Standardized Process to Generate Mapping of Priority Areas for Protection against Wildfires[1]

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Abstract

In the field of geographic information systems (GIS) there are certain tasks that are performed repetitively and are thus sometimes monotonous, where it is necessary to structure, integrate and analyze a series of georeferenced information, which, however, always carries the same sequence. Therefore, we developed a sequential model which allows automating certain processes in the definition of priority wildfire protection areas. For this, we used the Model Builder tool (ArcGis), which is based on a visual programming language that allows structuring the sequence of processes. To illustrate this, we used vector-type information layers corresponding to the variables of three criteria, namely risk, hazard and value, such as: towns and roads in forest areas, the historical fire record, burned land polygons, fire behavior in forest ecosystems, ecosystem classification, slope, exposure, precipitation, temperature, drought, fire regimes, protected natural areas, bird conservation areas, RAMSAR sites, payments for environmental services, priority land areas, indigenous communities, poverty levels and timber value. As a result, we obtained a sequential model of priority wildfire protection areas, based on which a map where these areas are located and dimensioned according to their classification (very low, low, medium high and very high) was generated. It is therefore concluded that it is a practical tool which saves time in processes and sequences, in addition to avoiding human errors when working manually. Finally, it is pointed out that the sequence model is useful for designating protection areas. This information is important to support decision-making in the definition of fire management strategies.

Keywords: ArcGis 10.1, GIS, Model Builder, Modeling

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Introduction

Mexico is a mega diverse country due to the great biological richness of its ecosystems. These ecosystems are considered part of Mexico's national heritage and should therefore be a conservation priority (Comisión Nacional Forestal, 2013). However, these resources are being affected by various factors, including wildfires. In Mexico, it is estimated that each year fires burn on average 250,000 hectares of forest ecosystems. Most of these (98%) are caused by man, while the rest are caused by natural phenomena (CONAFOR, 2013). In order to deal with the problem of wildfires, several strategies have been implemented, integrated under the concept of fire management, under which, due to limited human and economic resources among other aspects, areas requiring priority protection against wildfires should be defined (Nolasco, 1993).

For the definition of priority areas there are multiple methodologies, which generally consider risk, hazard and value criteria. Because these criteria involve a large number of variables, it is necessary to use technologies that are practical and ensure efficient management of georeferenced data and that optimize the management and analysis of geospatial information, such as geographic information systems. Accordingly, the purpose of this work is to perform geoprocessing for the generation of thematic cartography on priority areas for protection against wildfires, in such a way that it serves to homogenize processes and thereby make their overall results comparable and compatible, as well as allowing for the exchange of georeferenced information on the subject of wildfire protection areas. In addition, this paper presents an innovation, which consists of a generated application aimed at standardizing mapping. This methodology will support the evaluation processes for priority wildfire protection areas.

Model Definition

A model is a real representation or set with a certain degree of precision that is developed in the most complete way possible, but without attempting to provide a replica of what exists in reality (FAO, 2016). Models are useful for describing, explaining or understanding quality better, when it is impossible to work directly in reality itself (FAO, 2016).

The use of models is very common and they are especially important in GIS use, because with them spatial data functioning and structuring can be understood (FAO, 2016). The sequential model, also called the "classic life-cycle" or "cascade" model, suggests a systematic approach, in successive actions for the development of software that begins with the establishment of requirements and then passes to the analysis, design, coding, testing and maintenance phases (Flórez, 2009).

The "Model Builder" tool is an application in ArcGIS which is used for the creation, editing and management of models in an automated way. It is a visual programming language for building geoprocessing workflows (MappingGIS, 2016). For Esri (2012) Model Builder is an application that creates, edits and manages data. In addition, they are workflows that chain the sequenced execution of geo-processing tools and provide interaction with another complementary tool. The application can be very useful when it is necessary to perform repetitive and complex tasks (SIGnatura, 2014).

