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RESEARCH ARTICLE
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Temporal and Spatial *Trends* of Forest Fires in Algeria (1985–2023)

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ABSTRACT

Algeria is highly affected by forest fires, between 1985 and 2023, 1,408,547ha were recorded, caused by 76,427fires. Given the magnitude of the forest fires, analysis of fire reports and risk mapping are essential to understanding this natural disaster. This study investigates temporal and spatial trends in forest fire activity in Algeria over 39 years, using a combination of statistical and spatial analysis methods, aiming to identify trends in fire frequency and burned area, and to locate high-risk zones. The Mann-Kendall, non-parametric test, was applied to time-series data to assess monotonic trends in three variables: annual number of fires, total area burned, and average area burned per fire. The statistical analysis revealed a significant increase in fire frequency, with Kendall's Tau = 0.405 and an average rise of 44 fires annually, but no significant trends in total area burned or average area per fire, indicating stable fire extent despite increased frequency. The provinces: Alger, Boumerdes, Tizi Ouzou, Bejaïa, Constantine, Jijel and Tipaza have the highest priority for forest fire prevention and management due to their exceptionally high fire risk. These findings underscore the need for enhanced prevention strategies, including early detection and fuel management in Algeria's fire-prone ecosystems.

Keywords: Forest fire, Trends, Statistical analysis, Map risk, Algeria.

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INTRODUCTION

Forest fires occur hundreds of thousands of times worldwide (Ribeiro et al., 2024). These occurrences have serious ecological, climatic, economic, and social effects, making them a major global environmental problem. Driven by climate change, urban expansion, and increasing anthropogenic pressure on natural ecosystems, the frequency and intensity of forest fires have been rising steadily. According to Jones et al. (2024), during the 2023-2024 fire season, 3.9×106km^2 burned globally. Fire carbon (C) emissions were 16% above average, totaling 2.4Pg C. Notable events included record-breaking fire extent and emissions in Canada, the largest recorded wildfire in the European Union (Greece), drought-driven fires in western Amazonia and northern parts of South America, and deadly fires in Hawaii (100deaths) and Chile (131deaths).

In the Mediterranean basin, Forest fires are an integral part of the Mediterranean ecosystem (Adeyeri et al., 2024; Kirschner et al., 2024; Soulis et al., 2025). For several decades, thousands of hectares in northern Algeria have been highly vulnerable and vulnerable to this scourge (Bentchakal et al., 2022). Heatwaves, which are prolonged periods of exceptionally high temperatures, are one of the most prominent examples of such events, as they have become more frequent and intense due to climate change (Reddy et al., 2021; Adeyeri et al., 2022). There has been an increase in forest fire incidents over the five decades reflecting a broader pattern of heightened fire activity in uninhabited regions (Adaktylou et al., 2020). Although the scientific literature has produced a considerable amount of knowledge dealing with forest fires of the northern rim of the Mediterranean Basin (Cardil et al., 2019; Turco et al., 2019), issues related to these blazes in the southern part have largely been ignored (Belhadj-Khedher et al., 2018).

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In Algeria, a North African country along the Mediterranean basin, forest fires are the leading cause of forest degradation and have a significant impact on the environment and local economy (El Bouhissi et al., 2020). In general, it can be said that since independence (1962), and more particularly in the last decades, the achievements in forest management have been very significant. However, the risk is still present and the means are still insufficient (Benbakkar et al., 2024). This becomes an issue for a country highly threatened by desertification, with a very low rate of forestation, estimated at 1.76%. Recently, the study of Oubadi & Faci (2025) call attention to a significant increase in the frequency, intensity, and duration of heatwaves in Algeria over recent decades, exacerbating the situation. In 2022, major forest fires in Algeria resulted in the deaths of 54citizens (Afra, 2022) and cost an average of 2.5billion DZD (Algerian Dinars) for 35,000ha of forests burned (17million Euro, with an exchange rate of: 01DZD= 147Euros). For the same year (2022), material damage in agriculture and homes is estimated at 1.5billion DZD (10.2million euros). From August 18 to 24, 2022, according to Directorate for the Protection of Fauna and Flora (DGF, 2022a), large fires swept the east part of the country (Province of El Taref), during this week, the services concerned recorded the largest burned area with 16,756ha, representing 62.5% of the total balance sheet for the year 2022. As stated by DGF (2022a), the report on compensation for the 2022 campaign mentions that compensation operations included the distribution of sheep, cattle, goats, empty beehives, seedlings, straw bales, motor pumps, irrigation pipes, olive seedlings, and stable repairs. Afra (2022) add that the prevention is much less costly than intervention, generally, every 01DZD spent on prevention saves 15DZD in intervention. It would be interesting for research to evaluate in detail the economic impact of current and future forest fires and the avoided costs of implementing a very proactive policy in this area, taking into account climate change in particular.

Currently, forest fire analysis relies on modern methods, such as remote sensing and geographic information systems, which allow for a proper diagnosis of the phenomenon. These technologies are widely utilized, as evidenced by numerous published studies: Curt et al., 2020; Abdelbaki et al., 2021; El-Bouhissi et al., 2022; Kaddouche & Bekdouche, 2022; Djabri et al., 2023; Benbakkar et al., 2024; Kouachi et al., 2024; Matougui & Zouidi, 2025; Slimani et al., 2025). There aren't many studies looking at Algeria's entire forest landscape-most research zooms in on specific areas or single events. This scattered approach makes it hard to build a big-picture plan for managing forest fires across the country, putting forest conservation and ecosystem resilience at risk. In this context, this study aims at a spatial and temporal analysis of forest fires in Algeria over 39 years (1985-2023), identifying high-risk areas based on fire statistics will help prioritize preventive measures and fire-fighting resources, providing valuable decision-making support for forest fire management. By analyzing this data, we hope to contribute in improving the policies for managing and preventing these incidents.

MATERIALS & METHODS

Study Area

The study area, is the northern part of Algeria, covers 40 provinces which is equal to 421,273km^2 (Latitude: 34°N to 37°N, longitude: -2°E to 9°E), with a coastline stretching along a length of 1,355km (Fig. 1).

Northern Algeria has environmental and anthropogenic features acknowledged as conducive to high fire activity around the Mediterranean Basin (Pausas & Fernandez-Munoz, 2012). This region has also high biodiversity and a very high conservation value. It regroups many protected areas and the richest forest heritage in Algeria with 122,500ha of forests of Cork oak (*Quercus suber L.*), Zen oak (*Quercus canariensis*), Green oak (*Quercus ilex*), Aleppo pine (*Pinus halepensis*), and Cedar (*Cedrus atlantica*). This is also a hotspot for animal biodiversity harboring several biosphere reserves (WWF, 2001).

Fig. 1: Geographical location of study area.

Data Used

The Directorate General for Forestry (DGF) collects, assembles, processes and provides official data derived from local files collected (provinces). The data in the form of annual fire reports, containing area burned (ha), number of fires, date and time of detection and extinction, legal nature of the burned areas and the type of vegetation affected.... These data are stored in the form of annual tables, constituting the official dataset used for government reports. Fire statistics provided by the DGF, over a period of 39 years (1985-2023), for the 40 provinces studied, allowed us to make a good summary of forest fires in Algeria, both temporally and spatially.

