

Evaluation of Forest Fire Risk Criteria in the Thrace Region Using Pythagorean Fuzzy AHP

Burcu Tezcan^{*}, Tamer Eren²

¹Department of Enterprise Informatics Specialization, Cappadocia Vocational School, Cappadocia University, Nevsehir, Turkey

²Department of Industrial Engineering, Faculty of Engineering and Natural Sciences, Kırıkkale University, Kırıkkale, Turkey.

^{*}(burcu.tezcan@kapadokya.edu.tr) Email of the corresponding author

Abstract – Forest fires are critical environmental events that profoundly impact the structure, functioning, and biodiversity of ecological systems. The destruction of forest areas, which are vital for the continuity of ecosystem services, leads to loss of biodiversity, increased carbon emissions, and the intensification of climate change effects. Therefore, assessing the causes of forest fires is indispensable for effective fire management and the development of sustainable environmental policies. In this context, the Thrace Region occupies a critical position in terms of forest fire risk due to the interconnection of forested areas with residential and agricultural lands. The study area is the Thrace Region. Given the high likelihood of forest fires in this region, proposing a multi-criteria decision-making (MCDM) model is crucial for obtaining convincing results. In the literature, Pythagorean Fuzzy Sets (PFS) have been widely used, providing decision-makers with a broad evaluation scale. Moreover, PFS has been utilized to better model uncertainties in forest fire risk assessment and management. For evaluating forest fire risk in the Thrace Region, nine criteria were identified: forest density, temperature, humidity, population density, proximity to residential areas, proximity to agricultural lands, wind speed, biomass density, and slope. These criteria were weighed and prioritized using the Pythagorean Fuzzy Analytic Hierarchy Process (PFAHP), a multi-criteria decision-making approach. According to the analysis results, the criterion with the highest priority was population density. This suggests that the likelihood of fire outbreaks increases in areas with high human activity, underscoring the significant role of anthropogenic factors in forest fires. The study demonstrates the applicability of the PFAHP method in forest fire risk analysis and provides a scientific basis for policymakers to develop regional prioritization strategies that aim to reduce risk. In this respect, it offers both a methodological contribution to literature and significant outputs for the development of fire risk management policies specific to the Thrace Region.

Keywords – Forest Fires, Thrace Region, PFAHP

I. INTRODUCTION

Forest fires are recognized as one of the most destructive types of natural disasters globally, posing a particularly significant threat in Mediterranean climate zones characterized by hot and dry summer conditions (Rigolot, 2008). Each year, approximately 1% of Mediterranean forests are lost to fire, resulting not only in severe ecological damage but also in substantial economic losses (El Mazi et al., 2024). Rising global temperatures and decreasing precipitation, driven by climate change, have led to notable shifts in fire regimes and increased fire severity, thereby directly impacting the functioning of forest ecosystems (Busico et al., 2019; Driouech et al., 2020; Fernández-García et al., 2019). The increasing frequency of wildfires contributes to vegetation degradation, while the prevalence of flammable plant species and dense shrub layers further accelerates fire spread and intensity (Francos et

al., 2016; Moreno et al., 2023). The replacement of endemic plant species with highly flammable trees such as *Pinus brutia* (Turkish pine) exacerbates wildfire risk (Novo et al., 2020). Beyond their ecological impacts, forest fires also generate significant socioeconomic consequences; post-fire heavy rainfall increases erosion and surface runoff, with studies showing that surface runoff can rise by up to 150% in burned forests compared to unburned ones (de Pagter et al., 2023; Pereira et al., 2018; Vieira et al., 2023).

In Turkey, most forest fires are anthropogenic, with negligence and carelessness ranking among the primary causes (Avcı & Korkmaz, 2021). In this context, the Thrace Region presents a particularly vulnerable landscape due to the interspersed forest areas with agricultural and residential zones. The region's hot and dry summers, combined with low humidity levels and intensive human activity, significantly elevate wildfire risk. As such, the prevention and management of potential forest fires in Thrace demand the use of scientifically grounded decision-support systems.

This study aims to identify and prioritize the factors influencing wildfire risk in the Thrace Region through a multi-criteria evaluation framework. The analysis incorporates a set of criteria including forest canopy density, temperature, humidity, population density, proximity to settlements, proximity to agricultural lands, wind speed, biomass density, and slope. The relative importance of these criteria was determined using the Pythagorean Fuzzy Analytic Hierarchy Process (PFAHP). This approach not only facilitates a more robust prioritization for decision-makers but also offers a strategic foundation for developing effective wildfire prevention and response policies specific to the region.

