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Vegetation type shapes wildfire emissions in Northern Algeria: Implications for Mediterranean forest management

Aymen Moghli[1*], Mostefa E. Kouachi[2]

[1] Department of Ecology and Environment, Faculty of Nature and Life Sciences, University of Sétif 1- Ferhat Abbas, Campus El-Bez, Algiers Road, Sétif 19137, Algeria
[2] Department of Ecology, University of Alicante, 03690 San Vicente del Raspeig, Alicante, Spain
* Corresponding author's e-mail: moghliaymen@gmail.com

ABSTRACT

Wildfires are among the main environmental challenges in Mediterranean ecosystems affecting atmospheric composition, carbon cycling and ecosystem functioning. In North Africa the vegetation-specific contribution of wildfires to atmospheric emissions remains poorly studied despite the increasing frequency of large wildfires under climate change. This study assesses the effect of burned vegetation types (Forests, Shrublands-grasslands, Croplands and Savannas) on the emissions of five main atmospheric pollutants (CO_2, CO, CH_4, N_2O, NOx) in Northern Algeria during the fire seasons (May–October) from 2002 to 2024. Monthly burned area data from the MCD64A1 dataset and monthly wildfire emissions from FAOSTAT were combined to quantify vegetation-specific emissions. The results revealed substantial interannual variability in wildfire atmospheric emissions throughout the study period. Although shrublands-grasslands burned more than four times the area burned in forests, forests generated nearly twice the atmospheric emissions and consistently exhibited the highest emission efficiencies for all investigated pollutants. Together, these patterns demonstrate that wildfire atmospheric pollution is not controlled solely by fire extent but also by vegetation type. These findings provide new insights into wildfire atmospheric interactions in Mediterranean North Africa and underline the importance of integrating vegetation-specific fuel management into regional wildfire mitigation strategies aimed at reducing atmospheric emissions and improving ecosystem resilience under future climate change.

Keywords: Algeria, air pollution, climate change, forest fires, Mediterranean vegetation.

INTRODUCTION

Wildfires are among the main ecological disturbances affecting terrestrial ecosystems worldwide (Bowman et al., 2009). They exert profound impacts on biodiversity, vegetation dynamics, biogeochemical cycles, atmospheric composition, and human well-being (Bowman et al., 2009, 2020). In recent decades, wildfire activity has intensified in many regions due to the combined effects of climate warming, prolonged droughts, land-use change, rural abandonment, and the accumulation of combustible biomass (Flannigan et al., 2009). Beyond their immediate ecological and socio-economic consequences, wildfires have become a major concern in the context of global environmental change because of their role in releasing large quantities of greenhouse gases and atmospheric pollutants (Andreae, 2019; van der Werf et al., 2017). Several studies have assessed wildfire emissions using satellite-derived burned area products and fire emission models (Alvarez and Diaz, 2026; Das et al., 2026; Knorr et al., 2016; van der Werf et al., 2025). However, the relationship between burned vegetation type and emission magnitude and type remains unclear, particularly in North African ecosystems, which are still underrepresented in the wildfire emission literature.

Wildfire emissions are generated through the combustion of living and dead biomass, producing substantial amounts of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), and nitrogen oxides (NOx) among others (Le Quéré et al., 2018; Tian et al., 2016). These emissions contribute directly to atmospheric pollution and climate feedback mechanisms (Akagi et al., 2011). Indeed, the relationship between wildfires and climate change is increasingly described as a positive feedback loop (Stavros et al., 2014). Rising temperatures and prolonged drought conditions increase fuel dryness and fire susceptibility (Dupuy et al., 2020), while wildfire emissions further contribute to greenhouse gas accumulation and atmospheric warming (Knorr et al., 2017). Carbon dioxide released during wildfires represents a major source of atmospheric carbon, whereas methane and nitrous oxide possess substantially higher global warming potentials than CO_2 over long temporal scales (Akagi et al., 2011; Andreae, 2019). Similarly, nitrogen oxides and other combustion-derived pollutants contribute to ozone formation and deterioration of air quality, with important implications for public health (Jaffe et al., 2021; Liu et al., 2016).

Mediterranean Basin ecosystems, one of the global fire hotspots due to the strong interactions between climate, vegetation structure and composition, topography and human activities (Baeza et al., 2007), are particularly vulnerable to atmospheric pollution and climate feedback mechanisms. Mediterranean vegetation types differ considerably in their fuel characteristics, biomass density, combustion dynamics (Baeza and Santana, 2015; Fernandez-Anez et al., 2021; Pausas and Keeley, 2014), and consequently their emission profiles during fire events. Forests typically contain larger fuel loads and higher aboveground biomass, potentially generating larger quantities of greenhouse gases and pollutants during wildfires (Moghli et al., 2022; Pausas et al., 2004). Shrublands and grasslands; however, often burn frequently and over larger spatial extents (Baeza and Roy, 2008; Santana et al., 2018), and may produce different emission intensities depending on vegetation composition and combustion completeness. In the same way, croplands and savannas contribute to atmospheric emissions through agricultural fires and mixed vegetation combustion. Understanding how different vegetation types contribute to wildfire emissions is therefore paramount for improving regional carbon estimates, atmospheric modeling and fire management strategies.

