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DOMINGOS XAVIER VIEGAS
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Investigating the potential impact of climatic conditions on fire occurrence in Lebanon

George Mitri*; Karen Gebrael

Land and Natural Resources Program, Institute of the Environment, University of Balamand - Kelhat, El Koura, Lebanon, {george.mitri@balamand.edu.lb}

**Corresponding author*

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Abstract

As Lebanon has experienced an increasing number of fires, this work aimed at assessing the potential impact of climatic conditions on fire occurrence in the country. The results showed an increasing trend of fire events especially in high altitudinal ranges of vegetation levels. Simultaneously, increasing drought conditions were observed in high mountain lands. The results of this study strongly supported a link between changing climatic conditions and fire occurrence in Lebanon. This has resulted in clear impact on vulnerable forest ecosystems, however, a more detailed analysis about the consequences of frequent and intense fires on both vulnerable community livelihood and the natural environment is yet to be assessed.

1. Introduction

Wildfire intensity, extent and frequency are increasing in the Mediterranean ecosystems, causing major impacts on the ecological, economic, social and health systems (Mitri et al., 2016). Like other Mediterranean countries, Lebanon has increasingly suffered from devastating wildfires across the country during the past two decades. The total burnt area reached 21,674 ha and the minimum total number of fires amounted to 2,249 fires for the period extending from 2008 to 2021 (MOE/UOB, 2021). The average annual burnt area increased to 1,449 ha after it was around 1,000 ha per year before the year 2019.

Intense and large-scale wildfires were major causes of Lebanon's forest severe degradation (El Halabi et al., 2014). Tree growth and survival, yield and quality of wood/non-wood forest products, wildlife habitat, recreational, environmental and cultural value of forests were all affected by wildfires. Additionally, wildfires were linked to human injuries/death and loss of properties (MOE/UOB, 2021). In principle, the main direct causes of fires in Lebanon included cleaning lands using fire, burning waste/agricultural residues, camp fires, fireworks and arson, among others (Mitri et al., 2016). Other indirect causes comprised socio-economic changes, increase in the extent of Wildland Urban Interface (WUI) and land cover/land use changes, among others (Mitri et al., 2016; MOE/UOB, 2021). Climate extremes represented a major wildfire driver. In reference to IPCC (2021) heat wave increase, temperature increase, precipitation decrease (i.e., drought period increase), severe wind storms and heavy rainfall are expected to occur in the Mediterranean region (i.e., including Lebanon), therefore exacerbating the wildfire situation. As Lebanon has observed an increasing number of fire events and unprecedented annual extent of burnt areas, this work aimed at assessing the potential impact of climatic conditions on fire occurrence in the country. The specific objectives were to 1) evaluate trends in fire occurrence over the period 2001 to 2021, 2) assess the relationship between climatic drought conditions and elevation and 3) assess the relationship between fire frequencies and elevation levels.

2. Study area and dataset description

2.1. Study area description

The study area covered the country of Lebanon located on the Eastern Mediterranean. In reference to MOE/UOB (2021), the average start date and end date of the fire season is April 19 and November 6, respectively. The average peak month in number of fire events is August while the average peak month in extent of burnt areas is the month of September. Lebanon has a Mediterranean climate, with warm dry summers and cool wet winters. Most of the total annual precipitation (i.e., around 90%) occurs between November and March (Mitri et al., 2016; Mitri et al., 2015).

Lebanon is divided into four physiographic regions (i.e. coastal plain, Lebanon mountain range, Beqaa valley, and Anti-Lebanon Mountains). The Lebanon mountain range rises steeply from the coast to mountains reaching 3,088 meters above sea level (masl) and supports most of Lebanon's forests. The forest land and other wooded land in Lebanon cover around 13% and 11% of its territory, respectively (FAO, 2020). The major forest species are *Quercus calliprinos*, *Quercus infectoria*, *Quercus cerris var. pseudo cerris*, *Juniperus excelsa*, *Cedrus libani*, *Abies silicica*, *Pinus pinea*, *Pinus halepensis*, *Pinus brutia*, and *Cupressus sempervirens*. Around 33% of the national territory is classified as moderate to very high fire risk areas (Mitri et al., 2015). The sharp altitudinal gradients of temperature and precipitation lead to the appearance of different climatic zones running along mountain elevations. This explains the presence of five different vegetation levels (Abi-Saleh and Safi, 1998) as shown in **Figure 1**, namely the Thermomediterranean (0-500 m asl), Eumediterranean (500-1000 m asl), Supramediterranean (1000 -1500 m asl), Montanemediterranean (1500-2000 m asl) and Oromediterranean (>2000 m asl).

