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Research Article

The Contribution of Roads to Forest Fire Protection in Tamza Municipality, Northeast Algeria

Faicel Tout[1,*], **Nouh Rebouh**[2], **Haythem Dinar**[3], **Yacine Benzid**[4] and **Zakaria Zouak**[5]

[1] Territory Planning Research Center, Zouaghi Slimane Campus, Ain el Bey Road, 25000 Constantine, Algeria; faicel.tout@crat.dz (F.T.); nouh.rebouh@crat.dz (N.R.); haythem.dinar@crat.dz (H.D.); yacine.benzid@crat.dz (Y.B.); zakaria.zouak@crat.dz (Z.Z.).

** Correspondence: faicel.tout@crat.dz; tel.: (+213)044956961*

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Abstract

With rising forest fire frequency due to climate change, countries are advancing measures for prevention and faster emergency response. In Algeria, efforts centre on improving access to at-risk forests by expanding forest roads and paths. This study focuses on Ain Mimoun, Tamza in Khenchela Province, examining the role of these routes in forest protection. Using Geographic Information Systems (Google Earth Engine and ArcGIS) alongside field surveys, it identifies areas impacted by the 2021 fires through the difference normalised burn ratio (dNBR) and assesses road proximity to affected zones. Using a cartographic approach, this study highlights road density in fire-hit areas, revealing several constraints limiting the roads' effectiveness as fire barriers. Factors such as tree types and terrain influence fire spread, while fires near forest entrances impede firefighting vehicles due to risks from visibility and respiratory hazards. Maintenance issues further limit the utility of forest paths, and outdated forest road maps complicate firefighting efforts. Proposed solutions include upgrading the firefighting fleet with advanced tools like aircraft for isolated areas, intensifying forest road maintenance, and increasing forest monitors. Additionally, the study suggests exploring fire-resistant plant species, adopting strategic afforestation, and using Geographic Information Systems alongside advanced technologies like drones. These drones, which can provide real-time monitoring of fire and road conditions, support timely decision-making for rescue, evacuation and emergency response.

Keywords

Disasters; forest fires; roads; protection; Tamza; Algeria.

1. Introduction

With the impacts of climate change, human activities, and land use changes, the risk of forest fires has become a significant concern in various regions around the world (Delcourt et al., 2021; Eker et al., 2024; Gupta et al., 2024; Peña-Molina et al., 2024). This type of fire, which can be considered the most damaging, remains a critical challenge despite advancements in prevention, prediction, and response strategies in many countries. It appears that we still do not fully control this hazard, and many areas continue to experience substantial losses on various fronts (Belgherbi et al., 2018). Given the ongoing risk due to numerous factors that can trigger or contribute to fires whether naturally

or through human intervention—countries are developing and seeking better methods to intervene and prevent the spread of fires to mitigate the potential losses (Tout, 2023).

In Algeria, following recent fires that severely damaged forest cover (Zahira & Hadj, 2017), especially over the past decade, the government has focused on improving and modernizing its equipment. This includes increasing the number of firefighting vehicles, employing additional personnel, and imposing regulations on forest access, particularly during the summer season, to reduce the risk of both accidental and deliberate fires (Tout, 2023). Additionally, there is a growing emphasis on improving access to remote areas to facilitate firefighting operations and meet the needs of residents and investors.

Accessibility remains a crucial need for residents, land users, and those involved in forest management or protection. It is fundamental for emergency responses, and the development of roads and forest paths can offer better opportunities for detecting and controlling fires (Tout, 2023). Furthermore, it can improve conditions for evacuating and rescuing people (Wu et al., 2023). Accordingly, many current studies are working to find more efficient planning methods to provide optimal geographic coverage. This represents a significant shift in research in this context, as most studies focuses more on the role of roads as contributing factors to fire occurrence (Ganteaume & Jappiot, 2013). However, roads are now increasingly valued for their role as firebreaks and as central elements in managing wildfire risk and controlling associated hazards (Zhu et al., 2024). This shift has motivated authorities to include the expansion of road networks in their agendas to improve accessibility.

