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Translated from the original in spanish

Original article

Influence of geographic and meteorological factors in fire generation in las Tunas province

Influencia de factores meteorológicos en la generación de incendios en la provincia de las Tunas

Influência de factores meteorológicos na geração de incêndios na província de las Tunas

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ABSTRACT

Due to the repercussions of fires, it is necessary to know the territorial particularities that favor their emergence and dispersion. Because of its meteorological characteristics, Las Tunas is a vulnerable province to the occurrence of fires. For this reason, this study intends to relate the occurrence and magnitude of fires with the geographical and meteorological conditions of Las Tunas and Puerto Padre municipalities in Las Tunas province, Cuba, in the period 2008-2012. For this purpose, 249 fires were analyzed along with the behavior of meteorological variables. There were found differences among the municipalities regarding the occurrence of fires, the areas affected and the factors related to the spreading. For the case of small fires, it was verified the relationship between meteorological variables and the area affected by fires, although the correlation values were not high. The variables with greater influence, as it was expected, were those related to the moisture of the combustible materials the accumulated of precipitations at 15 and 20 days before each fire and the relative humidity. It was possible to group successfully the number of fires and affected area with respect to different ranges of the meteorological variables, obtaining qualitative criteria of fire risk.

Keywords: Vegetal formation; Fire; Las Tunas; Meteorological variables.

RESUMEN

Debido a las repercusiones de los incendios, se hace necesario conocer las particularidades territoriales que favorecen su surgimiento y dispersión. Por sus características meteorológicas, Las Tunas es una provincia vulnerable a la ocurrencia de incendios. Por ello, este trabajo pretende relacionar la aparición y magnitud de incendios con las características geográficas y meteorológicas de los municipios de Las Tunas y Puerto Padre de la provincia de Las Tunas, Cuba en el período 2008-2012. Para ello se analizaron 249 incendios y se estudió el comportamiento de

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variables meteorológicas relevantes para el estudio. Se encontraron diferencias entre los municipios con respecto a la ocurrencia de incendios, las áreas afectadas por estos y los factores relacionados con la dispersión. Para el caso de los incendios pequeños, se comprobó la relación entre las variables meteorológicas y el área afectada por los incendios, aunque los valores de correlación no fueron altos. Las variables con mayor influencia, como era esperado, fueron las relacionadas con la humedad de los materiales combustibles, debido a los acumulados de precipitaciones, 15 y 20 días antes de cada incendio y la humedad relativa. Se pudo agrupar con éxito el número de incendios y área afectada con respecto a diferentes rangos de las variables meteorológicas, logrando obtener criterios cualitativos de riesgo de incendio.

Palabras clave: Formación vegetal; Incendio; Las Tunas; Variables meteorológicas.

RESUMO

Devido ao impacto dos incêndios, é necessário conhecer as particularidades territoriais que favorecem a sua emergência e dispersão. Dadas as suas características meteorológicas, Las Tunas é uma província vulnerável à ocorrência de incêndios. Por esta razão, este trabalho visa relacionar o surgimento e a magnitude dos incêndios com as características geográficas e meteorológicas dos municípios de Las Tunas e Puerto Padre na província de Las Tunas, Cuba, no período 2008-2012. Para o efeito, foram analisados 249 incêndios e estudado o comportamento das variáveis meteorológicas relevantes para o estudo. Foram encontradas diferenças entre os municípios no que diz respeito à ocorrência de incêndios, às áreas afetadas por eles e aos fatores relacionados com a dispersão. No caso de pequenos incêndios, foi verificada a relação entre as variáveis meteorológicas e a área afetada pelos incêndios, embora os valores de correlação não fossem elevados. As variáveis com maior influência, como esperado, foram as relacionadas com a humidade dos materiais combustíveis, principalmente a pluviosidade acumulada, 15 e 20 dias antes de cada incêndio, e a humidade relativa. O número de incêndios e a área afetada poderiam ser agrupados com sucesso em relação a diferentes gamas de variáveis meteorológicas, obtendo-se assim critérios qualitativos de risco de incêndio.

Palabras clave: Formação vegetal; Fogo; Las Tunas; Variáveis meteorológicas.

INTRODUCTION

The natural balance of vegetal formations and fires has been modified by human action (Carrillo *et al.,* 2012), through increasingly aggressive intervention on renewable natural resources (Mondragón *et al.*, 2013), FAO 2016, Doerr and Santín 2016). Agricultural activity is one of the main causes of this damage (Vélez 1995), Castillo *et al*., 2003, Anaya *et al*., 2017). (Castillo *et al*., 2003).

Research on the occurrence of fires has gradually increased over the years, with a focus on developing hazard indices (Solano 2004, Torres *et al.,* 2007, Carrasco 2016). Most of the indices used for the study of fire danger, although they provide a panoramic view adjusted to the conditions observed, should be evaluated according to the territorial particularities, by not considering elements that influence the initiation and development of fires (Domínguez *et al.,* 2008).