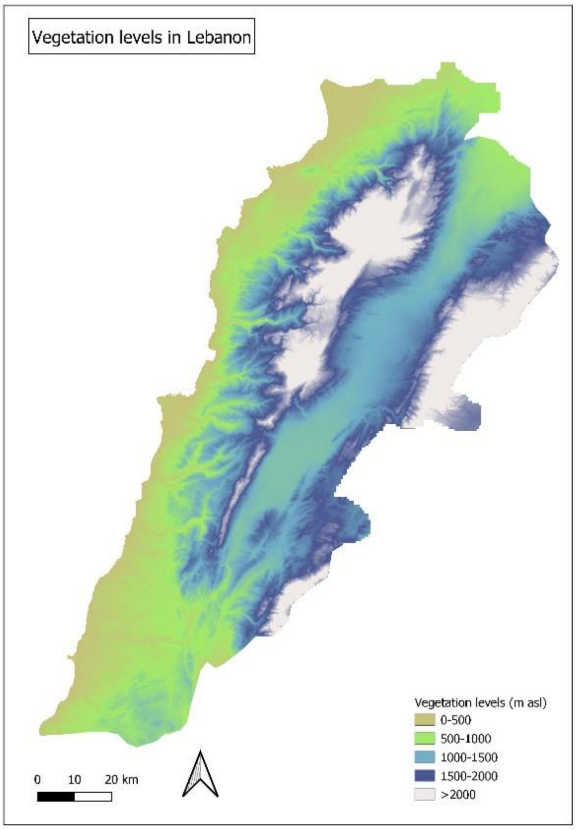

Figure 1. Altitudinal vegetation levels in Lebanon

2.2. Dataset description

Archived fire hotspots in Lebanon for the years 2001 throughout 2021 were collected in form of shapefile using the Fire Information for Resources Management System (FIRMS). Data courses included the J1 VIIRS C1, SUOMI VIIRS C2 and MODIS C6.1. The spatial climatic data needed to calculate the increase in the Keetch-Byram Drought Index (KBDI) between current averages and future averages were mostly obtained from simulated Global Climate Models (GCM). Datasets of historical averages (1950 to 2000) and future 30-year running averages (2010 to 2039) included: monthly maximum temperature, monthly precipitation and mean annual rainfall at 1x1 km of spatial resolution (Mitri et al. 2015). In addition, a Digital Elevation Model (DEM) of 25x25 m resolution and the 2017 land cover-land use map of Lebanon were employed.

3. Methodology

A total of 5095 fires were plotted against their years of occurrence between 2001 and 2021 to evaluate trends in fire events throughout the years. A Pearson correlation test (i.e., linear relationship between data) was performed to assess any significant increase in number of fires in most recent years.

Consequently, the relationship between climatic drought conditions and elevation above sea level was assessed. More specifically, the statistical relationship between increase in KBDI and high country lands was tested using Spearman correlation (i.e., non-linear relationship between data). This eventually helped in evaluating the increase of drought conditions in the range of high altitudinal vegetation levels and its possible relationship with fire occurrence in those areas. The ranges in elevation were chosen according to the categorization of Digital Elevation model (DEM) values into vegetation level zones (**Table 1**). A Pearson correlation test was performed in order to assess the link between fire frequencies and elevation levels. Furthermore, the fire occurrence in high mountain forest ecosystems (e.g., cedar, fir and juniper) was investigated.

Table 1-Vegetation levels (MOE/UNDP, 2011)

Vegetation level	Elevation (m)
Thermomediterranean	[0-500]
Eumediterranean	]500-1000m]
Supramediterranean	]1000-1500m]
Montanemediterranean	]1500-2000m]
Oromediterranean	>2000m

4. Results and discussion

4.1. Trends in fire occurrence (2001-2021)

The total number of fires per year was estimated from 2001 to 2021. **Figure 2** showed that the annual number of fires varied from 4 to 1077 fires, for the assessed period. The highest number of fires was in 2021 and the lowest one was in 2001. Moreover, the performed Pearson correlation test showed that the total number of fires increased significantly throughout years (p value = 0.000084, Pearson correlation coefficient = 0.752).

