate temperatures and high relative humidity due to their alignment with the Mediterranean Sea.

Accordingly, the elevation was classified into several categories represented by numerical values for each category according to its impact on the probability of fires existence and geographic spreading according to the following Table 1. Therefore, a map has been created for this factor (Fig. 5). This map shows that the coastal area is almost with the least possibility of a fire (very weak) due to its low elevation, and it has a surface area of about 355.703 km^2 (about 17.6 of the total area of the studied region) .

Besides, areas with higher elevations and thus a high effect on the possibility of fire existence occupy the largest part of the studied region where it has an area of about 1227.073 km^2, which is equivalent to 60.9% of the total studied region. Also, the table (Table 1) and the map (Fig. 5) show the rest elevations and their attribute to the forest fire risk.

Table 1. Area and percentage of fire risk based on elevation.

Zone	Color	Area (km^2)	Percentage (%)	Fire Risk	Weight
1	Dark green	355.703	17.673	Very low	1
2	Light green	160.890	7.994	Low	2
3	Orange	269.182	13.375	Moderate	3
4	Red	1227.073	60.958	Very high	5

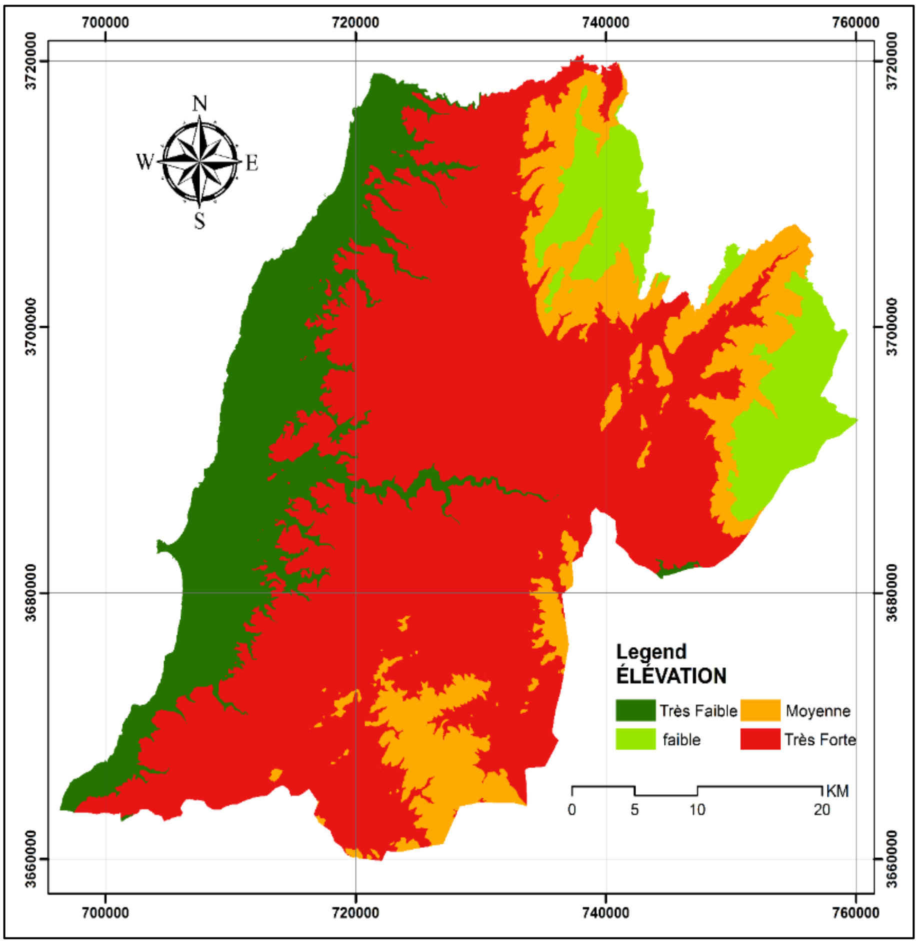


Figure 5. Elevation map for the studied region extracted from SRTM.

Slop Map

According to Vadrevu *et al*. (2010) the slope is an indicator of the rate of change of height. It is one of the factors that must be taken into consideration in studying forest fire risk and its geographic spreading. Hence, the fire spreading rate increases on steep slopes due to the angle of flames near the surface of the earth Ghobadi *et al*. (2012). The fire spread rate (ROS) increases twice if the incline is 10 degrees and four times if the incline is 20 degrees Butler *et al*. (2007).

In this study, the slope was classified into three categories with a numerical value for each category according to its impact on the probability of fires occurrence and spreading (Fig. 6). It is obvious from the map that the blue colour is dominant in the study region, and this reflects that the region is mainly with low sloping terrain, but it is cut by several valleys which are represented by the red colour. Therefore, the region is characterized by the least possibility for forest fire occurrence according to its slope index, and this dominates the entire study region. The surface area with a low possibility of forest fire according to the slope is about 990 km^2, which is equivalent to 49.62 % of the total area of the studied region.

Table 2 shows the percentage of the forest fire risk probability according to the slope where the highest value possibility occupies 761 km^2 and the moderate possibility is 257.7 km^2, which is equal to 37.8% and 12.8%; respectively.