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The frequency and intensity of fires is generally determined by climate, topography, and accumulation of combustible material (Castillo *et al*., 2003). Different studies, using surface meteorological stations, have confirmed the influence that the precipitation deficit, the increase in temperature, the speed of the wind and the decrease in relative humidity have on the occurrence and dispersion of fires (Solano 2004, Carrasco 2016). Other authors also evaluate the influence of synoptic patterns (Carracedo *et al.,* 2009) and climatic oscillations (Carracedo *et al*., 2009, González *et al.,* 2011, Mondragón *et al.,* 2013). Moreover, new research states that without forward-looking adjustments, climate change is very likely to increase the frequency and intensity of fires over longer seasons (Parry *et al*. 2007, FAO 2016, Doerr and Santín (2016), which will have significant negative effects on life on Earth.

Although the magnitude of the impact of fires in Cuba cannot be compared with other countries where the situations are critical, fires are a phenomenon that increases deforestation, soil degradation and loss of biodiversity (CITMA 2010). Even the Ministry of Science, Technology and Environment (CITMA) has included among the five major environmental problems of the country, the effect on the vegetation cover where fires play a very important role (Planos *et al.,* 2013).

The province of Las Tunas, has been considered one of the most vulnerable to the processes of aridity, desertification and fires (Planos *et al.,* 2013), Institute of Tropical Geography 2015), due to the characteristics of the soils and the climatic situation of the region (dry climate with low annual rainfall, high temperatures and drought processes). It is also one of the most deforested provinces in the country, with a small area of mostly degraded forests. The municipality of Puerto Padre, located in the north of the province, is among the 15 municipalities in the country where existing forests face the greatest risk of dying back (Planos *et al.,* 2013). Therefore, fires constitute an additional pressure to the development of agriculture and cause great damage to vegetal formations in general.

Due to the above, the following work aims to relate the occurrence and magnitude of fires with the local geographic and meteorological characteristics of the municipalities of Las Tunas and Puerto Padre in the province of Las Tunas in the period 2008-2012.

MATERIALS AND METHODS

Characteristics of the area of study

Las Tunas Province (Figure 1) is located in the eastern region of Cuba and is formed by eight municipalities (ONEI 2019). The territory presents a dry climate and semi-desert soils (Planos et al. 2013). The provincial capital is the municipality Las Tunas (latitude: 20° 57' 25" N and longitude: 76° 57' 13" W), which has a surface area of 908.9 km^2 and a resident population of 207 648 inhabitants. On the other hand, the municipality of Puerto Padre (latitude: 21° 11' 43" N and longitude: 76° 36' 5" W) has a surface area of 1,106.3 km^2 and a resident population of 92,441 inhabitants (ONEI 2019).

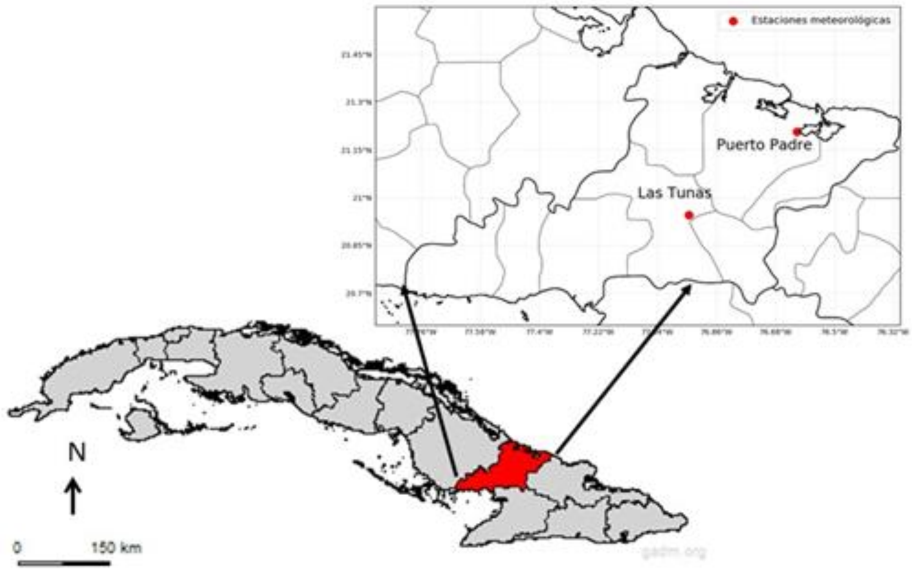

Figure 1. - Study area

Data collection

The fire data was obtained from the CITMA office in the province of Las Tunas, which in turn was provided by the Centro de Guardabosques. For the evaluation of the behavior it was taken into account the distribution in years, months, hours, days of the week, the affected forest formation, total affected area, class of danger, hydrological period and causes.

The series of meteorological data was obtained from the database provided by the Climate Center belonging to the Institute of Meteorology of the Republic of Cuba (INSMET). The variables considered are: Hr-relative humidity (%), T-air temperature (ºC), T-dew point temperature (ºC), FF-wind speed (km h^{-1}), DD-wind direction and P-precipitation (mm). The measurements of 13:00 hours were used in the meteorological stations of Las Tunas and Puerto Padre (Figure 1), except for the case of the precipitation that was analyzed its accumulated in cycles of 24 hours, as it is suggested in Carrasco (2016).