Algeria is one of the most fire-prone countries in North Africa, particularly within its Mediterranean region where the climatic and ecological conditions favor recurrent wildfires (Curt et al., 2020; Kouachi et al., 2024). Northern Algeria hosts a mosaic of forests, shrublands, grasslands, croplands and savannas that are increasingly affected by drought, heatwaves, and land degradation processes (Curt et al., 2020), whereas the southern part of the country is characterized by arid and desert environments where forest vegetation is quasi-absent. In recent years, the country has experienced several catastrophic wildfire seasons associated with substantial ecological damage, economic losses, and human casualties (Kouachi et al., 2024). Despite the increasing occurrence of large and extreme wildfires and their potential atmospheric implications, studies addressing wildfire emissions in Algeria remain limited. In addition, the atmospheric effects of wildfire emissions are often transboundary in nature because pollutants can be transported over hundreds or thousands of kilometers depending on meteorological conditions and atmospheric circulation patterns (Andreae, 2019; Bowman et al., 2020; van der Werf et al., 2017). Thus, wildfire emissions represent a global rather than a merely regional concern.

The present study aims to assess how different vegetation types contribute to wildfire emissions during the fire season (May–October) across Northern Algeria using vegetation-specific burned area and pollutant emission datasets. The study focuses on four representative vegetation classes: forests, shrublands-grasslands, croplands and savannas, and assesses their contributions to atmospheric emissions of the main pollutants including CO_2, CO, CH_4, N_2O and NOx. The specific objectives were to (i) evaluate the relative contributions of the main vegetation types to atmospheric pollutant emissions, (ii) quantify differences in emission efficiency among vegetation types, and (iii) examine the relationship between burned area, vegetation type, and atmospheric emissions.

MATERIAL AND METHODS

Study area

The study area covers Northern Algeria, on the southern rim of the Mediterranean Basin and spans longitudes from 2.92° W to 8.68° E and latitudes from 32.02° N to 37.08° N (Figure 1). This region is characterized by recurrent forest fires and highly heterogeneous landscapes composed of forests, shrublands, grasslands, croplands and semi-arid savanna ecosystems (Kouachi et al., 2024). Landscapes are typically Mediterranean, dominated by conifers (e.g., Aleppo pine (*Pinus halepensis* Miller.), maritime pine (*Pinus pinaster* Aiton.), Atlas cedar (*Cedrus atlantica* (Endl.) Carrière.)) and oaks (e.g., cork-oak (*Quercus suber* L.), Algerian oak (*Quercus canariensis* Willd.), African oak (*Quercus afares* Pomel.), and holm oak (*Quercus ilex* L.)). These forests are intermixed with shrublands, grasslands, croplands and semi-arid savannas.

Northern Algeria extends along the Mediterranean coast and includes the Tell Atlas and adjacent highland regions, where the majority of wildfire activity in the country occurs (Curt et al., 2020). The study region has a typical Mediterranean climate characterized by hot and dry summers and mild, wet winters. Climatic conditions are strongly influenced by topography, proximity to the Mediterranean Sea, and continental air masses, resulting in pronounced spatial variability in temperature and precipitation regimes. Wildfires in Northern Algeria are highly seasonal, with most fire events occurring between late spring and early autumn under conditions of elevated temperatures, reduced relative humidity and low fuel moisture content. These conditions are increasingly intensified by climate change, prolonged drought episodes and frequent heatwaves, which lead to higher fire susceptibility and larger burned areas (Abdelbaki, 2026).

Burned area and wildfire emission data

Monthly burned area by landcover type for the 2002–2024 period were derived from the MCD64A1 dataset in CSV format. The MCD64A1 is NASA's standard global burned area product at 500 m resolution derived using a hybrid algorithm employing 500 m MODIS surface reflectance imagery coupled with 1 km MODIS active fire hotspots (Giglio et al. 2018). This dataset includes burned area estimates in hectares for several vegetation classes (forest, shrublands-grasslands, croplands, and other) across Northern Algeria. Monthly biomass burning emissions (tons) by pollutants the 2002–2024 period were extracted from the IPCC Tier 1 global monthly emissions database (Rossi et al., 2016). This dataset provides pollutant-specific emissions, whereas the MCD64A1-based dataset provides explicit vegetation-specific burned area estimates. Emission estimates are derived using "bottom-up" inventory-based methods (Seiler and Crutzen, 1980) following the IPCC Tier 1 approach for Greenhouse Gas Inventories (GHGI), as outlined in the IPCC guidelines (Rossi et al., 2016). Combining both datasets allowed assessment of how vegetation type influences not only burned area extent but also pollutant production and emission efficiency (i.e., tons emitted per hectare burned). The study focused on five major pollutants commonly associated with biomass burning: CO_2, CO, CH_4, N_2O, and NOx. These pollutants represent key components of wildfire emissions with important implications for atmospheric chemistry, climate change, and air quality.