Study area

The analysis was applied to the state of Jalisco, located between the geographic coordinates of 101° 28' North latitude and 105° 42' West longitude. It is located in the central-western part of Mexico and is bordered to the northwest by the state of Nayarit, to the north by the states of Zacatecas, Aguascalientes and San Luis Potosí, to the east by the state of Guanajuato and to the south by the states of Colima and Michoacán (Fig. 1). Due to the different elevations in the state of Jalisco, it is located at a maximum elevation of 4,260 meters above mean sea level. Its territory covers 80,386 square kilometers (Municipios, 2016).

The state includes part of the Sierra Madre Occidental, the Central Mexican Plateau and the Trans-Mexican Volcanic Belt. It accounts for 4.01% of the national territory (INEGI S/F). The climate is warm sub-humid with an average annual temperature of 20.5 °C and average annual rainfall of 850 mm. The dominant vegetation is the coniferous and oak forests, followed by the tropical deciduous and perennial forests (Instituto Nacional para el Federalismo y el Desarrollo Municipal “Inafed”, 2016). There are also grasslands in the north and northwest (INEGI, 2016).

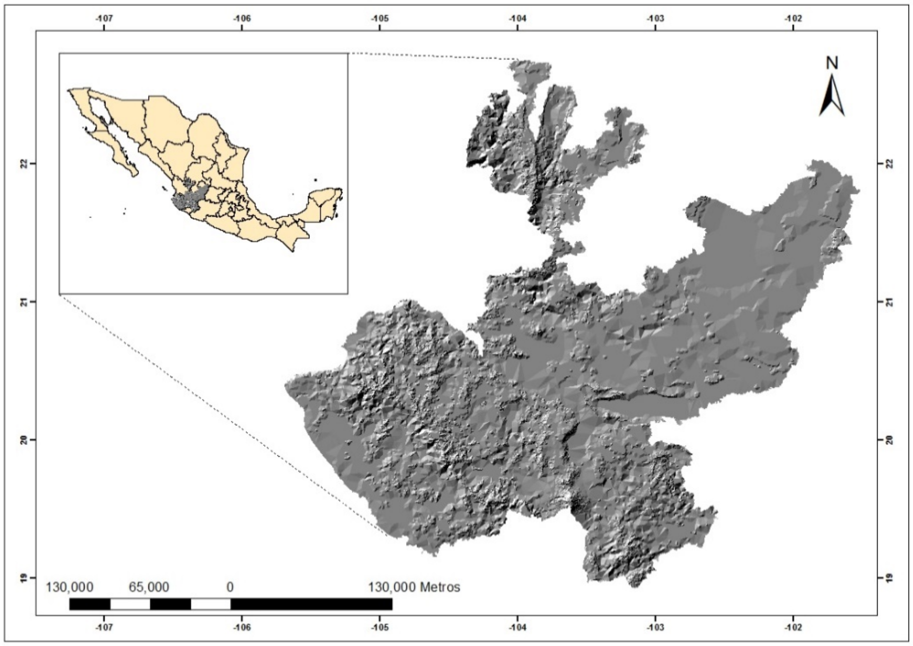

Figure 1– Study area, the state of Jalisco, used as a testing region to generate standardized mapping of priority wildfire protection areas.

Risk Analysis

It refers to a study of the variables that favor the start of wildfires, such as the presence of urban areas, agricultural activities with fire use, and roads or accesses near and within protection areas, among others (*Table 1*) (CONAFOR, 2010).

Table 1– Information used for the wildfire risk criterion.

CRITERION	VARIABLE	FORMAT	SOURCE
RISK	Town proximity		INEGI
	Number of town residents	Vector, points	INEGI
	Road proximity	Vector, lines	INEGI
	Type of road	Vector, lines	INEGI
	Occurrence of nearby fires	Vector, points	CONAFOR
	Occurrence of fire causes	Vector, points	CONAFOR
	Burned land polygons	Vector, polygons	CONAFOR

Hazard Analysis

It refers to the analysis of environmental variables, such as fuel characteristics and terrain conditions, which determine the possibility of a fire spreading (*Table 2*) (CONAFOR, 2010).

