FOREST FIRE HAZARD MODEL DEFINITION FOR LOCAL LAND USE (TUSCANY REGION)

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Abstract

In the present work, a forest fire hazard model is presented in order to evaluate the probability of the occurrence of forest fires in a given region. This probability is expressed in terms of hazard level of that particular region.

The model groups territorial and meteorological (all) parameters in order to calculate different levels of indexes, the combination of which constitutes the final Fire Hazard Index.

The present work describes the structure of the model and the parameters that are processed using values selected to represent spatial and seasonal variability. Two separated hazards, static and dynamic, are generated.

The Static Fire Hazard (or Land Fire Hazard) refers to all factors that do not change or change very slowly in time and includes natural features such as morphology (slope and aspect), land use and vegetation cover and the infrastructural factor, which is obtained considering any structure connected with the human activities: urban areas and road network.

The Dynamic Hazard takes into account all parameters showing short-term variations. There are two main factors: climatic and microclimatic conditions and vegetation status.

All these parameters are combined and as result of the elaboration, we obtain the Final Fire Hazard Index (FHI), in raster format, which can be superimposed on a topographic regional map. Successively In order to consider also the variable represented by the “social aspect”, the FHI is merged with a statistical analysis of fire occurrence, to produce maps on a municipal level to show a possible correlation between environmental and anthropic factors.

The present research is based on a simple database (maps, layers, data and measurements) made up of the information collected for the institutional activities of a public administration.

The objective of the present work is to perform a real-time routine for the meteo data, able to update the FHI maps with the frequency necessary to give a decision support tool to optimize the firefighting activities.

Introduction

In order to test and fine-tune the system, the present fire hazard model is actually being used by Tuscany Region Administration to organize the prevention and management of fire fighting activities.

In Tuscany, most fires (more than 90%) are due to human activities, therefore is important to know the danger level for different ecosystem in order to organize monitoring, prevention and repression operations.

Forest fires are strictly related to land use and vegetation characteristics in a specific area where the ignitions have been effected.

The ignition probability depends on a very large number of parameters, which should be considered and analyzed simultaneously; likewise the propagation, which is heavily influenced by the characteristic of the territory, the meteorological factor and the condition of fuel.

For this reason the fire hazard model groups all the parameters in order to calculate different levels of indexes, whose combination generate the final Fire Hazard Index.

Tuscany Region Administration involved IBIMET Institute in the elaboration of the model, where all different parameters are processed to generate two separated hazards - static and dynamic - then these two hazards are mathematically merged to obtain the final Global Hazard Index.

Subsequently, a social variable is introduced into the model in order to tune the global hazard index with the information of historical ignition point dataset. In the model five hazard levels, which characterize the potential danger of each area, are defined: very low, low, moderate, high and very high.

The structure of the fire hazard model

The structure of the fire hazard model is divided in the two main parts which are combined to give the global fire hazard. This is then merged with statistic information to obtain the final hazard index map.

For Tuscany the input of the system are: the digital terrain model (10 m), the forestry regional inventory (reclassified in accordance with CORINE land cover classes), the shape of the infrastructure (road and urban areas), the shape of administrative boundaries and the meteorological parameters derived from the regional meteorological station networks. The model elaborates all the data and obtains the global risk for each season and for each province.

Static fire hazard

Static hazard refers to all factors that do not change or change very slowly. These hazards can be further subdivided into two hazard components:

Intrinsic Factor, obtained considering morphological features such as topography (slope and aspect), land use and vegetation cover, which can be considered stable in time and space.

Infrastructural Factor, obtained considering any structure connected with the humans activities. Urban areas and road networks have been considered in this case.

Intrinsic Factor

The model takes into account the slope and the aspect as Morphology Factor. The slope affects the fire propagation through the spreading of the fire by the rolling of heated materials and to facilitate the fire diffusion by contact with the high part of canopy on the declivity. This aspect affects the plants water stress. Usually the aspect facing to south have higher solar radiation and temperatures than the aspect facing north.

On the basis of the test area features and according to the results of forest fires database analysis, the following classes of relative hazards have been defined and assumed as default classes:

Slope:

CLASS	HAZARD LEVEL
>45%	**Very high**
25-45%	**High**
15-25%	**Moderate**
5-15%	**Low**
< 5 %	**Very Low**

Aspect

CLASS	HAZARD LEVEL
s – sw	**Very high**
w	**High**
se	**Moderate**
e	**Low**
flat surface, n- ne;nw-n	**Very Low**

The Slope and Aspect influence has been weighted differently on the morphological hazard introducing a further multiplicative factor. For slope the factor is 0.6 while for the aspect it is 0.4.

The morphological hazard is calculated with following mathematical formula:

morphological hazard = (Slope * 0.6) + (Aspect *0.4)

The definition of the slope and aspect value is based on the statistical analysis of historical fire events in Tuscany (AIB) and takes into consideration the irregular distribution of vegetation and landscape complex morphology.

Intrinsic Factor considers also the influence of vegetation on the fire ignition and consequent behaviour.