In the Tamza municipality of Khenchela Province, the Ain Mimoun area has experienced several forest fires, the most recent of which occurred in 2021(figure.1). This fire resulted in significant damage to large forested areas and affected many agricultural investments, along with numerous other losses on various levels (Guehaz & Sivakumar, 2023).

Figure 1. A part of the fires that affected the Ain Mimoun area in 2021.

As a result, many official bodies and research efforts have sought to understand the underlying causes of forest fires, as well as the reasons behind the challenges in controlling and containing them (Meddour-Sahar et al., 2013; Tout, 2023). This has led to public and private entities pointing fingers at the perceived neglect by authorities, with many residents and stakeholders expressing frustration over the lack of control over these fires, attributing it to insufficient road infrastructure for effective intervention.

This assumption implies an inverse relationship between road density and fire spread (Lu et al., 2022). The prevailing hypothesis is that roads not only facilitate easier access for firefighting vehicles

and personnel to wildfire sites but also serve as barriers within forests, potentially preventing the spread of fires from one area to another (Suárez-Fernández et al., 2024).

In this research, we aim to validate this hypothesis by evaluating the role and contribution of roads in fire protection. This study represents an attempt to understand the actual needs of the region to address shortcomings in wildfire intervention and preparedness.

1.1. Study Area

The municipality of Tamza, located in northeastern Algeria (Figure 2), belongs to Khenchela Province and is characterized by dense forest cover in several areas (Guehaz & Sivakumar, 2023). It has experienced numerous forest fires in recent years, especially in 2014 and 2021, which caused significant damage. The municipality is administratively part of the al Hamma District and has an elongated administrative boundary with a semi-arid climate. Despite its distinctive features, this extensive administrative boundary poses challenges in terms of population distribution across settlements, service provision, and achieving stability. The municipality, with its limited financial resources, faces difficulties in ensuring adequate living conditions in the south, where the municipal headquarters are located, as well as in the north, which also requires attention to stability factors such as water, electricity, and roads. These issues continue to be a concern for many residents, particularly in rural and forested areas.

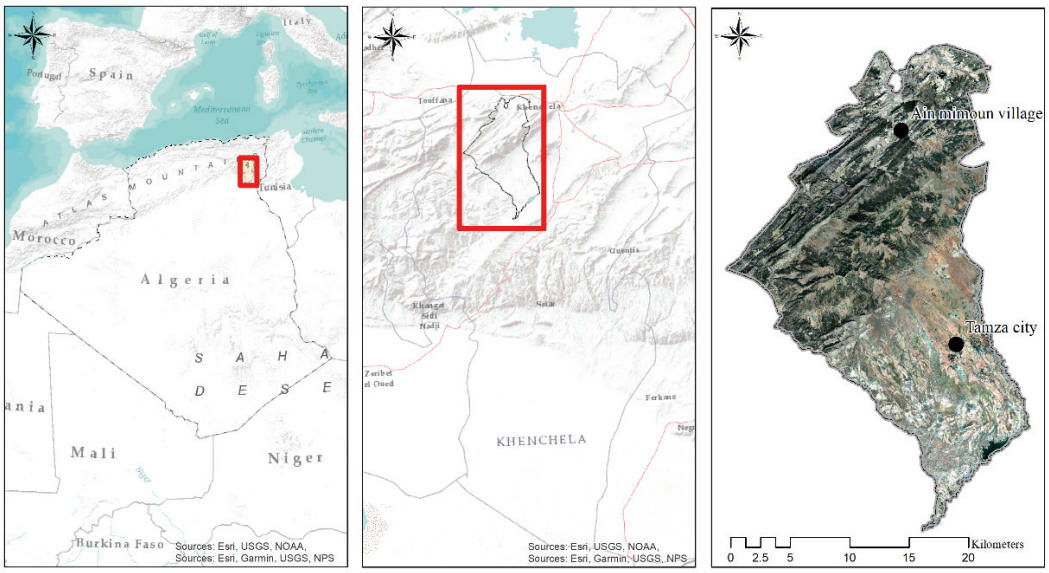

Figure 2. The location of the study area.