Data analysis

From the available variables and using the program in Python 3.6.3 programming language, two new variables were obtained, considered by Solano (2004) and Carrasco (2016) important for the analysis: DíasSLL (Number of days without rain before the occurrence of the fire) and Días SLL ≥5 mm (Number of days without rain greater than or equal to 5 mm before the occurrence of the fire). To analyze the situation before each of the fires, the accumulated rainfall was determined in intervals of 5, 10, 15 and 20 days before the occurrence of the fire, because the danger of a fire is determined both by the weather conditions on a particular day and by the number of days (Solano, 2004).

First, it was determined whether there were significant differences between the meteorological variables by municipality using the non-parametric Mann-Whitney U test. It was also determined if there were significant differences between vegetal formations in terms of meteorological variables by means of the non-parametric Kruskal-Wallis test followed by its corresponding analysis of multiple range comparisons. These tests were carried out using Statsoft Statistica software version 7.0 with a significance value of 0.05.

To relate the area affected by each fire and the meteorological variables wind speed (FF), temperature (T), dew point temperature (Td), relative humidity (Hr), days without rain (SLL days), days without rain greater than 5 mm (SLL days ≥5 mm) Accumulated rainfall 5 days before each fire (AccR5DA), Accumulated rainfall 10 days before each fire (AccR10DA), Accumulated rainfall 15 days before each fire (AccR15DA) and Accumulated rainfall 20 days before each fire (AccR20DA). The Spearman correlation coefficient calculated with the OriginPro software version 8.0721 was used. The areas affected by the fires in both municipalities were separated into two groups a priori: the small ones (for an affectation of less than 50 ha) and the large ones (for those greater or equal to 50 ha) and the correlation coefficients were recalculated for each group separately, to determine the relevance of the variables in the dispersion.

Then the total affected area was grouped for certain criteria of the meteorological variables temperature (T), dew point temperature (Td), relative humidity (Hr), wind speed (FF), days without rain greater than or equal to 5 mm (Días SLL≥5), accumulated rainfall 15 days before each fire (AcumR15DA) and accumulated rainfall 20 days before each fire (AcumR20DA). In addition, the probability of fire occurrence was determined for the criteria of the meteorological variables temperature (T), dew point temperature (Td), relative humidity (Hr), wind speed (FF). In addition, the relationship between wind direction and speed, the total number of fires and the area affected by fires in Las Tunas and Puerto Padre was determined by means of a radio chart.

Finally, to determine the degree of contribution of meteorological variables to the magnitude of the affected area, a principal component analysis (PCA) was carried out using Primer 5.2.9 software. This allowed explaining the existing variability and which variables contribute more to this variability from three graphic representations, taking into account the following grouping factors: municipality, cause of the fires and affected vegetal formation.

RESULTS AND DISCUSSION

Climatic characteristics of the region

From the meteorological data provided by the INSMET, it can be summarized that the municipality of Las Tunas, taking into account the period 1989-2018, has an average temperature of 26.34ºC, with the maximum for the month of July with a value of 28.55ºC and the minimum for the month of January with a value of 23.73ºC. The accumulated average annual rainfall is 1178.05 mm with a minimum for the month of February of 29.40 mm and a maximum for the month of June with 176.24 mm. As for the municipality of Puerto Padre, the average temperature is 26.44ºC, while the maximum is registered in the month of July with a value of 29.01ºC and the minimum in the month of January with a value of 23.66ºC. The accumulated average annual rainfall is 948.32 mm with a minimum for the month of February of 38.61 mm and a maximum for the month of October with 131.63 mm.

During the 2008-2012 study period, a total of 249 fires occurred between the municipalities of Las Tunas (89) and Puerto Padre (160). The largest number occurred in 2012 for the municipality of Las Tunas (61), while in Puerto Padre in 2008 there were 73. The year 2008 was highlighted for Puerto Padre due to the occurrence of a fire of great proportions (1935 has affected). The months with the highest number

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of fires were those of the low rainfall period of the year: February for Puerto Padre and March for Las Tunas. It is in this period where the lowest accumulated monthly rainfall and the lowest relative humidity values were concentrated (Table 1). The highest number of fires occurred between 1:00 p.m. and 5:00 p.m. for both municipalities.