Methodology

The forest fire risk mapping in Algeria relies on a detailed look at fire incidents over 39years, specifically across the 40 forested provinces in the northern region. The key steps of the procedure are illustrated in Fig. 2. This involved combining both temporal and spatial analyses: For the temporal analysis, we focused on observing fire trends. Over a given period, according to Meddour-Sahar (2008), the study of the forest fire phenomenon is characterized by three parameters:

- Fire outbreaks (number of fires);
- Area burned;
- Average area burned (Area burned/Number of fires).

These observations were statistically validated using the Mann-Kendall test, performed in Google Colab, (https://colab.research.google.com/) which helped us to confirm significant shifts in how often fires occurred over the years. Meanwhile, the spatial analysis was meticulously put together using Geographic Information Systems (GIS), primarily with QGIS software (open access). This allowed us to really dig into the spatial patterns and distribution of fire risk across the region, making it easy to see where the danger spots are. This evaluation relies on three key indicators: The Medium Risk Annual "MRA", the Frequency Risk Index "FRI" and the Average Area per Fire "AAF". Each of these indices tells a different part of the fire's story: MRA gives us an idea of fire severity, it tells us what proportion of the forest burns on average each year, which reflects the area's overall vulnerability. To understand fire frequency, we use the FRI, which shows us where and how often fires ignite, which is essential for pinpointing the "hottest" areas. AAF indicates the typical size of individual fires once they have started, which is crucial for understanding their spread potential. This choice is rooted in the necessity to capture a multifaceted understanding of wildfire dynamics, going beyond mere statistics. We move beyond isolated statistics to see how the frequency, severity, and magnitude of fires interweave within a given context. And because all these indices are based on historical data, they perfectly reflect the past trajectory of fires in the region, which is fundamental for accurately assessing risk today. The thresholds for the index classes are established by authoritative sources.

Our methodology aligns with numerous scientific studies that have similarly utilized one or all three of these indices for robust fire risk assessment (FAO, 2020; Sahar & Meddour, 2020; Tir, 2022).

Medium Risk Annual or Degree of Severity

MRA is expressed as a percentage of the forested area burned annually on average in relation to the total forest area of the solid considered (De Montgolfier, 1989). This risk is calculated by the formula (1):

$$MRA = ADM * 100 / TAFA \quad (1)$$

With:

ADM: Average Area burned per year (ha);

TAFA: Total area of the forest area (ha).

Table 1 explains the degree of risk of the RMA index classes.

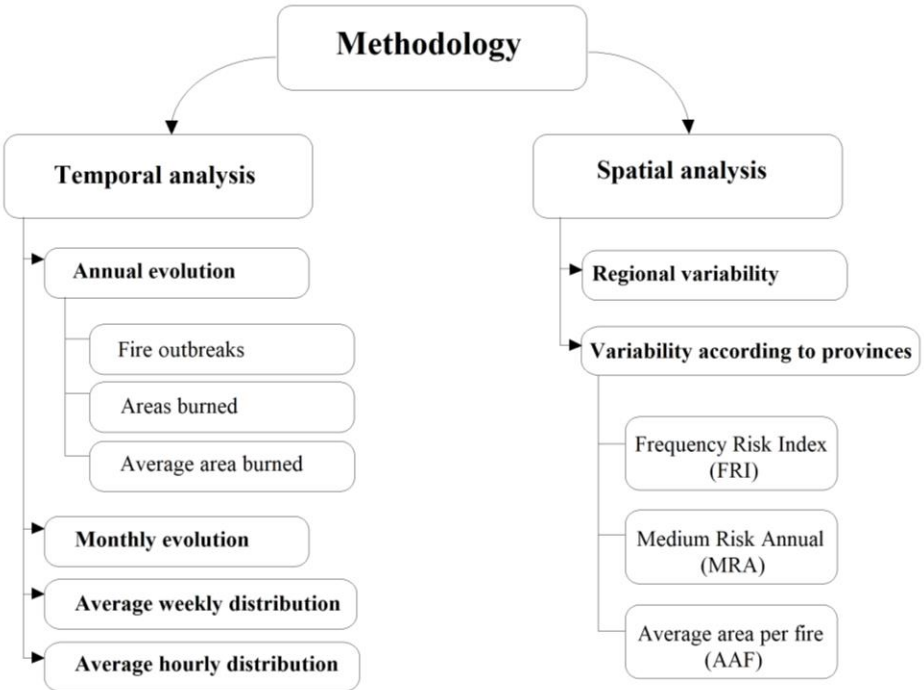

Fig. 2: Organizational chart of the key steps.

Table 1: Medium Risk Annual classes

Degrees of risk	MRA (%)	Average time between 02 fires (years)
Extremely low	< 0.25	> 400
Very low	0.25-0.5	200-400
Low	0.5-01	100-200
Average	01-02	50-100
High	02-04	25-50
Very high	04-08	12-25
Exceptionally high	> 08	< 12

Source: De Montgolfier (1989)

Frequency Risk Index

According to Velez (1999), in the current system for the determination of danger, the fire risk is defined as "the frequency the more likely of fires in a given territory, in a year," usually used in statistics (2, 3). It is determined as a function of the number of fires that are listed during a given observation period.

The formula of the FRI is:

$$FRI = Fi / AFM \quad (2)$$

With:

Fi: annual Frequency of fires (Fi = ∑ ni/a);

AFM: Areas of the forest massif (ha).

Table 2 illustrates the risk levels of IRF classes.

Annual frequency of fires Fi:

$$Fi = \sum n_i / a \quad (3)$$

With:

n_i: Number of fires;

a: Number of years.

Table 2: Frequency Risk Index classes

Degrees of risk	FRI (fire/year/ha)
Very low	≤ 01
Low	01-02
Average	02-05
High	05-10
Very high	10-20
Extremely high	> 20

Source: Velez (1999), scale modified by Meddour-Sahar (2008)

Average Area Per Fire

Average area per fire refers to the average surface area burned per fire event (unit: ha/fire), it is calculated as follows (4):

$$AAF = TAB / TNF \quad (4)$$

With:

TAB: Total area burned;

TNF: Total number of fire outbreaks.

RESULTS AND DISCUSSION

Annual Evolution of Forest Fires in Algeria between 1985 and 2023

Based on data from DGF, a more contextualized examination of the current situation reveals that 1,408,547ha of forest regions have been devastated by 76,427fires overall between 1985 and 2023. This analysis spans the last 39years, leading to an average of 1960fires and 36,117ha/year.

Annual Evolution of Fire Outbreaks in Algeria

The number of fires varied between 1985 and 2023, with the lowest being 595fires in 1989 and the highest being 5110fires in 2012 (Fig. 3). Over this period, there is an overall upward trend, with 19years surpassing the annual average (1992, 1993, 1994, 1999, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2019 and 2020), which has a value of 1960. For this parameter, our results highlight a statistically significant increasing trend (P=0.00030, which is well below the significance threshold of α=0.05). The z-value of 3.618 and a Kendall's Tau of 0.405 (indicates a moderately positive correlation) confirm this increase. More precisely, the Sen's Slope of 44.13fires/year indicates that, on average, the number of fires in Algeria has been going up by about 44 more fires each year, an important sign of increasing strain on forest ecosystems.

