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Developing Lebanon's fire danger forecast

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ABSTRACT

Lebanon lacks a system for forecasting wildfire danger with the combined use of dynamic weather forecasts and comprehensive fire risk information (i.e., hazard and vulnerability). Accordingly, the aim of this study was to develop a new national fire danger forecast system for use as an operational fire management tool in Lebanon. The specific objectives were to 1) produce an advanced fire risk map of Lebanon, 2) customize an index for use in fire danger forecasting, and 3) develop an automated system for daily fire danger forecasts. Producing an advanced fire risk map involved the combined use of collected fire risk data and predicted wildfire occurrence. Forward stepwise binary logistic regression analysis of 24 socio-economic and biophysical variables was initially adopted to predict wildfire occurrence. Geographic object-based image analysis (GEOBIA) approach was employed to map the different classes of fire risk. Consequently, the customization of an index for fire danger forecasting involved the use of both fire risk and Fire Weather Index (FWI) data using also the GEOBIA approach. Overall, modeling socio-economic and biophysical factors correctly predicted an average of 85.7% of fire occurrences between 1998 and 2012 across the country. In addition, a comparison of FWI forecasts and fire occurrence (i.e., observed fire events) during the fire season of 2015 resulted in sensitivity (76.2%) and specificity (18.6%) estimates. Finally, automated daily fire danger forecasts are expected to serve as essential tools for both scientific and operational purposes.

1. Introduction

Many Mediterranean ecosystems are experiencing increases in fire frequency, intensity and severity [1] resulting in various ecological, social and economic consequences [2,3]. The increase in number of forest fires and extent of burned areas in the Mediterranean is mostly related to human activities as more than 90% of fires of known cause are associated with deliberate or accidental human ignitions [4]. Simultaneously, increase in fire activity is accompanied by an expansion of the Wildland-Urban Interface (WUI), further promoting the risk of fire occurrence and spread [5]. Broader socio-economic and demographic trends (i.e., rural exodus, abandonment of arable land, and increase in ex-urban populations) are leading to accumulation in forest fuels adjacent to rapid ex-urban development [3,6].

Assessing and forecasting wildfire danger is an important step towards efficiently allocating resources for fire prevention, mitigation, and post-fire recovery efforts. Until present, Lebanon lacks a dynamic and comprehensive system for forecasting wildfire danger [7] that takes into account weather forecasts and fire risk information (i.e., hazard and vulnerability) in addition to socio-economic factors. In this work, the term "risk" considers the probability of a fire occurring and spreading (i.e., fire hazard) and includes values and expected losses (i.e., vulnerability) [8–10]. The probability of a fire event is initially associated with "hazard" which refers to the state of the fuel. Accordingly, hazard (e.g., fuel type and combustibility) and vulnerability (e.g., natural reserve versus un-protected area, forested area versus grassland, settlement boundary and occupation) in addition to socio-economic factors need to be considered in a comprehensive fire risk assessment. In turn, the combined use of fire risk and weather forecasts contribute to wildfire danger forecast. In view of that, danger is the result of both constant and variable danger factors which mainly affect the spread, difficulty of fire control, and fire impact [11].

In this context, the aim of this study was to develop a new national fire danger forecast system for use as an operational fire management tool in Lebanon. The specific objectives were to 1) produce an advanced fire risk map of Lebanon, 2) customize an index for use in fire danger forecasting, and 3) develop an automated system for daily fire danger forecasts.

Previous research led to modeling the first spatially explicit national map of fire risk as a function of fire hazard and vulnerability [12]. This model of fire risk, however, did not capture socio-economic drivers of fire occurrence. In recent years, many studies [13–15] have shown that

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socio-economic variables and human factors have a considerable impact on fire regimes. In Lebanon, negligence was reported as the main cause of fires (i.e., 14% of reported fire causes), followed by human activities on natural landscapes (i.e., 9% of reported fire causes) although the causes of ~ 67% of forest fires are neither identified nor reported [16]. Landfill and agricultural practices represented 6% and 4%, respectively, of the total fire causes. In this context, it was important to incorporate socio-economic factors into a new model estimating advanced fire risk [17].

Also, in order to develop forecasts of fire danger in Lebanon, it was necessary to couple the advanced fire risk map with the Fire Weather Index (FWI) derived from weather forecasts. The fire danger forecast module of the European Forest Fire Information System (EFFIS) was initially established as a unified platform for implementation of selected national fire weather indices throughout Europe [18]. The fire danger rating in EFFIS does not intend to replace the systems used by the countries, but to complement them by providing a harmonized European-wide assessment of fire danger. The fire danger forecast in EFFIS involves the components of the Canadian FWI system [19], of the Canadian Forest Fire Danger Rating System [20]. More specifically, the FWI system has six components that rate fuel moisture content and potential fire behavior in a common fuel type (i.e., mature pine stand). Calculations are based on daily noon measurements of air temperature, relative humidity, wind speed and previous 24-h precipitation.