2. Methods

Using Geographic Information Systems (GIS), which are crucial for analyzing and evaluating geographical issues (He et al., 2024; Ibrahim et al., 2024; Mitsopoulos et al., 2019; Singha et al., 2024), we aim to assess the role of roads in forest protection in the Tamza municipality. The study began with mapping the road network of significance, including national, provincial, and municipal roads with substantial traffic, as well as some rural and forest paths that are crucial for accessing certain population centers and agricultural investments. We also excluded newly constructed roads established after the fires based on our knowledge of the study area. These new roads were specifically created for transporting timber and other activities managed by the forest administration following the fires.

The study took into account the area affected by fires during 2021, where Landsat 8 images before and after the fires were used on the Google Earth Engine platform to calculate the dNBR index to identify the most affected areas. The Burn Severity Index, dNBR (Differenced Normalized Burn Ratio), is a commonly used indicator (R. Guo et al., 2024; Llorens et al., 2021; Mohammad et al., 2023;

Sobrino et al., 2019) for assessing burn severity and damage (Llorens et al., 2021). It is calculated using the formula:

$$dNBR = NBR\_PreFire - NBR\_PostFire$$

NBR is derived from Landsat 8 data using the formula:

$$NBR = Band\ 5 - Band\ 7 / Band\ 5 + Band\ 7$$

where:
Band 5: Near Infrared (NIR)
Band 7: Shortwave Infrared (SWIR)

In the maps from (Figure 3), negative values indicate areas with sparse or less dense vegetation or non-vegetative conditions, while positive values indicate significant and healthy vegetation cover. It is evident in map 2 of the same (Figure 3) that there is a significant change in values before and after the fires in some areas of the northern and northwestern regions, particularly in the areas that experienced the fires (Guehaz & Sivakumar, 2023).

As for the dNBR index, positive values usually indicate a high burn severity, decreasing as we approach zero, while negative values indicate either no damage or an improvement in the vegetation cover in the area. After classification.