It is noteworthy that globally, since 1960, there has been a consistent upward trend in both the number of fires and the affected area (San-Miguel-Ayanz et al*.,* 2024). It is relevant to analyze the trends across the Mediterranean basin. According to the same author, between 1960 and 2023, Morocco has an average of 307 fires per year, which, although lower, fits into a context where countries on the southern shore of the Mediterranean manage fire frequencies that differ from those on the northern shore. For Tunisia, based on the available data, Belhadj-Khedher et al. (2018) note no significant trend in the number of fires was detected for the period 1985–2010. Indeed, the northern shore of the Mediterranean presents a distinct dynamic. The trend for the five countries: Portugal, Spain, France, Italy, and Greece, moved from an increase in the 1990s to a period of stability over the following decade, followed by a general decrease in the last decade, which can be interpreted as a sign of progress made in fire prevention and suppression on a global scale (San-Miguel-Ayanz et al*.,* 2024).

Annual Evolution of the Areas Burned in Algeria

The area burned represents the area affected by fire, it is a value measured on-site (unit: ha).

The extent of forest burnt area varies annually between 1985 and 2023 (Fig. 3), with a minimum of 2,312ha in 2018. In 1994, Algeria recorded the highest burned forest area in the nation's history, with 271,598ha devastated by the fires. Belkaid (2016), however, argues that while the period's climate conditions are undoubtedly a contributing or exacerbating element, they are not the primary cause of this rise and can't fully explain the phenomenon. In addition, there were the political upheavals that occurred in the nation at the start of the 1990s, which partially account for the large forest fires.

Following 1994, the most significant years with 100,101ha and 99,061ha of recorded burnt area were 2021 and 2012, respectively. In this period, eleven years exceed the annual average which is 36,117ha (1993, 1994, 1999, 2000, 2007, 2012, 2014, 2017, 2020, 2021 and 2023). The general trend in the annual burned area is relatively stable.

This parameter shows no statistically significant trend (P=0.1679, which is above α=0.05). Although a weak positive trend is suggested by Kendall's Tau (0.155) and Sen's Slope (360.11ha/year), this variation is not significant enough to be considered statistically relevant in the long term. This suggests that even while the frequency of fires has increased, suppression efforts or other factors have not yet led to a significant increase in the total area impacted annually.

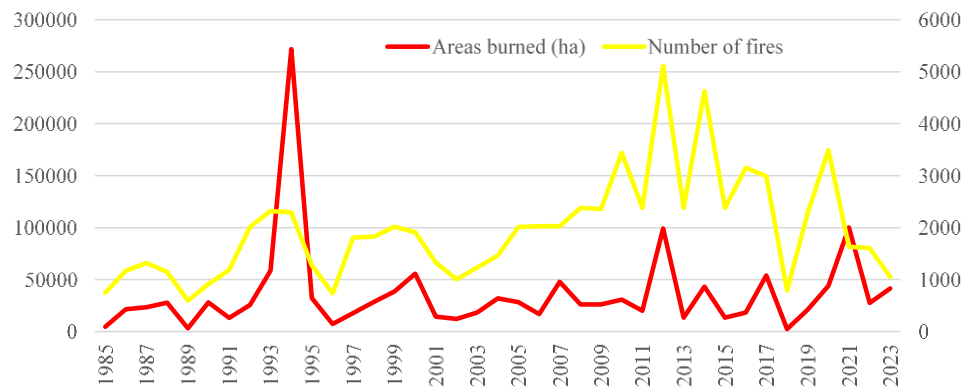

Fig. 3: Annual evolution of fire outbreaks and burned areas in Algeria "1985-2023"

The analysis of burnt area reveals crucial differences and commonalities. The absence of a statistically significant trend in Algeria, which is characterized by relative stability, is consistent with the results of Belhadj-Khedher et al. (2018) for Tunisia, for the period "1985-2010". Morocco, with an annual average of 3,383ha affected, confirms a fire regime where the burnt area remains globally contained, despite peaks such as that of 2022 (22,762ha). However, this stability contrasts with the much more pronounced and volatile patterns observed on the northern shore. In countries like Portugal, Spain, France, Italy, and Greece, the burnt area varies considerably from year to year, which underscores the decisive influence of seasonal meteorological conditions. In 2023, according to San-Miguel-Ayanz et al. (2024) the total burnt area for these five countries reached 354,244ha, with a particularly marked intensification in Greece, which recorded 136,499ha burnt, the highest figure since 2007. This volatility of the Northern Mediterranean resonates with Algeria's vulnerability to extreme fire years, as evidenced by the major events of 1994 (271,598ha) and 2021 (100,101ha). These peaks of destruction demonstrate that Algeria is just as exposed as countries such as Spain, Italy, or Greece to large-scale, highly destructive fires, a phenomenon that has become more pronounced throughout the region in recent years.

Annual Evolution of the Average Areas Burned Per Fire Event in Algeria

The average area burnt in Algeria over "1985-2023" ranges from 2.9ha in 2018 to 118.5ha in 1994 (Fig. 4). The national average is 18.43ha/fire. The year 1994 recorded the highest area burned by fire, this value is the result of a largest loss in area during the entire period analyzed, which is 271,598ha caused by 2,292fires, while for the year 2018; 2312ha were affected by 793fires only.

No statistically significant trend concerning the average area burned per fire ($P=0.2218$, above $\alpha=0.05$). With Kendall's Tau of −0.138 and Sen's Slope of −0.172 ha/fire/year, the data suggest a weak negative tendency. However, this average decrease per event is not statistically proven, while fires are more frequent, their containment capacity or nature have not resulted in individually larger or smaller fires in a statistically significant way over the study period.

The analysis of the average fire size in Europe provides additional insight. According to San-Miguel-Ayanz et al. (2024), a notable difference is observed before and after the 1990s, with a trend toward a reduction in average fire size. This progression is often attributed to improvements in fire protection and suppression services. Nevertheless, some recent years have recorded average fire sizes comparable to the figures of the 1980s. In 2023, the average fire size was 15.3ha, a figure similar to the previous two years, but above the mean for the last two decades. For Greece, in particular, the average fire size reached a record level, which largely explains the country's exceptional burnt area that year. This evolution suggests that, while prevention efforts may be effective in reducing the number of fires, the presence of extreme meteorological conditions can favor the ignition and spread of large-scale fires, severely testing suppression systems.

To minimize this parameter, which remains quite high (fire spreads quickly), significant work must be put into strengthening the first intervention, without even discussing the success of the struggle. According to DGF (2023b), as part of its strategy for preparing the 2023 forest fire campaign, the DGF reports a "2022-2025 Emergency Plan" with the objective of improving the prevention and fight against forest fires for a total budget of 18.428billion DZD (approximately 125.8million Euros). The actions that could be financed, depending on the commitments of the 2023-2025 finance laws, are: (i) Rehabilitation of burned forests for 9.524billion DZD (64.8million Euros); (ii) Carrying out studies on the development of forests and priority forest areas for 1.982billion DZD (13.5million Euros), 26 priority forest areas with an area of 896,700ha including 19 Aleppo pine forests over an area of 698,700ha and 7 cork oak forests over an area of 198,000ha falling within 18 provinces; (iii) Digitization to support forest fire risk management for 2.149billion DZD (14.6million Euros); (iv) Supply and installation of digital radio equipment and maintenance for 1.771billion DZD (12million Euros) and (v) Strengthening by human resources for surveillance and intervention against forest fires.