Table 1. - Monthly average of the meteorological variables in the municipalities of Las Tunas and Puerto Padre in the period 1989-2018

	Las Tunas						Puerto Padre					
Mes	$\overline{T}$ (ºC)	$\overline{Td}$ (ºC)	$\overline{Hr}$ (%)	$\overline{FF}$ (km h^{-1})	$\overline{P}$ (mm)	**FRI (%)**	$\overline{T}$ (ºC)	$\overline{Td}$ (ºC)	$\overline{Hr}$ (%)	$\overline{FF}$ (km h^{-1})	$\overline{P}$ (mm)	**FRI (%)**
1	23,73	17,98	75,66	11,95	30,46	3,37	23,66	19,52	79,32	13,00	60,04	16,88
2	23,94	17,46	72,61	12,42	29,40	24,72	23,79	19,07	76,47	14,08	38,61	25,00
3	24,81	17,46	70,03	12,61	36,66	38,20	24,55	19,25	74,73	14,42	46,59	23,13
4	26,42	18,66	70,12	12,12	73,26	22,47	26,13	20,51	75,02	14,72	43,60	17,50
5	27,36	20,52	74,94	10,59	148,18	11,24	27,25	21,97	77,70	13,25	113,47	15,63
6	28,21	22,26	78,54	8,48	176,24	0,00	28,52	23,55	79,85	12,00	91,99	1,25
7	28,55	22,43	77,60	9,69	128,60	0,00	29,01	23,81	78,04	13,78	59,55	0,00
8	28,51	22,58	78,51	8,72	156,94	0,00	28,89	23,81	78,41	11,73	72,22	0,63
9	27,94	22,63	80,60	6,91	175,63	0,00	28,21	23,51	79,67	9,06	115,96	0,00
10	26,91	22,23	81,62	7,93	145,93	0,00	27,18	23,08	81,20	9,30	131,63	0,00
11	25,37	20,56	79,69	10,82	45,88	0,00	25,64	21,64	80,30	11,55	108,27	0,00
12	24,31	19,15	77,94	11,88	30,88	0,00	24,43	20,50	80,28	12,30	66,39	0,00
Anual	26,34	20,32	76,49	10,34	1178,05		26,44	21,69	78,42	12,43	948,32	

FRI: Relative frequency of fire occurrence (%)

Differences were found at the local level between the meteorological variables due to the fires in Las Tunas and Puerto Padre with respect to the meteorological variables (Table 2). The comparison between the territorial averages determined that there were differences for the variables related to rainfall, with higher average values in Puerto Padre than in Las Tunas.

Table 2. - Comparison of the median values of ten meteorological variables between Las Tunas and Puerto Padre

Variables	$\overline{X}$ Las Tunas	$\overline{X}$ Puerto Padre	U Mann-Whitney
FF	17.49	22.34	2614.5 n.s
T	30.13	28.17	2 573.5 n.s
Td	14.04	18.87	2500 n.s
Hr	38.53	57.51	2624.5 n.s
DíasSLL	19.22	7.16	1860 **
DíasSLL≥5 mm	42.66	12.71	1928.5 *
AcumR5DA	3	7	2203.5 *
AcumR10DA	5	15	1848 **
AcumR15DA	12	23	1984.5 *
AcumR20DA	17	34	1422.5 ***

* significant differences (P<0.05), n.s-not significant diferences *(P<0.05)*

Table 3. - Comparison of the median values of ten meteorological variables between plant formations

Variables	$\bar{X}_{Plfor}$	$\bar{X}_{SCF-C}$	$\bar{X}_{SCF-MD}$	$\bar{X}_{MC}$	$\bar{X}_{caña}$	H
FF	17.8	19.0	26.0	33.0	22.0	16.29 ***
T	29.5	30.5	30.6	29.8	28.0	64.74 n.s
Td	14.1	15.6	13.6	21.2	18.8	81.38 ***
Hr	40.0	41.7	36.0	60.5	58.0	110.03 ***
DíasSLL	20	13	24	13	7	12.00 *
DíasSLL≥5 mm	41	33	54	50	12	60.68 ***
AcumR5DA	4	5	0	0	7	6.97 n.s
AcumR10DA	6	8	1	0	15	24.36 ***
AcumR15DA	14	13	1	2	23	37.41 ***
AcumR20DA	20	16	1	2	35	57.18 ***

* significant differences (P<0.05), n.s-not significant diferences *(P<0.05)*

These variables were also compared between vegetal formations (Plfor: Secondary bushes; SCF-C: Semi-deciduous on limestone soil; SCF-md: Semi-deciduous on soil with bad drainage; MC: Coastal mangrove and cane crop) affected by fires and significant differences were obtained for all of them, except temperature and accumulated precipitation 5 days before each fire (Table 3). The highest average values of wind speed, dew point temperature and relative humidity were for the coastal mangrove. Analyzing rainfall, the least amount of days without rain and days without rain greater than 5 mm was for sugar cane, however, this crop had a higher average accumulated 5, 10, 15 and 20 days before each fire.

Effect of weather variables on the magnitude of fires

The correlation values between the affected area by municipality and the meteorological variables were neither high (Table 4) nor significant, a result also found by Carrasco (2016) in the province of Pinar del Río. The exception was the wind speed in the municipality of Las Tunas and the accumulated rainfall 20 days before the fires in Puerto Padre. Based on the above results, it was decided to conduct the analysis by level of affected area. For the small fires, the correlations of all variables were significant except the accumulated precipitation 5 days before the fires. The highest correlations were for dew point temperature and relative humidity, but with a positive sense when the opposite should occur. The direction of the correlation was also opposite to what should occur for the temperature variables, days without rain, and days without rain greater than or equal to 5 mm and with accumulated rainfall. For large fires, the May 20, 2008 fire in Puerto Padre with 1935 lightning strikes was not taken into account as it was an extreme case. In this case the best correlation was for the accumulated precipitation 15 days before each fire, with negative sense, which showed the importance of precipitation not only if it rained or not, but its accumulated in a period of time.

