Using GIS in Hotspots Analysis and for Forest Fire Risk Zones Mapping in the Yeguare Region, Southeastern Honduras

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Abstract

Honduras experiences reduction in forest resources at the rate of more than 800 km^2 per year. This is largely caused by changes in the land use, firewood, forest fires and irrational logging (GOH, 2001). The Food and Agriculture Organization (FAO) report some of causes of fires in Mesoamerican countries are social inequity, devaluated natural resources, inadequate policies and lack of forest resource management by communities (FAO, 2007). Forest fires are an important part of forest life cycles and are an essential tool for many Honduran producers for land preparation and pest control. Fire is used by small producers and big agricultural industrials alike, and especially in the sugar cane industry. Even though fire is a useful and natural way of forest management, it may have adverse consequences in the environment. The economy and nearby communities can also be harmed if misused. Every year Honduras loses forest resources; forest fires are one of the main reasons for this loss. This study presents the use of GIS and remote sensing to identify forest fire risk zones in the Yeguare region and offers insight on outcomes from areas within fire risk zones.

Introduction

Forest fire occurrence and the factors affecting where fires occur are a major focus in studies determining forest fire risk zones (Chuvieco and Salas, 1996; Sunar and Ozkan, 2001; Jaiswal, Mukherjee, Raju, and Saxena, 2002; Rawat, 2003; Hernandez-Leal, Arbelo, and Gonzalez-Calvo, 2006). Factors listed in earlier fire risk analyses include land cover (fuel), slope, aspect, socioeconomic variables (nearby population, roads, etc.), temperature, and relative humidity (Chuvieco and Congalton, 1989; Carrão, Freire, and Cateano, 2003; Bonazountas, Kallidromitou, Kassomenos, and Passas, 2005).

In recent years, an increasing focus has been directed towards understanding the impact human activity has had on the world's environment. Climate change is causing a fluctuation in the frequencies and amount of precipitation and as a result temperatures are rising and so does the risk of forest fires (Cotter, 2009).

The $G_i(d)$ used in this study measures concentration or the lack of weighted points within a radius of a specified distance d from an original weighted point according to Getis and Ord (1992).

The main objectives of this analysis were to 1) identify forest fire risk zones from FIRMS fire hotspots reported between 2003 and 2009 in the

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Yeguare region, southeastern Honduras and 2) model fire hotspots through $G_i(d)$ statistics to determine how and to what extent commonly known fire factors contribute to fire occurrences.

Study Area

The Yeguare region was chosen for study by the Panamerican Agricultural School's (also known as El Zamorano) outreach program "Iniciativa del Yeguare" (Yeguare Initiative). In the initial phase, five municipalities were chosen for study (Table 1).

Table 1. Total study area in km^2 and total population (Source 2001 Census).

Municipalities	**Area km^2**	**Population**
Villa de San Francisco	78.36	8,122
San Antonio de Oriente	211.23	12,721
Morocelí	362.83	13,424
Yuscarán	331.97	12,209
Güinope	200.75	7,384
Total	1,185.14	53,860

The Yeguare region is located in the Departments of Francisco Morazán and El Paraíso southeastern Honduras (Figure 1). It lies between eastings 488000 m 1580000 m and northings 533000 m 1520000 m (UTM WGS84) and covers an area of approximately 1,185 km^2.

The precipitation in the area varies between 500 – 2200 mm, the temperature between 16 Cº - 26 Cº and the relative humidity between 49% – 82%. Climatic factors were not included in this analysis as it was not possible to obtain data.

Data and Methodology

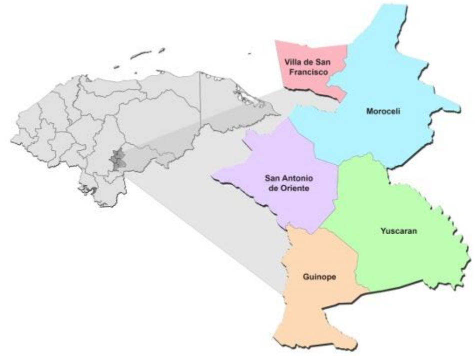

Figure 1. The Yeguare Region is located in Southeastern Honduras.