To focus on the main wildfire season, our analyses were restricted to the period extending from May to October of each year, corresponding to the months during which the majority of wildfires occur in Mediterranean ecosystems (Kouachi et al., 2024). To homogenize and facilitate ecological comparison, vegetation classes were aggregated into four major ecosystem categories: (i) Forests, representing wooded ecosystems with relatively high biomass density; (ii) Shrublands-grasslands, combining closed shrublands, open shrublands and grasslands because of their similar fuel characteristics and fire behavior; (iii) Croplands, representing agricultural ecosystems, and (iv) Savannas, combining savanna and woody savanna vegetation types. Because wildfire emissions are not restricted to administrative boundaries, burned area values were summed, for each year, across all regions of Northern Algeria and aggregated by vegetation class.

Data preparation and processing

To assess the amount of pollutants emitted per unit burned area and compare the relative atmospheric impact of different vegetation types independently of fire size, emission efficiency was calculated using Equation 1.

$$Emission\ Efficiency = \frac{Emission(tons)}{Burned\ Area\ (ha)} \quad (1)$$

To identify vegetation classes contributing disproportionately to atmospheric emissions relative to their burned area extent, the relative contribution of each vegetation class to total burned area and atmospheric emissions was calculated annually. Contribution percentages were computed using Equation 2.

$$Contribution\ (\%) = \frac{Vegetation\ Value}{Total\ Value} \times 100 \quad (2)$$

where: the *vegetation value* corresponds to the pollutant emissions associated with a specific ecosystem type.

Statistical analysis

Differences in emission efficiency among vegetation types were evaluated using the non-parametric Kruskal–Wallis test. When significant differences were detected, pairwise comparisons were performed using Dunn's post-hoc test with Bonferroni correction. Relationships among burned areas, atmospheric emissions and emission efficiency were assessed using Pearson correlation analyses. All statistical analyses were performed in *R v 4.5.1* software (The R Core Team, 2024) using FSA and stats packages.

RESULTS

Vegetation classes differed significantly in terms of burned area and pollutant emissions (Figure 2). Shrublands-grasslands class showed the largest mean burned area during the study period (54×10^3 ha) and differed significantly from the other vegetation classes (Figure 2A, Table 1, p-value < 0.05). However, forests showed the highest pollutant emissions among all vegetation classes (mean total emissions of 198×10^3 tons; Figure 2B). Emissions from burned forests and shrublands-grasslands were not significantly different, yet significantly higher than those associated with croplands and savannas (Figure 2B, Table 2).

The relative contribution of vegetation classes to total wildfire emissions showed high interannual variability and varied significantly among them (Figure 3A, Table 3). Forest and shrublands-grasslands vegetation classes represented the dominant contributors throughout most of the study period. Forest contributions exceeded 50% of total emissions during several fire seasons, particularly after 2005 and during the late study period. Shrublands-grasslands showed episodic dominance during years characterized by extensive shrubland burning. Forests showed the highest contribution compared to all other vegetation classes (Figure 3B, Table 3). Shrublands-grasslands and croplands showed higher contribution compared to savanna ecosystems (Figure 3B, Table 3).

Emission efficiencies differed significantly among vegetation classes and for all investigated pollutants (Figure 4, Tables 4 and 5). Forest ecosystems consistently showed the highest emission efficiencies across all pollutants, indicating higher atmospheric emissions per unit burned area compared with other vegetation classes. For CH_4 emissions, forests showed significantly higher efficiencies than savanna and shrublands-grasslands classes (Figure 4, Table 5; p-value < 0.05). CO emissions also showed a similar pattern to CH_4 emissions, where forests displayed higher efficiencies compared with all other vegetation classes. CO_2 emissions also demonstrated strong vegetation-dependent differences, with forests producing the highest emission efficiencies,