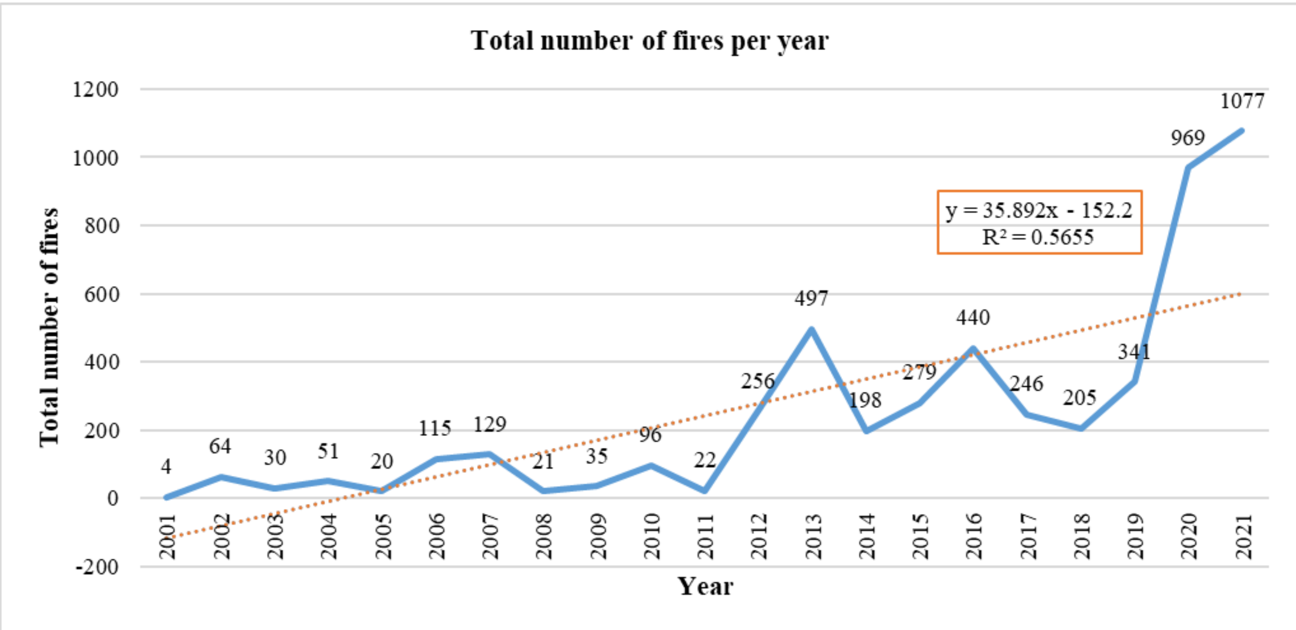

Figure 2-Total number of fires per year in Lebanon

4.2. Climatic drought conditions and elevation

The average KBDI increase varied between 9 (i.e., Supramediterranean level) and 27 (i.e., Oromediterranean level) (**Figure 3**). Moreover, a notable increase in KBDI was remarked in high altitudinal ranges of vegetation levels (i.e., above 1000 m). Accordingly, the relationship between KBDI increase and elevations was evaluated in ranges above 1000 m using the Spearman correlation test. The test showed a significant positive correlation between the 2 variables (p value = 9.182E-17, Spearman correlation coefficient = 0.308). Accordingly, it was assumed that any increase in fire occurrence within high altitudinal ranges of vegetation levels could be linked to increase of drought conditions in those areas.