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Table 4. - Relationship between area affected by fire and weather variables in the municipalities of Las Tunas and Puerto Padre; considering as groups small and large fires in the two municipalities

Variables	FF (km h^{-1})	T (ºC)	Td (ºC)	Hr (%)	Days SLL	DaysSLL ≥5 mm	AcumR 5DA (mm)	AcumR 10DA (mm)	AcumR 15DA (mm)	AcumR 20DA (mm)
Las Tunas	-0.279*	0.220	-0.071	-0.110	-0.110	0.095	0.078	-0.093	-0.145	-0.182
Puerto Padre	-0.126	0.024	-0.014	-0.066	-0.018	-0.007	-0.015	0.110	0.119	0.315*
Incendios pequeños	0.153*	-0.372*	0.485*	0.545*	-0.140*	-0.353*	0.077	0.245*	0.317*	0.389*
Incendios grandes	0.086	-0.132	-0.197	-0.239	-0.106	0.286	0.058	-0.202	-0.433*	-0.056

* significant differences *($P<0.05$)*

According to the hazard class established by Oharriz and Davidenko *et al.,* (1989), in Las Tunas type II (small) fires predominated with only 1 to 10 ha of affected area and in Puerto Padre type III (medium) fires with 10.1 to 20 ha of affected area. The most affected vegetal formations were secondary shrubs for Las Tunas and sugarcane for Puerto Padre. Intentional fires were predominant in Puerto Padre and negligence in Las Tunas.

Qualitative fire risk criteria

In order to identify possible qualitative criteria of fire risk according to meteorological variables, these were grouped into intervals of variation (Figure 2). In the case of temperature (Figure 2 A) the maximum value of affected area was between 27.5ºC and 30.4ºC, as well as the highest probability of fire. For the relative humidity (Figure 2 B), the highest probability of fire was for lower values equal to 43%. Taking into account the dew point temperature (Figure 2 C) in Las Tunas, the maximum value of the affected area and the highest probability was found for values lower than 18.5ºC. In relation to wind speed (Figure 2 D) the greatest area affected and probability of fire occurred for values below 22 km h^{-1}.

In relation to the influence of rainfall, the days without rain greater than or equal to 5 mm and the accumulated rainfall 15 and 20 days before each fire were analyzed (Figure 3). For the total number of days with less than 5 mm of rainfall (Figure 3A), the behavior in each municipality was different, since in the case of Las Tunas, the largest area affected was for more than 60 days without rain, while for Puerto Padre, for less than 20 days. When analyzing the accumulated rainfall 15 days before each fire (Figure 3B) it was found that in both municipalities the maximum value of affected area was for the accumulated less than 10 mm. Finally, for the accumulated rainfall 20 days before each fire (Figure 3C) it was found that in Las Tunas the maximum value of affected area was for accumulated less than 10 mm, while for Puerto Padre it was between 10 and 49 mm.

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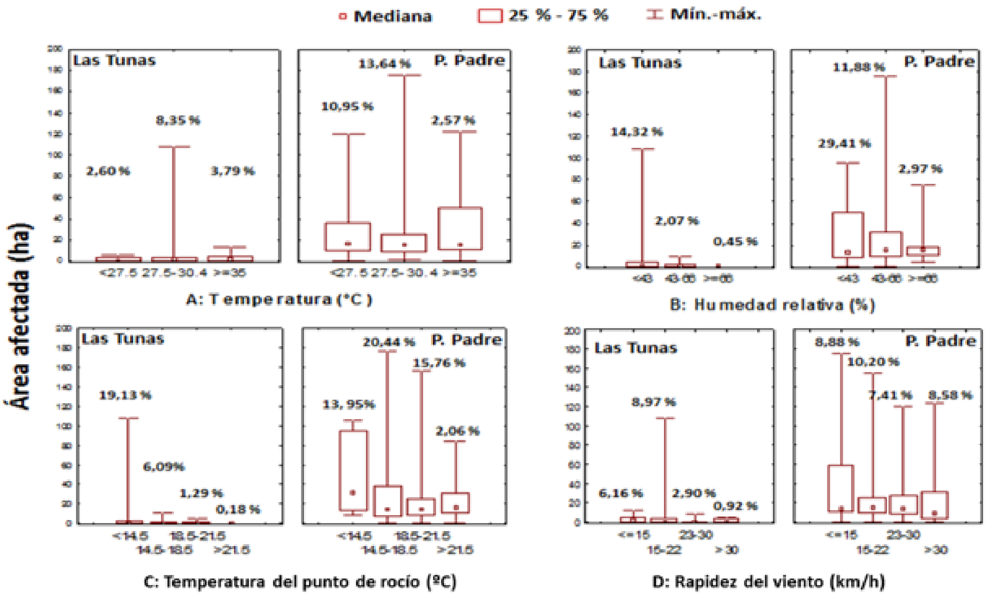

Figure 2. - Variation of the area affected by fires according to meteorological variables
A: Temperature (ºC), B: Relative humidity (%), C: Dew point temperature (ºC) and D: Wind speed (km h^{-1}).