Monthly Evolution of Forest Fires in Algeria between 1985 and 2022

In Algeria, the fire season spans 5 months, from the first of June to the end of October every year, as per the reports from DGF. Analyzing the monthly national forest fire balance sheet for the period from 1985 to 2022 (refer to Table 3) reveals the following observations:

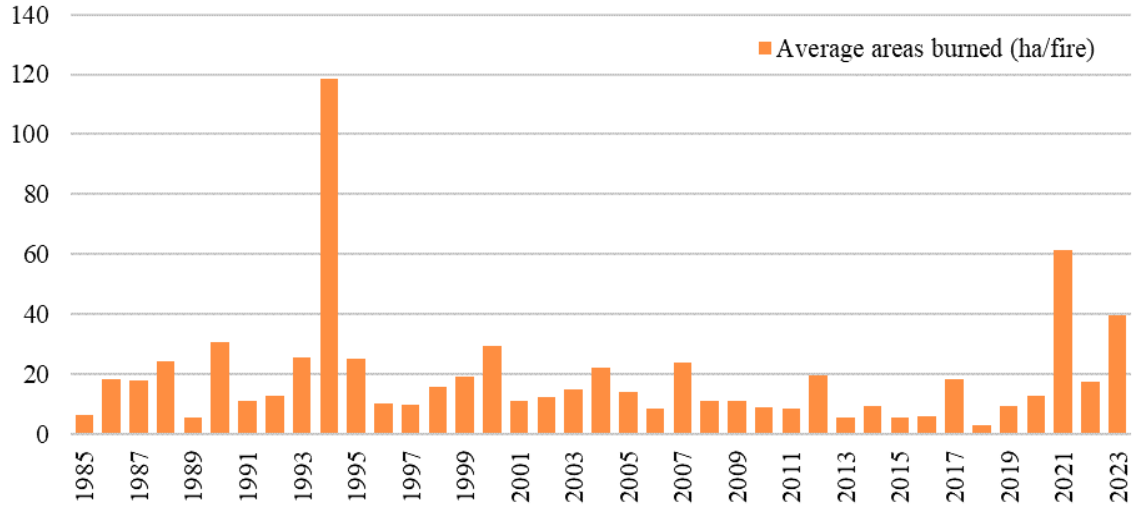

Fig. 4: Annual evolution of the average areas covered by fire in Algeria "1985-2023"

Table 3: Monthly distribution of the fire outbreaks and the areas burned (1985- 2022)

Parameters	Months				
	June	July	August	September	October
Number of fires (%)	07.66	26.39	40.94	18.04	07.04
Burned area (%)	03.99	24.69	57.03	10.79	03.51
Average area burned (%)	09.35	16.79	25.00	10.73	08.94

Source: DGF data source

(i) August, the summer month in Algeria, has received the largest number of fires (40.94%) and the largest burnt area (54.03%). This high toll for the month of August is the consequence, at least in large part, of climatic conditions very favorable to the occurrence and spread of fires, i.e. 25ha per fire on average. Prolonged and cumulative drought, frequent sirocco and drying, add to that the massive influx of vacationers, the frequent travel on the roads and the large number of negligence (PNGIF, 2021).
(ii) July accounts for 26.39% of total fires, and 24.69% of all area lost, during a 38-year period (1985-2022), with an average fire area of 16.79ha.
(iii) September corresponds, beginning with the first rains, with field preparation for planting, which is done using fire (eco-burning). Even now, Algerians adhere to this historic practice (PNGIF, 2021). The significance of the number of fires (18.04%) and burnt surfaces (10.79%) during this month can be explained by carelessness during these agricultural tasks (Meddour-Sahar, 2008).
(iv) Furthermore, fires are not uncommon in October, autumn rains make the climate milder, the vegetation wetter and reduce the risk of forest fires. However, in recent years, these showers have become increasingly late. In any event, the fires in October (07.04% in number) are predominantly arson fires started in the bushy grounds to renew the courses (pastoral fires), which are subsequently accidentally transferred to the next forest (with an average fire of 08.94ha).
(v) Finally, the month of June witness a number of fires (07.66% of the total), with a burnt area of 03.99%. This is the month with the fewest fires after September, owing to the fact that the cumulative effect of the drought has not yet taken hold and that human influence is minimal, as this month coincides with a non-holiday time (PNGIF, 2021).

Average Weekly Distribution of Forest Fires

There is no particular day of the week that is more likely for fire to occur, the frequency of fires is fairly consistent across all days, ranging between 13 and 14%. Therefore, the hypothesis "fires broke out more frequently on weekend" is not verified for Algeria during the period 1985-2010 (PNGIF, 2021).

Average Hourly Distribution of Forest Fires

The hourly distribution of fire frequency reveals significant variance (Table 4). It focuses on the time span of 10a.m to 18p.m, accounting for about 77.75% of the total. The maximum is achieved between 12 and 16p.m, with a total of 31,909fires, or 47.85% (PNGIF, 2021). This corresponds to the highest insolation and warmest times of the day. The night time shifts of 10 hours, ranging from 20p.m to 06a.m, have a low proportion of fires, at 8.16% (PNGIF, 2021). These fires, which were reported at night, under fairly harsh climatic conditions, are typically of purposeful origin. This large nychthemeral difference in fire frequency between day and night is attributed to plants' higher flammability and low water content, resulting in the evaporation of nocturnal dew (Susmel, 1974).

Spatial Variability of Forest Fires

Regional Variability

Forest fires have happened and continue to burn throughout Algeria's northern area. They did, however, concentrate far more on areas with high rates of forest cover, such as the country's east (Madaoui, 2013). According to the same source, the areas burnt in Algeria have a strong correlation with the pace of afforestation. The provinces with a high rate of forest cover experience the most fires. Overcoming this issue has become an important requirement of forest management in order to limit and reduce resource degradation and extend faunistic and floristic life. As a result, forest fires, due to their spatial and temporal characteristics, necessarily require the use of techniques and tools that can collect and process spatial data sources. GIS and remote sensing appear to be the most effective tools for resolving multi-decisional spatial problems (Fekir et al., 2022).

The areas burned during the period of 1985-2023 are classified by region as follows: The North-East region is in first position with 702,442.39ha (49.87%) of affected areas. The North-Central region is in second position with 450,171.62ha, or 31.96%. The least affected region is the North-West, with 255,932.99ha, which accounts for 18.17% (Fig. 5).

The classification by region according to the number of fires (Fig. 6) does not obey the same logic as that of the burned areas covered: The North-Central region of the country comes in first place with 34,698fires, either 45.40% of the total, the North-East region in second position, with 29,975fires (39.22%) and the North-West region in last place, with 11,754fires (15.37%).

Table 4: Evolution of the hourly frequency of the fire outbreaks (1985-2018)

Time slot	00-06h	06-10h	10-12h	12-16h	16-18h	18-20h	20-24h
Number of fire (fire)	2,176	4,774	10,224	31,909	9,718	4,619	3,270
Number of fires (%)	03.26	07.16	15.33	47.85	14.57	06.93	04.65
Risk	Low	Medium	High	Very high	High	Medium	Low

Source : PNGIF (2021).

