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Wildfire analysis in the Cobos-Parga Hydrographic Basin, Aguascalientes, through satellite images: impacts and solutions

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ABSTRACT

Objective: Detect and analyse forest fires happening in the Cobos-Parga Hydrographic Basin.
Design/methodology/approach: For this analysis, the methodology that was followed ranges from the extraction of satellite images to the calculation of the Normalised Burn Ratio, thus enabling the detection of combusted zones. All this work was done thanks to the use of Geographic Information Systems.
Results: Frequent occurrence of fires was found in the area, mainly of anthropogenic origin and registered mainly from January to May. The increasing trends in annual precipitation and extreme maximum temperature are also evident in the study area. Therefore, climatic conditions do not exhibit a clear correlation between them and fires, supporting the idea that forest fires are mostly caused by anthropogenic reasons.
Limitations on study/implications: Finally, it is suggested that the CPHB is not suitable for the construction of real estate complexes, since it is estimated to be a zone of high fire risk.
Findings/conclusions: This highlights the necessity of establishing protection measurements that could control illegal activities, as well as monitoring fires and along with it, guarantee the biological and cultural preservation of the area.

Keywords: Aguascalientes, Cobos Forest, Fires, NBR, Remote sensing.

INTRODUCTION

Fire is a key ecological factor that is part of the natural dynamics of some ecosystems, with benefits such as the reproduction of certain species and soil fertilisation (Pérez-Verdín *et al.*, 2013). However, currently, the vast majority of wildfires have an anthropogenic origin (SEMARNAT, 2018), triggered both in accidental and intentional ways (Vaiciulyte *et al.*, 2023). This, along with higher and higher temperatures, as well as more and more recurrent and prolonged droughts (Roy *et al.*, 2021), can overcome the regeneration

capacity of these ecosystems against this phenomenon (Mastachi-Loza *et al.*, 2024), even for species well adapted to it (Azpeleta-Tarancón *et al.*, 2023).

Some of the negative consequences of recurrent wildfires are biodiversity loss, soil erosion, global warming, the expansion of invasive species and affections to human health (Pérez-Verdín *et al.*, 2013; Cruz-Núñez *et al.*, 2014). Therefore, forest fires have impacts on the environment, as well as on society and economy (Mastachi-Loza *et al.*, 2024).

One of the countries with greatest susceptibility to these phenomena is Mexico (Cruz-Núñez *et al.*, 2014), since it has ecosystems found under high anthropogenic pressure and characterised by a marked precipitation seasonality, both of which favour ignition (Azpeleta-Tarancón *et al.*, 2023). Moreover, due to ongoing climate change and natural growth of its population, particularly in medium and small-sized cities, it is foreseen that the risk of this type of events in Mexico will increase (Vaiciulyte *et al.*, 2023), including natural areas of high ecological value (Ressl *et al.*, 2009). In spite of this, these phenomena are not being investigated with the urgency they deserve.

There are some detailed studies in certain Mexican states like Puebla (Carrillo-García *et al.*, 2012), Durango (Pérez-Verdín *et al.*, 2013), Jalisco (Cerano-Paredez *et al.*, 2015), State of Mexico (Gutiérrez-Martínez *et al.*, 2015) and Nuevo León (Roy *et al.*, 2021). Nevertheless, this type of studies do not exist for Aguascalientes, even though it is the 13^{th} Mexican state with greatest number of wildfires in relation to its area, reporting 335 events between 2010 and 2020 (Cruz-Núñez *et al.*, 2014). Furthermore, on account of its dense urbanisation, it is considered a fire-prone area, since in this entity, more than 10% of these phenomena are registered in the so-called wildland-urban interface (Vaiciulyte *et al.*, 2023). This evidences the great pressure that the city of Aguascalientes exerts over the natural landscape.

An example of such threatened landscapes is located at the south of the state of Aguascalientes, in the municipalities of Aguascalientes and El Llano, and is known as the Cobos-Parga Hydrographic Basin (CPHB). It is an area of great ecological and cultural value, which is part of the state strategy for the protection and conservation of natural resources, contributing with ecosystem services such as climate regulation, flood mitigation and aquifer recharge, among others (SEGGOB, 2021a). However, this high richness is now at severe risk, as numerous real estate complexes have been proposed for this zone (M. Vázquez, personal communication, 12^{th} of August 2023).