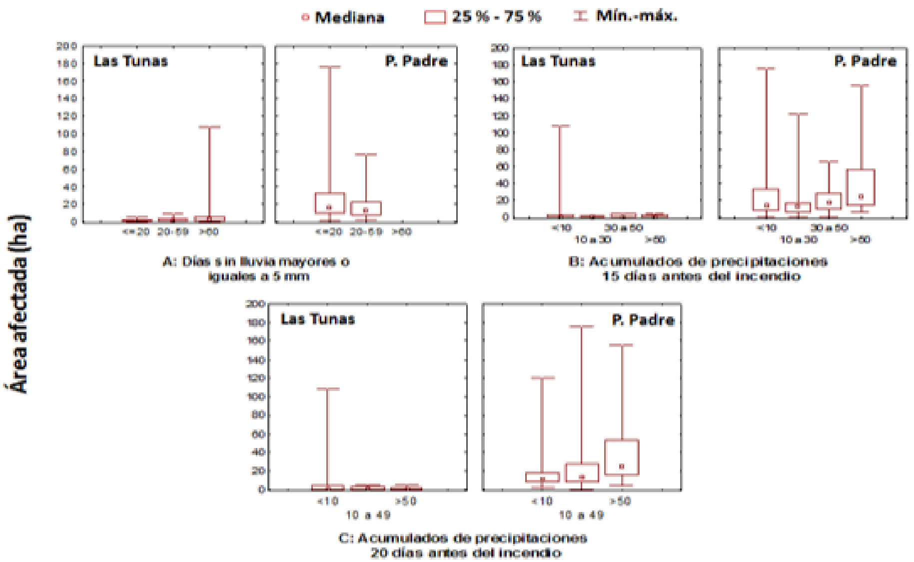

Figure 3. - Variation of the area affected by fires according to rainfall
A: Days without rainfall greater than 5 mm, B: Accumulated rainfall 15 days before each fire and C: Accumulated rainfall 20 days before each fire.

If it is analyzed the wind direction in both municipalities (Figure 4), in the municipality of Las Tunas the highest average wind speed, predominant wind direction in 2008-2012, Total fires and Affected Area coincide with the east (E) and northeast (ENE).

In the municipality of Puerto Padre, however, a greater variability is found, since the directions where the greatest number of fires occur and the greatest amount of affected area are northeast (NE) and east-northeast (ENE), which in turn, are the predominant wind directions in the study period, but not the fastest (WSW: west-southwest). In summary, in the municipality of Puerto Padre the wind direction is more important in the occurrence and magnitude of fires than wind speed.

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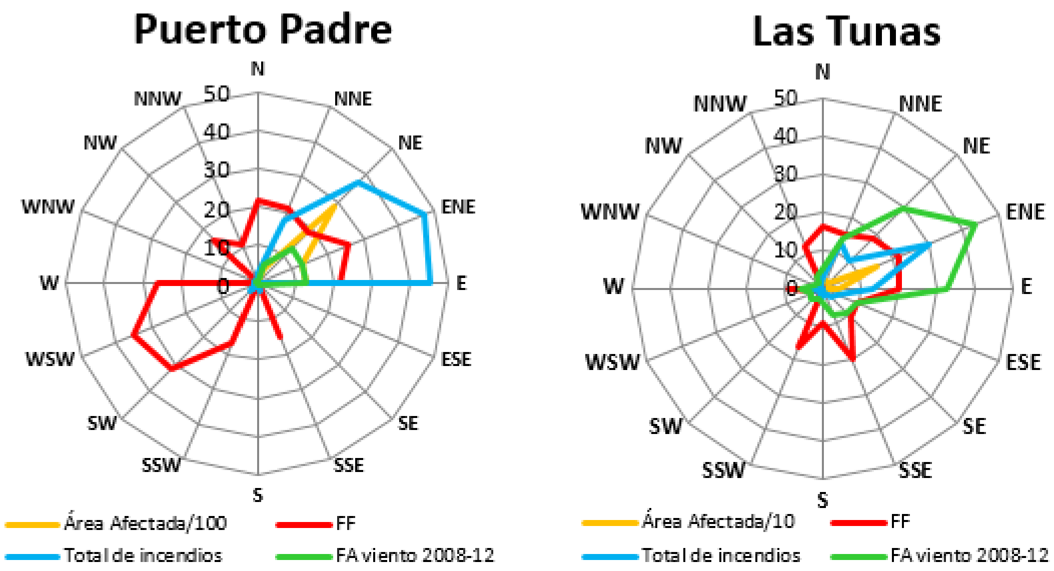

Figure 4. - Relationship between wind direction, wind speed, total fires and area affected by fires in Las Tunas and Puerto Padre

Multivariate analysis

The principal component analysis (PCA) showed the variables that stood out the most in order of importance in axis 1 (PCA 1) with a 37.7 % of variation were those related to the level of precipitation, among which, those accumulated 15 and 20 days earlier are those that contributed most to the dispersion of data in that axis. As for the variation explained by the second axis (PCA 2) with a 15.8 %, the variables with the greatest weight were wind speed (FF) and temperature (T) (Table 5).