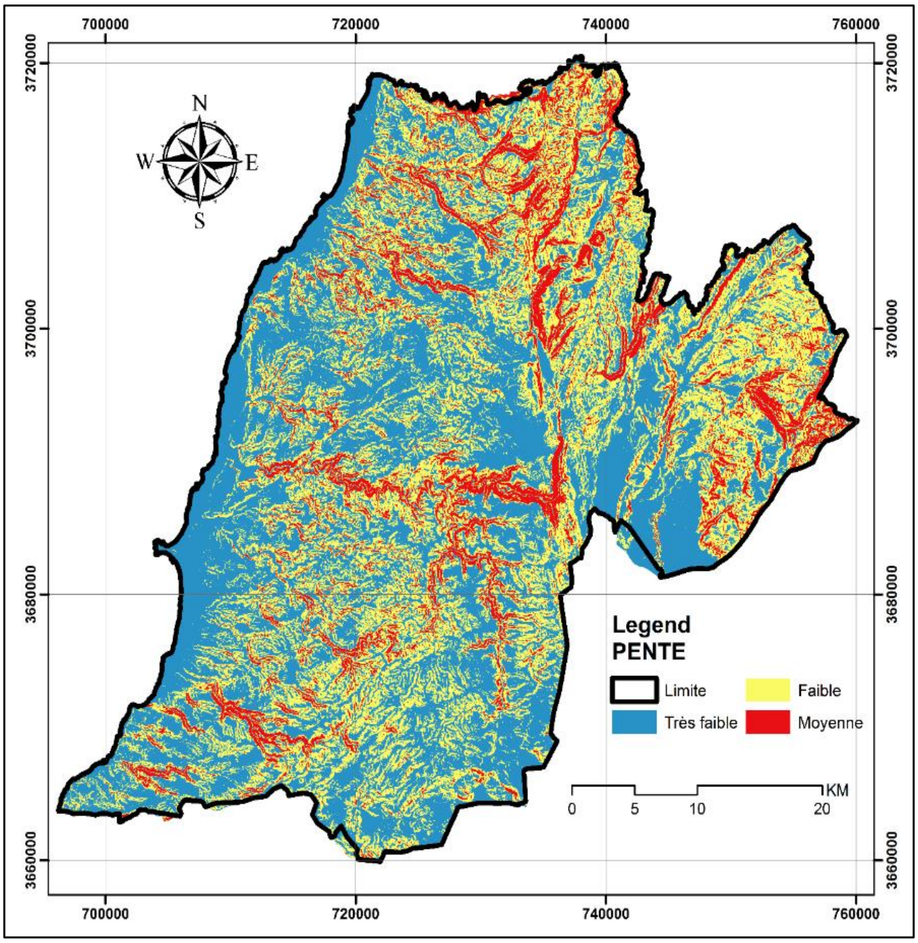


Figure 6. Slope map for the studied region extracted from SRTM.

Table 2. Areas and the percentage of the fire risk according to the slope.

Zone	Color	Area (km^2)	Percentage (%)	Fire Risk	Weight
1	Light Bleu	990.001	49.266	Very low	1
2	Yellow	761.077	37.872	Low	2
3	Red	257.7214	12.862	Moderate	3

Aspect

The direction of the slope is defined as the side or aspect Setiawan *et al*. (2004). It is sometimes considered according to the sunlight confrontation or according to the wind direction, as in the case of the studied region where the temporal path is represented by the influence of the southeastern hot and dry winds. This index is significant in terms of its effect on the possibility of the occurrence of forest fire and its spread, and it can be considered as a supplementary index to wind direction .

The studied region is directly exposed to the dry wind at different periods, and it was given a numerical value ranging between 0 and 7 for each aspect according to its impact on the probability of fire occurrence and its spread (Fig. 7; Table 2).

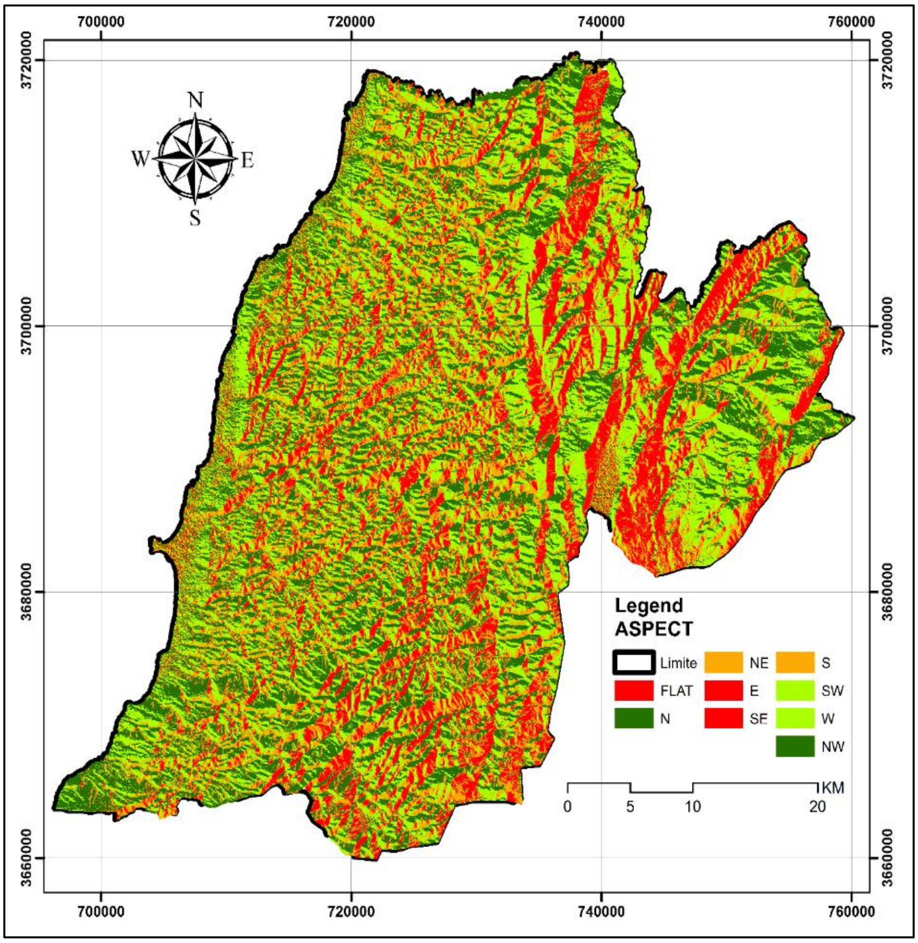


Figure 7. Aspect maps of the studied region.

The east and south-east aspects and the flat areas were given a value of 7 and that is because one of the characteristics of the study area is that it is exposed to east and southeast winds blowing from the side of Jordan and the north of Palestine and this wind is hot and dry. It therefore leads to an increase in degrees of temperature and a decrease in the relative humidity in the atmosphere. This is reflected in the fertility of the vegetation cover located in these aspects and then they are highly flammable with high possibility of forest fires. Thus, the high possibility occupies 386.6 km^2, which is equivalent to 18.14% of the entire studies region.

Table 3. The area and the percentage of the fire risk according to the slope exposure.