II. CASE STUDY DESIGN

The Thrace Region, located in the northwestern part of Turkey, holds strategic importance in terms of forest fire risk due to the proximity and interconnection of forested areas with agricultural lands and residential settlements. During the summer months, the combination of high temperatures and low humidity levels significantly increases the likelihood of wildfires. The region's dense population centers, widespread agricultural activities, and intensive human mobility in rural areas contribute to the predominantly anthropogenic origin of forest fires. Additionally, Thrace's wind-exposed topography particularly under the influence of strong winds such as *lodos* and *poyraz* facilitates the rapid spread of fires across large areas. Climate change-induced increases in temperature and prolonged periods of drought further exacerbate both the frequency and severity of wildfire risks in the region.

In this context, the Thrace Region has been selected as the study area, with the aim of assessing the wildfire risk levels of its districts. The overall process followed in the study is presented schematically in Figure 1. The research focuses on the evaluation of wildfire risk criteria specific to the region.

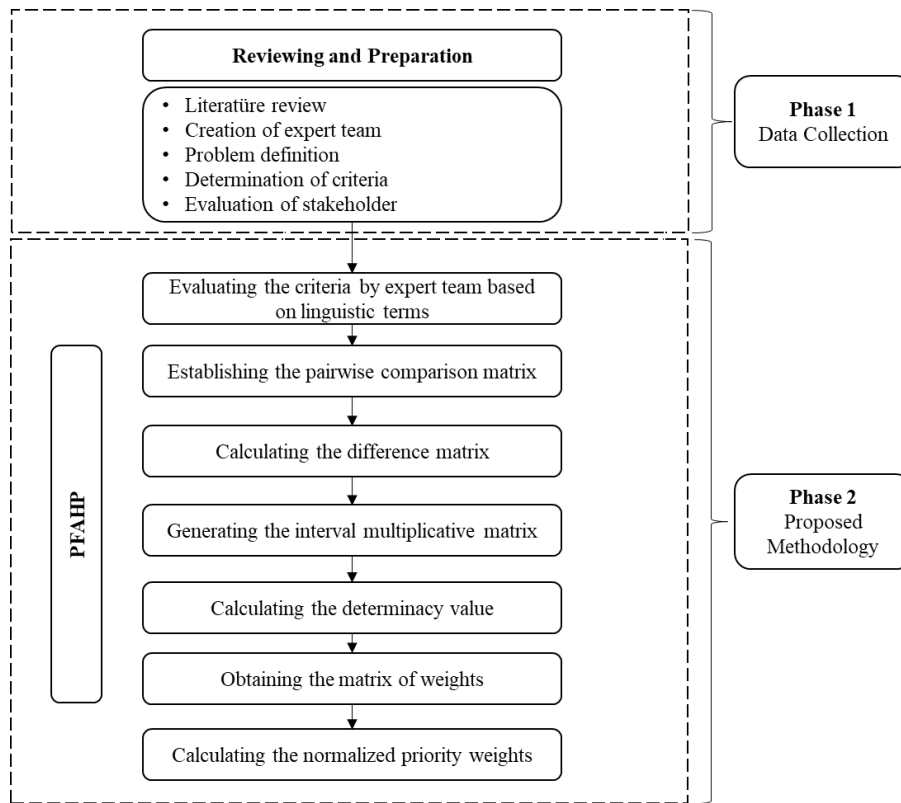


Fig. 1 Application flow

Based on the literature review and expert opinions, a total of nine key criteria influencing forest fire risk in the Thrace Region have been identified. The definitions of these criteria and their implications for wildfire risk are presented in Table 1. Upon examining the table, it becomes evident that these criteria are directly influential in the ignition, spread rate, and severity of forest fires. Moreover, they play a critical role in planning regional wildfire risk management and prioritizing resource allocation, offering a structured foundation for effective decision-making in fire prevention and response strategies.

Table 1. Explanation of criteria (Tezcan & Eren, 2022, 2023, 2024, 2025)

Criterion	Description
Forest Closure	As tree density increases, so does the risk of ignition and fire spread. High canopy density indicates a larger volume of combustible materials such as branches, leaves, and resins. Densely forested areas in Kırklareli and Edirne exemplify this risk.
Temperature	Elevated temperatures reduce moisture in vegetation, increasing flammability and facilitating fire ignition and rapid spread. In the Thrace Region, summer temperatures often reach up to 40°C, significantly exacerbating fire risk.
Humidity	Low humidity levels make forest floor materials such as leaf litter and understory vegetation more prone to ignition. When relative humidity drops below 30%, the probability of wildfire occurrence rises substantially. Thrace commonly experiences dry summer conditions.
Population Density	Higher population density correlates with increased human activity near forested areas, raising the likelihood of human-induced fires. Activities such as land clearing, picnicking, and discarded cigarette butts contribute to this risk. Urban centers like Çorlu, Lüleburgaz, and Edirne are particularly vulnerable.
Proximity to Settlements	The closer forests are to settlements, the higher the probability of ignition due to human interaction, and the greater the risk of fire spreading to residential areas. Many forested areas in Thrace are located near rural villages and towns.
Proximity to Agricultural Lands	Agricultural practices such as stubble burning can inadvertently lead to wildfires, especially during harvesting periods. In Thrace, crops like wheat and sunflower are harvested during the dry season, increasing fire risk significantly.
Wind Speed	Strong winds accelerate fire spread and can carry embers over long distances, igniting new fires. Prevailing

