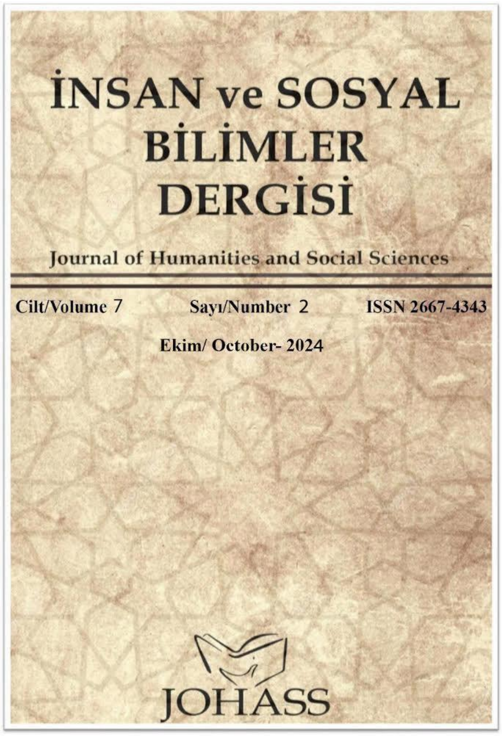
**JOURNAL OF HUMAN AND SOCIAL SCIENCES (JOHASS)**



**https://dergipark.org.tr/tr/pub/johass**

# The Use of Geographic Information Systems and Multi-Criteria Decision-Making Methods in the Creation of Forest Fire Susceptibility Maps: A Literature Review

**Ali Bahadır KÜÇÜKARSLAN**[1]
*İstanbul Ticaret University, Faculty of Engineering Department of Occupational Health and Safety Program*
*Dr.*
*bahadirkucukarslan@gmail.com*
*Orcid ID: 0009-0000-2580-146X*

**Mustafa KÖKSAL**[2]
*İstanbul Ticaret University, Faculty of Engineering Department of Occupational Health and Safety Program*
*Prof. Dr.*
*mkoksal@ticaret.edu.tr*
*Orcid ID: 0000-0001-6026-9798*

**İsmail EKMEKÇİ**[3]
*İstanbul Ticaret University, Faculty of Engineering Department of Occupational Health and Safety Program*
*Prof. Dr.*
*iekmekci@ticaret.edu.tr*
*Orcid ID: 0000-0002-2247-2549*

---

**Article Type:** Research Article
Received: 13.10.2024
Accepted: 29.10.2024
Published online: 29.05.2024

**Citation:** Küçükarslan, A. B., Köksal, M., & Ekmekçi, İ. (2024). The use of geographic ınformation systems and multi-criteria decision-making methods in the creation of forest fire susceptibility maps: A literature review. *Journal of Human and Social Sciences*, *7*(2), *259-285*.

*Journal of Human and Social Sciences (JOHASS), 2024, 7(2), 259-285.*

# The Use of Geographic Information Systems and Multi-Criteria Decision-Making Methods in the Creation of Forest Fire Susceptibility Maps: A Literature Review

**Ali Bahadır KÜÇÜKARSLAN**[*1]

*İstanbul Ticaret University, Faculty of Engineering Department of Occupational Health and Safety Program*

**Mustafa KÖKSAL**[2]

*İstanbul Ticaret University, Faculty of Engineering Department of Occupational Health and Safety Program*

**İsmail EKMEKÇİ**[3]

*İstanbul Ticaret University, Faculty of Engineering Department of Occupational Health and Safety Program*

**Abstract** **Research Article**

Forest fires are natural disasters that cause significant environmental, economic, and social damage worldwide. This study provides a literature review examining how Geographic Information Systems (GIS) and Multi-Criteria Decision-Making (MCDM) methods are utilized in the prevention of forest fires and the identification of high-risk areas. GIS, as a system used for the collection and analysis of spatial data, enables the consideration of various factors influencing fire risk, such as climate change, topography, vegetation, and weather conditions. The spatial analysis capabilities offered by GIS play a critical role in identifying regions with high fire susceptibility when generating fire risk maps. Additionally, MCDM methods contribute significantly to the decision-making process by allowing the evaluation of multiple criteria in fire risk analysis. Logistic Regression and Frequency Ratio, which are frequently employed in the literature, are widely used in fire risk analysis and improve the accuracy of susceptibility maps. Furthermore, MCDM methods have been proven effective in estimating the likelihood of forest fire occurrences and identifying fire-prone areas. The integration of GIS and MCDM methods allows for more precise identification of risk zones and supports the development of fire prevention strategies. This literature review highlights the advantages of utilizing GIS and MCDM in the production of forest fire susceptibility maps and suggests that these methods may have broader applications in future research. The effective use of technology in combating forest fires enhances the accuracy of fire risk assessments, contributing significantly to environmental protection efforts.