Zone	Color	Area(km^2)	Percentage (%)	Fire Risk	Weight
1	Dark Green	576.97	29.06	Very low	1
2	Light Green	619.43	29.71	Low	2
4	Orange	433.48	23.09	High	4
5	Red	386.60	18.14	Very high	7

The value 4 has been given to the south and north-east, because the effect of this wind remains stronger compared to its effect on areas located in the north-eastern side, with an area of 433.48 km^2 or 23.09% of the total area of the studied region. While west and southwest were given a value of 2 considering that the effect of these winds become very small. Its area is equal to 619 km^2 which is 29.71% of the total area of the studied region. As per the north and northwest aspects, a value of 1 was given, because they are not affected by these winds. In fact, the wind blowing from the north has a low temperature compared to the eastern wind. The surface of this aspect is 576 km^2 is equivalent to 329.06% of the total area region.

Vegetation

Vegetation is the fuel component of fires; and therefore, it must be accounted for in forest fire risk assessment. To determine the density of the vegetation cover in the study area, NDVI has been performed after being acquired from

(Landsat 8). It helps to distinguish the fertility of the vegetation cover from the other component on Earth's surface. The following equation represents the NDVI:

$$NDVI = \frac{NIRED - RED}{NIRED + RED} \qquad (1)$$

The red is the electromagnetic field in which the wavelength ranges from 6.0 to 7.0 μm and it is the longest among the visual fields. On the other hand, near-infrared (NIR) is included in the electromagnetic field which fluctuates between 0.7 and 1.3 μm.

To elaborate this equation, data was obtained from the sensor on the Landsat 8 satellite, and this is precisely visible 30 meters in September 9, depending on the time course, like the time when the most inflammable period has been determined between months 9 and 11, and because the vegetation does not change in these three months we can choose it from any month of the three months.

Landsat 8 sensor contains 11 bands, where band 8 is responsible for receiving the infrared, and band 4 is responsible for receiving the lengths of waveforms associated with the red color. This is converted to the following equation

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4} \qquad (2)$$

Usually, the result of this equation ranges between -1 and +1; therefore, the area with a high value is an area with dense and green vegetation cover. In this study, NDVI has been divided into 4 categories (Table 4). Thus, the area with zero value indicates the urban and water areas, and not to the vegetation cover, hence the risk of fire is null.

As for the grassy areas, which lie between 0.1 and 0.3 it is the most vulnerable area to fire because the moisture content in plants is almost non-existent; and therefore, its susceptibility to fire is very high; especially with the appropriate atmosphere of high temperature and relative humidity. However, the area shows an index between 0.3 and 0.5, which evidences less susceptibility to fire than grassy areas, this is due to the relatively high humidity that exists in these areas. Hence, it has less flammability than the previous region so we gave it a value of 5. As for the area with an index between 0.5 and 0.8, it is characterized by dense vegetation cover, usually orchards and woody trees. Thus, its relative humidity is high then it has a low chance of fire.

GEE Google Earth Engine Based Mapping

Medium spatial resolution satellite data available in the GEE platform were used for this paper, such as Sentinel-2 level-2A (ID: COPERNICUS/S2_SR which acquires 13 spectral bands with spatial resolutions that range from 10 to 60 m. The spectral channels include four bands at 10 m spatial resolution, six bands at 20 m spatial resolution, and three bands at 60 m spatial resolution. S2 products are available as elemental granules, also called tiles (100 km^2) According to our study, first, we compute the value of Normalized Burn Ratio (NBR) and then Normalized Difference Vegetation Index for our location. The methodology herein proposed was optimized through the use of the GEE cloud computing platform, to map the changes of NDVI area affected by fire using the GEE procedure.

As fundamental, we identify the location (to set the area to investigate, south Lebanon) and the date when the fire occurred to search for the median cloud-free images, between July and October for the two years 2015_2020.

Pre_Post Normalized Burn Ratio

NBR is considered to be very effective in the estimation of the identification of fire-affected areas because it is exceptionally responsive to changes in the amount of moisture content, living green vegetation, and soil conditions that generally occur after the fire. Here, use the (NBR) is to confirm the presence of fires.

Processing Steps

To compute NBR image, we need some Processing steps as follows:

1- Selection of study area, time frame, and satellite sensor for two different time zone (2020-2015) according to month (10-7);
2- Application of cloud-mask (less than 10%) algorithm to pre-and post-fire Image Collections;
3- Creation of cloud-free composites;
4- Calculation of Normalized Burn Ratio for pre-and post-fire dates according to the difference between the NIR and SWIR bands.

NBR=NIR−SWIR / NIR+SWIR

Pre _Post Normalized Difference Vegetation Index

NDVI is the difference between near-infrared (NIR) and red (R) radiations emitted by vegetation divided by its sum .

NDVI = NIR-RED/NIR+RED

To compute NDVI image, we need the following processing steps:

1- Selection of study area, time frame, and satellite sensor for two different time zone (2020-2015) according to year /months;
2- Application of cloud-mask (less than 10%) algorithm to pre-and post-fire Image Collections;
3- Creation of cloud-free composites;
4- Calculation of Normalized Difference Vegetation Index for pre-and-post-NDVI dates according to the difference between the NIR and RED bands.

$$\Delta \text{ NDVI} = \text{NIR-RED/NIR+RED}$$

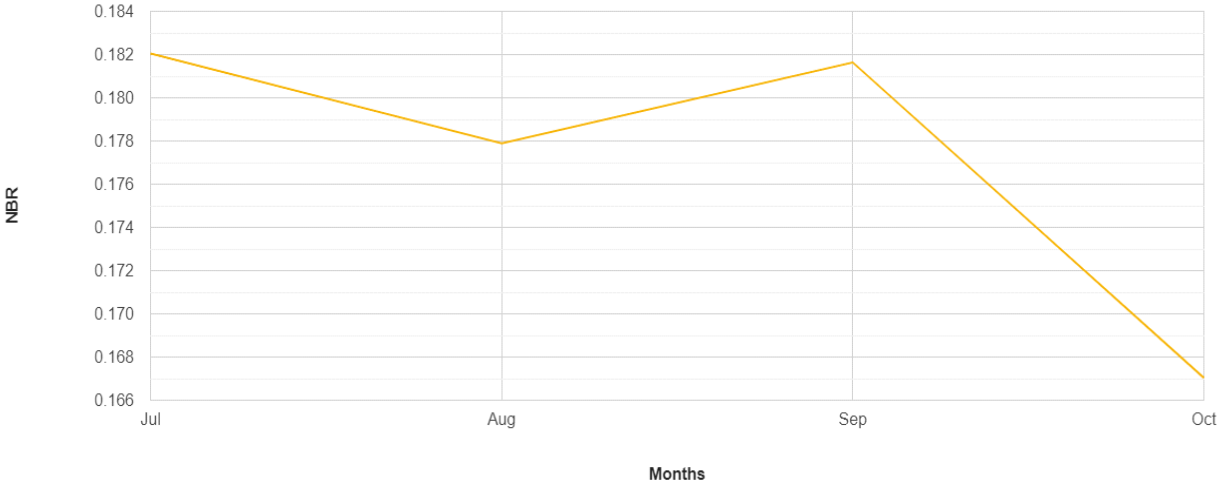


Figure 8. The Average NBR percentage filtered by month (July - October) in 2015.