This is why it is important to preserve the ecological integrity of this area and minimise the risks that threaten it, for example, wildfires. To do that, a series of wildfires that occurred in this area between 2010 and 2021 are analysed through satellite images and Geographic Information Systems (GIS), along with associated climate data. The general objective of this investigation is to provide information about the wildfire problematic in the CPHB in Aguascalientes, Mexico. Specific objectives are, on the one hand, to analyse a series of wildfires that took place in the study area for the 2010-2021 period and determine the vegetated areas affected by them and, on the other hand, to establish the potential relationship between climate data and wildfires occurred in the CPHB. It is hypothesised that wildfires happening in the CPHB make this area inviable for the construction of real estate complexes.

MATERIALS AND METODS

Study area

The study area is the CPHB, which is situated at a latitude of 21° 48' 47.7"- 21° 49' 25.6" N and a longitude of 102° 15' 23.9"-102° 14' 16.1" O (Figure 1), and has a surface area of 20,962 ha. This zone captures a large amount of water every year, being an important zone for aquifer recharge and a supply source for the Parga Dam (SSMAA, 2019). The Programme for the Local Ecological Management of the Municipality of Aguascalientes 2016-2040 (SEGGOB, 2021b) classifies this area under the "protection" category, within the Environmental Management Unit number 32 "Cobos" (SEMADESU, 2016).

Figure 2 represents the climate graph for the municipality of Aguascalientes, whose data was obtained from the weather station "Aguascalientes", with code 1030 from the

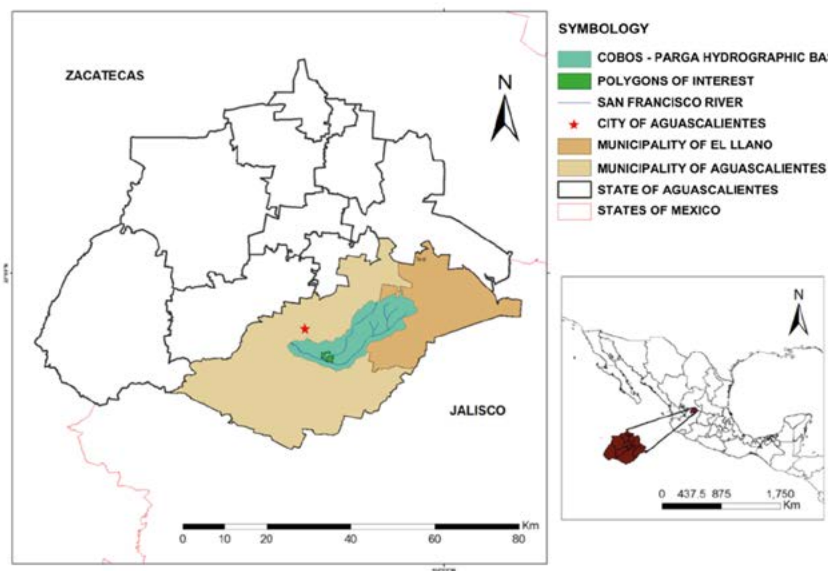

Figure 1. Geographic location of the study area in the city of Aguascalientes, Mexico.

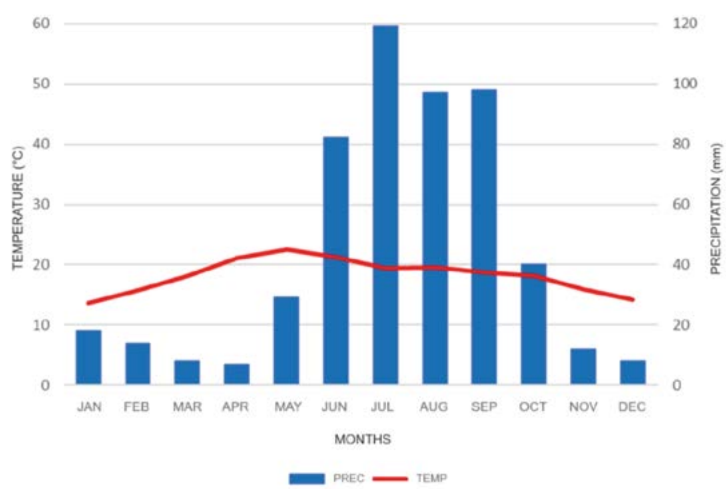

Figure 2. Climate graph of the municipality of Aguascalientes, Mexico (1948-2021).