In the present model, this component is weighted in the static hazard in accordance with an analysis of the vegetation status related only with the physiologic status in the different season (ex.: presence/absence of lives, quiescence/metabolic activity status etc.). We haven't introduced dynamic aspect of vegetation (eg.: humidity contents, damp foliage, phenological phases etc.) to have a less complex tool that doesn't need a complex information dataset to run.

The change and short time evolution of vegetation status are implicitly considered when weighting opportunely the meteorological factors.

Different types of land cover are defined re-classifying the Forestry Regional Inventory in according with CORINE land cover classes. To simulate the seasonal evolution of vegetation cover, a different set of hazard classes has been defined for each season and for each vegetation classes.

The seasons are defined considering :

Winter : 22/12 - 20/03

Spring : 21/03-20/06

Summer : 21/06-23/09

Autumn : 24/09-21/12

The main groups of vegetation typology introduced in the model are the following:

Anthropic areas

Agricultural areas

Forest areas

Damp zones

For each class a sub-classification is defined to separate different species and land cover structure (annex 1)

To obtain a final grid expression of the Intrinsic Factors the respective influence of morphology and of vegetation are combined with the following formula:

Intrinsic hazard = (vegetation hazard *0.6) + (morphological hazard *0.4)

Infrastructural factor

Infrastructural factor involves the road network density per square kilometre and considers the distance from the urban areas. The relevance of these two components is due to an observation that in Italy the majority of fires (more than 90%) are due to human activities, both legal or illegal. Statistically it can be shown that most of ignition points are concentrated close to urban areas and along the roads, and they are probably caused by accidents or by illegal acts.

For the road network, a different hazard level is assigned according to the road-line density per square kilometre. Five classes are defined on the basis of Natural Breaks Jenkins classification: "very-high" the value 4 (which represents the higher value detected) and consequently "very low" the value 0 (the minimum value detected). Also in this case, a multiplicative factor (0.6) has been introduced to take into account the density of the road.

The urban areas are defined and classified according to the Urban areas layer created by Tuscany Region. The hazard levels have been assigned on the basis of distance buffer from urban boundaries, using the same classification method applied for the road network.

In this case the multiplicative factor that has been introduced to weigh the buffer distance layer is 0.4 considering the results of AIB statistical analysis, which show higher fire events frequency nearer roads than urban areas.

The final computation of Infrastructural Hazard Layer is obtained using following formula:

Infrastructural Hazard= (road factor*0.6)+(urban factor* 0.4)

Finally the Static Hazard Final is computed in raster format as the sum of previous factor:

Static Hazard = (Intrinsic Hazard 0.6)+(Infrastructural Hazard * 0.4)

DYNAMIC FIRE HAZARD

The dynamic factor takes into account all parameters showing short-term variations. The main factors are climatic and microclimatic conditions and vegetation status. Since the vegetation stress conditions are usually closely related to local meteorological conditions, this element is not considered in the model.

The meteorological parameters affecting the probability of ignition considered in the model are:

- Temperature: High temperature affects the evapotranspiration rate and increases the drying speed of the soil-moisture and consequently the probability of ignition.

- Rainfall: The rainfall amount affects the water balance of the forest and agricultural ecosystem. The soil gains moisture from rainfall and loses water by evapotranspiration. The vegetation, which represents the fuel available during the ignition, increases or decreases its humidity level in relation to the soil water content and atmospheric humidity.

-Day-since rain number: This factor is introduced in the model to quickly classify the ecosystem water decreasing. Drought is the most important indicator for danger of wildfire occurrence. Statistically very intense fires can occur also during the 2nd or 3rd days after precipitation, because the fuels reach a drying level which requires significant humidity elevation to return to the moisture extinction point. The day-since rain represents an estimation of the progressive water-loss of ecosystem, and this factor is weighted with the rainfall threshold .

- Rainfall threshold: is the mm of precipitation during a period. In the dynamic part of the model different seasonal thresholds are defined to represent the quantity of water needed for an ecosystem to reach the moisture extinction point.

-Global radiation: this parameter influences the drying speed of the fuel. To use the system easily the global radiation is directly estimated from the DTM layer with a internal function of GIS system (Solar analyst)

As the objective of this study is to give a practical tool, at the moment the model uses only these parameters since they are easily available or estimated. In the future the model could be integrated with other factors, such as Global radiation (measured), Ground and relative humidity and Fuel moist contents, to better simulate the behaviour and the influence of the meteorological and atmospheric components.

Meteorological factor are combined with the model to elaborate two different meteo-related hazards:

-Thermal Hazard Factor (TFH), computed by means of the maximum air temperature analysis and

-Drought Hazard Factor (DFH), which takes into account the net rain and the days-since rain number.

In particular for Thermal Hazard Factor has analysed the wildfire distribution in relation to the maximum temperature values and we have defined the threshold to classify temperature hazard.

This analysis is performed daily to produce a seasonal index. Each daily temperature value is classified on the basis of the threshold value, according to the following rules :

T max < 1 = 0

T max > 1 and t max < 15 = the value range between 0.1 and 1 with a linear function

T max > 15 and t max < 25 = the value range between 1.1 and 2 with a linear function

T max > 25 and t max < 28 = the value range between 2.1 and 3 with a linear function

T max > 28 = 4

Then the daily TFH index is summarised for each season to obtain the average value.