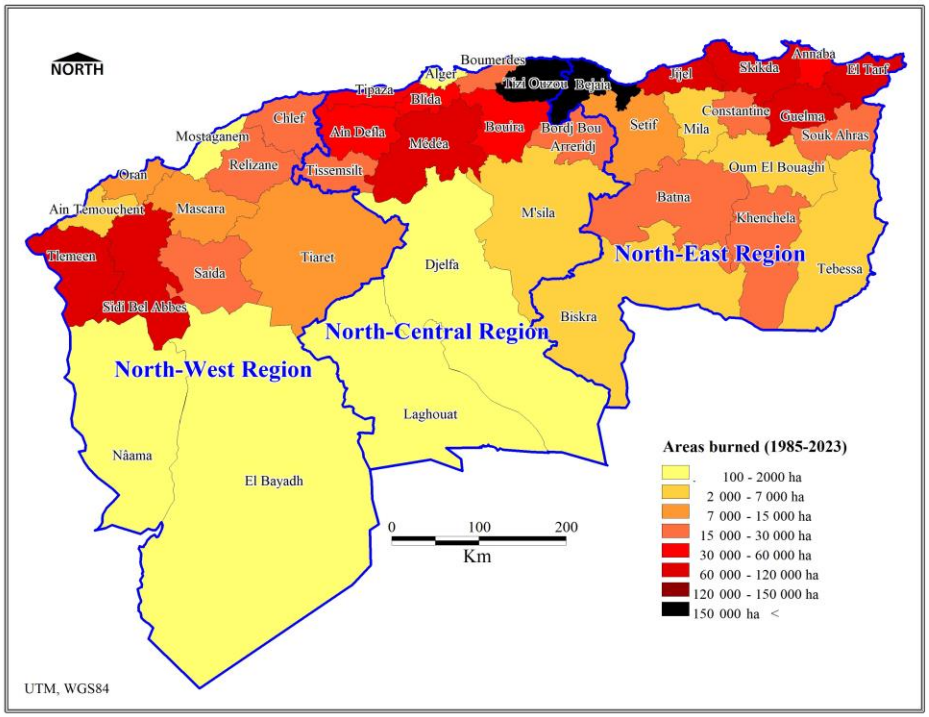

Fig. 5: Distribution of forest areas burned by region in Algeria "1985-2023".

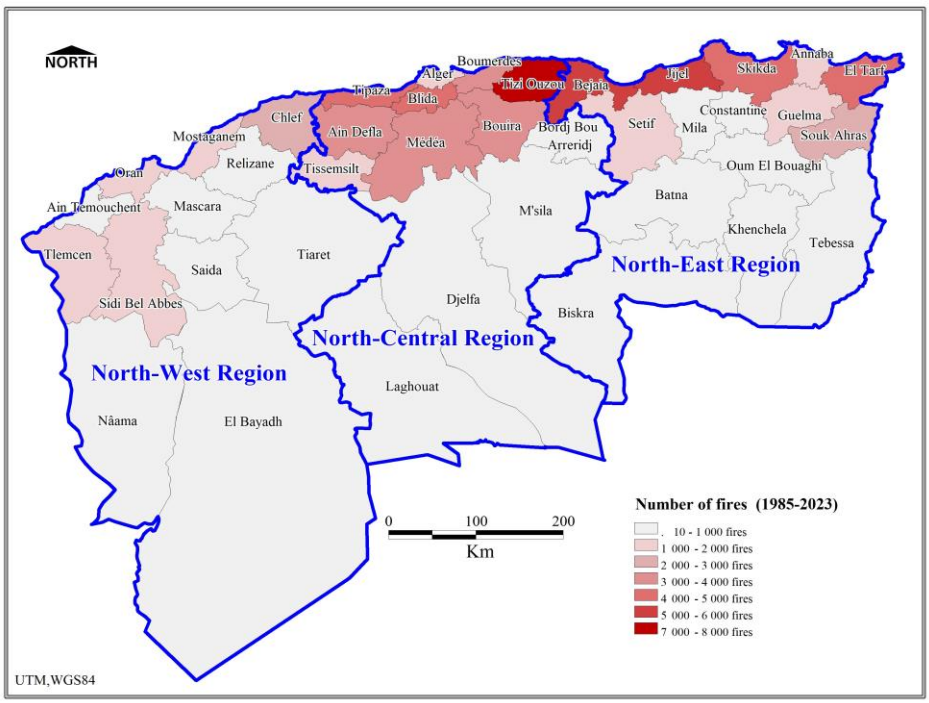

Fig. 6: Distribution of fire numbers by region in Algeria "1985-2023".

In the North-Central region, the high number of fires can be explained mainly by a higher population density of "370inhabitants/km^{2}", compared to 170inhabitants/km^{2} for the North-East and 16 inhabitants/km^{2} for the North-West (PNGIF, 2021).

The average area burned by fire is 23.43ha for the region North-West, 21.77ha for the region North-East and 12.97ha in the North-central region. The high average area burnt in the North-West region might be attributed to several variables, including the slowness of the intervention owing to the road network's inadequacy, the nature of the difficult terrain, and the remoteness of intervention centers' forest regions.

Variability According to Provinces

The analysis of burned forest areas reveals significant variations among Algeria's 40 forest provinces. This section examines the differences in burned areas for each province during the fire season. From 1985 to 2023, the circumstances in provinces appear to be significantly different spatially, with some experiencing severe damage from forest fires (Fig. 7). Béjaïa has the highest area burnt among Algerian provinces, with 160,737.95ha (11.41% of the total area lost). The provinces with the next highest burned areas are: Tizi Ouzou, totaling 153,131.12ha, Skikda 106,430.77ha and El Taref with 102,730.27ha. Other significantly affected provinces include: Sidi Bel Abbès (95,035.35ha), Jijel (93,249.77ha), Guelma (64,969.09ha), Tlemcen with 61,594.23ha and Médéa totaling 60,036382.79 ha. These figures underscore the varying severity of fire impacts across different provinces and highlight the diverse challenges in forest management and fire prevention.

In terms of fire frequency (Fig. 8), over a 39-year period (1985-2023), Tizi Ouzou led the list with 7,054fires, more than 181fires per year on average, followed by Bejaïa with 5,378fires (138fires/year) and Jijel with 5,035fires (129fires/year). Provinces with significant fire frequency are: Blida (4,436fires); Tipaza (4206fires); El Taref (4,141fires); Skikda (4,026fires); Médea (3,908fires) and Bouira (3,634fires). Ain Defla with 3,429fires and Boumerdes had 3,175fires, are also severely impacted.

Spatially, forest fires are concentrated mainly in the coastal provinces of the North-East, from Tizi Ouzou to El Tarf, which display the highest rates of forest cover (37% to 59%) corresponding to the cork oak region. The analysis of the origin of the seriousness of the fires highlights certain specificities of this region and in particular the relationships between pastoralism and fires (PNGIF, 2021). These provinces, with significant populations of cork oaks, are strongly affected by fires forest, which can be explained by the fact that is the most loaded with livestock numbers and that anthropogenic pressure is very significant there (DGF, 2007). For example, in National Park of Kala, in a few years, the increase in numbers of cattle has been exponential, going from 15,000 to 100,000head (FOSA, 2000). These numbers show how various provinces have differing fire activity levels, which emphasizes the necessity for focused fire management techniques.