Fire Information for Resource Management System (FIRMS)

As in many developing countries, Honduras lacks reliable information and the tools for fire monitoring. This makes the country vulnerable to forest fires. Remote sensing offers a way to observe and analyze forest resources and monitor forest fires risk zones. The Global Observation of Forest and Land Cover Dynamics (GPFC-GOLD) has promoted the use of space-borne instruments for the detection, monitoring and calculating the impact of fires (FAO, 2007).

FIRMS also provides users with near real-time hotspots/fire information through their Web Fire Mapper, email and cell phone text messages. FIRMS provides information on active fires using the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on board NASA's Aqua and Terra satellites (NASA/University of Maryland, 2002). Information for this study was delivered through email and was tailored to meet project needs.

Fire detection is based on the absolute recognition of its intensity. If a fire is weak, the detection is based on the emission of surrounding pixels (Justice, Giglio, Korontzi, Owens, Morisette, Roy, Descloitres, Alleaume, Petitcolin, and Kaufman, 2002).

FIRMS sends an email with a CSV file. The file includes the following fields: latitude and longitude (center of point location), brightness (brightness temperature measured in Kelvin), scan and track (spatial resolution of the scanned pixel), acqdate (Acquisition date), time (time of the overpass of the satellite), satellite (Terra or Aqua), and confidence (quality flag of the individual hotspot, this is an experimental field) (NASA/University of Maryland, 2002).

To add this field, the files of the selected month were merged in a new DBF table. The new field was added here. After the month was added for each table, they were merged to form one event layer and converted to a new feature class. The process for creating shapefiles of fire occurrence from the files sent by FIRMS was performed using ArcGIS Model Builder as show below in Figure 2.