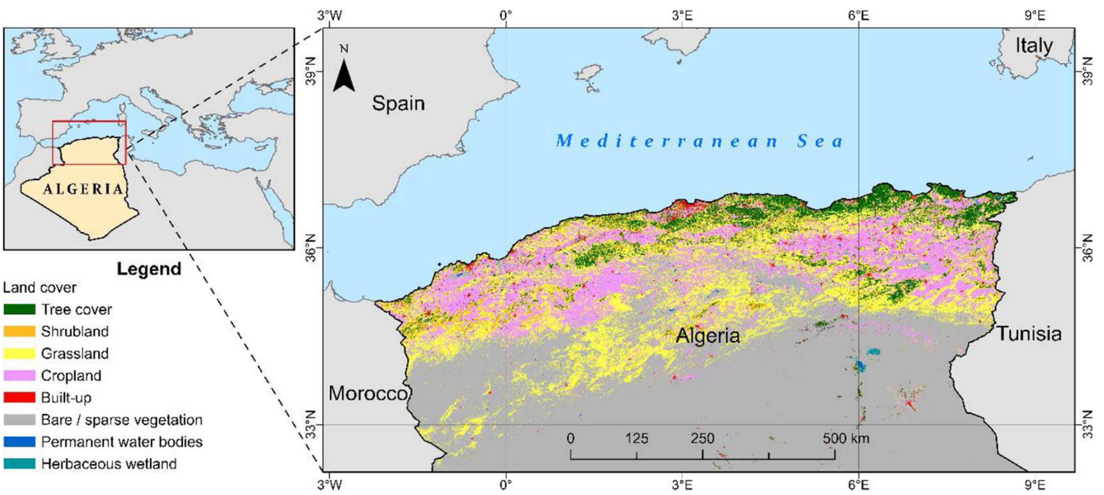

Figure 1. Study area with spatial distribution of land cover composition showing the dominant vegetation classes based on ESA WorldCover (Zanaga et al., 2022)

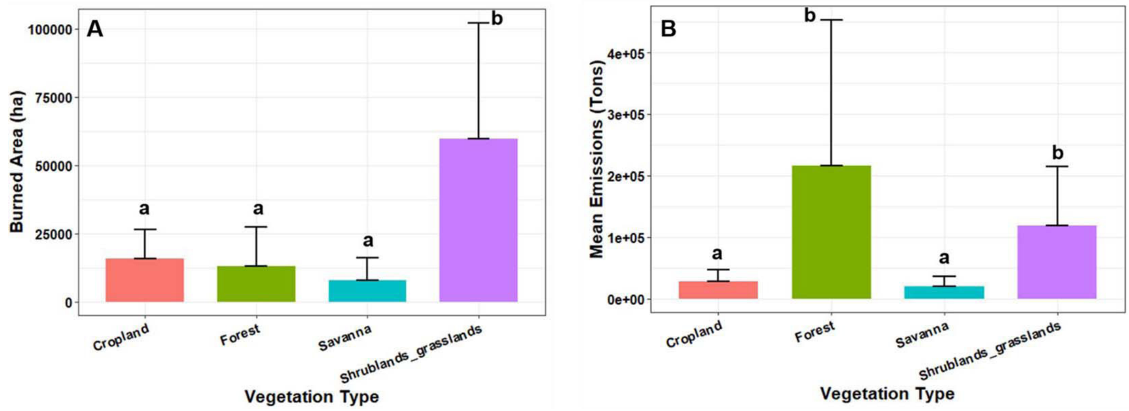

Figure 2. Mean burned area and associated atmospheric summer wildfire (May–October) emissions across vegetation classes in Northern Algeria between 2002–2024: (A) mean burned area (ha), (B) mean total wildfire emissions (tons) from each vegetation class. Different letters indicate significant differences

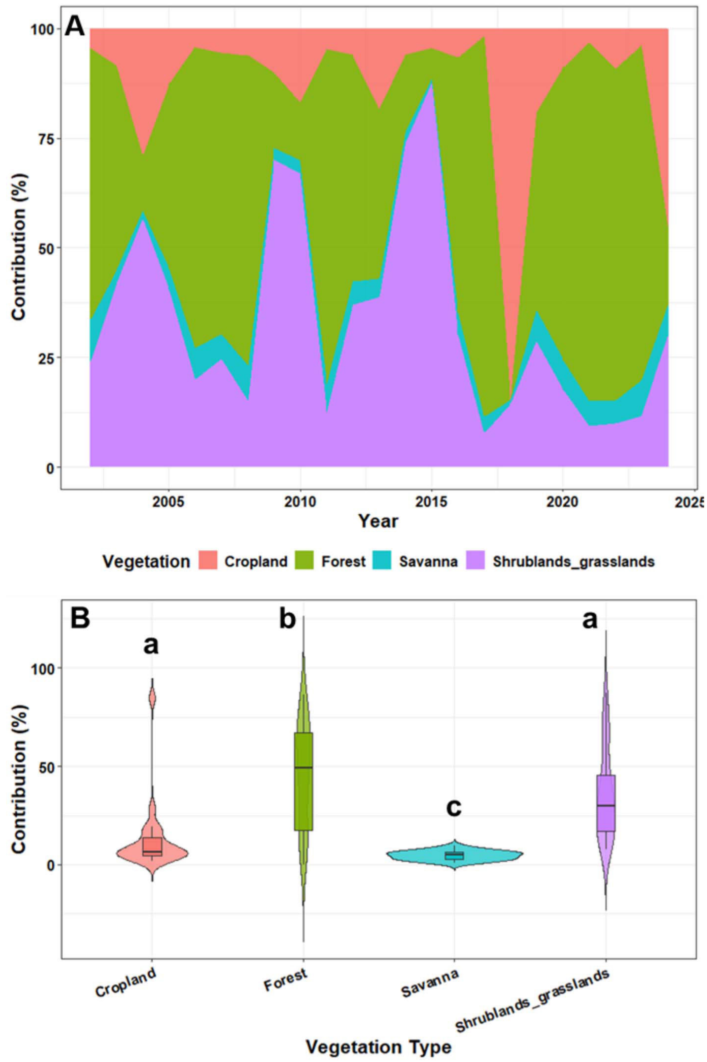

Figure 3. Temporal variability and statistical comparison of vegetation specific contribution to wildfire emissions between 2002–2024 (May–October): (A) interannual relative contributions of the four main vegetation classes to total wildfire emissions and (B) vegetation specific contributions across the study period (2002–2024). Different letters indicate significant differences among vegetation classes based on Dunn's post-hoc test following a Kruskal–Wallis analysis ($p < 0.05$)