**Keywords:** Forest fire, Geographic Information Systems, Multi-Criteria Decision-Making, susceptibility map, fire risk analysis

*Received*: 13.10.2024
*Accepted: 29.10.*2024.

---

[*] **Corresponding author:**
[1] Dr.
*bahadirkucukarslan@gmail.com*
*Orcid ID: 0009-0000-2580-146X*
[2] *Prof. Dr.*
*mkoksal@ticaret.edu.tr*
*Orcid ID: 0000-0001-6026-9798*
[3]*Prof. Dr.*
*iekmekci@ticaret.edu.tr*
*Orcid ID: 0000-0002-2247-2549*

## Introduction

Forest fires are among the most devastating natural disasters, causing severe environmental, economic, and social damage worldwide. As climate change continues to increase the frequency and intensity of these events, there is an urgent need for more effective tools and methodologies to predict and manage forest fire risks. Geographic Information Systems (GIS) and Multi-Criteria Decision-Making (MCDM) methods have emerged as powerful tools in this regard, offering the ability to analyze spatial data and assess multiple risk factors simultaneously. This paper presents a comprehensive literature review examining how GIS and MCDM methods are employed in the creation of forest fire susceptibility maps, which are essential for identifying high-risk areas and informing fire prevention strategies.

GIS is a system designed to collect, manage, and analyze spatial data, making it a critical tool in assessing the factors that contribute to forest fire risk. These factors include climate change, topography, vegetation types, and weather conditions, all of which can significantly influence the likelihood of fire outbreaks. GIS enables the spatial visualization of these variables, helping decision-makers to identify regions with high fire susceptibility. This spatial analysis capability is particularly valuable in forest fire risk management, where accurately predicting the areas most vulnerable to fire is crucial for effective prevention and mitigation efforts (Hicks, 1993; Longley et al., 2001).

In addition to GIS, MCDM methods play a significant role in enhancing decision-making processes by allowing for the evaluation of multiple criteria in fire risk analysis. MCDM methods such as Logistic Regression and Frequency Ratio are widely used in the literature and have been shown to improve the accuracy of forest fire susceptibility maps. These methods enable decision-makers to integrate diverse datasets, assign weights to different risk factors, and generate more precise predictions of fire-prone areas. By providing a structured framework for analyzing complex risk factors, MCDM methods contribute to more informed and reliable fire risk assessments (Eastman et al., 1995; Aydin et al., 2019).

The integration of GIS and MCDM methods represents a significant advancement in forest fire management. The combination of these tools allows for the precise identification of high-risk zones and supports the development of targeted fire prevention strategies. This is particularly important in a context where environmental conditions are rapidly changing due to global warming, making fire risk assessments more complex and dynamic. As such, the use of GIS and MCDM in fire risk management is not only timely but also essential for enhancing the accuracy of fire risk assessments and improving the effectiveness of fire prevention measures.

This study aims to provide a detailed examination of the current applications of GIS and MCDM in forest fire risk management. By reviewing the existing literature, this paper highlights the advantages of these methods in producing accurate fire susceptibility maps and offers insights into their broader applications in future research. The integration of technology in combating forest fires is crucial, as it allows for more precise risk identification and contributes significantly to environmental protection efforts. Given the increasing threat posed by forest fires globally, the effective use of GIS and MCDM methods has the potential to significantly reduce the impact of these disasters, safeguarding both natural ecosystems and human communities.

The primary objective of this research is to investigate the integration of GIS and MCDM methods in creating forest fire susceptibility maps, with a focus on their effectiveness in improving fire risk analysis. This paper aims to provide a comprehensive review of the methodologies used in the field, evaluate the strengths and limitations of these approaches, and propose recommendations for their future application. The research also seeks to emphasize the importance of GIS and MCDM in developing more accurate fire prevention strategies, which are critical in the context of increasing fire risks due to climate change.