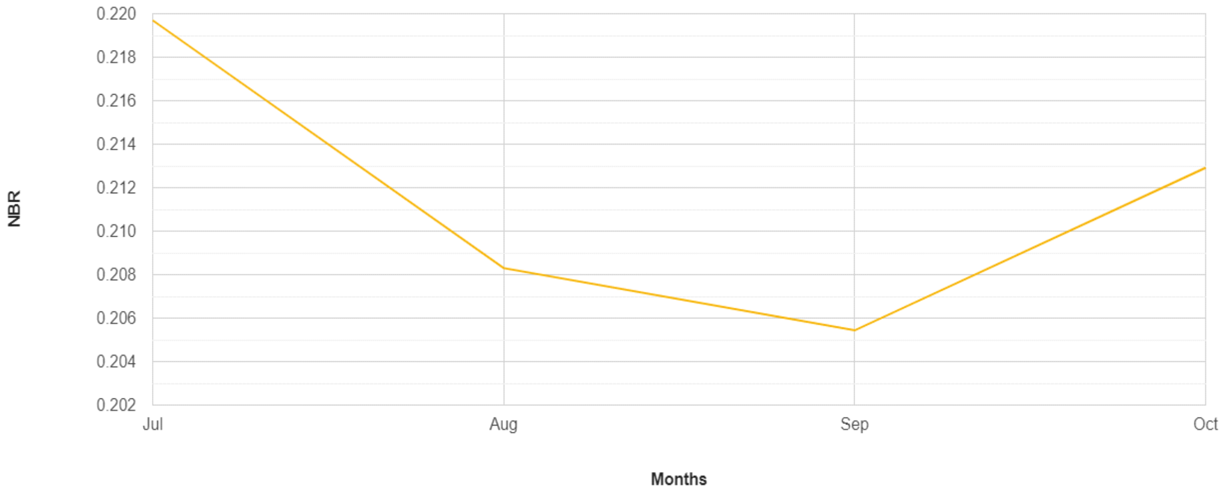


Figure 9. The Average NBR percentage filtered by month (July - October) in 2020.

Pre_NDVI

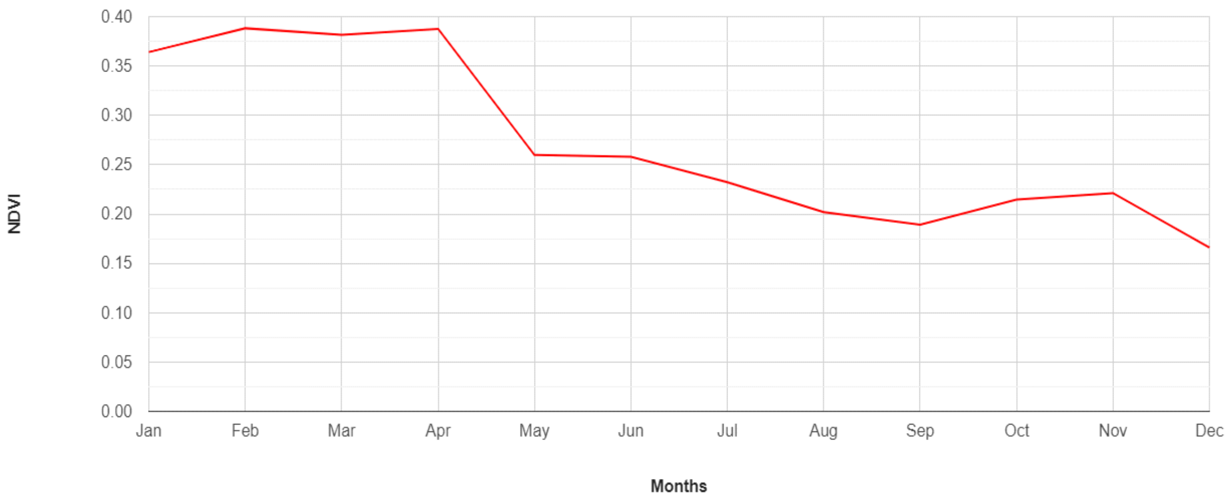


Figure 10. The Average NDVI percentage in 2015.