Table 2– Information used for the wildfire hazard criterion.

CRITERION	VARIABLE	FORMAT	SOURCE
HAZARD	Fire behavior and effect in ecosystems	Vector, polygon	INEGI
	Ecosystem classification (sensitive, dependent, independent)	Vector, polygon	CONAFOR
	Slope	Raster	INEGI
	Exposure	Raster	INEGI
	Hurricanes	Vector, line	SMN
	Mean annual temperature	Vector, polygon	CONABIO
	Mean annual precipitation	Vector, polygon	CONABIO
	Drought	Vector, polygon	SMN
	Fire regimes in forest ecosystems	Vector, polygon	Jardel

Value Analysis

It refers to the valuation of elements that socially, culturally and/or ecologically represent an interest in protection from the effects caused by wildfires (*Table 3*) (CONAFOR, 2010).

Table 3– Information used for the wildfire value criterion.

CRITERION	VARIABLE	FORMAT	SOURCE
VALUE	Protected natural areas	Vector, polygon	CONANP
	Important area for bird conservation	Vector, polygon	CONABIO
	RAMSAR sites	Vector, polygon	CONABIO
	Eligible hydrological areas	Vector, polygon	CONAFOR
	Areas for biodiversity conservation	Vector, polygon	CONAFOR
	Priority land areas	Vector, polygon	CONABIO
	Indigenous communities	Vector, points	CONABIO
	Human development index	Vector, polygon	CONABIO
	Degrees of poverty	Vector, polygon	CONABIO
	Priority attention areas	Vector, polygon	SEDESOL
	National Anti-Hunger System	Vector, polygon	SEDESOL
	Actual natural forest stocks	Vector, polygon	INEGI
	Timber value	Vector, polygon	INEGI

Information processing

The aforementioned georeferenced data were used in this geo processing, with the aid of a geographic information system (ArcGis 10.1). Also, the sequential model (Model Builder) was used as a tool to standardize this information. First, a search was made of the vector and raster information, through different available and reliable information sources that exist in the country and the state. Subsequently, data-cleaning was performed so that each variable would be assigned the same coordinate system and the same representation size (scale), in order for the variables to be extrapolated from each other. The projection type assigned to the state of Jalisco corresponds to WGS84 zone 13 North, according to the UTM (metric) coordinate system. Subsequently, the variables were assigned to the criterion to which they correspond, namely risk, hazard and value, and then the weighting criteria for each of the variables were assigned. This was done to obtain a value for each pixel to be able to perform arithmetic operations such as the adding of layers (map algebra) (*Fig. 2*)..

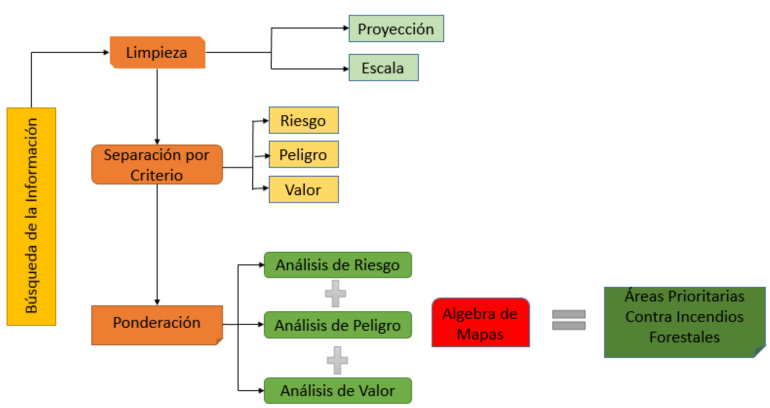

Figure 2–Structure of the process to map areas requiring priority protection against wildfires.