	winds such as lodos (southwesterly) and poyraz (northeasterly) intensify fire behavior due to the region's exposed topography.
Biomass Density	High biomass density implies an abundance of flammable material such as dry shrubs, grass, and forest floor debris. Summer droughts in Thrace contribute to the accumulation of dry biomass, increasing the probability and intensity of wildfires.
Slope	Fires spread more rapidly uphill due to preheating of vegetation above the flame front. While most of Thrace is characterized by flat terrain, areas like the Yıldız Mountains may present slope-related fire behavior dynamics.

According to the results obtained through the PFAHP, population density emerged as the most critical criterion influencing forest fire risk in the Thrace Region. This finding highlights the decisive role of human-induced factors in wildfire occurrence, particularly in forested areas located near densely populated settlements. Following population density, proximity to agricultural lands ranked second, underscoring the fire-triggering potential of agricultural practices such as stubble burning during harvest periods. Figure 2 presents the prioritization of wildfire risk criteria in the Thrace Region, based on the criterion weights derived through the PFAHP method. The resulting ranking offers valuable insights for decision-makers by identifying which factors should be prioritized, thereby contributing to the development of more effective and strategic wildfire risk management and planning processes.

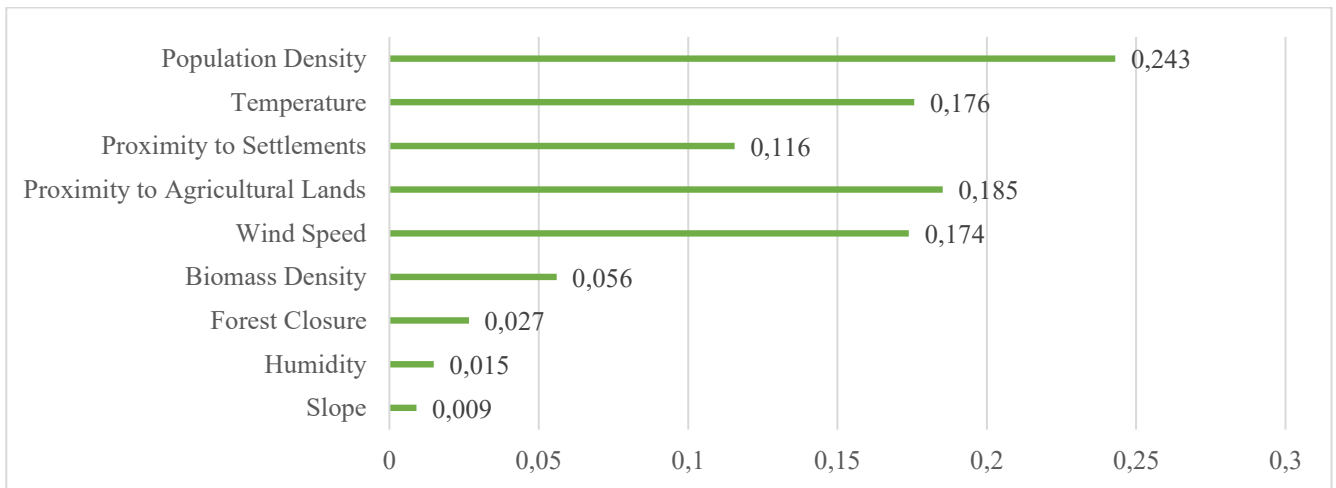


Fig. 1. Prioritization of Criteria Based on PFAHP

III. CONCLUSION

In this study, wildfire risk factors in the Thrace Region were evaluated using the PFAHP, allowing for a region-specific prioritization of risk criteria. As an application area, Thrace stands out due to the interconnection of forested areas with agricultural lands and settlements, the prevalence of high temperatures and low humidity during summer months, intensive human activity, and a topography highly exposed to wind. According to the PFAHP analysis, population density was identified as the most critical criterion, followed by proximity to agricultural lands and proximity to settlements. These findings indicate that wildfire risk in the region is largely associated with anthropogenic factors. In contrast, criteria such as humidity and slope received lower weights, reflecting the relatively flat terrain and specific climatic conditions of the region that render these variables secondary in terms of fire propagation dynamics.