Frequency Risk Index

According to Fig. 9, from 1985 to 2023, 11 provinces, including: Bouira, Skikda, Annaba, Constantine, Médéa, Mostaganem, Oran, El Tarf, Tissemsilt, Souk Ahras, and Ain Defla, have a high risk of fire, with 5 to 10fires/year. Additionally, Chlef, Bejaïa, Blida, Tizi Ouzou, and Jijel have a very high risk, with 10 to 20fires/year. Alger, Boumerdes, and Tipaza have an extremely high risk of fire, with FRI

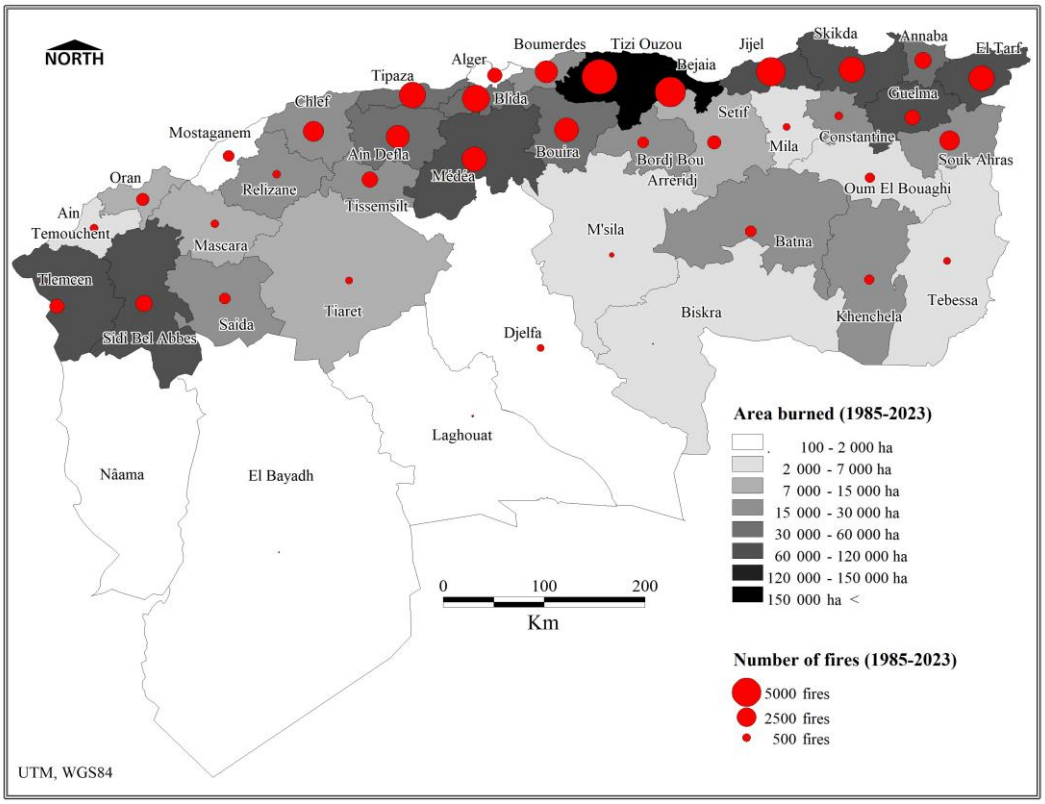

Fig. 7: Map of forest fire variability according to provinces in Algeria "1985-2023".

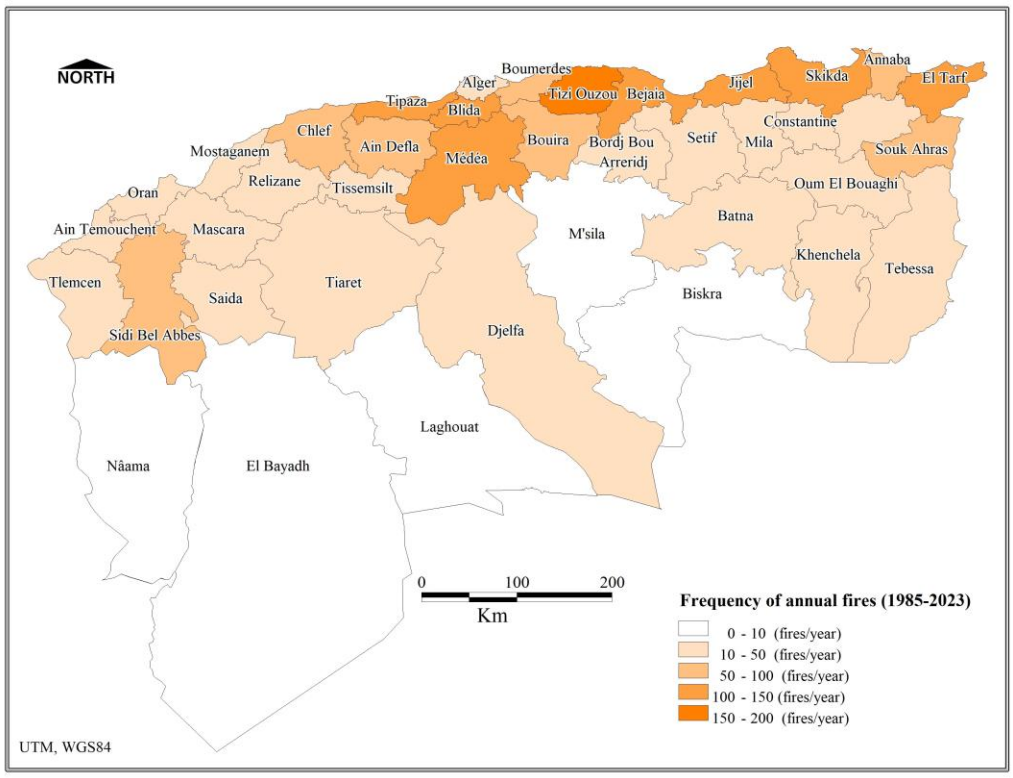

Fig. 8: Map of Frequency of annual fires according to provinces in Algeria "1985-2023".

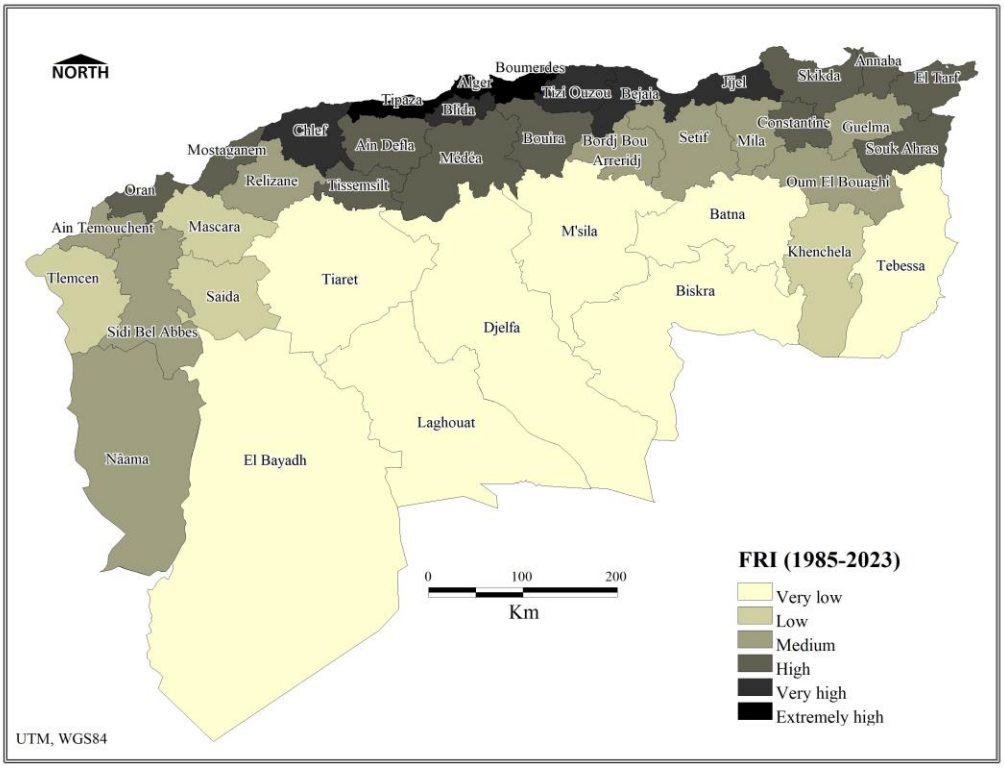

Fig. 9: Map of Frequency Risk Index (FRI) according to provinces in Algeria "1985-2023".