Starting with a series of geoprocesses for the wildfire "risk analysis," tools assigned to the sequential model were used. Subsequently, the raster-format layers for each of the variables are obtained as results. This is done in order to obtain values in the pixels and be able to calculate the map algebra. In the case of wildfire risk, the geoprocessing established for this analysis is shown in *Figure 3*. The geoprocess allowed standardizing the tools which were worked with to obtain the risk map. It is also a practical application, where the circles (blue) are the parameters or fields where the variables are assigned, in this case the risk ones; then the model is "*run*" and automatically the tools (yellow circles) begin to work and results are thus obtained (green circles).

Figure 3– Structure of the sequential model to generate standardized processes for the wildfire risk analysis.

In the case of *"hazard analysis,"* a procedure similar to that used in risk analysis is performed; however, different variables and tool methods are used in this. Once again the Model Builder application is used, with the aim of automating and/or standardizing the mapping, subsequently obtaining the results of the information layers in raster format of each of the variables, and again applying the map algebra calculation to finally obtain the wildfire hazard map. The sequential model for the hazard analysis allows automating the tools which are being worked with, and also assigns parameters so that the mapping is obtained in a standardized way (*Fig. 4*).

Figure 4– Structure of the sequential model to generate standardized processes for the wildfire hazard analysis.

In the case of *"value or potential damage analysis,"* a procedure similar to that used for risk and hazard analysis is performed; however, in this different variables and tool methods are used. The main objective in using the Model Builder application is to automate the geoprocesses and standardize the mapping, where finally the results of the information layers are obtained in raster format of each of the variables; in addition, the map algebra calculation is applied to finally obtain the wildfire value map (*Fig. 5*).

Figure 5– Structure of the sequential model to generate standardized processes for the wildfire value analysis.

Results

The *"thematic risk map"* was obtained according to the indicators used, which were based on background information on the location and size of population centers, the network of roads classified according to their surface types, the historical occurrence of fires and their possible causes, and lastly the size of the areas affected. This was done with the integration of the aforementioned variables in a standardized way in a sequential model.

The three analysis categories ("low, medium and high") were classified by means of an arithmetic operation, which consisted of a division, where the minimum score obtained was "0" and the maximum "20". Based on this, it was decided to respect the weighting proportions initially granted, with which this grade obtained proportionally for each of the levels was divided, that is, into thirds, where the low risk level was assigned scores from 1 to 6, the medium risk level from 7 to 12 and the high risk level from 13 to 20. With this, the wildfire risk map was generated (*Fig.* 6).