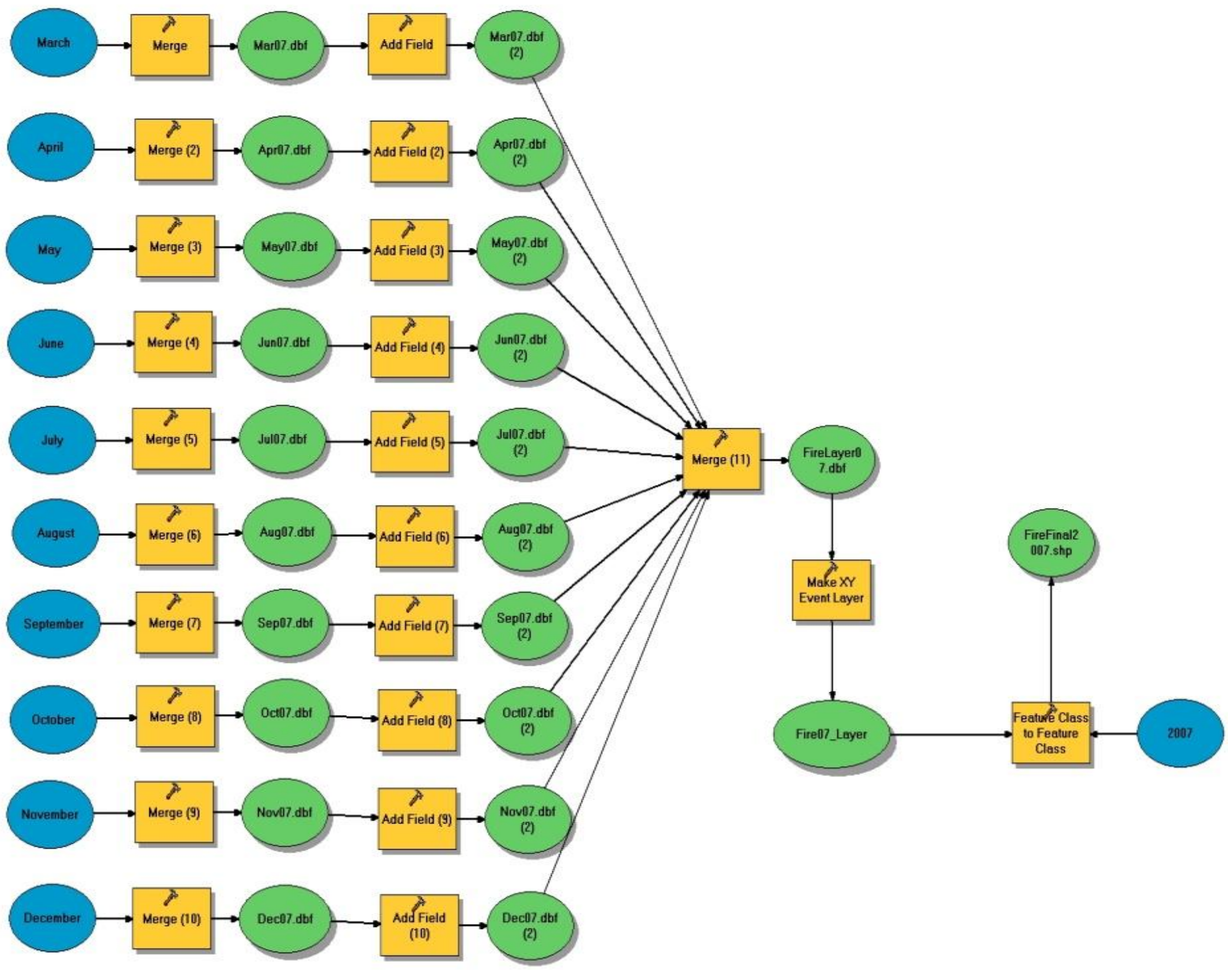

Figure 2. Shapefile creation process for 2007 Fires using Model Builder.

Forest Fires in the Yeguare Region

A depiction of fire occurrences is presented in Figure 3. From feature classes created, it was possible to obtain data on the number of fires per month in the Yeguare region since 2003. The months of March, April and May have the highest number of fires and since 2008, forest fires have increased (Figure 4).

Data shows Morocelí, Yuscarán and San Antonio de Oriente had the highest rates of fire occurrence since 2003 (Figure 5).

Through the use of the ArcGIS Kernel Density tool, a fire occurrence density map (Figure 6) was created.

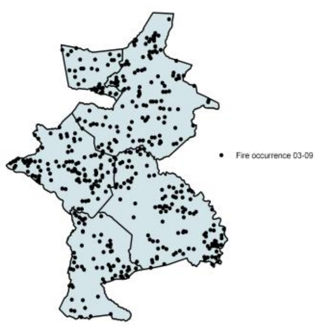

Figure 3. Fire occurrence from 2003 – 2009.

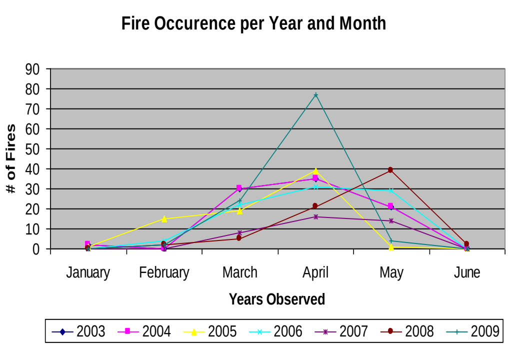

Figure 4. Fire occurrence per month and year.

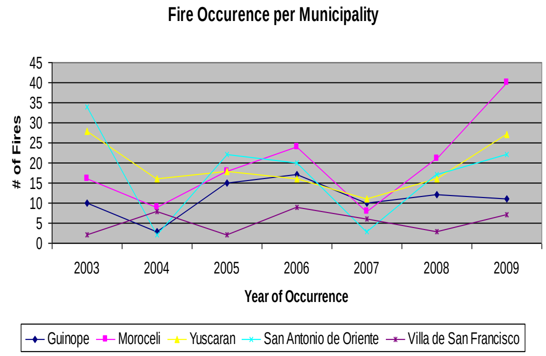

Figure 5. Fire occurrence per municipality.

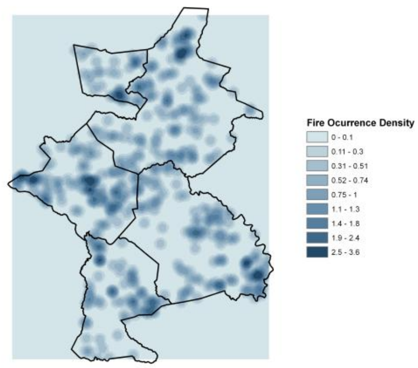

Figure 6. Fire occurrence density (fire/km^2).

Human Factor

The two main sources of fire ignition in Honduras are lightning and human activity (Myers, O'Brien, and Morrison, 2006). Even with lightning fires, which are highly under-reported in many areas, local authorities conclude majority of fire ignition is due to human activity.