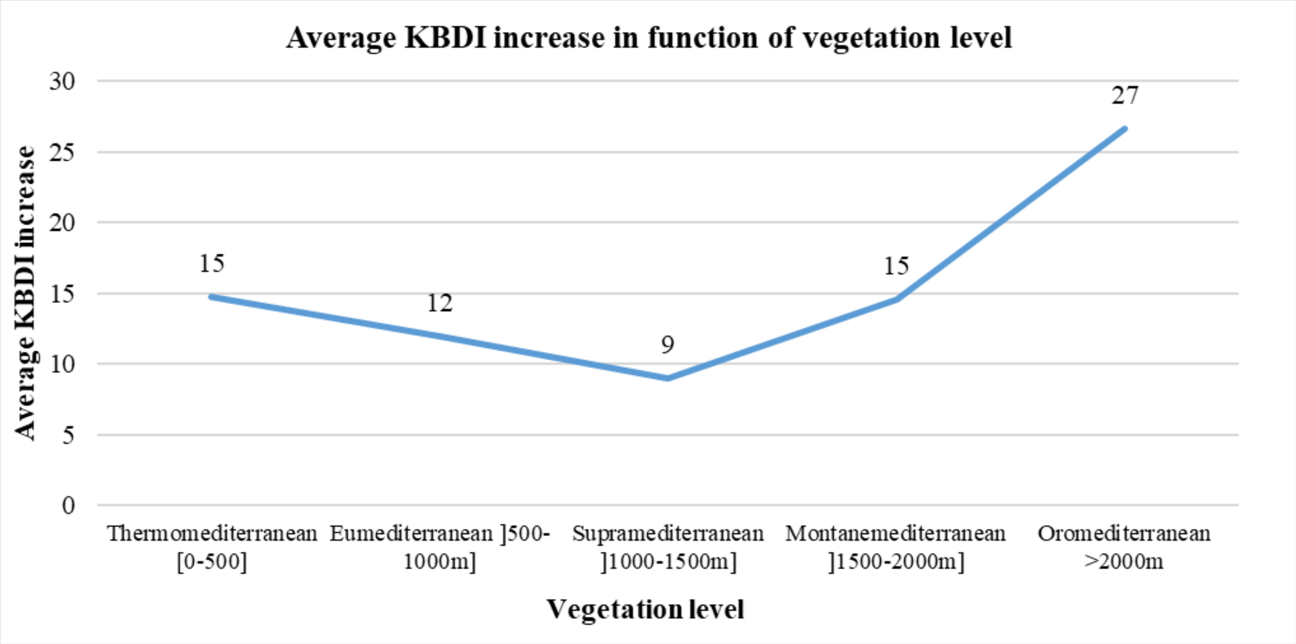

Figure 3-Average KBDI increase variation in function of vegetation levels

4.3. Fire frequencies and elevation levels

The variation in total number of fires in function of vegetation levels was also evaluated for the period extending between 2001 and 2021. **Figure 4** showed that the highest number of fire events occurred in Thermomediterranean level (i.e., 2644 fires) and the lowest number was in Oromediterranean level (i.e., 24 fires). In addition, the statistical analysis showed a negative significant correlation between the total number of fires and elevations (i.e., p value = 5.57 39E-109, Pearson correlation coefficient = - 0.537). These results were expected as high country lands encompass low density vegetation cover therefore lower fire hazard.

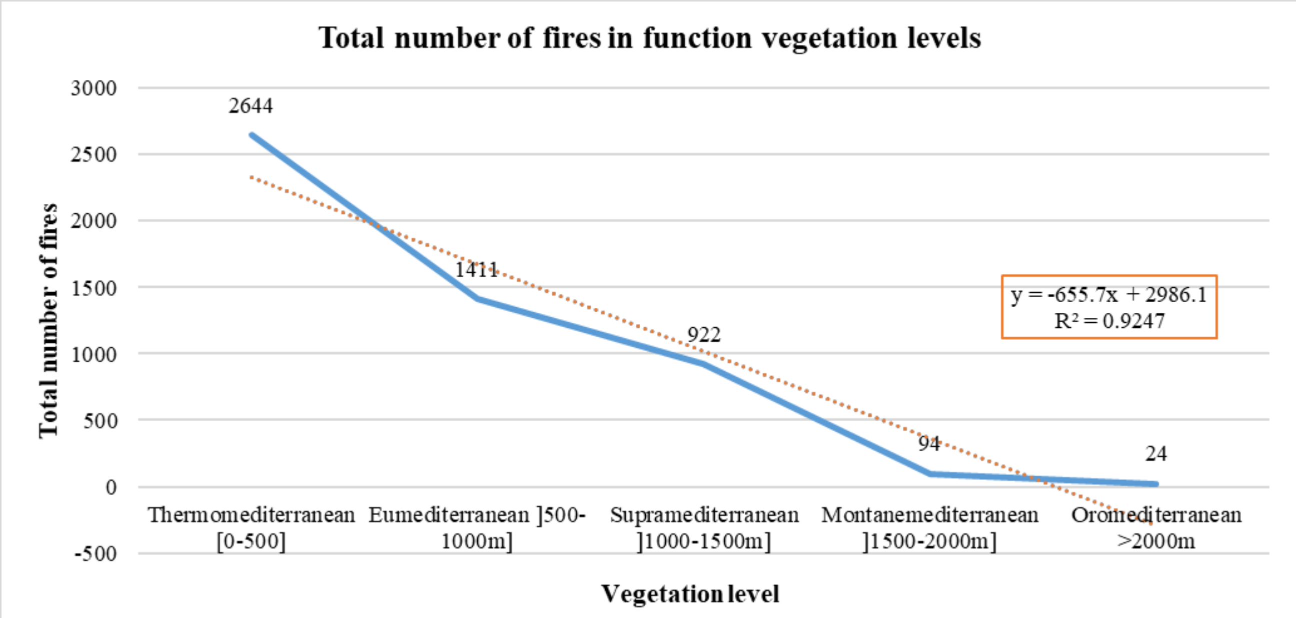

Figure 4-Total number of fires in function of vegetation levels

Yet, the multi-temporal variation in the total number of fires in each vegetation level was further assessed (**Figure 5** – **Figure 9**). The performed statistical analysis showed that the total number of fires increased significantly throughout years, in all vegetation levels. The results were summarized in **Table 2**.