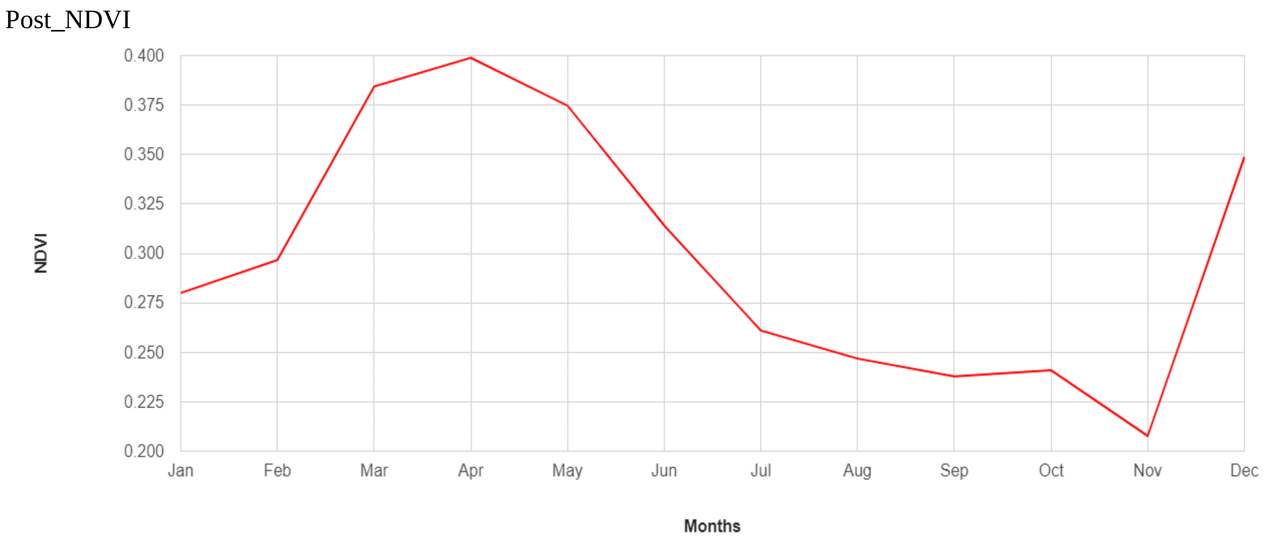


Figure 11. The Average NDVI percentage in 2020.

The NDVI map was generated for the study region (Fig. 12). The Dark green is areas with a null possibility of a fire occurring and spreading because they are areas where there is no vegetation cover it could be buildings or roads or bodies of water or likewise. It has an area of about 689.6 km^2, which is equal to 34.2 % of the total region as shown in table 4.

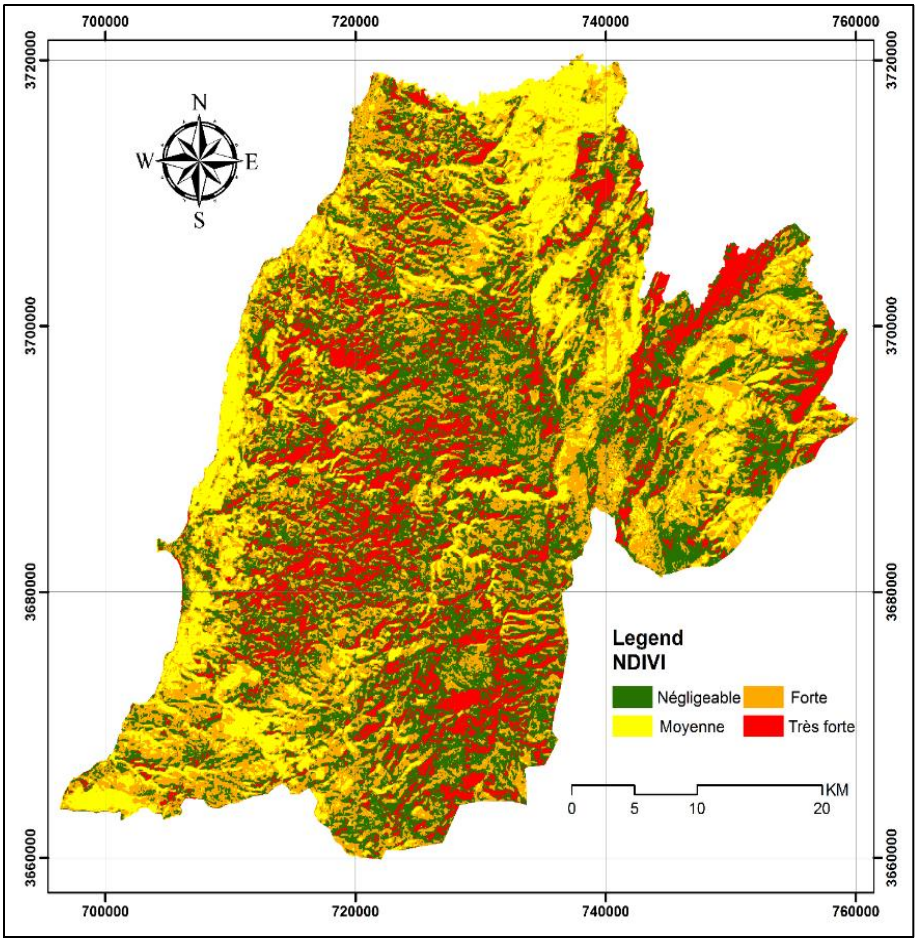


Figure 12. Generated NDVI for the studied region.

In the map, yellow colour are areas with low possibility of a forest fire occurring and spreading because regions where the vegetation cover is always wet, they are agricultural lands that depend on irrigation, and it is mainly in the Sahel region (*i.e.* flat area), where banana and citrus, orchards are present. Whereas, it exists in the east and northeastern, where the beginning of the Bekaa Plain is an agricultural-abundant flat area. The area of this category is about 353.3 km^2, which equals 17.5% of the total area.

The orange color in the maps indicates area where fire and spread probability is medium. They are areas where the vegetation cover still has some moisture. It has an area of 625.7 km^2 which is equivalent to 31% of the total area of the studied region.

The area with higher fire spreading probability is indicated in red color in the maps. These are located in where the vegetation cover has become dry with no moisture. It is mostly grassy areas and it is the most flammable area. The high possibility occupies an area of about 343 km^2 equals about 17% of the total area of the studied region.

Table 4. Area and percentage of fire risk based on vegetation density.

Zone	Color	Area (km^2)	Percentage (%)	Fire Risk	Weight
1	Dark Green	689.603	34.264	Negligible	0
2	Orange	353.319	17.555	Moderate	3
3	Yellow	625.773	31.092	High	4
4	Red	343.941	17.089	Very high	7