Human activity may be often times difficult to understand due to the vague nature of how precisely fire ignition may begin. Lightning may or may not be documented as well during ignition events. Therefore, accounts to document absolute completeness for data was unavailable.

Land Cover

Chuvieco and Congalton (1989) suggest the type and character of the vegetation is the main factor in determining the manner in which a forest fire might spread. They also suggest that the fuel available for fire is of primarily importance (Chuvieco and Congalton 1989).

The images selected for this study were two ASTER images with 3 band natural color, with acquisition dates of April 15, 2006, path 17, row 51. The second image was from January 29, 2004, path 17, row 50, both obtained through USGS TerraLook.

Using Multispec, a combination of supervised and unsupervised classification techniques, image classification was performed generating six classes: Agricultural Land, Barren Land, Forest Land, Range Land, Urban or Built-up Land, Water. From the resulting analysis, 50% of the study area was forest land, 35% rangeland, 14% agricultural land, 0.24% barren land, 0.45% urban or built up land and 0.15% water (Figure 7). Land cover is summarized in Table 2.

Topographic Data

A main factor in any risk analysis is the topography with slope being a critical factor. Fire travels up slope faster than down (Chuvieco and Congalton, 1989; Jaiswal et al., 2002).

For this study, contours were digitized from a topographic map scale of 1:50,000 and converted to raster data. The elevation data was then used to obtain slope and aspect (Figures 8-10).

Distance to Roads and Settlements

Identifying distance to roads in the area can be useful in locating possible paths used for fire suppression as well as identifying risk areas where a high level of human activity might occur (Chuvieco and Congalton, 1989). For this study, multiple buffers with 7 intervals were created starting with a 50 m interval and then 100 m intervals thereafter (Figures 11-12).

Table 2. Land Cover Information.

Land cover	**Area Km^2**
Agricultural Land	158.02
Barren Land	2.76
Forest Land	586.29
Range Land	411.12
Urban or Built-up Land	5.29
Water	1.73
Total	**1,165.21**

A similar analysis was performed for settlements in the area. A multiple buffer layer was created starting with a 500 m interval and then 1000 m intervals thereafter.

Fire Risk Model

Several studies have proposed the integration of variables into a single fire model (Chuvieco and Congalton, 1989; Hernandez et al., 2006; Carrão et al., 2003; and Jaiswal et al., 2002).

This study integrates six layers of information: slope, vegetation, aspect, distance from roads, distance to settlements, and elevation.

Chuvieco and Congalton (1989) suggest a hierarchical scheme of fire rating (Table 3) which was followed in this study. Layers of importance from highest to lowest were as follow: land cover, vegetation, slope, aspect, proximity to roads, proximity to

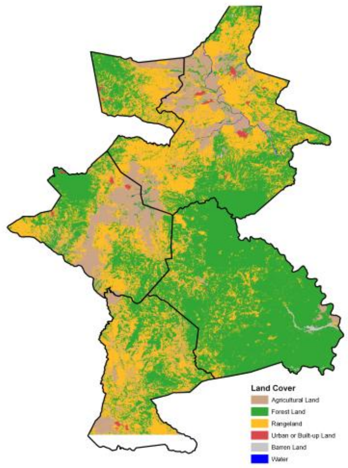

Figure 7. Land cover map.

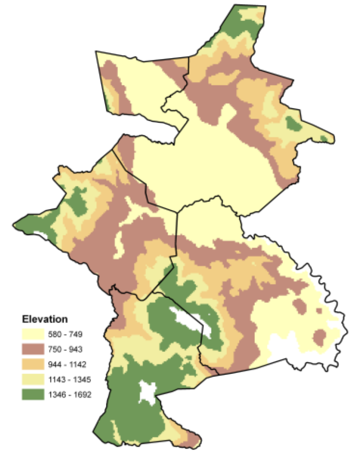

Figure 8. Elevation map.

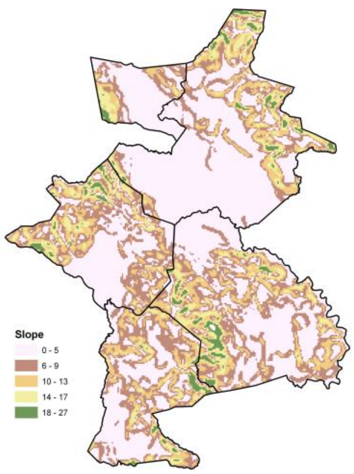

Figure 9. Slope map.