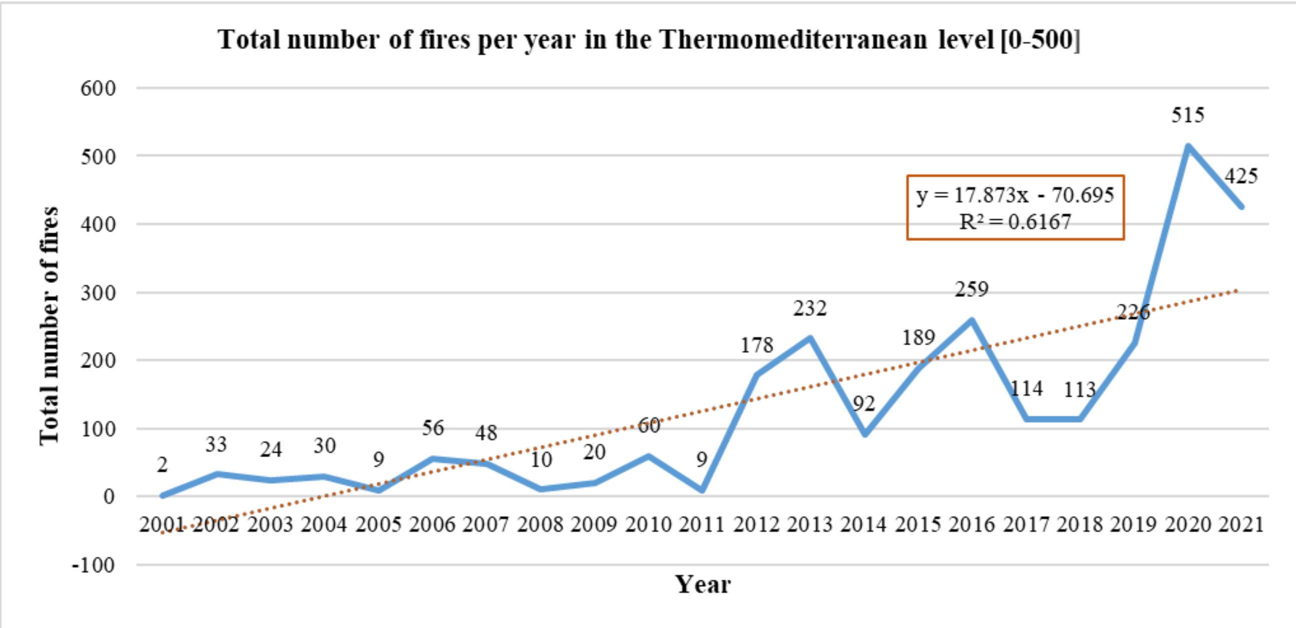

Figure 5-Total number of fires per year in the Thermomediterranean level

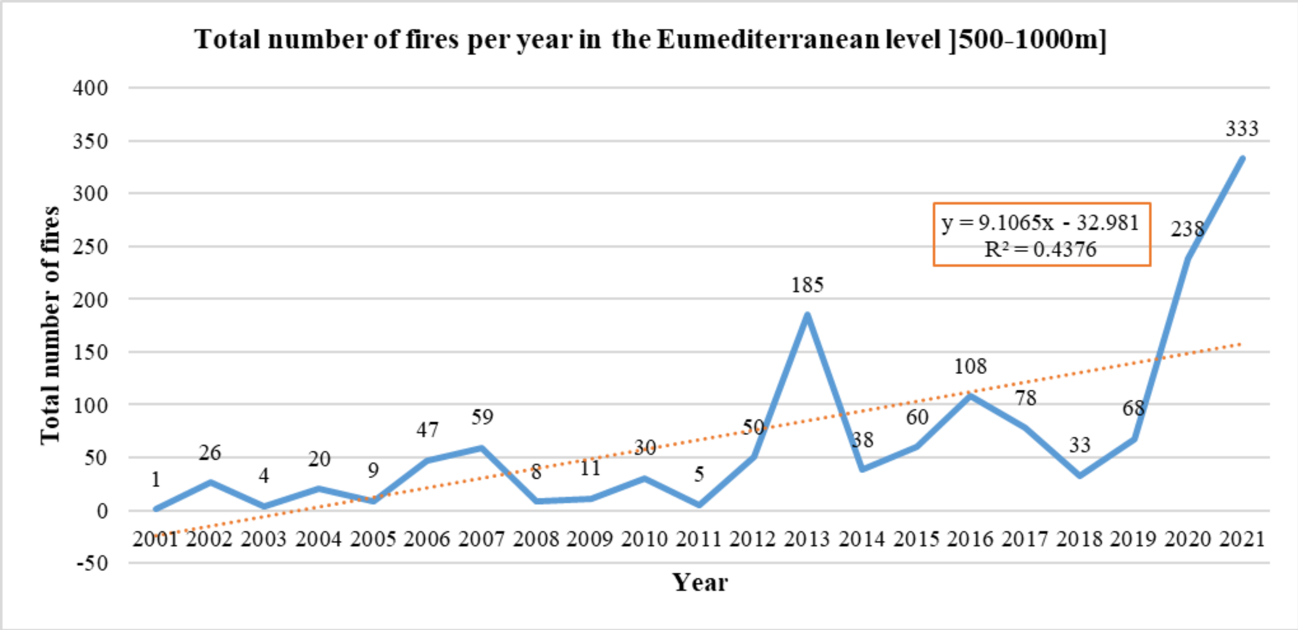

Figure 6-Total number of fires per year in the Eumediterranean level

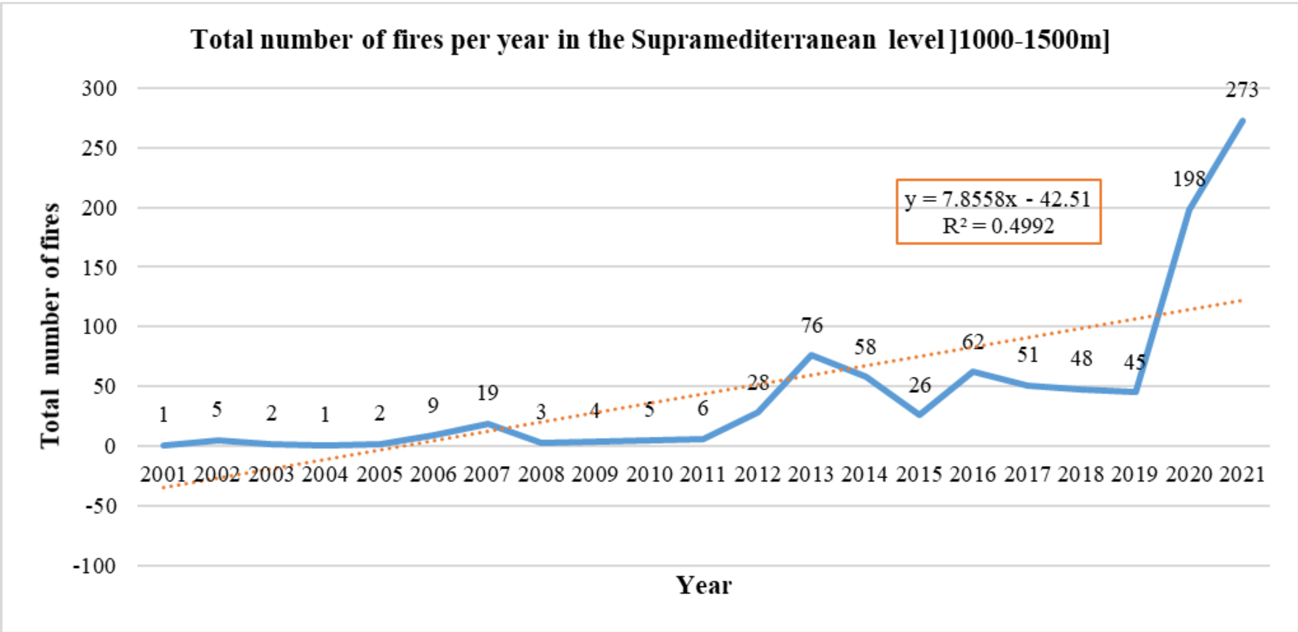

Figure 7-Total number of fires per year in the Supramediterranean level

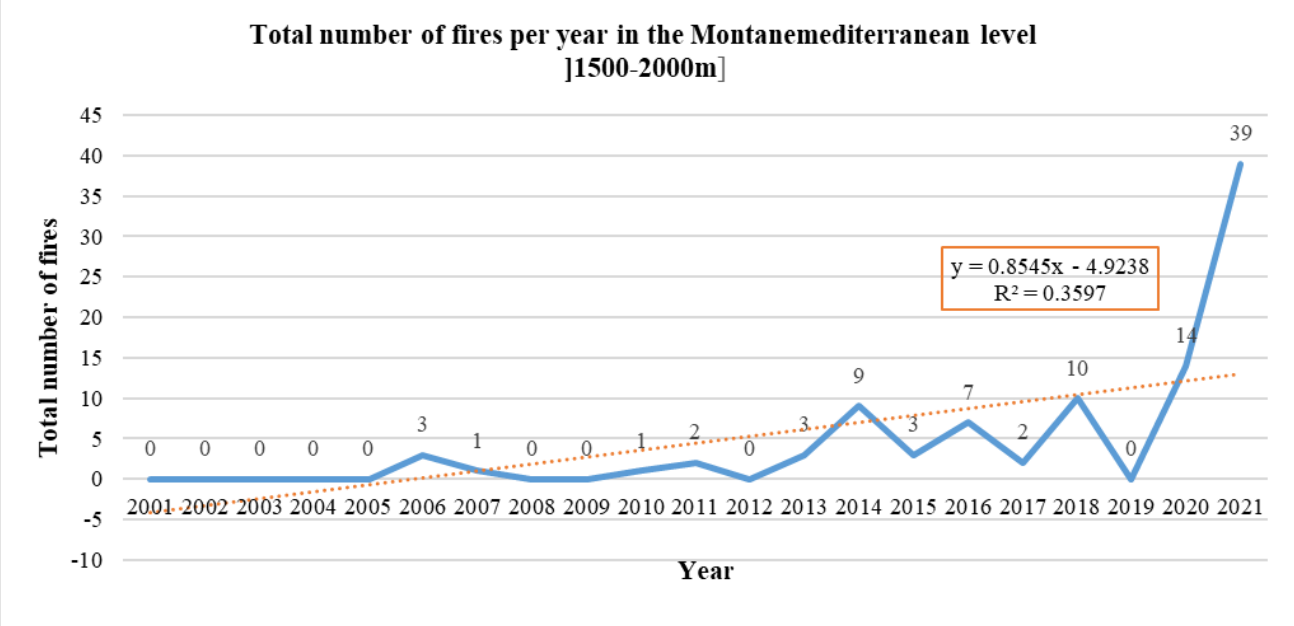