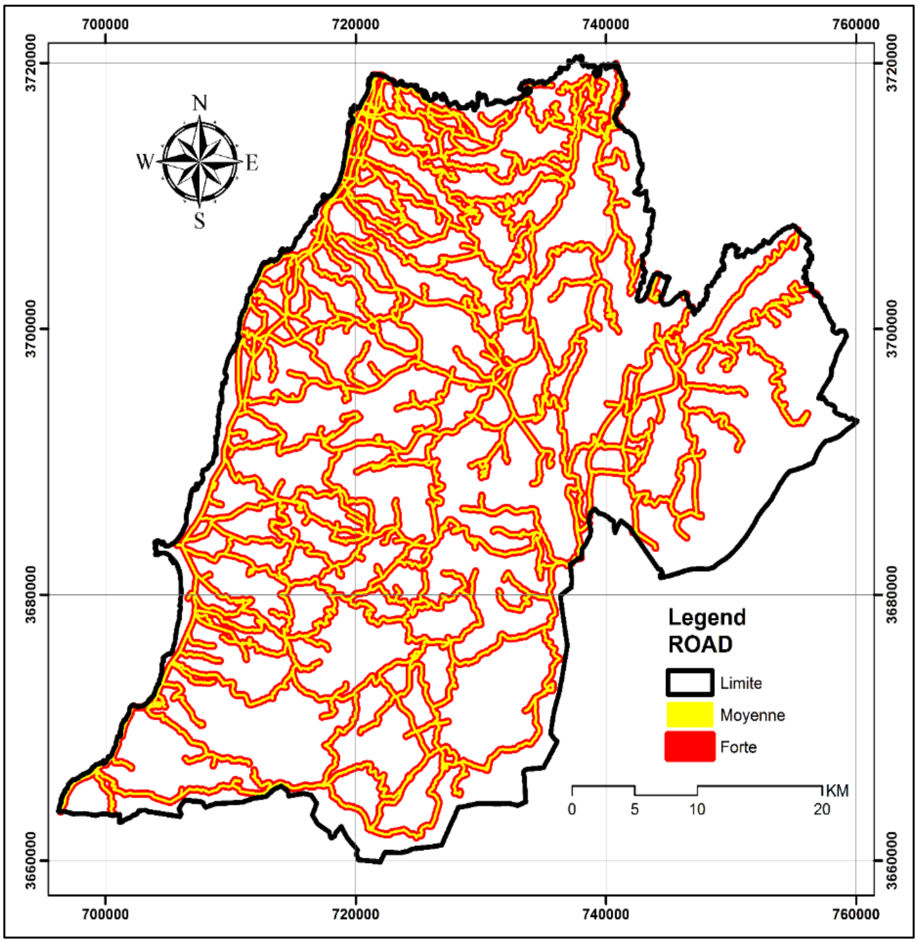


Figure 13. Proximity to roads.

Factors Anthropic

Human activities play a key role in the outbreak of fire. In order to determine the locations of human activity and the extent of its impact on the possibility of a fire, two indicators were used: residential places and roads.

The possibility of a fire breaking out in a specific area is closely linked to the road transportation network and residential places. Reckless human activities, indifference, lack of perception and Proximity of roads was classified into three categories with a numerical value for each category according to its impact on the probability of fires occurrence and spreading (Table 5).

Two maps have been created for this two factor (Fig. 13 & Fig. 14). It is obvious from the map (Fig. 13) that the areas along both sides of the road areas with a distance between 0 and 15 m have a high possibility of fire occurrence. Its area is 30.646 km^2 that is 1.523% of the total area of the study area environmental awareness, such as throwing bottles on the sides of the road, setting fires in forests for barbecue, throwing cigarette butts and so on, leading to the inevitability of fires.

Areas with a low possibility of fire occurrence, are located between 15 and 25 m its area is 46.686 km^2 that is 2.320% of the total area of the study area km^2.

Table 5. Area and percentage of fire risk based on proximity to the roads.

Zone	Color	Area (km^2)	Percentage (%)	Fire Risk	Weight
2	Yellow	30.646	1.523	Moderate	3
3	Red	46.686	2.320	High	5

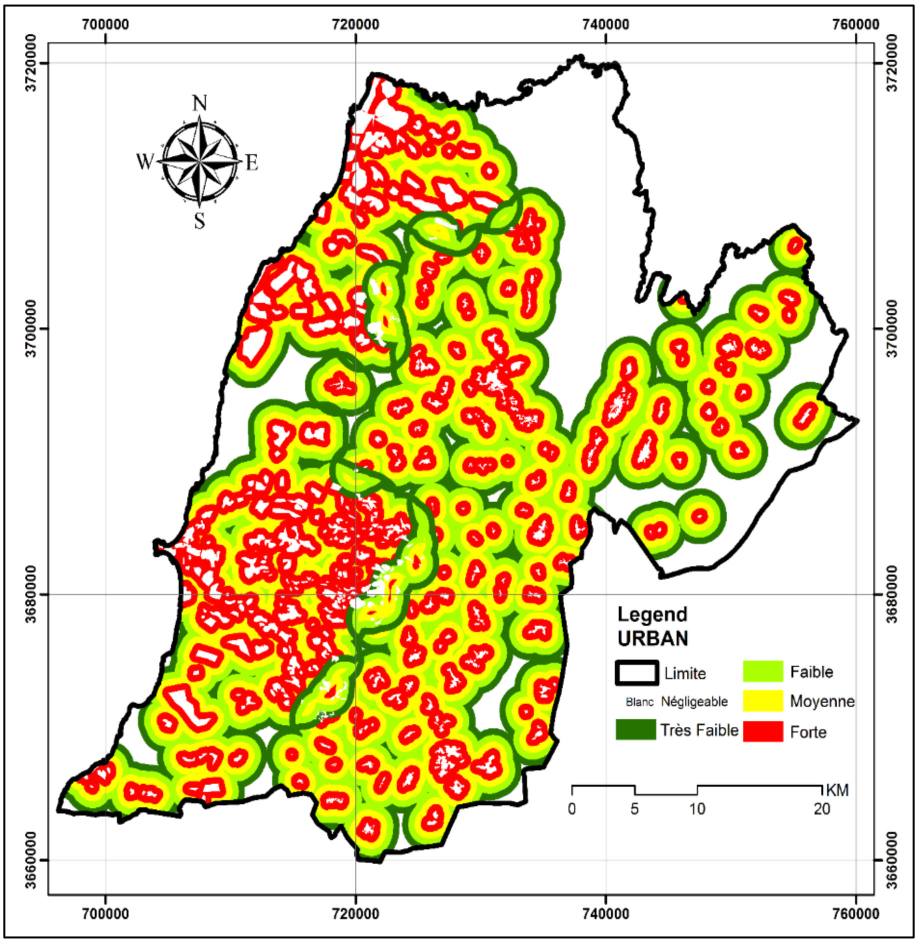


Figure 14. proximity to settlements

In the map (Fig. 14), the white color represents areas with very low (or zero) probability of forest fire occurring and spreading because they are the areas of urban sprawl (settlements), its area is 371.896 km^2 which is 18.478%. The dark green colour stands for the most far from the residential areas, with a very low possibility of fire occurrence and it, its area is 232.653 km^2 that is 11.560% (Table 6).