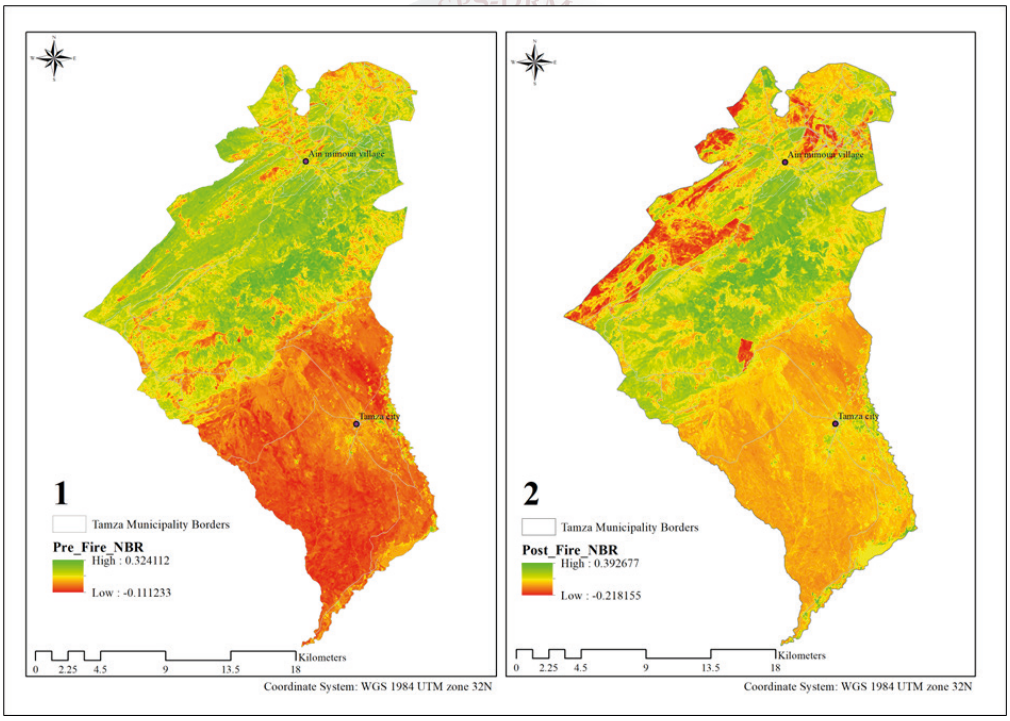

Figure 3. The Normalized Burn Ratio (NBR) values for the study area before and after the fires.

Table 1 refers to the classification of the normalized burn ratio (dNBR) as proposed by the United States Geological Survey (USGS) (Sobrino et al., 2019):

Table 1. dNBR classification

Severity Level	Pixel Values
High Regrowth	-0.5 ≤ dNBR < -0.25
Low Regrowth	-0.25 ≤ dNBR < -0.1
Unburned	-0.1 ≤ dNBR < 0.1
Low	0.1 ≤ dNBR < 0.27
Moderate-Low	0.27 ≤ dNBR < 0.44
Moderate-High	0.44 ≤ dNBR < 0.66
High	0.66 ≤ dNBR < 1.33

Although accurate assessment of areas affected by fires using remote sensing techniques requires precise data, some free data provided by relevant agencies like USGS allow for generally acceptable results that can be relied upon in many fields (Delcourt et al., 2021; Erzurumlu & Yıldız, 2024; Marra et al., 2024). This study also required numerous field visits to assess the actual condition of roads and areas directly impacted by the fires. Despite the extensive spatial reach of the fires, the research aims to integrate remote sensing systems with actual field visits to provide a better reality analysis and reliable study results

The map in (Figure 4) indicates the most severely affected areas after the 2021 fires according to the adopted classification.

According to the map, the northern and northwestern regions were significantly affected by the fires, which are generally areas with dense vegetation cover. Additionally, part of these regions can be considered areas that were previously affected by fires in 2014 (Guehaz & Sivakumar, 2023). These past fires may have made the region more vulnerable, creating conditions more prone to ignition (Fernández-García et al., 2019).