The persistence of high temperatures has an important effect on the drying speed of fuels.

The Drought Hazard Factor is also computed on a daily basis and then integrated for each season. The drought index is computed in two phases: rain net definition, rainy days definition. The rain net is not easy to define because the effect of a rain event, related to the moisture extinction point, could change due to many factors.

There are many formulas to estimate the rain net, but all produce approximate results because it is impossible to express mathematically all the components.

In this study the threshold is computed using evapotraspiration for each day and the values for each season are summarised using the equation :

$$SeasonalThreshold = \sum_{sd}^{ed} etp * 2$$

Where ***sd*** and ***ed*** are the first and last day of the season

Net rain is computed by an iterative sequence of conditions on the daily rainfall value. The first step is the definition of the current day as a dry or a wet day:

Wet day (rainy day) value greater than 0 and day before wet, or value greater than threshold on the day before dry.

Dry day (rain = 0) day without mm of rain.

value greater than 0, but lower than the threshold, the rainfall is cumulated for each rainy day (rain event = consecutive rainy day) until a dry day (rain = 0) or until the cumulated rainfall exceeds the threshold

The Day-since rain number is calculated by an iterative counter. It expresses the number of no-rain days before the current day. The first day the counter is set with the number of day since the last net rain event in the previous month.

For each day without net rain the counter is increased by one. When a no-rain day occurs, the counter is increased by one and the next day is set at zero. If there are consecutive rainy days, the counter remains at zero until a no-rain day occurs. Then the count of the days start again. At the end of the calculation, each day will have a number to which we have assigned a value in relation to a hazard level:

Day-since rain = 0 -> 0

Day-since rain > 0 and Day-since rain < 12 -> Value range between 1 and 3 according a linear function

Day-since rain >= 12 -> 4

These values are then put together to form an average value for the season.

The two indexes are dimensionless and can be easily equated with the following formula

Meteorological Hazard Factor= ((*TFH+DFH*) / 2) * w_g

where: w_g= *weight of the meteorological layer*

Final Fire Hazard Index and Statistic Information

The static and dynamic hazard are mathematically combined in the model to obtain the Final Fire Hazard Index (FHI).

Final Fire Hazard Index = (Static Hazard 0.6)+(Dynamic Hazard * 0.4)

The FHI is then integrated with the statistic information to value the social factor.

Statistic information is elaborated from the AIB, historical ignition point dataset of Tuscany Region. For each Tuscany province the number of fire has been calculated for years from 1984 to 2002.

Then all this data has been normalized and starting from the more statistic relevant number of events elaborated and divided into five hazard classes.

Finally we obtain the Global Risk Index in raster format that can be superimposed on a topographic regional map.

The risk can be visualized on two different levels: a raster layer with the Final Fire Hazard Index classes expressed for each pixels, or a Global (global + statistic) which shows the risk for each Municipality. This difference depends on the data level aggregation of AIB that are organized for municipality.

Conclusions

The following table shows the results obtained with the Global model, where the percentage value is related to the pixel number in each class. The seasonal percentages have a good correspondence to the level of warning for each season, recorded by the Regional fire fighting organization.

In fact most of the Region has an "very high" or "high" global risk in summer (37% of regional territory is in "very high" hazard class and 16% is in "high" class). The other most dangerous season is autumn (35% of municipalities in "very high" class and the 31% in "high"). For the summer season this danger distribution is strictly related to the meteorological conditions, high temperatures and low precipitations. In the autumn the vegetation aspect became relevant. In fact during this season the agricultural areas are covered by stubble, and their high level of danger determines the high level of ignition risk.

In Winter, with low temperatures and good precipitation, the percentage of areas classified "very high" by the system is, however, 15%. This figure is determined by the areas covered by coniferous forest, characterized as a high risk level in winter.

	Winter	Spring	Summer	Autumn
Very high	15%	26%	37%	35%
High	11%	19%	16%	31%
Moderate	21%	19%	27%	19%
Low	35%	30%	15%	12%
Very Low	18%	6%	5%	3%

Tab. Global risk percentage of pixel for class in each season

The main objective of this study was to organize a easy- to- use modular tool, suited to the needs of a public operative structure. The analysis, the statistical evaluation and the re-classification are adapted to be applied on the dataset of Tuscany Region (road map, forestry inventory etc.). The final map and table have been compared with the historical data and matched with practical experience of the technicians. This check gives satisfactory results. Furthermore, the grid map will be used, during this summer, to test the efficacy to use the system not only to define the risk but also to base and manage interventions.

The most interest tool for Tuscany Region is represented by the risk modelization starting from the territory characteristics and meteorological conditions. The statistical analysis is additional information to adjust the level of danger for each municipality, testing the "social components" of different areas.

These results represent an intermediate objective, but some implementations are possible, in particular for the Dynamic Hazard. A real time tool able to update the meteorological information each 12-24 hours will be implemented. At the same time, if a set of detailed data relative to the humidity becomes available, this information could be introduced into the system to update both the dynamic index and the static index, deriving from the humidity vegetation status and the soil moisture.