values: 79.3, 46.84 and 28.2fires/year, respectively. Whereas, the southern part of Algeria such as EL Bayadh, Laghouat, Djelfa, Biskra, M'sila, Batna, Tebessa have a very low forest fire risk with a low FRI value.

The provinces with high, very high, and extremely high FRI are the top priority for forest fire prevention and management. According to DGF (2023b), integrated forest fire management includes prevention efforts such as awareness campaigns, communication, and national campaigns. It also involves forecasting using special weather reports from the National Office of Meteorology, detection and early warning through a network of lookout posts and mobile forestry brigades, intervention during forest fires using the command post of the General Directorate of Civil Protection, mobile columns, mobile brigades, and aerial groups, and post-forest fire intervention including reporting, outlining by the Algerian space agency, and researching the causes and circumstances of the fires. Despite the Algerian State's significant efforts, substantial additional human and logistical resources are needed to address the scale of the problem.

Medium Risk Annual

In order to identify the Algerian provinces prone to frequent fires and prioritize intervention areas, we calculated the MRA (1985 to 2023) for the concerned 40 provinces (Fig. 10).

The results indicate that provinces with an MRA between 2% and 4% are at high risk. Specifically: Boumerdes, Tizi Ouzou, Bejaïa, Constantine, Tipaza, and Jijel have MRAs of 3.73, 3.60, 3.55, 3.17, 2.27, and 2.19%, respectively. On the other hand, the provinces of Annaba, El Tarf, Guelma, Skikda, Blida, Sidi Bel Abbes, Ain Defla, Tissemsilt, and Mostaguanem have medium risk MRAs of 1.87, 1.67, 1.65, 1.48, 1.33, 1.27, 1.17, 1.02, and 1.01%, respectively (where 1% < MRA < 2% indicates an average annual forest area burn of 1 - 2%).

Average Area per Fire

Out of 40 Northern provinces of Algeria, 18 exceed the national average of AAF, which is 18.35ha/fire (Fig. 11), indicating a slow response, or a poor command of the fight against the forest fires. The province of Biskra has the highest AAF at the national level, which is 79.95ha/fire.

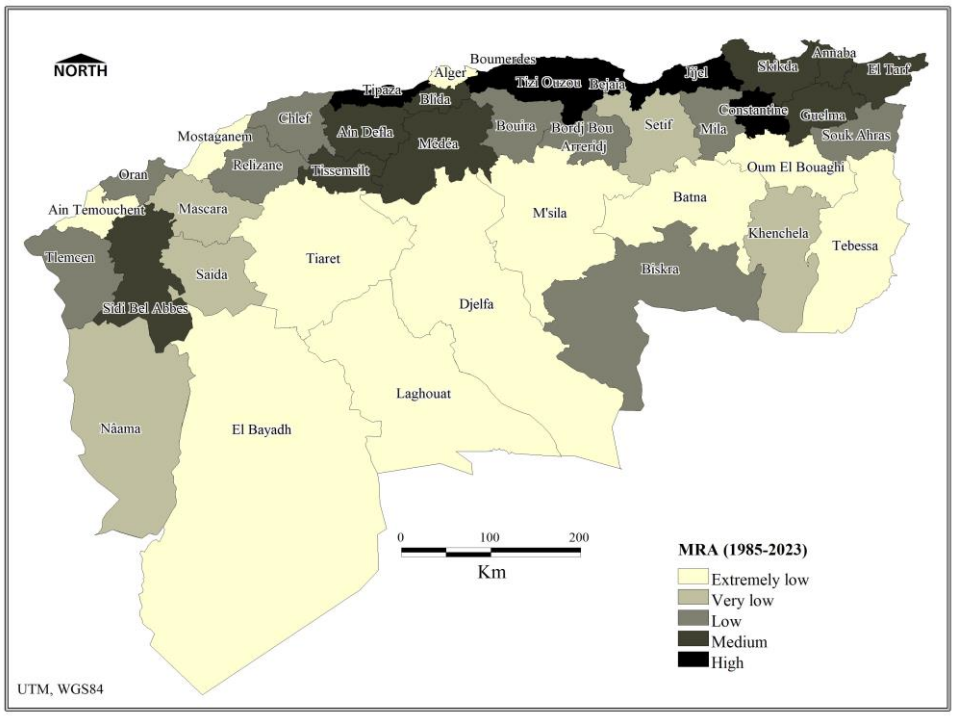

Fig. 10: Map of Medium Risk Annual (MRA) according to provinces in Algeria "1985-2023".

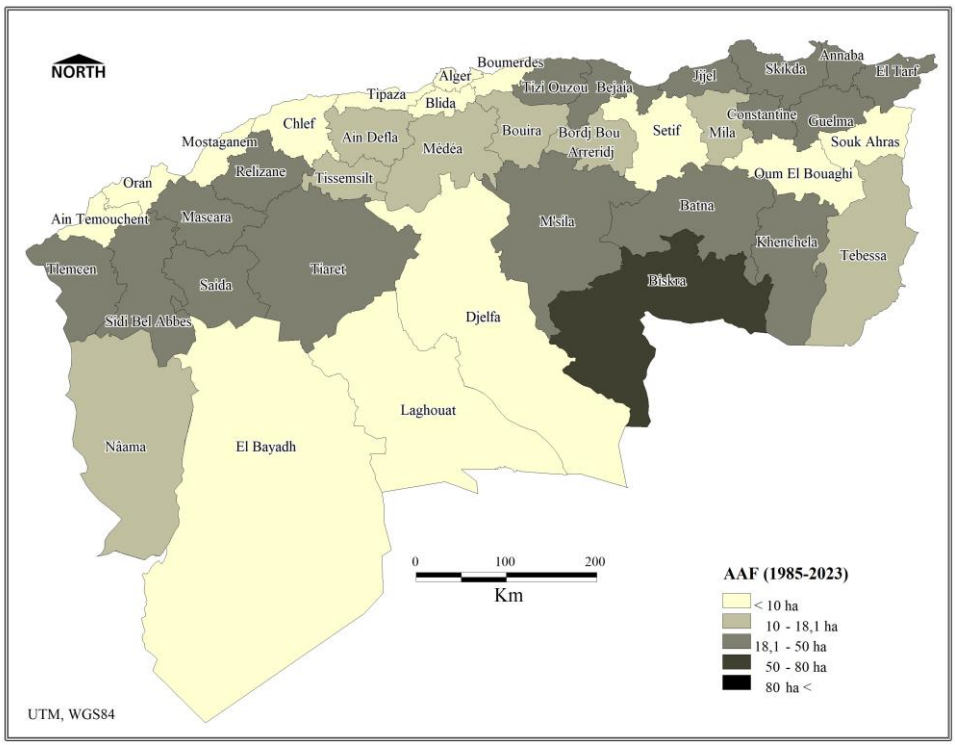

Fig. 11: Map of Average Areas by Fire "AAF" according to provinces in Algeria "1985-2023".