National Weather Service (SMN, 2024). As can be observed, climate is predominantly temperate semi-arid, BSh according to the Köppen classification system modified by García (2004). Thus, lowest temperatures are recorded in winter, the moment with lowest insolation, whereas maxima are registered in late spring-early summer, when insolation is high and summer storms have not initiated yet. Regarding precipitation, Aguascalientes has eight months of aridity (October-May) that give rise to a markedly dry season, which highly contrasts with the wet season (June-September), in which precipitation is both abundant and intense, in the form of convective storms. Also, it is noteworthy that interannual precipitation variability is very high, with a coefficient of variation higher than 50%, since rainfall regime may undergo alterations induced by El Niño Southern Oscillation (Cerano-Paredes *et al.*, 2015).

On the other hand, Figure 3 represents the temporal evolution of climate. As can be appreciated, although precipitation registers important interannual oscillations, an upward trend can be inferred, both annually (Figure 3A) and in the dry season (Figure 3B). As for temperature maxima (Figure 3C), it exhibits peaks between 1948-1955, 1997-2008 and 2017-2020, and it also displays an upward trend. This means that, in this municipality, precipitation and temperature maxima are getting higher and higher over time.

The intense aridity of Aguascalientes favours the development of vegetation adapted to water scarcity, with most of the CPHB covered with thorny shrub represented by mesquites (*Prosopis* sp.), huisaches (*Vachellia farnesiana*), prickly pear cacti (*Opuntia* sp.), gatuño (*Mimosa monancistra*) and cane cholla (*Cylindropuntia imbricata*). According to the Sustainability, Environment and Water Secretary of Aguascalientes (SSMAA, 2019), another important soil use is temporal agriculture, although, currently, that use is barely present and is gradually being replaced by the recolonisation of native natural grasslands. Due to natural wildfire occurrence in this ecosystem, enhanced by precipitation seasonality, vegetation is also adapted to this element, which increases wildfire risk (SEGGOB, 2021a). Regarding wildlife, the CPHB has a wide variety of mammals, birds, reptiles and amphibians, highlighting mud turtles (*Kinosternon* sp.) or mountain tree frogs (*Dryophytes eximius*), both of them highly vulnerable to fire occurrence (Mastachi-Loza *et al.*, 2024).

Finally, it is important to point out that, despite having low population density, the area is not exempted from anthropogenic threats, like brick factories, debris dumping, uncontrolled livestock grazing or the entrance of unauthorised people, who occasionally vandalise the property (SEGGOB, 2021a).

WORKFLOW

The present investigation was carried out in several phases (Figure 4), which are detailed hereafter.

PHASE 1: Delimitation of the study area

For the delimitation of the study polygon, QGIS software version 3.28.11 - Firenze (QGIS, 2023) was used, and different geospatial layers were accessed through various sources (Table 1).