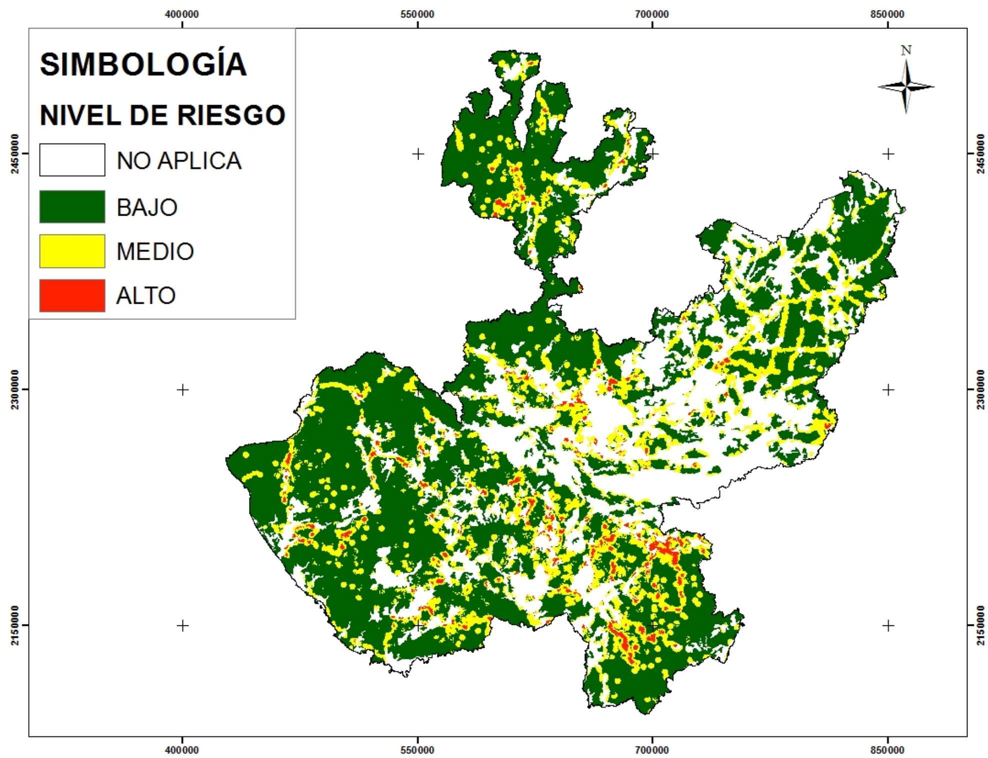

Figure 6– Wildfire risk in the state of Jalisco, with its three categories of analysis ("low, medium and high").

After analyzing each variable for the fire hazard criterion, they were all integrated, resulting in *"the thematic hazard map."* It is important to understand what aspects are taken into account and how the different values for each of the variables for the geozoning process are handled. It is also necessary to determine what level of danger each variable represents. Therefore, it is considered appropriate to analyze each of them in detail, in order that the scores are granted for zoning and on what criteria they were based.

The three analysis categories ("low, medium and high") were classified by means of an arithmetic operation, where the minimum score obtained was "5" and the maximum "29". Based on this, it was decided to respect the weighting proportions initially granted, with which this grade obtained proportionally for each of the levels was divided, that is, into thirds, with which the low risk level was assigned scores from 5 to 13, the medium risk level from 14 to 21 and the high risk level from 22 to 29. With this, the wildfire hazard map was generated (*Fig. 7*).