Following Biskra, the provinces of Sidi Bel Abbes, Constantine, Guelma, and Tlemcen have AAF of 48.05, 44.32, 40.84, and 40.21ha/fire, respectively. The remaining 11 provinces have the following AAF: Batna (31.21ha), Relizane (30.33ha), Bejaia (29.89ha), Mascara (29.13ha), Saida (27.63ha), Skikda (26.44ha), Annaba (26.38ha), El Tarf (24.81ha), Tizi Ouzou (21.71ha), Khenchela (21.30ha) and Jijel (18.52ha). In contrast, five provinces that have experienced over 2,600 fires over the past 39 years have significantly lower AAF compared to the national average. These provinces are Chlef (06.37ha), Blida (07.26ha), Boumerdes (07.97ha), Tipaza (08.03ha), Souk Ahras (09.91ha). This may indicate a greater readiness to extinguish fires in these areas.

A More Complex Problem than it Seems

The analysis of forest fire dynamics in Algeria, when considered in the context of broader Mediterranean trends, reveals that the fire regime is a complex issue shaped by an intricate web of factors. While the long-term stability of Algeria's burnt area may be misleading, it masks a growing vulnerability to extreme and destructive fire years. Understanding this phenomenon requires linking our observations to the fundamental drivers of fires: climate, landscape, and human behavior. The forest fire threat is escalating due to climate change, which acts as a powerful amplifier. Algeria, situated in a climate hotspot, is experiencing prolonged droughts and more intense heatwaves that dry out vegetation, turning it into highly flammable fuel. These extreme weather conditions are directly linked to the increased intensity of fires and the formation of big fires, as evidenced by the devastating areas burned in Algeria in 2021 and in Greece in 2023. At the same time, land-use changes, particularly rural depopulation, have caused in a significant accumulation of vegetation, creating a continuous fuel load that permits fires to spread rapidly and uncontrollably over vast areas. This accumulation of dry biomass is a shared problem on both sides of the Mediterranean, amplifying the risk. Finally, the ultimate trigger remains human activity. The vast majority of fires are human-caused, whether through negligence (uncontrolled agricultural burning, discarded cigarettes) or intentional acts. This explains why the number of fires tends to remain constant or decrease only slightly: prevention efforts are challenged by a landscape that has become far more susceptible to ignition due to a changing climate and unmanaged land.

Given this complex threat, Algeria's approach to fire management has to change from a predominantly reactive model to a proactive, holistic, and integrated approach. To this end, strategic investments in climate adaptation are crucial, starting with early detection systems such as satellite monitoring and fire-weather forecasting. Increasing the civil protection services' operational capability with modern aerial resources and continuous training is also indispensable. Furthermore, proactive land management must be implemented through policies that encourage traditional land-clearing practices and the creation of strategic firebreaks. It is also vital to integrate fire risk mapping into land-use planning to better protect communities expanding into forested areas. Finally, community engagement is a cornerstone of any effective strategy. Targeted national awareness campaigns must educate the public on the risks and legal consequences of starting fires. Meanwhile, empowering local communities with training and resources to act as first responders can be crucial in containing fires at their initial stage, transforming citizens into essential partners in environmental protection.

Analyzing the Etiology of Forest Fires

In Algeria, one of the challenges in combating forest fires is the lack of understanding about their causes, which contributes significantly to Algeria's statistics, with over 80% of the causes being unknown (Meddour-Sahar & Derrij, 2012). Official data from 2000 to 2020 indicates that 85% of reported forest fires have unknown origins. Additionally, it's estimated that 6% of forest fires are intentional and difficult to identify (DGF, 2023b). Research conducted in several provinces by (Meddour-Sahar et al., 2015; Meddour-Sahar, 2014) confirms that most forest fires are primarily caused by human activities, such as intentional pastoral fires for pasture renewal, uncontrolled landfill site incineration, changes in land use, and honey collection. Careless fires are mainly caused by cigarette butts, agricultural work (burning after clearing, stubble burning), fire rekindling, and forestry activities in the forest. These causes of forest fires have remained relatively constant over time and are closely linked to local culture and traditions (DGF, 2023b). Lightning, the only natural cause of forest fires, is rare and almost unknown in Algeria, even in mountainous regions, likely due to the scarcity of summer thunderstorms. Similarly, this is the case in Morocco, but not in Tunisia (Ben Jamâa & Abdelmoulla, 2004).

Without reliable data about the origins of forest fires, it is difficult for the sector to put in place relevant strategies for raising awareness, communicating, and integrating the social groups responsible. It is therefore necessary to refine the collection and processing of information: adoption of a standardized nomenclature of the causes of forest fires, training of field staff, systematization of research into the causes and circumstances of fires, establishment of inter-institutional units in charge, and dynamic data recording and sharing tools (DGF, 2022b, 2023a).

Study Limitations

Based on historical reports spanning several decades, our study acknowledges that the data-collection method may have varied over time, potentially affecting year-to-year consistency in the findings. Another important limitation is the absence of validation from satellite imagery. While satellite data offers a precise and objective measure, our work relies on ground-based measurements that can sometimes lack detail, particularly in hard-to-reach areas. Despite these drawbacks, our work still offers a valuable long-term picture. It's a solid starting point. The ideal for future research would be to combine this old data with modern technology to get a truly complete and accurate image of the situation.

Conclusion and Recommendations

Long-term fire history reconstructions provide fruitful information in the context of global change (Belhadj-Khedher et al., 2018). The analysis of forest fire trends reveals a significant increase in the fire outbreaks, but no clear trends in total area burned or average area per fire. These results suggest an intensification of forest fire activity, likely driven by climate change and human factors, with current fire suppression efforts effectively restricting the extent of burned areas. Further research integrating environmental and social factors will enhance understanding and guide effective policy responses. For the spatial analysis, results show that, the coastal region of northeastern Algeria, which stretches from Tizi Ouzou to El Tarf, experienced the highest extent of forest fire damage, with nearly 50% of all affected areas in Algeria. The extensive burning in the North-East not only contributes to significant ecological and economic challenges but also highlights the urgent need for enhanced fire management and preventive measures to protect this critical area.

To enhance fire management in Algeria, we should focus on a few key areas. First off, we need to lean into fire prevention by running awareness campaigns for local communities about safer farming and forestry practices. It would also be smart to upgrade basic infrastructure, like making sure firefighters have easy access to water points and roads, and to create vegetation buffer zones to help stop fires from spreading. On top of that, it's crucial to get ahead of the problem by developing an early warning network. This system could use weather forecasts and real-time sensors to automatically send notifications via text or mobile apps to both authorities and the public whenever a risk is identified. Finally, to make all of this as effective as possible, we should use GIS-based risk mapping. By creating detailed maps that combine data on vegetation, climate, and fire history, we can pinpoint the most vulnerable spots and better direct our prevention and planning efforts.

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Data Availability: Data will be available at request.

Ethics Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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