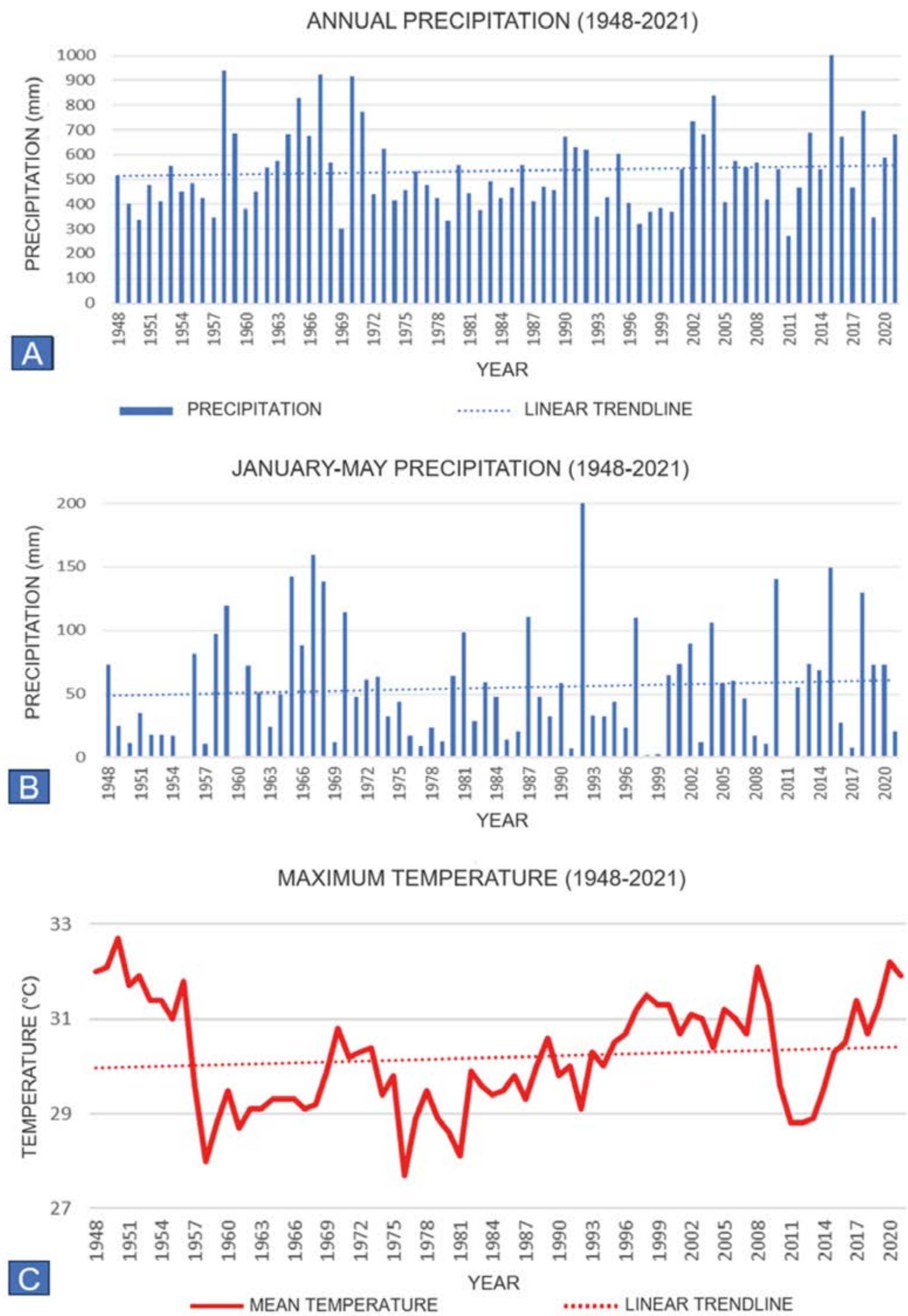

Figure 3. Temporal evolution of climate in the municipality of Aguascalientes (1948-2021): annual precipitation (A), January-May precipitation (B), maximum temperature (C).

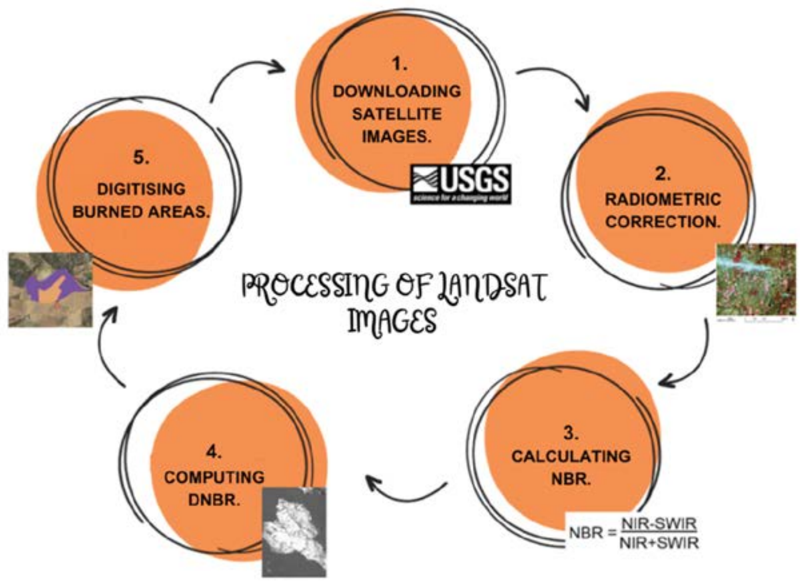

Figure 4. Conducted workflow for the processing of satellite images.