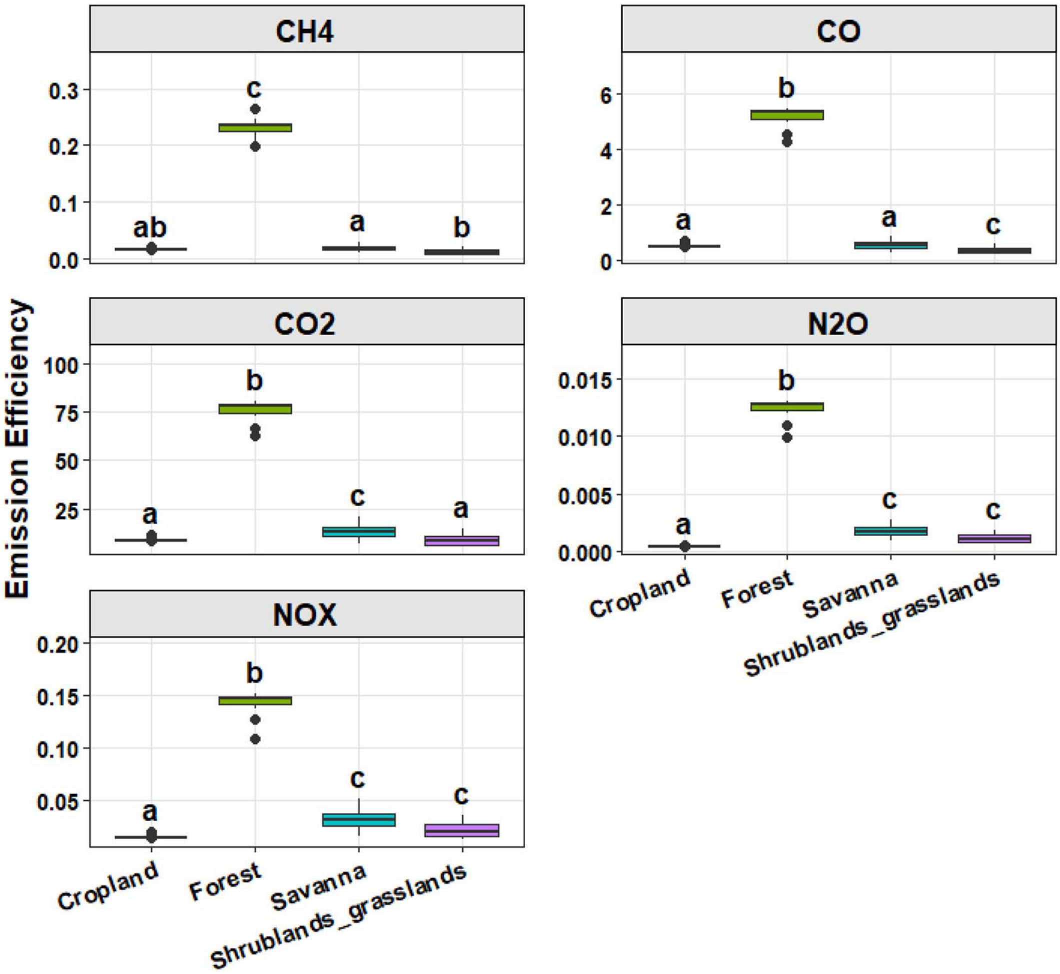

Figure 4. Vegetation specific emission efficiency for main pollutants generated by summer wildfires (May–October) in Northern Algeria between 2002–2024 study period. Emission efficiency represents the amount of pollutant (tons) emitted per one hectare of burned area. Different letters indicate significant differences among vegetation classes according to Dunn's post-hoc test following Kruskal–Walis analyses ($p < 0.05$)

followed by savanna systems and shrublands-grasslands. Croplands exhibited comparatively lower CO_2 emission efficiencies. Nitrous oxide (N_2O) and nitrogen oxides (NOx) showed consistent patterns with the other pollutants. Forest ecosystems generated significantly higher N_2O and NOx emission efficiencies than the remaining vegetation classes, whereas savanna and shrublands-grasslands generally exhibited intermediate values. Croplands displayed the lowest efficiencies for these nitrogen-related pollutants.