Figure 8-Total number of fires per year in the Montanemediterranean level

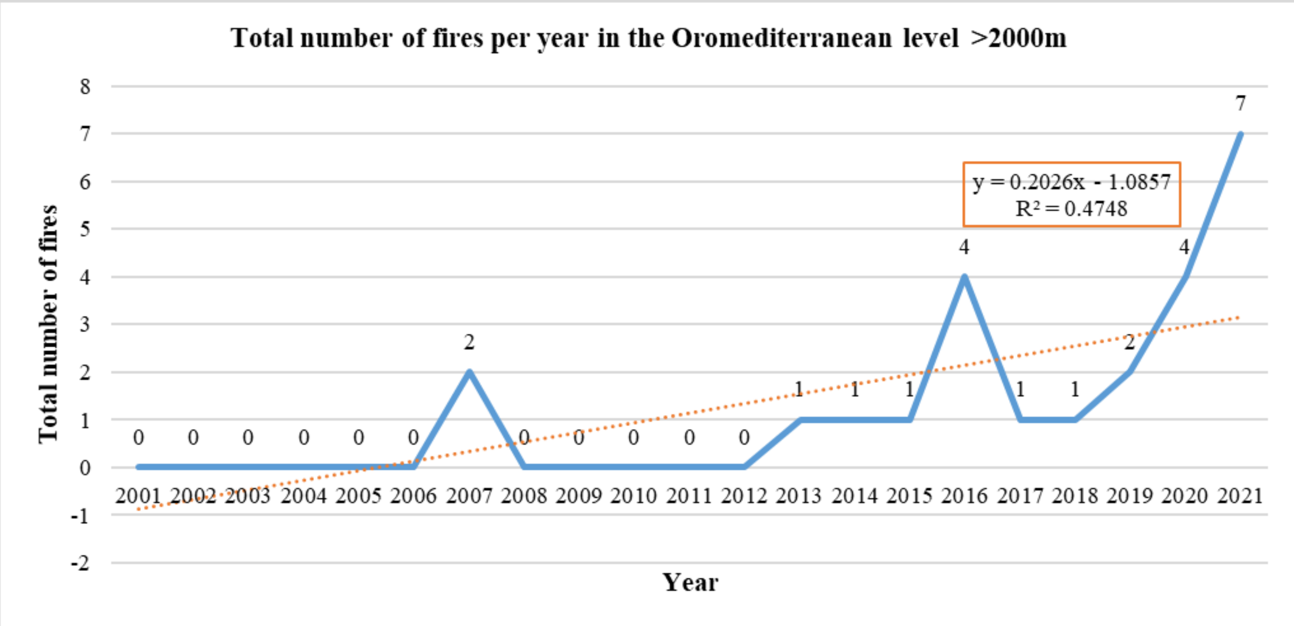

Figure 9-Total number of fires per year in the Oromediterranean level

Table 2-Correlation between total number of fires and years results

Vegetation levels	p value (Correlation between total number of fires and years)
Thermomediterranean [0-500]	p value = 0.000025 (Pearson correlation coefficient = 0.785)
Eumediterranean]500-1000m]	p value = 0.000035 (Spearman correlation coefficient = 0.777)
Supramediterranean]1000-1500m]	p value = 2.2227E-7 (Spearman correlation coefficient = 0.874)
Montanemediterranean]1500-2000m]	p value = 0.00036 (Spearman correlation coefficient = 0.704)
Oromediterranean >2000m	p value = 0.000018 (Spearman correlation coefficient = 0.794)