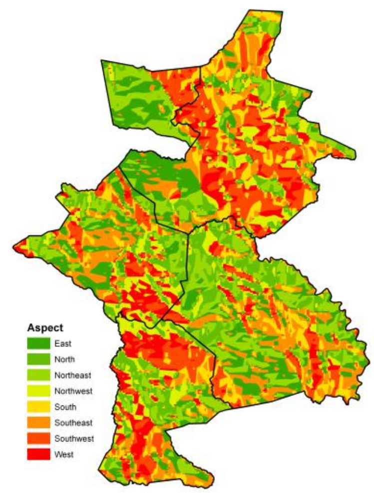

Figure 10. Aspect map.

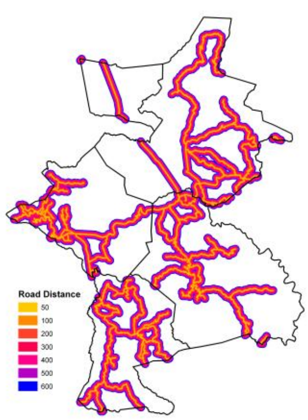

Figure 11. Distance to Road Buffer.

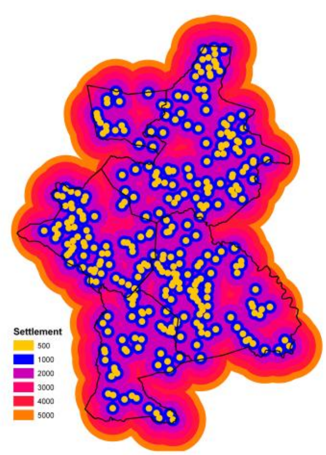

Figure 12. Distance to Settlement Buffer.

Table 3. Fire Hazard Model.

Classes	Coeff	Fire Rating
Land cover (weight 100)		
Rangeland (Scrub/ Shrubs)	0	Very high
Forest Land	1	High
Agricultural Land	2	Medium
Urban or Built-up Land	3	Low
Barren Land and Water	4	Very Low
Slope (weight 30)		
> 35 %	0	Very high
35 – 25 %	1	High
25 – 10 %	2	Medium
10 – 5 %	3	Low
< 5 %	4	Very Low
Aspect (weight 10)		
South	0	High
Southwest	0	High
Southeast	1	Medium
East	1	Medium
North	2	Low
Northeast	2	Low
Northwest	2	Low

Classes	Coeff	Fire Rating
Distance from roads (weight 5)		
<50	0	Very high
50 - 100 m	1	Very High
100 – 200 m	2	High
200 – 300 m	3	Medium
300 – 400 m	4	Low
> 400 m	5	Very Low
Distance to settlements (weight 5)		
<500 m	0	Very high
500 - 1000m	1	High
1000 – 2000 m	2	High
2000 – 3000 m	3	Medium
> 3000 m	4	Low
Elevation (weight 2)		
> 1501	0	Very high
1001 - 1500	1	High
501 - 1000	2	Medium
< 500	3	Low

settlements and elevation (Chuvieco and Congalton,1989).

The fire risk model can be summarized in the following equation:

FH = 1 + 100lc + 30s + 10a + 5r + 5sm + 2e

Where lc, s, a, r, sm, and e are the land cover, slope, aspect, roads, settlements and elevation.

Fire risk modeling involved several steps. First layers were weighted depending on the risk they represented. Land cover was weighted the highest, followed by slope, aspect, distance to roads, settlements, and elevation. Every layer was assigned a coefficient starting with 0, 1, 2, etc. with 0 being the highest hazard.

Land cover was evaluated first as an estimate of fuel available for a fire. Weighting of the classes in the land cover layer were determined by the moisture; the dryer the vegetation, the higher the risk of flammability (Figure 13).

Aspect was the second factor to be evaluated. It was divided into seven categories. South and southwest aspects were given the highest weight due to a higher insolation. Southeast and the east were weighted as medium risk, while north, northeast, and northwest were weighted as low risk (Figure 14).

Slope was the third factor to be evaluated. Weighting was determined by the fact fire travels more rapidly up slope. Slope layer was divided into five groups: greater than 35% (very high hazard), between 35% and 25% (high), between 25% and 10% (medium), between 10% and 5% (low), under 5% (very low) (Figure 15).