Light green colour are the areas with a low possibility of fire to occur, its area is 366.267 km^2, which is 18.198% . Yellow colour are the areas close to residential areas between 500 and 1000 m, for they are areas of direct human activities, with a moderate possibility of fire to occur, its area is 505.432 km^2 which is 25.113% of the total area. Red color covers an area of 536.387 km^2 that is 26.651% from the total area, are the areas where the possibility of fire occurrence is high.

Table 6. The Area and the percentage of the fire risk according to the proximity of the settlements.

Zone	Color	Area (km^2)	Percentage (%)	Fire Risk	Weight
1	White	371.896	18.478	Negligible	0
2	Dark Green	232.653	11.560	Very low	1
3	Light Green	366.267	18.198	Low	2
4	Yellow	505.432	25.113	Moderate	3
5	Red	536.387	26.651	High	4

Wind Speed

The relationship between wind speed and the spread of fire is a parallel relationship where the wind speed increases the spread of fire. Moreover, the wind speed in the study area fluctuates between 1 and 5 m s^{-1} in general. In some occasion, the wind speed reaches 14 m s^{-1} and sometimes it can reach greater than this. The numerical values were determined according to the effect of speed on the spread of fire (Table 7). In this study, the wind speed was classified into four categories with a numerical value for each category according to its impact on the probability of fires occurrence and spreading (Fig. 15).

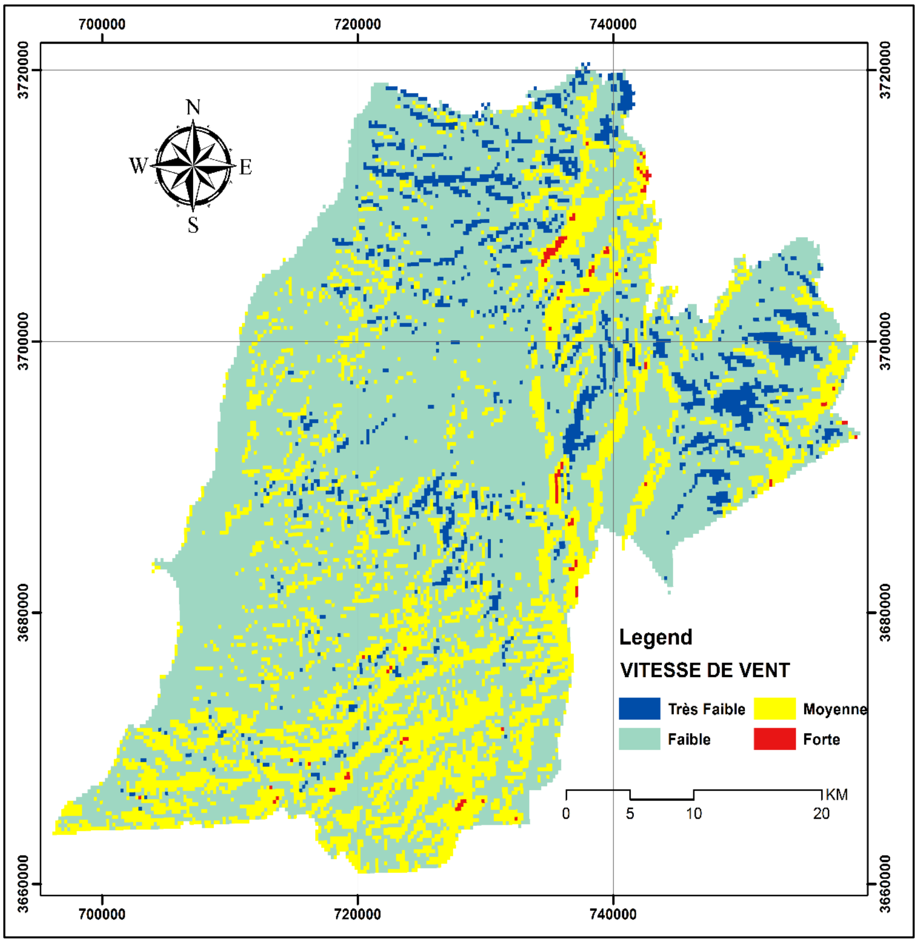


Figure 15. Wind speed.

The dark blue colour has a very low effect. Its area is 115.002 km^2 that are 5.239% of the total area of the study area. Light blue colour has a low effect. Its area is 1428.626 km^2 that are 70.508% that is more than half of the study area. Yellow colour has a moderate effect. Its area is 440.321 km^2 that are 21.403%. The red colour is the speed of the wind which has a huge effect on the possibility of fire spreading. Its area is 22.385 km^2 that is 1.112% of the total area of the study area.

Table 7. Area and percentage of fire risk as a function of wind speed.

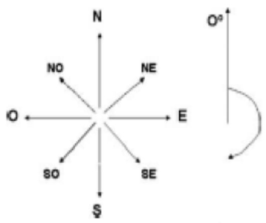
Zone	Colour	Area (km^2)	Percentage (%)	Fire Risk	Weight
1	Dark Bleu	115.002	5.239	Very Low	1
2	Light Bleu	1428.626	70.508	Low	2
3	Yellow	440.321	21.403	Moderate	3
4	Red	22.385	1.112	High	4

RESULTS AND ANALYZES

Depending on the feature of overlaying the maps in GIS, the weights of the factors affecting the occurrence and spread of fires were added as shown in table 8, which resulted in the final map (Fig. 16) of the places most vulnerable to the outbreak and spread of fires in the study area.

Table 8. Weights assigned to each variable and classes for fire risk.

