Science of the Total Environment xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

A comparative study of fire weather indices in a semiarid south-eastern Europe region. Case of study: Murcia (Spain)

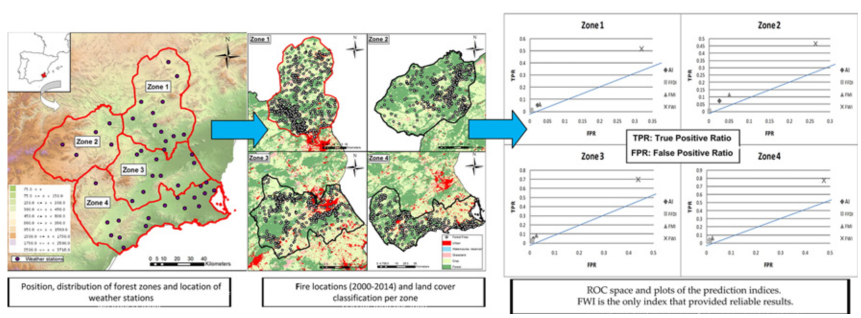
Julio Pérez-Sánchez [a,*], Javier Senent-Aparicio [a], José María Díaz-Palmero [b], Juan de Dios Cabezas-Cerezo [b]

[a] Department of Polytechnic Science, University of Polytechnic Science, UCAM University of San Antonio of Murcia, Campus los Jerónimos, n° 135, 30107 Guadalupe, Murcia, Spain
[b] Consejería de Agricultura y Agua, CARM, Murcia, Spain

HIGHLIGHTS

- The study area is in southern Spain, has a surface area of 11314 km^2 and wildfires in 2000-2014 burnt 40 km^2 of forests.
- The FWI is shown to be the most suitable index in a semiarid region for all types of vegetation.
- The AI is capable of distinguishing fire-danger warnings in the driest and highest temperature areas.
- The use of a single comparison method is inaccurate, confusing and, in some cases, useless.
- The ROC space highlights the results of an index and benefits operational wildfire predictions in semiarid regions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 22 November 2016
Received in revised form 21 February 2017
Accepted 5 March 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Wildfire
Fire weather index
Rank percentile method
ROC space
Spain

ABSTRACT

Forest fires are an important distortion in forest ecosystems, linked to their development and whose effects proceed beyond the destruction of ecosystems and material properties, especially in semiarid regions. Prevention of forest fires has to lean on indices based on available parameters that quantify fire risk ignition and spreading. The present study was conducted to compare four fire weather indices in a semiarid region of 11,314 km^2 located in southern Spain, characterised as being part of the most damaged area by fire in the Iberian Peninsula. The studied period comprises 3033 wildfires in the region during 15 years (2000–2014), of which 80% are >100 m^2 and 14% >1000 m^2, resulting around 40 km^2 of burnt area in this period. The indices selected have been Angström Index, Forest Fire Drought Index, Forest Moisture Index and Fire Weather Index. Likewise, four selection methods have been applied to compare the results of the studied indices: Mahalanobis distance, percentile method, ranked percentile method and Relative Operating Characteristic curves (ROC). Angström index gives good results in the coastal areas with higher temperatures, low rainfall and wider range of variations while Fire Weather Index has better results in inland areas with higher rainfall, dense forest mass and fewer changes in meteorological conditions throughout the year. ROC space rejects all the indices except Fire Weather Index with good performance all over the region. ROC analysis ratios can be used to assess the success (or lack thereof) of fire indices; thus, it benefits operational wildfire predictions in semiarid regions similar to that of the case study.

* Corresponding author.
E-mail addresses: jperez058@ucam.edu (J. Pérez-Sánchez), jsenent@ucam.edu (J. Senent-Aparicio), josemaria.diaz@udif.es (J.M. Díaz-Palmero), juand.cabezas@carm.es (J.D. Cabezas-Cerezo).

http://dx.doi.org/10.1016/j.scitotenv.2017.03.040
0048-9697/© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Forest fires are major hazards that can cause not only great ecological and economic losses but also endangering human life. C02 emissions in a wildfire are similar to the ones from fossil fuel combustion process (Bowman et al., 2009). The loss of human lives is the worst outcome of wildland fires and populated areas have a higher exposure to large wildland fires than ever before (Viegas et al., 2006). Wildfire-related fatalities not only entail direct victims of fires but also those who perish because of exposure to degraded air quality caused by fires (Analitis et al., 2012; Jayachandran, 2009; Vedal and Dutton, 2006; Bowman and Johnston, 2005). In Spain wildfire fatalities are on average 8 people per year due to, mostly, entrapment in a fire and fire-fighter staff air crash (MAGRAMA, 2016).

Taking into account that fire starts when a fuel is warmed until it produces enough gases that combined with oxygen provides the energy to proceed the process, probability of ignition is closely linked to environmental conditions and, specially, to weather conditions (Reinhard et al., 2005). Furthermore, in semiarid ecosystems the influence of these factors on fuel availability plays a very important role. Thus, temperature, wind and, mainly, moisture and precipitation are the most important factors in forest fires. Furthermore, in southern Europe most fires occur in the summer period due to the severe droughts and high temperatures in this season.

Fire indices assess probability of ignition and fire importance under the consideration of several factors that can influence the beginning, spreading and danger of a wild fire. These factors include, among others, weather data, topographic attributes, fuel characteristics (Chandler et al., 1983). However, not all these factors are possible to obtain in an easy and accurate way (Cheney and Gould, 1995) so most used fire indices across the world integrate available meteorological and fuel information into a small number of measures (Dowdy et al., 2009). Moisture in vegetation determines the probability of ignition and possibility of wildfires spread (Castro et al., 2003; San-Miguel-Ayanz et al., 2003), so the estimation of moisture content is the key factor in fire indices (Chuvieco, 2003; Burgan, 1988). Various methods have proposed to determine moisture content for all fuel levels (Spano et al., 2005; Dennison et al., 2003). In the last two decades satellite information gives extra information apart from weather data for more accurate values of moisture content (Benali et al., 2016; Verbesselt et al., 2006; Chuvieco, 2003; Dennison et al., 2003; Chen et al., 2011).