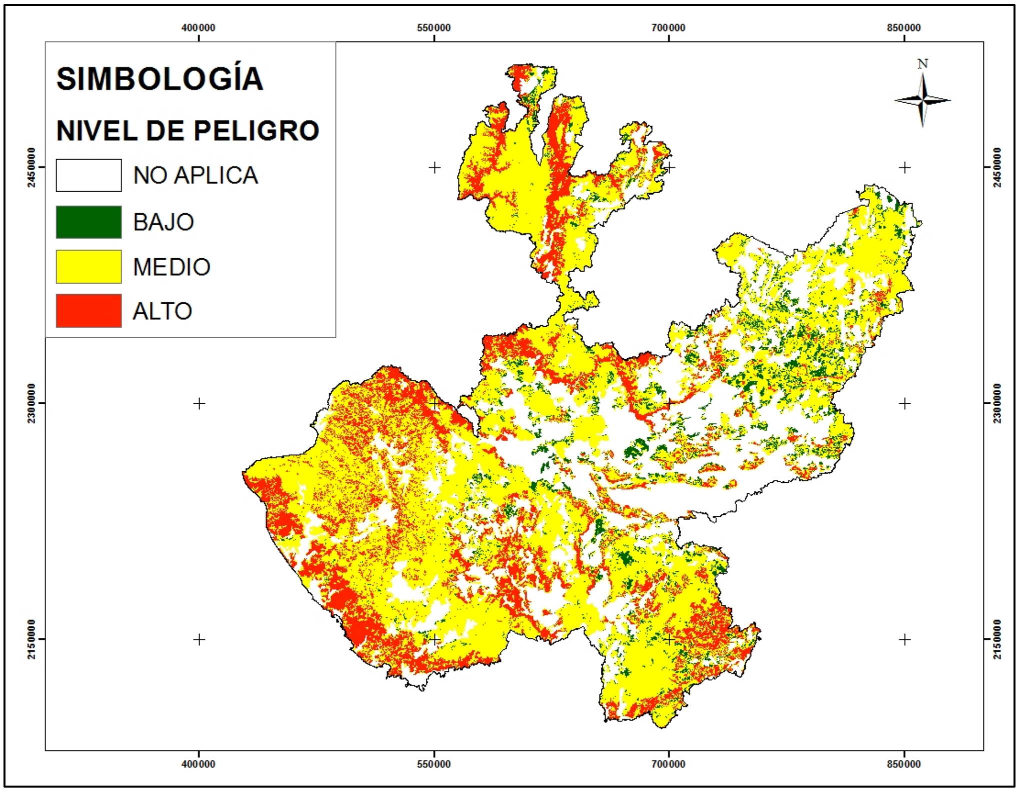

Figure 7–Wildfire hazard in the state of Jalisco, with its three categories of analysis ("low, medium and high").

When summing the information layers with their weighted values for this analysis, they are categorized into three different grade types, according to the level that corresponds to them. The three analysis categories ("low, medium and high") were classified by means of an arithmetic operation, where the minimum score obtained was "1" and the maximum "24". Based on this, it was decided to respect the weighting proportions initially granted, with which this grade obtained proportionally for each of the levels was divided, that is, into thirds, with which the low risk level was assigned scores from 1 to 8, the medium risk level from 9 to 16 and the high risk level from 17 to 24. With this, the *"thematic wildfire value map"* was generated (*Fig. 8*).

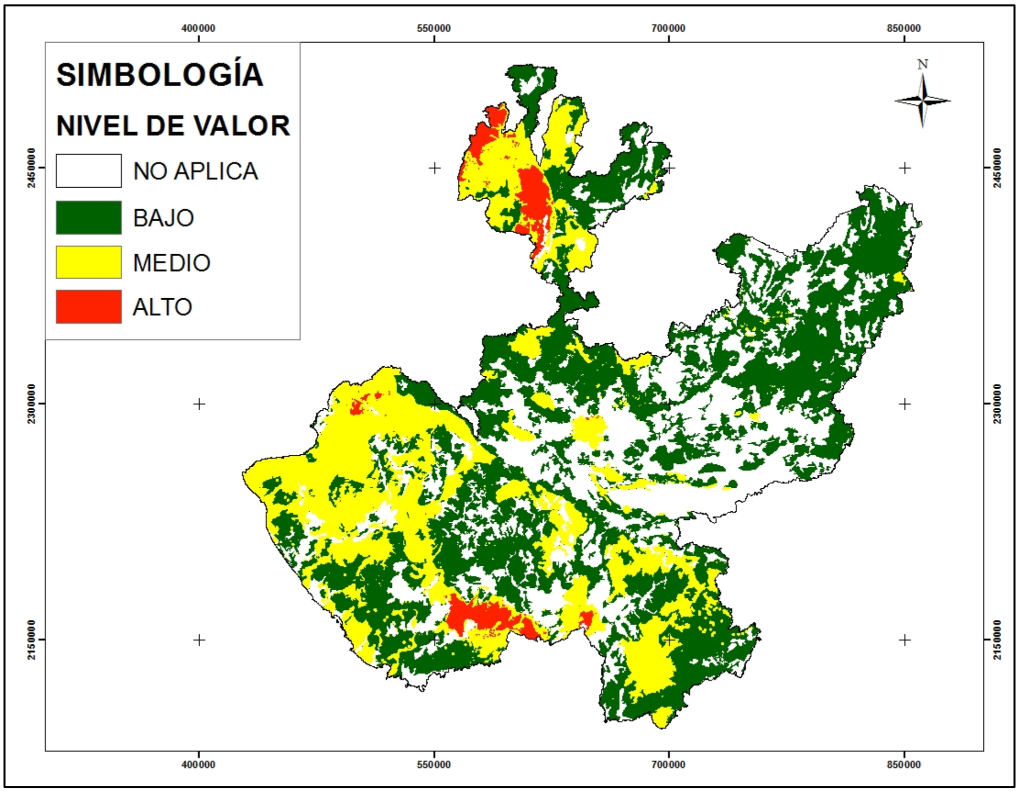

Figure 8– Value of wildfires in the state of Jalisco, with its three categories of analysis ("low, medium and high").