Proximity to settlements had a similar weighting as the distance from roads. Proximity was divided into five groups. Areas less 1000 meters as very high risk, 1000 and 2000 as high, 2000 and 3000 as medium, and areas within a distance greater than 3000 meters as low risk (Figure 16).

The distance from roads was evaluated since nearby areas have a higher risk of a fire. The buffer layer was divided into six groups. The areas within a distance of less than 100 meters were noted as a very high risk, between 100 and 200 meters was assigned high risk, between 200 and 300 meters was noted medium risk, between 300 and 400 was assigned low risk and areas with a distance greater than 400 meters were identified as very low risk (Figure 17).

The last layer evaluated was elevation. This layer was divided into four categories. Areas with an elevation greater than 1,500 meters were considered as very high risk and areas less than 500 meters were considered as having low risk (Figure 18).

Hotspot Analysis

Another objective of this project was to determine how and to what extent commonly known fire factors contribute to fire occurrences. This was examined using the Spatial Statistics Hot Spot analysis tool from ArcGIS which uses the Getis-Ord G_i* algorithm (Figure 19).

The Getis-Ord local statistic is given as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\left[n\sum \quad - \left(\sum \quad\right)^2\right]}} \quad (1)$$

Figure 19. Getis-Ord Gi* (ESRI, 2009).

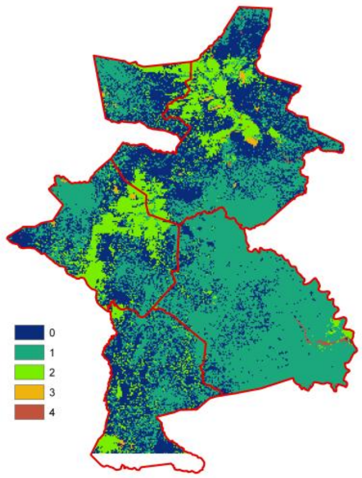

Figure 13. Land cover map weighted.

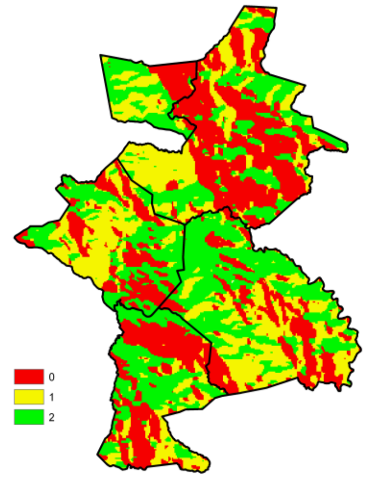

Figure 14. Aspect map weighted.

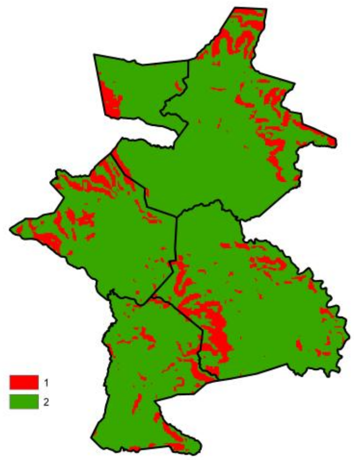

Figure 15. Slope map weighted.

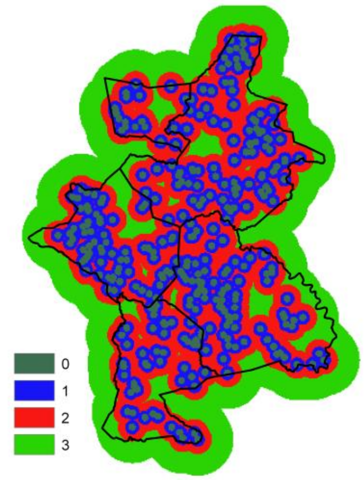

Figure 16. Settlements map weighted.

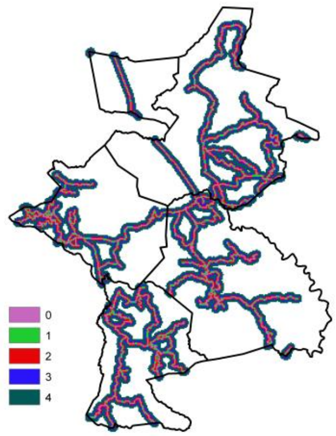

Figure 17. Distance from roads weighted.