Climate is the main factor in wildfire frequency and probability of occurrence because it determines the wet and dry periods and, consequently, fuel build-up, fuel load and water status. Weather affects the moisture of vegetation through different processes (Viney, 1991) and fire weather indices evaluate the dryness of the vegetation (Käse, 1969; Nesterov, 1949; Keetch and Byram, 1968) by using algorithms of varying difficulty. There are simple models than only consider temperature, humidity or precipitation (Sharples et al., 2009a; Bruschek, 1994; Angström, 1949). Wind profiles and conditions near earth surface are also important factors to consider in fire activity (Brotak, 1991; Haines, 1988) particularly in Spain and in Portugal (Viegas et al., 2006; Millán et al., 1988). But there are more complex fire indices that not only predict fire start probability but also the possibility of spread and fire danger (Willis et al., 2001).

Many different indices are used in countries across the world depending on the development of techniques and models according to weather characteristics. In Australia the Forest Fire Danger Index (FFDI) (McArthur, 1966, 1967) is widely used, mainly in eastern Australia. The FFDI takes into account precipitation, relative humidity, wind speed and daily temperature. The moisture content of the litter fuels, the quantity of fuel and the in-forest wind speed near the ground are considered in the Forest Fire Behaviour Table (FFBT) (Beck, 1995; Sneeuwjagt and Peet, 1985) which is also very widely used in Western Australia. The Forest Fire Weather Index (FWI) (Lawson and Armitage, 2008; Van Wagner, 1987) was developed in Canada and it is widely used all over the world and in Europe (Venäläinen et al., 2014). It has been found that FWI has the best performance in certain areas of Australia (Cruz and Plucinski, 2016) and in some regions in France, Italy and Portugal (Viegas et al., 1999), as well as in many other countries (De Groot et al., 2006; Taylor and Alexander, 2006; Dudfield, 2004). Field et al. (2015) have developed a global database of daily FWI system calculations, beginning in 1980, called the Global Fire WEather Database (GFWED). As well as FFDI, FWI is based on precipitation, relative humidity, wind speed and daily temperature. The National Fire Danger Ratings System (NFDRS) (Bradshaw et al., 2016; Loveland et al., 1991; Burgan, 1988; Deeming et al., 1977) is the official index in the United States. The key inputs into the NFDRS model are fuels, weather, topography and risks.

In Europe, every country has developed its own fire index suitable for each region weather conditions and with different factors required. In Germany there are two main indices that are used for fire risk on a daily basis, M-68 (Käse, 1969) based on precipitation, wind speed, snow cover and phenology and the Baumgartner Index (Baumgartner et al., 1967) which only uses precipitation and potential evapotranspiration. The French index, known as Numerical Risk (Drouet and Sol, 1993; Sol, 1989) requires air temperature, humidity, cloud cover, wind speed and soil initial conditions. Bovio et al. (1984) developed the IREPI index for north western Italy, which estimates evapo-transpiration and is applied mainly to winter-spring fires. The inputs for this index are: air temperature, relative humidity, wind speed, rainfall amount in the previous 24 h and direct solar radiation. The Portuguese method is a modified version of Nesterov Index and it is currently used by the Portuguese Meteorological and Geophysical National Institute (Gonçalves and Lourenço, 1990). Air temperature, dew point, wind speed and rainfall 24 h previous are required. In Spain, ICONA index (ICONA, 1993) is usually evaluated to estimate the risk of ignition. It is based on litter and fine dead fuels moisture content which are quite sensible to meteorological variation. Air temperature and relative humidity are the basic inputs required to derive a so called basic moisture humidity. Basic humidity is then corrected according to period of the year, hour of the day, terrain cover (by vegetation or clouds), aspect and slope.

Finding the best universal index seems an impossible task due to the wide global variety of climatology and the factors a probability ignition method depends on. The ideal index could even be modified at small scale regions (Padilla and Vega-García, 2011), so validation must be particularized and analyzed for the region under study. The task of comparing and choosing the best fire index for a region is not trivial due to the different schemas of each index, the factors to take into account and the thresholds considered to start ignition. A large spatial and temporal data must be used in order to ensure of the representativeness of the values and ranges obtained (Viegas et al., 1999). Depending on the author, the methods of comparing fire indices are different. A median linear model based in percentile results of fire and non-fire values is used by Arpaci et al. (2013) to compare 22 fire indices in Austria, finally selecting the M68dwd index. The study of percentile values according to burnt area, fires per day, class of fires, etc. is used by Viegas et al. (1999) to compare several regions in Europe. FWI is considered, in this case, the index that fits the best. Cane et al. (2012) make use also of percentiles of fire days to redefine FWI thresholds in alpine area of Italy. Others prefer to use Mahalanobis distance (Crotteau et al., 2013; Vilar et al., 2010; Sirca et al., 2006), the so-called skill-score S (Mandallaz and Ye, 1997) or the ROC method (Karouni et al., 2013; Vilar et al., 2010; Çelik and Demirel, 2009).

The aim of this study is to select the best fire index or indices in a semiarid region among the four ones selected: the Angström Index, the Forest Fire Drought Index, the Forest Moisture Index and the Fire Weather Index, in order to establish a methodology that can be replicated for fire prevention in similar areas. To achieve this goal four comparison methods have been used to test the sensitivity of the index in the 2000–2014 period in the study zone and to have different research