The results emphasize the need to prioritize human-centered strategies in wildfire prevention and management efforts in the Thrace Region. Establishing early warning systems near settlements, monitoring agricultural practices such as stubble burning, and implementing public awareness campaigns in high-risk zones should be considered key interventions. The prioritization of risk criteria also facilitates more efficient allocation of firefighting resources and equipment according to spatial vulnerability levels.

In this regard, the study offers a scientifically grounded, systematic, and context-specific decision-support tool for policymakers. Furthermore, it demonstrates the effectiveness of multi-criteria decision-making methods in addressing complex environmental problems such as forest fire risk assessment.

REFERENCES

- [1] Avcı, M., & Korkmaz, M. (2021). Türkiye’de orman yangını sorunu: Güncel bazı konular üzerine değerlendirmeler. *Turkish Journal of Forestry*, 22(3), 229–240.
- [2] Busico, G., Giuditta, E., Kazakis, N., & Colombani, N. (2019). A hybrid GIS and AHP approach for modelling actual and future forest fire risk under climate change accounting water resources attenuation role. *Sustainability*, 11(24), 7166.
- [3] de Pagter, T., Lucas-Borja, M. E., Navidi, M., Carra, B. G., Baartman, J., & Zema, D. A. (2023). Effects of wildfire and post-fire salvage logging on rainsplash erosion in a semi-arid pine forest of Central Eastern Spain. *Journal of Environmental Management*, 329, 117059.
- [4] Driouech, F., ElRhaz, K., Moufouma-Okia, W., Arjdal, K., & Balhane, S. (2020). Assessing future changes of climate extreme events in the CORDEX-MENA region using regional climate model ALADIN-climate. *Earth Systems and Environment*, 4(3), 477–492.
- [5] El Mazi, M., Boutallaka, M., Saber, E., Chanyour, Y., & Bouhlal, A. (2024). Forest fire risk modeling in Mediterranean forests using GIS and AHP method: case of the high Rif Forest massif (Morocco). *Euro-Mediterranean Journal for Environmental Integration*, 9(3), 1109–1123.
- [6] Fernández-García, V., Fulé, P. Z., Marcos, E., & Calvo, L. (2019). The role of fire frequency and severity on the regeneration of Mediterranean serotinous pines under different environmental conditions. *Forest Ecology and Management*, 444, 59–68.
- [7] Francos, M., Úbeda, X., Tort, J., Panareda, J. M., & Cerdà, A. (2016). The role of forest fire severity on vegetation recovery after 18 years. Implications for forest management of *Quercus suber* L. in Iberian Peninsula. *Global and Planetary Change*, 145, 11–16.
- [8] Moreno, M., Bertolín, C., Arlanzón, D., Ortiz, P., & Ortiz, R. (2023). Climate change, large fires, and cultural landscapes in the mediterranean basin: An analysis in southern Spain. *Heliyon*, 9(6).
- [9] Novo, A., Fariñas-Álvarez, N., Martínez-Sánchez, J., González-Jorge, H., Fernández-Alonso, J. M., & Lorenzo, H. (2020). Mapping forest fire risk—a case study in Galicia (Spain). *Remote Sensing*, 12(22), 3705.
- [10] Pereira, P., Francos, M., Brevik, E. C., Ubeda, X., & Bogunovic, I. (2018). Post-fire soil management. *Current Opinion in Environmental Science & Health*, 5, 26–32.
- [11] Rigolot, E. (2008). Impact du changement climatique sur les feux de forêt. *Forêt Méditerranéenne*, 29(2), 167–176.
- [12] Tezcan, B., & Eren, T. (2022). Orman Yangınlarına Etki Eden Faktörlerin Önceliklendirilmesi. 3rd International Disaster Management Congress. Tokat, Türkiye.
- [13] Tezcan, B., & Eren, T. (2023). Sürdürülebilir Kalkınma İçin Çam İğnelerinin Enerji Üretimine Olanak Sağlayan Kriterlerin Önceliklendirilmesi. 42. Yöneylem Araştırması ve Endüstri Mühendisliği (YA/EM) Ulusal Kongresi, 1-3 Kasım 2023, Gaziantep, Türkiye.
- [14] Tezcan, B., & Eren, T. (2024). Orman yangınlarında iş sağlığı ve güvenliği uygulamalarının değerlendirilebilmesi için AHP ve ANP yöntemleri ile ölçütlerin belirlenmesi: Türkiye Örneği. *Ağaç ve Orman*, 5(2), 98–105.
- [15] Tezcan, B., & Eren, T. (2025). Forest Fire Risk Assessment in Balıkesir using Pythagorean Fuzzy AHP and Pythagorean Fuzzy TOPSIS. *Politeknik Dergisi*, 1.
- [16] Vieira, D. C. S., Borrelli, P., Jahanianfard, D., Benali, A., Scarpa, S., & Panagos, P. (2023). Wildfires in Europe: Burned soils require attention. *Environmental Research*, 217, 114936.