Table 5. - Contribution to the natural variation of the variables analyzed in each of the three main components that explain 64.6 % of the variation of the area affected by fires in Las Tunas

	Causa	FF	T	Td	Hr	Días SLL	Días SLL≥5	Acum R5DA	Acum R10DA	Acum R15DA	Acum R20DA
PCA 1 (37,7 %)	0,049	0,026	0,195	-0,324	-0,361	0,173	0,353	-0,329	-0,338	-0,416	-0,414
PCA 2 (15,8 %)	-0,233	0,463	-0,459	0,222	0,381	0,277	-0,082	-0,33	-0,349	-0,072	-0,062
PCA 3 (11,1 %)	0,668	0,092	0,097	0,205	0,102	-0,059	-0,032	-0,055	-0,06	-0,103	-0,045

From the integral analysis of the produced fires and taking into account all the meteorological variables, two fundamental groups could be distinguished: in the first one, the intentional fires produced in Puerto Padre in the cane fields and in the second group, the fires produced in the Tunas by negligence in different vegetal formations (Figure 5). The differences between the two groups were mainly determined by the behavior of precipitation in the first axis (PCA 1), in particular, the accumulated precipitation of 15 and 20 days before each fire, while for axis two (PCA 2), wind speed and temperature.

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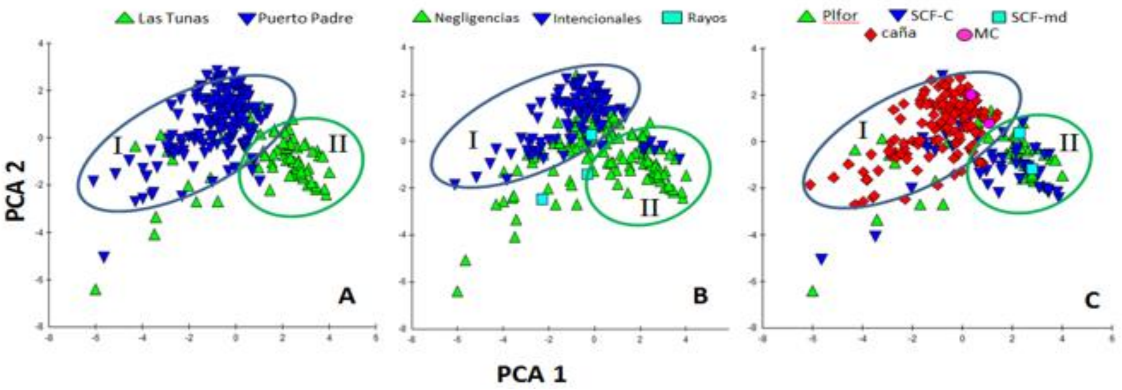

Figure 5. - Analysis of main components in which the distribution of data is shown taking into account three factors:
A: Municipality, B: Cause of the fires and C: Affected vegetal formation

The highest number of fires and the largest amount of affected area occurred in the low rainfall period of the year, because combustible material tends to increase its flammability and availability due to the low water content of the fibers (Carrasco 2016). The months of greater occurrence did not correspond with those of other zones of the country like Pinar del Rio (Ramos and Soares 2004, Ramos and Cabrera 2011, Carrasco 2016) where the month of greater occurrence was May, fact that has its cause in the geographic location of the regions and to the influence of meteorological systems in the winter period like the cold fronts, which cause a greater number of precipitations in the first months of the year in the regions of the West of the country. The months of greatest occurrence also did not correspond with those of other areas such as Brazil (Ramos and Soares 2004) due to the fact that the locations are in different hemispheres and the period with little rainfall is the opposite, but they do correspond with Spain, especially in the region of Cantabria (Carracedo 2009).

With respect to the time of occurrence of the fires, these did resemble the previously mentioned investigations (opcit), in which all pointed to the afternoon hours, between 14:00 and 18:00 local time, as the most likely. This behavior corresponds to the daily distribution of temperature and relative humidity, two weather variables that influence the humidity of combustible materials (Domínguez *et al.*, 2008, Carrasco 2016, Barcia *et al.,* 2019).

The comparison between the territorial averages showed the importance of differentiating the behavior of precipitation in the occurrence of fires and also showed that to analyze the influence of meteorological variables on fires it is important to take into account the type of forest formation affected, since not all respond to weather conditions in the same way (Domínguez *et al.,* 2008).

Correlations between the affected area and meteorological variables were generally not very informative because the degree of affectation does not depend only on meteorological variables, a fact found by Carrasco (2016). Other factors that could have influenced were the topography, characteristics of the fuel material, early warning systems and available means of control (Carracedo 2009, Barcia *et al.*, 2019). The statistics of fires in Cuba indicate that the origin of the fires is also determinant, because most of them are caused by men in an intentional or accidental way (Solano 2004). In Puerto Padre the fires originated in an intentional way predominated and in Las Tunas by negligence, and it was differentiated with the province of Pinar del Río where the most common cause was the lightning (Ramos

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and Soares 2004, Ramos and Cabrera 2011, Carrasco 2016). In the fires, therefore, social factors and vegetable factors influence, but without suitable meteorological conditions neither the most skillful arsonist could make burn the most inflammable plant (Vélez, 1995).