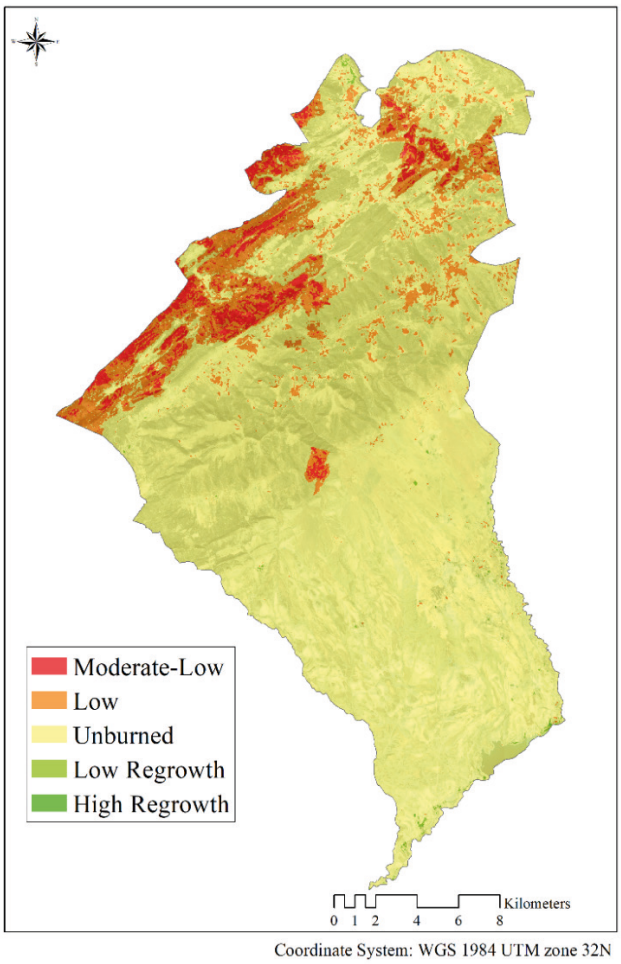

Figure 4. The fire severity for the study area is according to the adopted classification.

3. Results and Discussion

It is commonly recognized that roads significantly contribute to halting the spread of fires by facilitating the access of firefighting teams to the locations where these fires break out, allowing them to extinguish the fires and prevent their spread. Additionally, roads act as buffer zones, separating forested areas and preventing the fire from spreading on the ground or between trees and shrubs (Lourenço et al., 2023; Lu et al., 2022; Suárez-Fernández et al., 2024).

In the map from (Figure 5) which indicates the overlay of roads and areas affected by fires in the study area, there is a relative density of roads, especially in the Ain Mimoun area in the northern part of the municipality. This suggests that the roads did not contribute as expected to stop the spread of the fire, even for the major roads in the area, such as the paved road connecting the village of Ain Mimoun to National Road No. 88 (Figure 6).

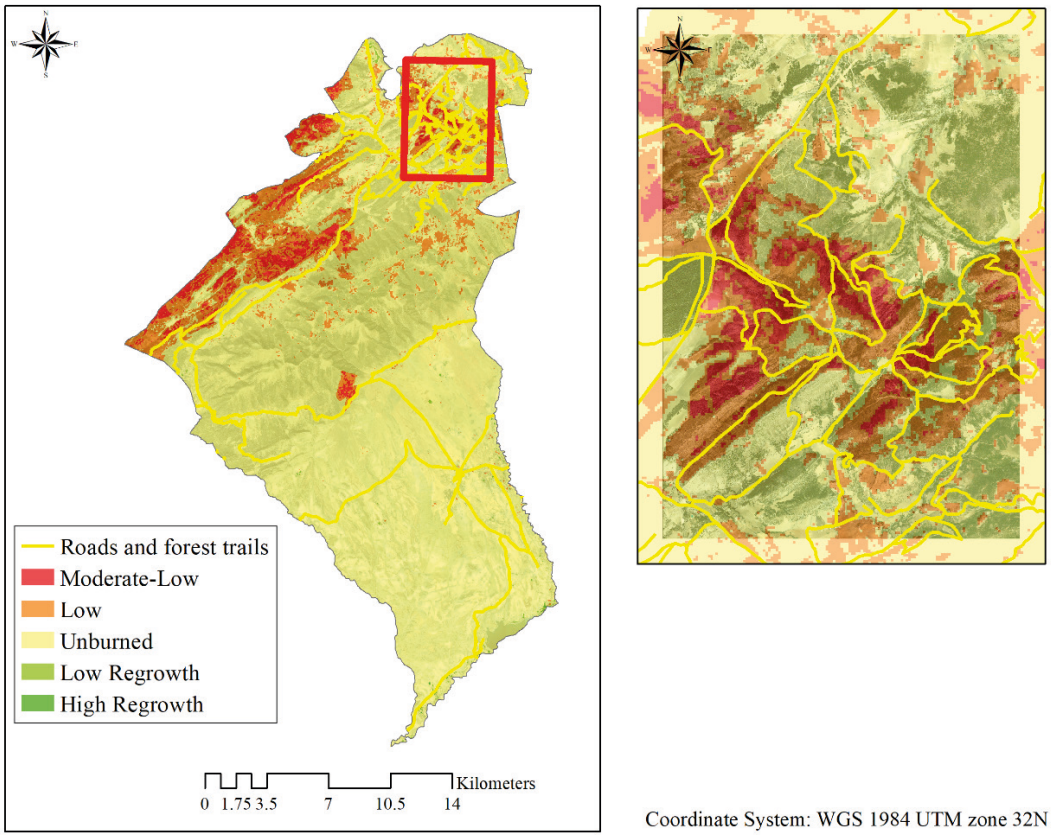

Figure 5. Road density in the burned areas.