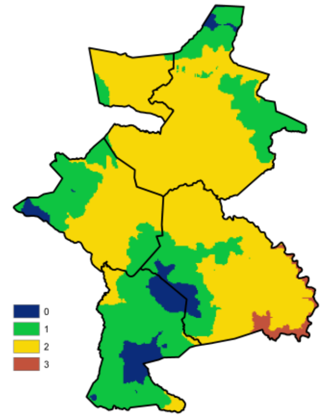

Figure 18. Elevation map weighted.

According to Getis and Ord, the Gi * statistic is used to measure the degree of association from a concentration of weighted points (Getis, and Ord, 1992).

Greater G_i* values indicate significant spatial clustering with values >2 (Potter, 2009). A total weighted field calculated from the six layers used in the fire risk model was added to the total fire risk data. This new field was used as the input for the hotspot analysis. The areas having a significant Gi* values are summarized in Table 4 and Figure 20.

Table 4. Communities with GiZ Score > 2.

Department	Municipality	Village
Francisco Morazán	San Antonio de Oriente	La Cienega San Antonio de Oriente
El Paraíso	Güinope	Güinope Las Liquidambas
	Yuscarán	El Rodeo

The municipalities of Güinope, Yuscarán from El Paraíso and San Antonio de Oriente from Francisco Morazán showed a statistically significant ($P < 0.05$) spatial clustering. This indicates these areas had a higher risk than other areas. Data from the resulting analysis were then interpolated using an inverse distance weighted (IDW) technique (Figure 21).

Cliff and Ord suggest an existence of spatial autocorrelation may exist if in a given area there is a systematic spatial variation (Cliff and Ord, 1981). To test the hypothesis of spatial correlation, Moran's I was used from the Spatial Statistics Hot Spot analysis tools in ArcGIS (Figure 22). The tool is readily available in ESRI's ArcGIS version of GIS software toolbox options.

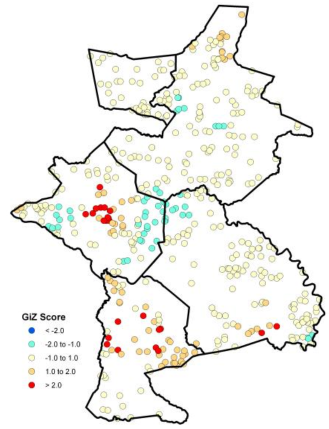

Figure 20. GiZ Score Map.

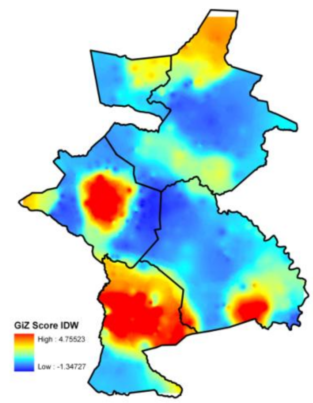

Figure 21. IDW from the GiZ Score.

The Moran's I statistic for spatial autocorrelation is given as:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{S_0 \quad \sum_{i=1}^{n} z_i^2} \qquad (1)$$

Figure 22. Moran's Index (ESRI, 2009).

A Moran's Index of 1.19 was calculated with a Z score of 9.85. The Z score indicated that the pattern observed was not random ($P<0.01$) but clustered.

Results

The layers analyzed are summarized in Tables 5-9. The area included in the fire risk analysis included range land, forest land and agricultural land. These three classes occupied 99.2% of the area. This area was characterized as medium, high and very high fire risk areas respectively (Table 5). From the total fire layer, 161 hotspots occurred in range land, 249 in forest land, and 83 in agricultural land.

Table 5. Land Cover Results.

Classes	Fire Hazard	Area Km^2	%
Agricultural Land	Medium	158.0	13.6
Barren Land	No Risk	2.8	0.2
Forest Land	High	586.3	50.3
Rangeland	Very High	411.1	35.3
Urban or Built-up Land	Low	5.3	0.5
Water	No Risk	1.7	0.1

The outcome of the slope analysis yielded only areas of low and medium hazards. Apparently slope was not a major contributor to fire risk in the area (Table 6).

The aspect analysis resulted in areas of low, medium and high hazard (Table 7). Using the historical hotspots layer, 184 hotspots occurred in the high hazard aspect area, 136 in the medium hazard areas, and 183 in the low hazard area. 64% of the fires occurred in high and medium hazard areas. It appears that aspect does have a significant influence on the fires.