Overall, the results indicated a significant increase of drought conditions in high mountain lands across the high altitudinal ranges of vegetation levels simultaneously to obvious increase of fire events in those same areas. Accordingly, it was assumed that changing climatic conditions were expected to directly drive the increase of fire occurrence in high country lands therefore pausing an increasing threat to vulnerable high mountain forest ecosystems such as cedar, fir and juniper forests and other types of natural landscape which comprise very often rare endemic species not adapted to fires. In fact, specific vulnerable mountainous ecosystems (i.e., cedar forests) experienced disastrous fire events for the first time in the recorded history of fires in Lebanon. As shown in **Figure 10**, there was a remarkable increase of fire events in high mountain forest ecosystem especially in the years of 2020 and 2021.

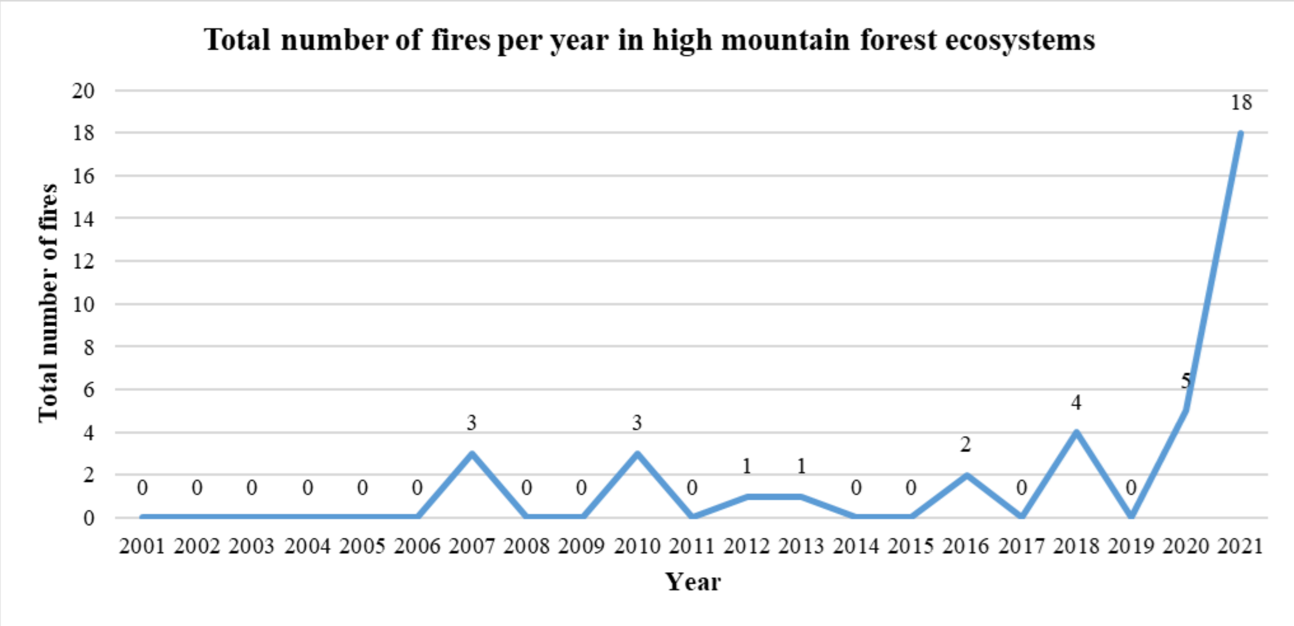

Figure 10-Total number of fires per year in high mountain forest ecosystems

5. Conclusions

As the climate science community sources a suite of global climate models to help decision makers understand the projections of future climate change and related impacts, the Coupled Model Intercomparison Project , Phase 5 (CMIP5) models, as included in the IPCC's Fifth Assessment Report (AR5) showed increase in fire weather conditions throughout the next 30 years with high confidence for the Mediterranean basin. Building on the results of this work, Lebanon is expected to face an increasing risk of fires, whether that's forest fires or grassland fires. More specifically, as the landscape becomes increasingly dry from multiple years of gradual change, an increase in the frequency and intensity of fires is expected. This necessitates developing and implementing all necessary adaptation measures to mitigate the impact of fires on both vulnerable community livelihood and the natural landscape.

6. References

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