After both sides of road number 88 were exposed to fire, it not only isolated the forested area but also isolated the village during the fires, particularly since the alternative roads were in extremely poor condition. They require long distances to reach populated areas and neighbouring cities, and reaching hospitals involves travelling even greater distances. Moreover, some of these roads have been affected or are at risk of being affected by fires or dense smoke, including the road connecting the village to the city of Kais, the southern road linking the village to the city of Tamza, and the road that connects it to the city of Khenchela via the Ras Serdoun mountains. These routes cannot be considered actual alternatives, especially given the paths they take through forests or the challenging terrain they traverse (Lu et al., 2022; Suárez-Fernández et al., 2024).

The extensive spread of some areas affected by the fire in regions with a high density of roads and forest paths also confirms that factors are limiting the role of roads as protective measures. In the Ras Al-Assa area, which provides multiple entrances to some agricultural investments located within forested areas, large fires occurred, causing harm to the residents who were isolated by these fires. The resulting smoke led to cases of suffocation among some of them, especially since the fires did not give them enough time to leave the area.

Our investigation into the factors that limited the role of roads indicates that even with the isolation provided by the road (Suárez-Fernández et al., 2024), fires still spread across the sides of the road due to several other factors. For instance, pine cones, one of the most common and possibly the most widespread trees in the area, can jump several meters, as well as embers are carried by the wind, which can transfer the fire to neighbouring areas.

Figure 6. The spread of fires between both sides of the road connecting the village of Ain Mimoun to National Road No. 88.

It is also worth noting that the mere occurrence of a fire on both sides of the road prevents the passage of vehicles due to dense smoke, reduced visibility, the risk of suffocation (Li et al., 2023), and the potential for vehicles to catch fire, especially those running on gasoline. This includes firefighting vehicles or private cars, which automatically nullifies the road's role, This is what happened on the road that leads to some of the farms in the Farkanfath area (Figure 7). Moreover, this interruption of roads hinders efforts to evacuate residents, significantly increasing the danger of the situation (Wu et al., 2023).

The lack of necessary maintenance for roads and forest paths has eliminated the possibility of relying on many of them (Akay et al., 2021), significantly limiting the options for firefighting vehicles, complicating operations, and increasing the risk for firefighting crews. Some of these paths were used only temporarily and were not rehabilitated, while others did not meet actual technical standards and only allowed the passage of light firefighting vehicles (Figure 8).

The failure to update road maps by civil defence agencies, which is one of the most important measures to facilitate effective fire response (Lourenço et al., 2023), was a key factor that limited their ability to act quickly in evacuating residents and preventing the spread of fires on time. This left them with only one option: consulting local shepherds to find paths that would allow passage.

Figure 7. The only accessible entrance to one of the agricultural investments, which has been blocked by smoke and fires, preventing the evacuation of residents and leading to the destruction of large areas of the forest.

Figure 8. The deteriorating condition of one of the forest trails in the study area.

The terrain of the area has significantly facilitated the spread of fires between the sides of roads, especially on slopes. The falling of trees, shrubs, or their fruits contributes to the transfer of fires from areas higher up the road to lower ones. Numerous studies have highlighted the role that elevations and slopes, in general, play in facilitating and intensifying the spread of fires (L. Guo et al., 2022, 2024; Ibrahim et al., 2024; Tout, 2023).