Table 1. GIS layers used during this investigation.

Layer	Type	Resolution	Source
Elevation	Raster	15×15 m	INEGI (2023)
States	Vector	N/A	CONABIO (2023)
Municipalities	Vector	N/A	CONABIO (2023)
Satellite images	Raster	15×15 m	USGS (2023)
Wildfires	Vector	N/A	CONAFOR (2023)
Rivers	Vector	N/A	CONABIO (2023)

PHASE 2. Information about forest fires occurred within the study area

The next step involved using the shapefile of wildfires in the Mexican territory reported by CONAFOR (2023), to select those events coinciding with the study area (Figure 1), adding up a total of 45 events between 2010 and 2021 (Table A1).

PHASE 3. Downloading satellite imagery

Later on, satellite images from Landsat missions 7, 8 and 9 were downloaded from the EarthExplorer portal by the US Geological Survey (USGS, 2023), corresponding to bands 5 (Near Infrared) and 7 (Short-Wave Infrared), together with the MTL file.

PHASE 4. Radiometric correction

Radiometric correction was conducted in order to reduce non-desired artifacts due to atmospheric effects or differential light caused by the time of the day, the place on Earth or the relief (Palazón-Fernando, 2006). To do that, the Semi-Automatic Classification Plugin from QGIS was utilised (2023).

PHASE 5. Computing the Normalised Burn Ratio (NBR)

Finally, the Normalised Burned Ratio (NBR) was calculated in grey levels (Formula 1). As can be observed, this algorithm exclusively focuses on the infrared region, where burned vegetation has a more distinctive spectral signal (Keeley, 2009). The final step involved computing the Differenced Normalised Burn Ratio (DNBR), that is to say, the difference between the satellite image before and after the event, which makes burned areas stand out, facilitating subsequent digitising. This index has been successfully applied in other investigations about wildfires in Mexico (Ressl *et al.*, 2009).

$$NBR = \frac{NIR - SWIR}{NIR + SWIR}$$

Formula 1. Algorithm used in the calculation of NBR, where NIR=Near Infrared (*i.e.* Band 5) and SWIR=Short-Wave Infrared (*i.e.* Band 7).

RESULTS AND DISCUSSION

A total of 120 wildfires were registered within the CPHB, mainly from January to May, with March, April and May being the months with highest occurrence (31.67%, 25.83% and 20%, respectively), that is to say, spring months coinciding with the end of the dry season (Figure 2), albeit with a lower percentage compared to the findings by Cerano-Paredes *et al.* (2015) for the state of Jalisco. In turn, Gutiérrez-Martínez *et al.* (2015) also detected a peak in wildfire occurrence in spring for the state of Mexico, although, in their case, maximum was registered in April.

The reason why wildfires concentrate in spring responds to climatic reasons. Indeed, during the wet season, a large amount of biomass is accumulated, which gets dehydrated during the dry season and, due to high temperatures, becomes more fire-prone (Minnich *et al.*, 1994). As for the study years, 2019 recorded a greater number of wildfires and these affected larger areas, with more than half of the hectares of the time series combusted during this specific year. Conversely, the 2011-2015 period did not present any wildfire. All reported fires were superficial, since prevailing shrubland does not constitute closed arboreal formations.

It must be underlined that CONAFOR (2023) identified 45 wildfires in the zone (Table A1), whilst the present study detected 120 events, *i.e.* 272% more. Likewise, based on the methodology of the present study, 16% of the basin is found to have fire presence, a figure that doubles that of CONAFOR (2023), whose total burned area was only 8% of the catchment.

This could be due to the fact that CONAFOR (2023) excludes non-forested surfaces from burned areas. However, dominant thorny shrubland and grassland of the study area (SEGGOB 2021a) could have been left out from this classification. Thus, it is considered that the methodology presented in this investigation fits better with the dynamics of the study area.