Correlation analysis showed moderate associations among burned areas, total emissions and emission efficiency (Figure 5). Wildfire emissions were positively correlated with both burned areas ($r = 0.45$) and emission efficiency ($r = 0.51$). In contrast, burned area and emission efficiency showed a weak negative correlation ($r = -0.20$).

DISCUSSION

The findings of this study demonstrate that wildfire atmospheric pollution in Mediterranean ecosystems is not controlled solely by fire extent, but also by vegetation types. Vegetation classes exhibit marked differences in terms of burned areas, relative contribution to total emissions and pollutant-specific emission efficiencies (Figures 2–4, Tables 1–3). Although shrublands-grasslands exhibited the largest burned areas during the study period, forest ecosystems generated the highest atmospheric emissions and consistently displayed the greatest emission efficiencies for all pollutants (Figure 4). Studies addressing wildfire atmospheric emissions in North Africa remain scarce. While most wildfire research has focused primarily on fire activity, burned area

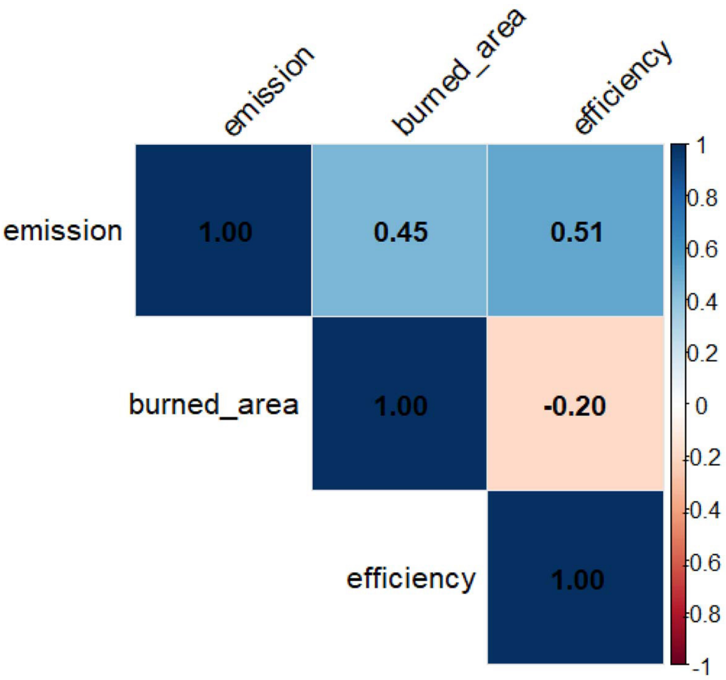

Figure 5. Correlation matrix showing the relationship among wildfire emissions, burned area and emission efficiency across vegetation classes and years in Northern Algeria between 2002–2024 fire seasons (May–October)

Table 1. Pairwise comparison of burned areas between 2002–2024 in northern Algeria among vegetation classes.

Comparison	Z	P.unadj	P.adj
Cropland – Forest	0.96	3.38E-01	1.00E+00
Cropland – Savanna	2.07	3.81E-02	2.29E-01
Forest – Savanna	1.12	2.65E-01	1.00E+00
Cropland – Shrublands_grasslands	-3.43	6.05E-04	3.63E-03
Forest – Shrublands_grasslands	-4.39	1.15E-05	6.88E-05
Savanna – Shrublands_grasslands	-5.50	3.74E-08	2.24E-07

Note: Pairwise differences were evaluated using Dunn's post-hoc tests following significant ($p<0.05$) Kruskal Wallis analyses

Table 2. Pairwise comparison of total pollutants emissions between 2002–2024 in northern Algeria among vegetation classes

Comparison	Z	P.unadj	P.adj
Cropland – Forest	-3.62	2.98E-04	1.79E-03
Cropland – Savanna	1.00	3.17E-01	1.00E+00
Forest – Savanna	4.62	3.89E-06	2.34E-05
Cropland – Shrublands_grasslands	-2.98	2.89E-03	1.73E-02
Forest – Shrublands_grasslands	0.64	5.24E-01	1.00E+00
Savanna – Shrublands_grasslands	-3.98	6.90E-05	4.14E-04

Note: Pairwise differences were evaluated using Dunn's post-hoc tests following significant ($p<0.05$) Kruskal Wallis analyses

mapping, or climatic and socio-economic drivers (Curt et al., 2020; Kouachi et al., 2024; Meddour-Sahar, 2015), the atmospheric implications of vegetation-specific emissions have received limited attention. The present study provides one of the first integrated assessments of wildfire

Table 3. Pairwise comparison of vegetation contribution to the total summer wildfire (May-October) emissions in Northern Algeria between 2021–2024

Comparison	Z	P.unadj	P.adj
Cropland – Forest	-3.80	1.43E-04	8.56E-04
Cropland – Savanna	1.85	6.42E-02	3.85E-01
Forest – Savanna	5.65	1.57E-08	9.39E-08
Cropland-Shrublands_grasslands	-3.35	7.95E-04	4.77E-03
Forest-Shrublands_grasslands	0.45	6.53E-01	1.00E+00
Savanna-Shrublands_grasslands	-5.21	1.94E-07	1.16E-06