Although the application of the FWI system in EFFIS during the last years has confirmed it can be used in modeling fire danger in Europe [18], the FWI output only depends on meteorological observations and does not consider differences in fuel types or topography. While it provides a uniform rating of fire danger, the lack of these key drivers of fire occurrence and spread limits its application. Consequently, there is a need to develop a model that includes fuel condition and topography [19].

Here we used multi-scale sensors and multi-source biophysical and socio-economic data to derive maps of fire risk and consequently of fire danger forecast. In order to integrate multi-dimensional data sets and accurately extract the required information [21,22] we used GEographic Object-Based Image Analysis (GEOBIA). This approach addresses the production of meaningful image-objects and the assessment of their characteristics [23].

However, implementing environmental automated models in a web context is necessary to help bridge between high-level fire danger data analysis and access usability for and by national authorities (i.e., the new Disaster Risk Reduction and Management Unit) and the general public. In summary, we combined multi-source and multi-resolution data to provide daily forecasts of fire danger in Lebanon. It was also essential to incorporate automated model forecasts of fire danger into a web-based platform that could be easily accessed by a diverse array of policymakers and stakeholders, addressing important national priorities (i.e., Lebanon's National Strategy for Forest Fire management – Decision no. 52-2009).

Overall, this work is expected to help in efficiently managing firefighting resources and imposing prevention of large and disastrous wildfires. At a different level, the outcome of this work is expected to promote know-how sharing, monitoring and dissemination of knowledge on wildfire risk management among all relevant actors (science/research, policy makers, land managers, grassroots' groups), bridging science and traditional knowledge.

2. Materials and methods

2.1. Study area description

The study area covers the entire Lebanese territory (total area of 10,452 km^2) on the eastern part of the Mediterranean (Fig. 1). Lebanon is divided into four distinct physiographic regions: the coastal plain, the Lebanon mountain range, the Beqaa Valley, and the Anti-Lebanon mountain range [12]. Forests and other wooded land cover 24.5% of the Lebanese territory [24]. Other categories of land cover/land-use comprise grassland, cropland, bare land and land with little vegetation, and settlement. The climate in Lebanon is characterized by dry summers extending from June to November [25] with average daytime temperatures above 30 °C, and little rain (i.e., around 90% of the total annual precipitation falling between November and March).

The Lebanon mountain range rises steeply from the coast to mountains reaching 3088 m above sea level (masl) and supports most of Lebanon's forests. 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 [12]. Like other Mediterranean countries, most fires occur during the dry season and a majority of ignitions are attributed to human activities. Fire spread is primarily driven by the interactions between fuel accumulation, seasonal drought, temperature, and precipitation [25,26]. Main land cover types affected by fires include mixed forest and other wooded lands (64%), cropland (16%), and grassland (13%), among others [27]. The average length of fire season is approximately 147 days and the average peak month is September [25]. In general, Lebanon is expected to face in the future increasing number of fire occurrence and increasing length of fire seasons [25].

2.2. Dataset description

The advanced mapping of fire risk necessitated first the collection of Lebanon's initial fire risk data. Lebanon's initial fire risk map [12] was previously developed by employing geospatial biophysical and climatic data in addition to land cover/land-use map of Lebanon. More specifically, the biophysical data comprised landcover and land-use spatial information [28], including extent of protected natural reserves. Drought spatial characteristics were integrated in the initial fire risk map. More specifically, datasets of monthly maximum temperature, monthly precipitation, and mean annual rainfall (1-km spatial resolution) of current 1950–2000) conditions were extracted from the "Worldclim" database for the calculation of the Keetch-Byram Drought Index (KBDI). These data were generated through interpolations of representative observed data from major global climate databases [29].

Other data were collected in addition to the initial fire risk map. These included Lebanon's administrative map showing the boundaries of villages (i.e., cadastral units) and a Digital Elevation Model (DEM) of 30 × 30 m. Terrain slopes and aspects were extracted from the employed DEM. The vegetation fuel type map [12] was also collected. In reference to this map, the Prometheus fuel type classification system [30] was used for characterizing fuel type (Table 1).

Spatial distribution of fruit trees, mixed culture, field crop, olive trees, vineyard, and greenhouses were extracted from the land cover/land-use map of Lebanon [12]. Conversion of lands (i.e. cropland, forest, and grassland to settlement) between 1998 and 2005 were also acquired [31]. Animal production was obtained from the homogeneous agricultural zones data of the Ministry of Agriculture (MOA) produced in 1998. In addition, population density as acquired from the Central Administration of Statistics (CAS), distance to big cities (i.e., 1000–10,000 inhabitants), distance to bigger cities (i.e., above 10,000 inhabitants), the agricultural-urban interface, and roads in agricultural lands were also acquired [26]. Fire occurrence and annual extents of burned areas from 1998 throughout 2012 [31] were collected for use in the logistic regression analysis and for evaluation of the results. These data were extracted from multi-temporal Landsat TM imagery [31]. The list of main datasets employed in this study for the advanced mapping of fire risk, and their corresponding units and sources were listed in Table 2.

In addition, daily FWI forecast data were collected for use in combination with the advanced fire risk map to customize a new fire danger