Variables	Classes	Ratings of hazard/risk	Description of fire hazard/ risk
Wind Speed	0.0-1.5 m s^{-1}	1	Very low
	1.5-3.0 m s^{-1}	2	Low
	3-4.5.0 m s^{-1}	3	Moderate
	4.5-10.0 m s^{-1}	4	High
Vicinity to settlements (m)	1500-2000 m	1	Very low
	1000-1500 m	2	Low
	500-1000 m	3	Moderate
	0-500 m	4	High

Distance from roads (m)	Road	0	Negligible
	15-25 m	3	Moderate
	0-15 m	5	Very High
Vegetation	0	0	Low
	0.5-0.8 m	3	Moderate
	0.3-0.5 m	4	High
	0.1-0.3 m	7	Very High
Elevation	0-200 m	1	Very low
	>1000 m	2	Low
	700-1000 m	3	Moderate
	200-700 m	5	Very High
Slope	0-10 %	1	Very low
	10 – 20 %	2	Low
	>20 %	3	Moderate
Aspect	Flat	7	Very High
	East	7	Very High
	Southeast	7	Very High
	South	4	High
	Northeast	4	High
	West	2	Low
	Southwest	2	Low
	North	1	Very low
	Northwest	1	Very low

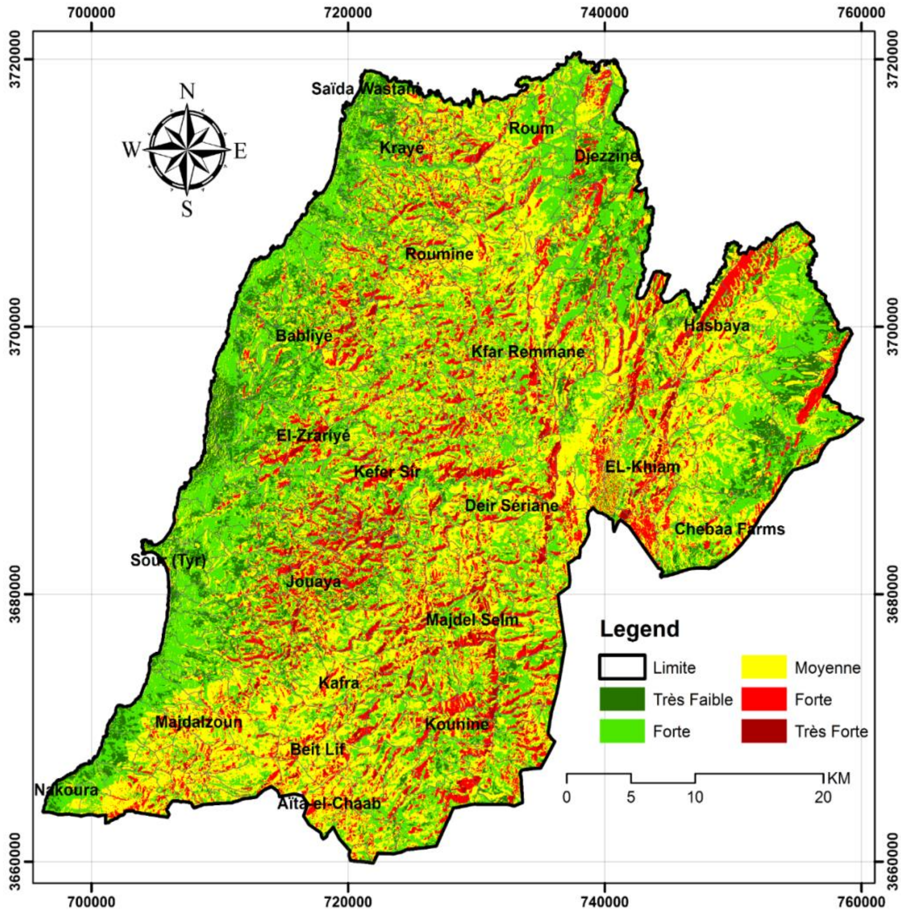


Figure 16. Map of (TSFI).

Fire risk map

The map (Fig. 16) of the probability of the occurrence and spread of fire is divided into five categories: very weak, weak, medium, strong, and very strong (Table 9).

-The first category: the areas with a very low fire risk which are mainly concentrated on the Lebanese coast, its rate is 20.5% which is approximately equivalent to 413 km^2 from the total area of the study area.

-The second category: the areas with a low fire risk an area is 664 km^2 that is 33%.
-The third category: the areas with a medium fire risk its area is 629 km^2 that is 31%.
-The fourth category: the areas with a high fire risk. Its area is 247 km^2 with a percentage 12%
-The fifth category: the areas with very high fire risk. It has the least percentage of 3% with an area of approximately 59 km^2.

Table 9. Area and percentage of fire risk based on TSFI.

Zone	Colour	Area (km^2)	Percentage (%)	Fire Risk
1	Dark Green	413.78	20.56	Very Low
2	Light Green	663.86	32.98	Low
3	Yellow	629.15	31.26	Moderate
4	Orange	247.43	12.29	High
5	Red	58.42	2.90	Very High

CONCLUSION

Forest fires in Lebanon became a seasonal natural risk, statistically every year tens of severe forest fire events occur. The Lebanese government is tackling this environmental issue, but it is usually come with no creditable solution due to the lack of geospatial data that decision-makers can rely on. This study presents a typical example of how to produce a vulnerability map that points out the risk localities. This in turn will help identify the required measures as well as the preparedness methods. It would be a significant tool to avoid harmful consequences on human life and the relevant environmental, social, and economic consequences.

The produced vulnerability map in this study shows that approximately 15 % of the study area is under high and very high-risk probability to fire occurrence with wide geographic spread. It has been concluded that fire possibilities increase with the increase in atmospheric temperature, as a global warming phenomenon, and this interprets the dramatic increase in the number of forest fires not only in Lebanon but also in other regions worldwide. Nevertheless, many countries could put the proper management approaches in their strategies to reduce/ postpone the impact of forest fires. Tanks to the produced vulnerability fire risk map, it has been highlighted that dry grassy areas are the most exposed to fire outbreaks especially in the mountain slopes of the south and southeast. Based on this finding, there must be a national campaign at all official and popular levels and reforesting and encouraging agricultural investment and overcoming the obstacles expected by the competent departments.

From the produced map, it was obvious that the high temperature along with the wind index is the major reason behind the high possibility of forest fires, notably when they are accompanied by the lowest humidity. From this point of view, it can be an alerting signature from the weather with these conditions to adopt the appropriate measures.

Other than these, the other mentioned indices must be well-considered and based upon these geographic distribution, prevention techniques can be proposed, likewise what has been applied in many other countries, such as forests fragmentation, fixing firefighting sites, demonstrating awareness with locals, plus many other success stories.

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