The aforementioned factors significantly impact the feasibility of relying on roads for firefighting interventions or as barriers between fire-vulnerable areas. Several exceptional conditions often accompany these fires, partially or entirely negating the reliance on certain roads and forest pathways. From another perspective, some researchers argue that roads themselves may contribute to the ignition of forest fires, especially when combined with visitors' lack of awareness. Various studies have shown that many fires have started near roads and inhabited areas (Guehaz & Sivakumar, 2023; L. Guo et al., 2022; Tout, 2023).

This difference in viewpoints underscores that roads should be part of a comprehensive strategy for protecting against forest fire hazards (Meddour-Sahar et al., 2013). Roads must also meet specific conditions and standards to enhance their reliability during emergencies. Additionally, the consideration of increasing road density in forested areas should take into account various spatial criteria, primarily providing multiple access points to potential fire zones and ensuring proximity to water sources. Roads must also be appropriately located with respect to the terrain and be cost-effective and existing ones must be maintained. In addition, alternative fire extinguishing measures should be adopted. For example, trenches could be created specifically for this purpose, and reforestation planning should utilize strategic spacing between forested areas. Special plant species that do not support the spread of fire could also be used, although this would require further research and development.

This study also highlights the need for more effective and reliable emergency response tools that can improve access to remote areas, such as firefighting aircraft and helicopters, especially given the difficulties and challenges associated with using rural and forest roads for this purpose. There is also a significant need to increase the number of surveillance and warning units to enable early detection of fires.

In addition, risk prevention requires the use of advanced technologies to predict areas at risk of wildfire, such as geographic information systems (GIS) that apply appropriate criteria. These systems can also be used in disaster management to plan rescue, evacuation and urgent preventive measures, together with the use of appropriate monitoring tools, such as drones, which provide real-time updates on the status of roads, routes and fires to support timely decision-making.

4. Conclusions

Despite the important role that roads play in providing access to fire-affected areas and aiding firefighting efforts, several factors limit their use during wildfires. In the study area, the fires created exceptional and complex conditions that automatically rendered some of these roads unusable. For example, the fire that affected the side of National Road 88, considered the main entrance to the village of Ain Maimoun and its forests, prevented access to contain the spread to other areas and isolated the village.

The study also highlights the role of other factors that contribute to the spread of fires along roadsides, such as wind, slope, and tree species, and emphasizes that roads cannot be relied upon as firebreaks between forests. The study calls for the maintenance and upgrading of roads and trails with new technical specifications to support the passage of heavy firefighting vehicles and reduce the potential for fire to spread along roadsides. It also suggests updating road maps for civil defense authorities and increasing road inspection activities.

The study recommends the adoption of an appropriate reforestation strategy using plant species that do not promote fire spread, and the use of more advanced technologies, such as drones, to provide real-time updates on road, trail, and fire conditions for informed decision-making and effective risk management during emergencies. The study also highlights the need to establish new forest guard and civil protection units in the village and surrounding rural areas, and to strengthen the civil protection fleet with helicopters and firefighting aircraft, especially in densely vegetated areas. Given the continued risk of wildfire outbreaks, additional forest guards should be deployed and residents should be more actively involved in fire prevention and forest fire risk management.

Author Contributions: The research required the use of different tools to analyze the data, find and verify the results, and it required cooperation in many stages between the researchers, but some of them contributed to specific aspects in particular, Tout Faicel, the author of the research idea and its director, did the bibliographic research and determined the research methodology and is the owner of the results related to Google Earth Engine, Nouh Rebouh contributed to the analysis and interpretation of the different results and helped in the preparation of maps, an aspect in which Yacine Benzid and Haythem Dinar also contributed, in addition to verifying the results and following up the research. Zakaria Zouak also contributed to this, especially in field investigations, translation, and finalizing the text of the article.

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Conflicts of Interest: "The authors declare no conflict of interest."

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