The most affected vegetal formations were the secondary bushes for Las Tunas and the cane for Puerto Padre, differing from the province of Pinar del Río, where the most affected vegetal formation was *Pinus spp.,* which is also one of the predominant in the region (Rodríguez *et al*., 2015, Carrasco 2016), but it did coincide with the province of Cienfuegos, where fires occurred due to uncontrolled burns in cane formations or induced by people who violated security measures (Barcia *et al.*, 2019).

With respect to semideciduous on limestone soil (SCF-C), these lose their leaves in the dry period and therefore occasional surface fires may occur (Domínguez *et al.*, 2008). For Las Tunas, most of the fires occurred in undifferentiated, mostly secondary, marabout and shrubby grasses (Figure 6), but also, as in Puerto Padre, are affected in the SCF-C.

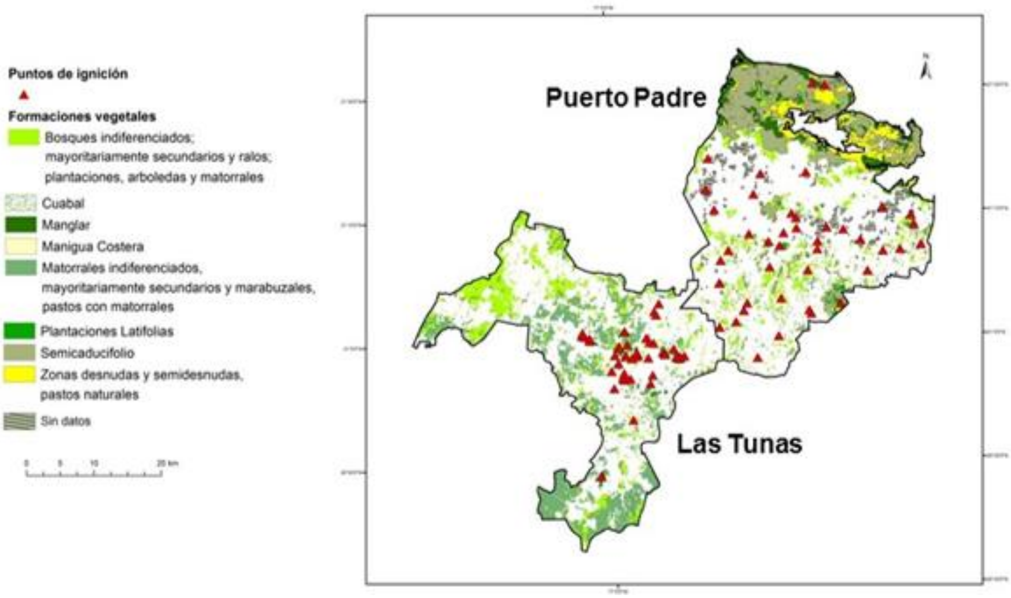

Figure 6. - Ignition points and plant formations in Las Tunas and Puerto Padre

Taking into account everything analyzed above, it can be summarized that the highest probability of fires in both municipalities is found in the low rainfall period of the year, between 13:00 and 17:00 local time. The most affected vegetal formations are the cane for Puerto Padre and the secondary bushes for Las Tunas. According to the criteria of the meteorological variables it can be affirmed that a major probability exists for days with conditions of temperature major of 27,5ºC, temperatures of dew point minor of 14,5ºC for Las Tunas and minor 18,5ºC for Puerto Padre, with relative humidity minor of 43 %, a predominant direction of the wind of the E and the ENE and high values of rapidity of the wind do not have to exist in both municipalities.

The rainfall is grouped differently: in Las Tunas it is dangerous when there are more than 60 days with rainfall less than 5 mm, but for Puerto Padre this is not as representative a variable as the accumulated rainfall 15 days before, because for accumulated less than 10 mm, the amount of affected area is greater. For 20 days before, the vegetation and soil conditions of Puerto Padre allow that, even if it rains 50 mm, there is a risk of fire, however, for Las Tunas less than 10 mm accumulated generates favorable conditions for fires. According to the PCA, the influence of variables related to the humidity of combustible materials, especially the accumulated rainfall 15 days before each fire, is highlighted.

CONCLUSIONS

Differences were found between municipalities with respect to the occurrence of fires, areas affected by fires and factors related to dispersion. The climatic characteristics and the type of vegetal formation, are determinant in the occurrence of fires, although the action of man increases the probabilities of occurrence.

The variables with greater influence were those related to the humidity of the combustible materials, mainly the accumulated of precipitations, 15 and 20 days before each fire and the relative humidity.

It was possible to group successfully the number of fires and affected area with respect to different ranges of the meteorological variables, obtaining qualitative criteria of fire risk.

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