Note: Pairwise differences were evaluated using Dunn's post-hoc tests following significant ($p<0.05$) Kruskal Wallis analyses

Table 4. Pairwise comparison of total summer wildfire emission efficiency (May-October) in Northern Algeria between 2021–2024 among vegetation classes

Comparison	Z	P.unadj	P.adj
Cropland – Forest	-4.44	9.06E-06	5.43E-05
Cropland – Savanna	-1.77	7.75E-02	4.65E-01
Forest – Savanna	2.69	7.06E-03	4.24E-02
Cropland – Shrublands_grasslands	-0.02	9.86E-01	1.00E+00
Forest – Shrublands_grasslands	4.42	9.80E-06	5.88E-05
Savanna – Shrublands_grasslands	1.75	8.04E-02	4.83E-01

Note: Pairwise differences were evaluated using Dunn's post-hoc tests following significant ($p<0.05$) Kruskal Wallis analyses

Table 5. Pairwise comparison of summer wildfire (May-October) emission efficiencies (Tons of pollutants/ha) among vegetation classes in Northern Algeria between 2002–2024

Comparison	CH_4		CO		CO_2		N_2O		NO_x	
	Z	P.adj	Z	P.adj	Z	P.adj	Z	P.adj	Z	P.adj
Cropland – Forest	-5.14	1.67E-06	-3.91	5.64E-04	-6.08	7.08E-09	-7.62	1.51E-13	-7.45	5.58E-13
Cropland – Savanna	-1.88	3.62E-01	0.16	1.00E+00	-3.24	7.20E-03	-4.93	4.86E-06	-4.76	1.18E-05
Forest – Savanna	3.26	6.70E-03	4.07	2.83E-04	2.84	2.67E-02	2.69	4.32E-02	2.69	4.23E-02
Cropland – Shrublands_ grasslands	1.16	1.00E+00	2.82	2.91E-02	-0.31	1.00E+00	-3.23	7.38E-03	-2.90	2.25E-02
Forest – Shrublands_grasslands	6.30	1.78E-09	6.72	1.07E-10	5.77	4.76E-08	4.39	6.84E-05	4.55	3.19E-05
Savanna – Shrublands_ grasslands	3.04	1.41E-02	2.65	4.78E-02	2.93	2.06E-02	1.70	5.34E-01	1.86	3.79E-01

Note: Pairwise differences were evaluated using Dunn's post-hoc tests following significant ($p<0.05$) Kruskal Wallis analyses

emissions across major vegetation classes in Northern Algeria, highlighting the differential roles of forests, shrublands-grasslands, croplands, and savanna ecosystems in shaping regional fire-related atmospheric pollution.

Burned vegetation types were key drivers of pollutant emissions rather than fire size in Northern Algeria. This finding is consistent with other studies conducted in Mediterranean Europe and other fire-prone ecosystems (Alvarez and Diaz, 2026; Andreae, 2019; van der Werf et al., 2017). Shrublands-grasslands burned more extensively than other vegetation types (more than four times the area burned in forests) yet burned forest ecosystems generated almost twice the atmospheric emissions of shrublands-grasslands. Indeed, the emission efficiency of forest ecosystems was almost nine-fold higher than that of shrublands-grasslands (Figure 4, Tables 4 and 5). The large contribution of shrublands-grasslands to burned areas reflects broader regional land-use transitions occurring across the Mediterranean Basin. Rural abandonment, grazing decline, and reduced traditional land management have promoted shrub encroachment and fuel accumulation in many Mediterranean landscapes, increasing the susceptibility of shrub-dominated ecosystems to recurrent fires (Baeza et al., 2007). This is because, besides being the dominant vegetation types, shrublands in Mediterranean ecosystems are often dense and dominated by seeder species (e.g., *Cistus albidus*, *Ulex parviflorus*) which accumulate high proportions of dead fuel putting the ecosystem at higher risk of fire ignition (Baeza et al., 2002; Baeza and Santana, 2015). In Northern Algeria, these processes are likely intensified by socio-economic changes, demographic pressures, and increasing climatic aridity (Curt et al., 2020; Kahli et al., 2026).