Thematic mapping of priority areas for protection against wildfires

The integration of the risk, hazard and value criteria allows establishing areas with protection priorities for wildfire control. The procedure consisted of assigning weighted scores to each of the criteria. These scores are summed by means of the math algebra calculation, and each pixel contains a priority value (*Fig. 9*).

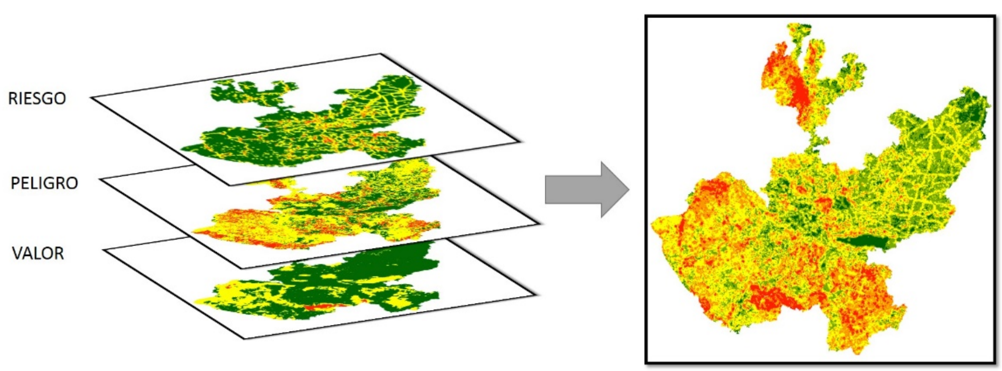

Figure 9–Arithmetic operation, for the summing of layers for the risk, hazard and value criteria, to establish the map showing priority areas for protection against wildfires.

The sequential model for the priority analysis allows automating the *"Raster Calculator or Map Algebra*" tool that was used to generate the thematic map showing areas requiring priority attention against wildfires (*Fig. 10*).

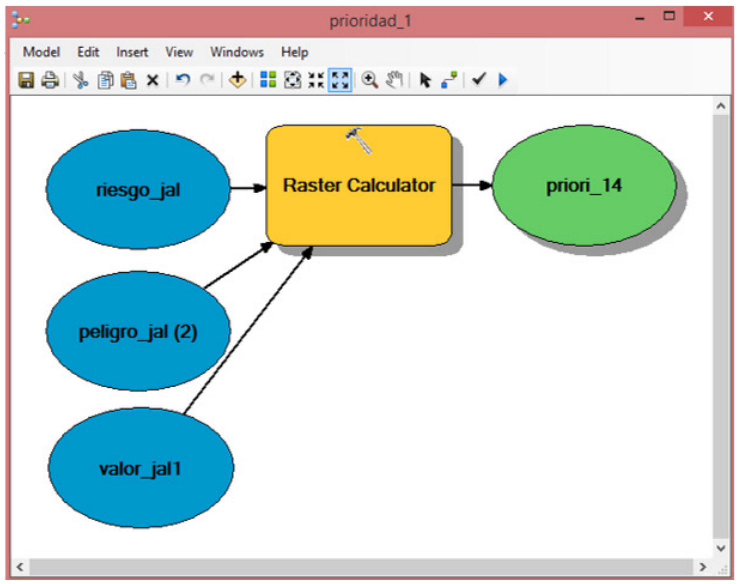

Figure 10– Structure of the sequential model to generate standardized processes for the analysis of areas requiring priority protection against wildfires.