Table 6. Slope Hazard.

Fire Hazard	Area Km2	%
Low	1032.2	87.1
Medium	153.0	12.9

The distance from the settlements (Table 8) resulted in buffer areas from very high to very low areas.

The historical hotspots layer revealed that 18.6% of the fires occurred in very high hazard areas, 33.2% in high hazard areas, 37.1% in medium hazard, and 11.1% in low areas. It appears the distance to settlements has a direct influence on the occurrence of historical fires.

Table 7. Aspect Hazard.

Fire Hazard	Aspect	Area Km^2	%
Low	North	130.1	11.0
	Northeast	188.7	15.9
	Northwest	108.9	9.2
Medium	East	178.0	15.0
	Southeast	157.2	13.3
High	South	126.2	10.6
	Southwest	178.4	15.1
	West	117.6	9.9

Table 8. Distance to Settlements.

Fire Hazard	Area Km^2	%
Low	745.2	116.3
Medium	570.7	89.0
High	416.6	65.0
Very High	224.4	35.0

The outcome of the distance to road analysis (Table 9) resulted in 5 classes from very high to very low hazard. The historical hotspots occurred as follows: 1.9% in very high hazard areas, 4% in high areas, 8% in medium areas, and 4.4% in low areas. It appears that the distance to roads did not have a major influence in the historical hotspots.

Table 9. Road Distance.

Fire Hazard	Area Km^2	%
Very Low	192.0	44.8
Low	71.5	16.7
Medium	77.9	18.2
High	41.9	9.8
Very High	45.6	10.6

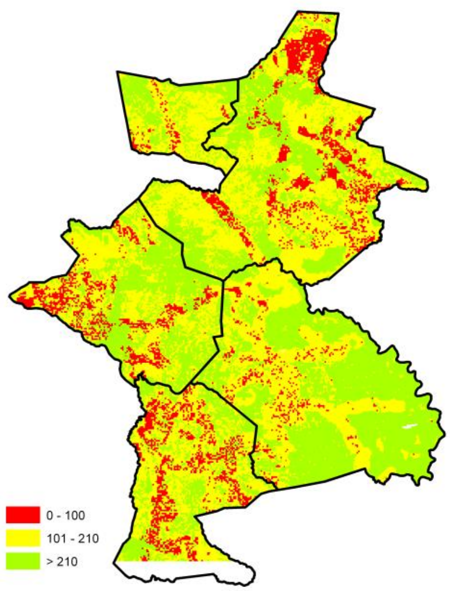

Figure 23. Composite Fire Risk Map.

The fire risk layer was obtained using the equation noted earlier. The results are illustrated in Figure 23 and the fire dispersed hazard information is summarized in Tables 10-12. This layer was further divided as high risk (0 – 100), medium (101 – 210) and low risk (greater than 211). 11% of the area occurs in the high risk category, 46% in the medium risk and 43 % in low risk areas.

Using the layer of historical hotspots and the new risk classification it was possible to determine how many fires have occurred in areas as well as the ability to compare results and findings.

Table 10. Historical Hotspots in High Hazard Areas.

High Hazard	
Month	**# of Fires**
January	1
February	7
March	25
April	38
May	21
September	1
Total	93

Table 11. Historical Hotspots in Medium Hazard Areas.

Medium Hazard	
Month	**# of Fires**
January	1
February	11
March	42
April	74
May	39
September	1
Total	168

Table 12. Historical Hotspots in Low Hazard Areas.

Low Hazard	
Month	**# of Fires**
January	2
February	8
March	43
April	128
May	52
June	2
Total	235

April has the greatest number of fires, followed by March and May. 18% of the historical hotspots were in areas considered by the fire risk model to be high hazard, 33.4% in a medium hazard area and 46.7% in low hazard areas.

Conclusion

In this study GIS was used to integrate varying layers of data for use in forest fire risk modeling. Remote sensing provided important access to imagery that was needed to collect fire information.

From the total area of 1,185.14 km^2 included in this study, 18% occurred in areas of high hazard, 34% in medium hazard and 47% in low hazard areas. Using historical fire data, a correlation between several variables and risk areas was determined. It was observed that 51% of historical fires occurred in high and medium risk areas.

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