Similarly, the main wildfire occurrence reasons in the CPHB were analysed (Figure 5). To do that, data from CONAFOR (2023) were obtained, because of the lack of this type of information about burned areas additionally detected in this research. As can be observed, almost 2/3 of the fires were intentionally triggered, followed by 16% of unknown reasons and 9% owing to negligence (landfill burning or cigarettes, among others):

On the other hand, Figure 6A illustrates the 120 fire events that took place in the study area for the 2010-2021 period, whereas Figure 6B displays a zoomed in sector of high interest. It can be concluded that most of the wildfires in the CPHB are concentrated in the medium and low areas of the basin. Furthermore, more than half of them are located in the surroundings of the conurbation area of the city of Aguascalientes, which was also pointed out by Mastachi-Loza *et al.* (2024) for the State of Mexico, an entity that, just like Aguascalientes, is subject to great urban pressure.

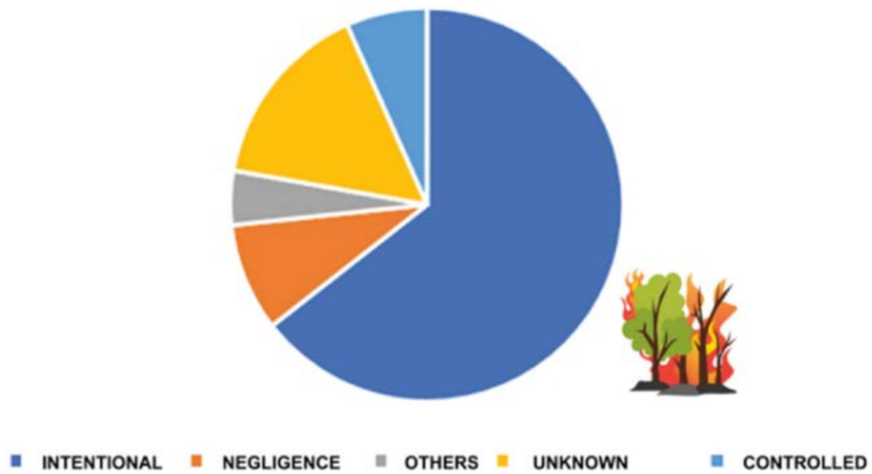

Figure 5. Main causes of wildfires in the CPHB.

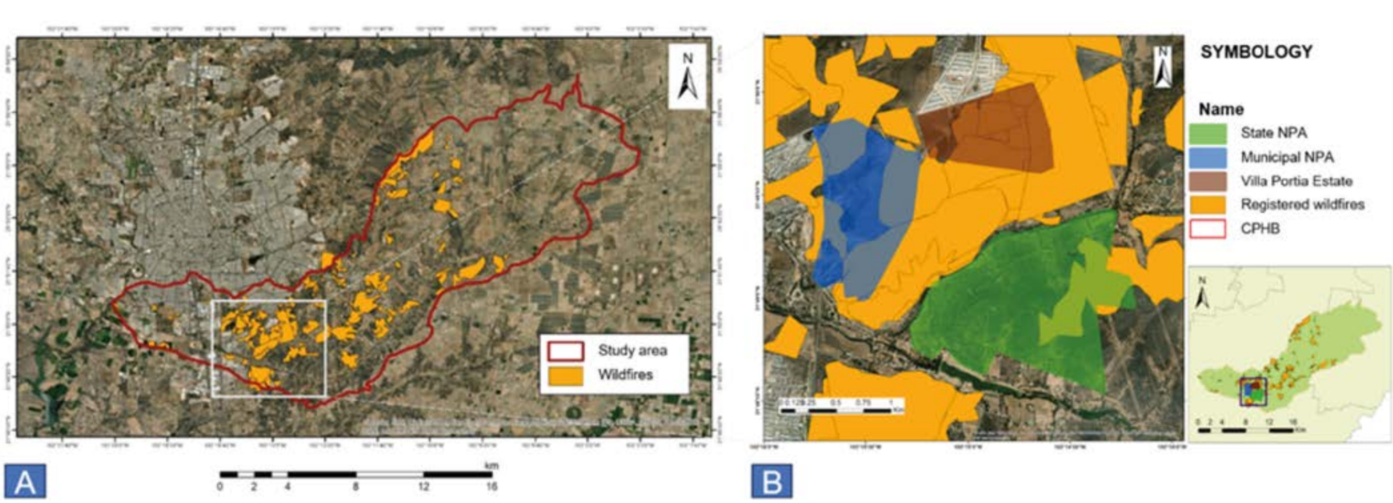

Figure 6. Map of identified wildfires in CPHB: general overview (A) and zoomed in view with polygons of interest (B).