The correlation analysis further supports the hypothesis that wildfire atmospheric emissions are not solely controlled by burned area extent (Figure 5). Although a positive relationship was observed between burned area and wildfire emissions, the stronger correlation between emissions and emission efficiency suggests that vegetation type plays a key role in determining atmospheric pollutant production. Similar findings have been reported in Mediterranean and global fire studies, where fuel composition, biomass density, combustion completeness and fuel moisture had a strong influence on emission generation (Ottmar, 2014; Peterson and McCaffrey, 2022). The weak negative relationship observed between burned area and emission efficiency provides additional evidence that extensive fires do not necessarily generate the greatest atmospheric impacts. In the present study, shrublands-grasslands accounted for the largest burned areas yet generated lower emission efficiencies. On the other hand, forests generated higher emissions despite smaller burned areas. This pattern likely reflects differences in fuel loads and vegetation structure as forest ecosystems generally contain higher fuel load, greater aboveground biomass accumulation, and more vertically structured canopies compared with shrublands or croplands (Bowman et al., 2009). The predominance of Aleppo pine forests in the Mediterranean region is particularly relevant because this species is characterized by rapid post-fire regeneration through serotinous cones. However, the success and rate of regeneration can vary depending on pre-fire biotic and abiotic conditions (Pausas et al., 2004). For example, these forest types may regenerate massively, after a fire, from seeds protected and released from serotinous cones leading to extremely dense and homogeneous stands (Pausas et al., 2004; Rodríguez-García et al., 2022). These ecosystem types represent a high fire risk due to the accumulation of dead fuels and stand continuity, facilitating fire ignition and spread (Moghli et al., 2022). Fires in these stands may also show higher combustion intensity and longer residence times, likely leading to increased production of greenhouse gases and atmospheric pollutants (Alvarez and Diaz, 2026).

Wildfire emissions represent a major source of trace gases and aerosols that directly influence atmospheric composition, regional climate, and air quality (Andreae, 2019; Stavros et al., 2014). The dominance of CO_2 emissions observed across all vegetation classes highlights the important impact of wildfires on regional carbon dynamics (Bowman et al., 2009; Knorr et al., 2016). Thus, Mediterranean forests may act as substantial episodic carbon sources during severe fire seasons, partially offsetting their role as long-term carbon sinks. In addition, the elevated CO and CH_4 emissions associated with forest fires are especially relevant for atmospheric chemistry because these pollutants contribute to tropospheric ozone formation and indirectly influence radiative forcing (Jaffe et al., 2021). Similarly, NOx emissions generated during biomass combustion participate in complex photochemical reactions that affect ozone production and secondary aerosol formation (Andreae, 2019). In densely populated coastal regions of Northern Algeria, wildfire smoke may therefore exacerbate existing air quality problems, particularly during summer periods characterized by stagnant atmospheric conditions and high temperatures. The large interannual variability observed in vegetation contributions (Figure 3) suggests that wildfire atmospheric impacts in Northern Algeria are highly dynamic and strongly influenced by climatic variability and fire occurrence patterns. Years dominated by extensive shrubland fires differed substantially from years characterized by intense forest fire activity. Such variability has also been documented in Mediterranean Europe, where drought conditions and heatwaves strongly modulate fire regimes (Ruffault et al., 2020) and thus associated atmospheric emissions.

Some limitations should be acknowledged when interpreting the findings of this study. First, wildfire emissions were derived from inventory-based estimates rather than direct atmospheric measurements. Second, emissions were aggregated at the vegetation-class level and therefore do not account for within-class variability in fuel characteristics, fuel moisture, fire severity, or combustion completeness. Despite these limitations, the use of long-term datasets spanning two decades provides a robust basis for assessing vegetation-specific wildfire emission patterns at the regional scale. Our findings have important implications for wildfire management and atmospheric pollution mitigation in Northern Algeria and the Mediterranean region. The results clearly demonstrate that vegetation type strongly controls both the magnitude and efficiency of wildfire atmospheric emissions, suggesting that fuel management strategies should prioritize ecosystems characterized by disproportionately high pollutant emissions. Forest ecosystems emerged as the most critical vegetation class in terms of atmospheric emissions. Thus, reducing forest fuel loads should constitute a major management priority. Silvicultural treatments including thinning, understory clearing, the introduction of resistant resprouting species such as *Quercus* sp., prescribed burning, and fuel breaks may be appropriate actions to reduce fire risk and increase ecosystem resilience (Moghli et al., 2025; Morcillo et al., 2022). These management actions may decrease fire ignition probability, fire intensity and spread and the associated atmospheric emissions by limiting biomass accumulation and vertical fuel continuity (Agee and Skinner, 2005; Santana et al., 2018; Valdecantos et al., 2009).

CONCLUSIONS

This study provides a first assessment of vegetation-specific contributions to wildfire emissions in Northern Africa, highlighting the key role of vegetation type in controlling both the magnitude and efficiency of pollutant emissions in the Mediterranean region. The findings indicate that management actions should not rely exclusively on burned area reduction as a performance indicator. Vegetation-specific emission efficiencies show that ecosystems producing the highest atmospheric emissions per unit burned area may require targeted management even when their total burned area remains comparatively moderate. Integrating atmospheric emission metrics into wildfire management planning could therefore improve the environmental effectiveness of mitigation strategies. Furthermore, atmospheric pollution is transboundary, as smoke emissions from Northern Algeria may also affect broader Mediterranean atmospheric conditions. Regional cooperation among North African and southern European countries may therefore become increasingly important for monitoring and mitigating wildfire-related air pollution under future climate change scenarios.

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