Priority areas for protection against wildfires allows assessing the spatial distribution of the problem caused by the occurrence and spread of wildfires and provide the basis for the planning of prevention and combat activities that need to be implemented or reformulated in a protection program (Nolasco, 1993). A classification of five categories (very low, low, medium, high and very high) was used, in order to determine more precisely the areas to be protected (*Fig*. 11).

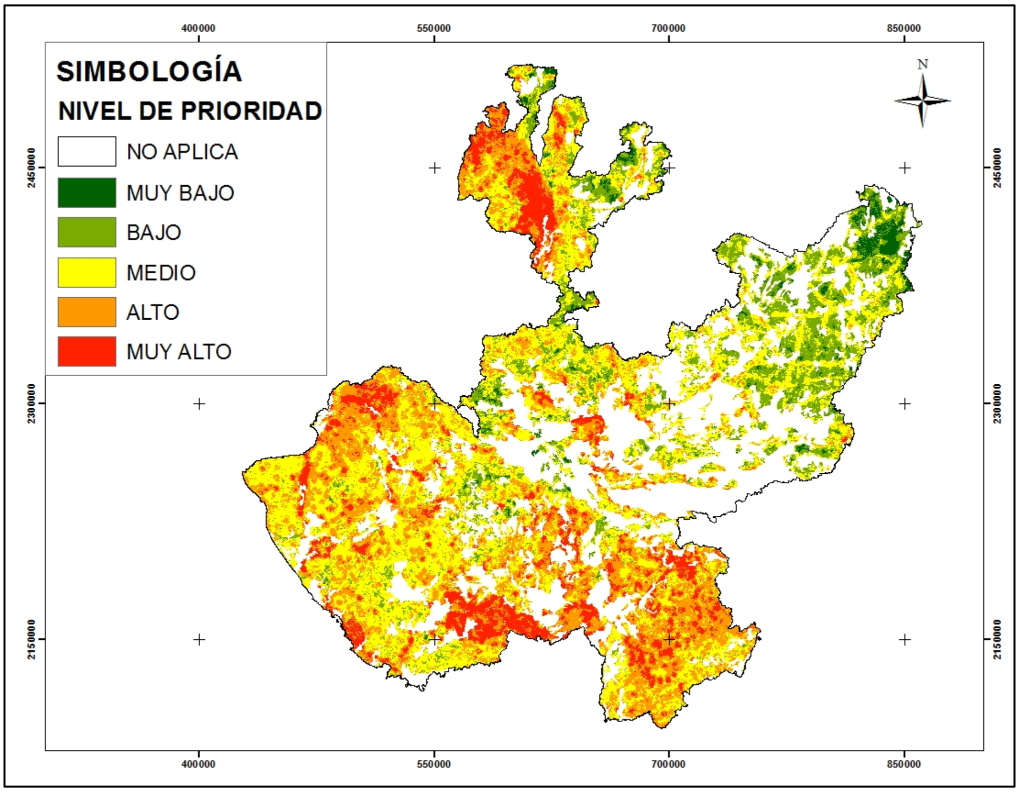

Figure 11– Priority areas for protection against forest fires in the state of Jalisco, with their respective categories of analysis ("very low, low, medium, high and very high").

Conclusions

One of the main advantages in using a sequential model is the automation of work, in that it allows the users to avoid having to repeatedly use the same tools with which they are working. It is a clear and simple application, since its visual environment greatly simplifies the understanding of the geoprocesses that are carried out. It is a way of understanding how geospatial processes work. In addition, the user does not need to know a programming language like Java, html, php and sql, among others, since the graphical environment allows understanding the model structure.

The use of compact models prevents making mistakes when running the tools. It also saves time and effort. It is also possible to know the time each tool is run. Finally, the analysis of the thematic map provides the necessary basis to design, implement, organize and apply in future periods the best decision-making in fire management. It also allows using the maps for dissemination purposes at conferences and as teaching material in Mexican and foreign universities.

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