In addition, as shown in Figure 6B, several events were registered close to the state Natural Protected Area (NPA) and especially, the municipal NPA, which facilitated the protection of the latter (SSMAA, 2019). In spite of this, both NPAs only comprise a small portion of the CPHB and they are separated from each other, thereby evidencing the necessity of a green infrastructure that could connect them, for instance, an ecological corridor. Related to this, the polygon where the Villa Portia Estate is proposed exhibits an even greater number of wildfires, which makes it inviable for construction.

Additionally, temporal analysis of precipitation (Figures 3A and 3B) shows that this parameter has been increasing over time, both annually and in the dry season, when almost all the events are recorded. Similarly, maximum temperature (Figure 3C) also exhibits an upward trend over time. The selection of this parameter, rather than mean monthly temperature, is justified by the fact that fires are enhanced by extreme climatic phenomena. This means that, even if temperature increase could favour the occurrence of fires in the last years, precipitation would act in the opposite sense, inhibiting this type of events. Therefore, climatic factors do not seem to have a clear correlation with respect to wildfires. Instead, this supports the hypothesis that wildfires have an anthropogenic origin, which coincides with the analysis presented in Figure 5.

The former hypothesis is corroborated while analysing the geographical centres of wildfires per year (Figure 7), where it can be appreciated that these are located close to the city centre of Aguascalientes or even inside it in 2016. This agrees with the findings by Pérez-Verdín *et al.* (2013), who detected that the mean centre of wildfires in the state of Durango got closer and closer to its capital. Temporally, it must be underlined that, since 2017, wildfires are moving further and further west (except for 2019), that is to say, towards the urban area of Aguascalientes, staying just a few metres away from the location proposed for the Villa Portia Estate in 2021. This evidences the great pressure that this zone is

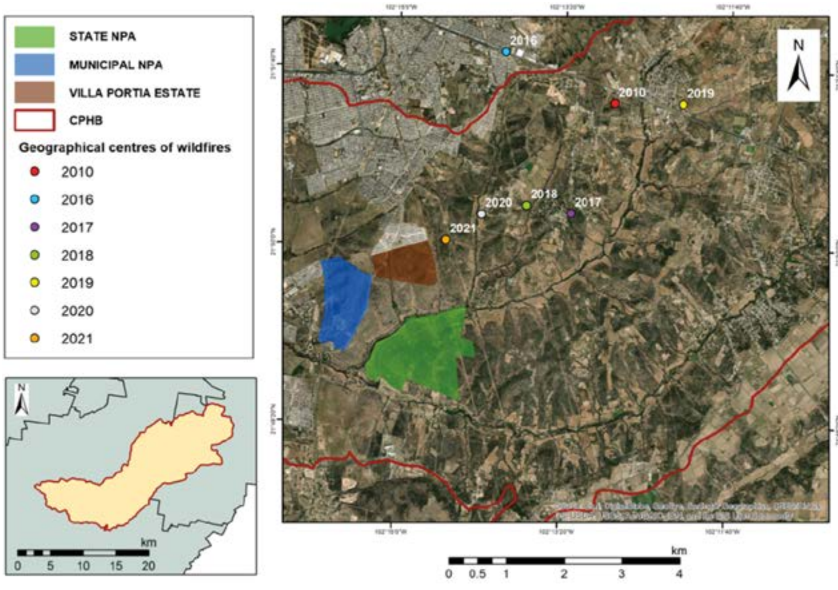

Figure 7. Mean centre of wildfires occurred in the CPHB per year.

currently suffering from urban expansion, with recent real estate complexes being built in the area, like Lunaria (SSMAA, 2019). Moreover, since the area is located at the wildland-urban interface, wildfires can suppose an alarming risk for its inhabitants (Vaiciulyte *et al.*, 2023).

Consequently, it can be stated that the CPHB is severely threatened by fire, primarily of anthropogenic origin, which is why it is necessary to monitor, through GIS, the occurrence of fires in this zone. This material would provide useful tools for decision-makers, which would help real estate management and the protection of natural and cultural resources at the CPHB.

For that, visitor control and surveillance of the area should be intensified, so as to avoid these events in a valuable area that is still undergoing intense vandalism (M. Vázquez, personal communication, 10^{th} of September 2024). In addition, with ongoing climate change, drought events are expected to be more and more recurrent and prolonged in the future (IPCC, 2023).

In this situation, it is noteworthy that the basin acts as an area of aquifer recharge and drinkable water supply for the city, so the occurrence of human-induced fires and the construction of real estate complexes would negatively impact water quality and quantity, putting water security of the inhabitants of Aguascalientes at risk (SSMAA, 2019). Again, this highlights the urgent necessity to protect this space.

To do that, studies about physical and chemical soil properties in the area are projected, which would permit the identification of optimal areas for the installation of permanent water bodies. These would guarantee the quality of water, as well as the survival of sensitive organisms like amphibians and reptiles, such as the mountain tree frog (*Dryophytes eximius*), mud turtles (*Kinosternon* sp.) or the western black-tailed rattlesnake (*Crotalus molossus*). Simultaneously, these protected areas would function as ecological corridors between the state and municipal NPAs, acting as conservation and genetic exchange zones and being subject to protection figures that would effectively regulate the activities that could potentially threaten them.

CONCLUSIONS

The Cobos-Parga Hydrographic Basin presents multiple wildfires during the 2010-2021 period, affecting state and municipal NPAs, as well as the area proposed for the Villa Portia Estate, which makes it inviable for the construction of real estate complexes. On the other hand, since climate does not exhibit a clear correlation with wildfire occurrence, these are of anthropogenic origin, with threats such as vandalisation or urban expansion, which evidences the necessity of environmental education and protection of the zone. The results of the present study can support decision-making that guarantees the correct functioning and sustainable exploitation, through protection figures, of the precious natural resources and ecosystem services offered by the CPHB.

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Table A1. Cronología de incendios forestales ocurridos en el área de estudio, todos de tipo superficial. Modificado de CONAFOR (2023).

DATE	CAUSE	BURNED AREA (Ha)
22/04/2010	Unknown	2.50
11/01/2016	Intentional	1.24
22/01/2016	Negligence	31.72
04/03/2016	Intentional	24.11
06/03/2016	Others	6.80
30/03/2016	Others	97.38
18/02/2017	Intentional	15.00
02/03/2017	Intentional	8.00
03/03/2017	Intentional	4.57
04/03/2017	Unknown	51.40
23/03/2017	Intentional	11.14
02/04/2017	Intentional	33.00
18/04/2017	Negligence	92.14
06/03/2018	Intentional	2.29
06/03/2018	Intentional	8.32
09/03/2018	Intentional	3.79
19/03/2018	Negligence	21.01
21/03/2018	Intentional	21.46
22/03/2018	Intentional	2.59
22/03/2018	Intentional	6.14
03/04/2018	Intentional	12.91
09/04/2018	Intentional	9.57
16/04/2018	Intentional	72.53
26/01/2019	Unknown	35.39
26/01/2019	Unknown	1.47
02/02/2019	Intentional	8.24
03/02/2019	Unknown	2.96
19/02/2019	Intentional	29.42
07/03/2019	Negligence	80.65
10/03/2019	Intentional	48.27
11/04/2019	Intentional	238.40
01/05/2019	Intentional	44.71
06/05/2019	Unknown	31.18
11/05/2019	Controlled	39.86
13/05/2019	Unknown	218.43
24/03/2020	Intentional	12.44
25/03/2020	Controlled	1.67
21/04/2020	Controlled	3.03
19/05/2020	Intentional	20.26
24/05/2020	Intentional	14.14
04/01/2021	Intentional	1.16
13/03/2021	Intentional	5.37
16/03/2021	Intentional	159.49
17/03/2021	Intentional	8.75
18/04/2021	Intentional	4.15