The significance of this study lies in its potential to contribute to the ongoing efforts to mitigate forest fire risks. By offering a detailed review of the literature, this paper underscores the value of integrating GIS and MCDM methods in fire risk management and highlights their potential to enhance the resilience of ecosystems and communities to fire-related disasters. As forest fires continue to pose a significant threat, the development of more accurate and effective risk assessment tools is essential for preventing and managing these destructive events.

## Background

### Risk Analysis in Geographic Information Systems

Risk management, designed as a systematic process, comprises the identification, analysis, and assessment of risk factors. In the event of a fire, minimizing the loss of life and property, as well as mitigating the adverse effects of the fire, can only be achieved through effective risk management in areas prone to fire hazards. Risk management activities include identifying hazards and risks, preparing risk scenarios, selecting protective and mitigation measures, presenting results using updated maps and graphs, identifying available resources and opportunities, making decisions on the most appropriate alternatives and priorities, and selecting and implementing disaster prevention and response methods (Özcan et al., 2009).

Globally, various methods and tools have been developed for fire risk management, with Geographic Information Systems (GIS) being one of the most important tools. It is evident that the use of GIS, particularly in analyzing risk scenarios, has been steadily increasing. The combined use of remote sensing and GIS technologies across broad geographical areas makes GIS a highly attractive tool.

The growing use of GIS worldwide by individuals and institutions involved with spatial information has led to new studies and applications. From this perspective, GIS is both a scientific concept that encompasses all spatial information systems and a computer-based tool and database management system that digitizes spatial information (Yomralıoğlu, 2002). This system enables the collection, storage, classification, updating, synthesis, and generation of alternative strategies related to geographical events within a short period. All studies prepared from different perspectives are essential for recognizing and expanding the use of GIS.

One of the key functions of GIS today, which serves various disciplines, is identifying and solving environmental problems. One such issue is determining and measuring risk. Financial risk, for example, refers to the possibility that an investment may not yield a return, or that the actual return may differ from the expected return (Jones, 1998). In financial theory, risk is classified according to its sources into systemic risk, systematic risk, and unsystematic risk. Systemic risk refers to risks that arise from the system itself and affect all securities in the market, beyond the control of the organization (Okka, 2010). Since market actors are the primary sources of systematic risk, neither countries nor organizations have direct control over it. Many factors related to systematic risk also encompass financial risk factors. Additionally, changes in a country’s financial management and economy can significantly impact that country’s trade (Hoti and McAleer, 2005).

Country-specific risks primarily consist of financial, economic, and political risk factors, with financial risks being particularly important for both countries and businesses. Financial risks encompass all types of risks related to money, including uncollectible receivables, declining income, inability to repay debts, unemployment, inflation, and many other variables (Altan et al., 2016). Examining these risk factors on a more granular level, rather than as a whole, offers significant benefits. For example, when defining financial risks for a country, regionally differentiating these risk values from a geographical perspective allows for a more dynamic analysis from both the investor and national perspectives.

In the relevant literature, several studies focus on creating financial risk maps. Cecchetti et al. (2010), for example, developed a risk map of countries exposed to systematic risk by using data from the international banking sector. Pegion et al. (2008) developed a risk assessment study using GIS, while Colletaz et al. (2013) created a risk map by employing value-at-risk. Altan et al. (2016) mapped the financial risk in Turkey by using average financial risk factors. In these studies, risk maps were generated not only using GIS methods but also through graphical analyses. Additionally, there are studies that employ spatial regression and GIS analysis. Çelik (2017) conducted a spatial regression analysis to assess the effectiveness of incentive policies in Turkey, while Baktemur and Özmen (2017) analyzed unemployment convergence in developed EU countries using spatial econometrics, finding a spatial effect on unemployment. Akıncı et al. (2017) used geographically weighted regression analysis to investigate the socio-economic determinants of terrorism.

In conclusion, GIS provides a comprehensive framework for risk management and analysis across various disciplines, with a particular emphasis on environmental and financial risk assessment. The ability of GIS to combine spatial and attribute data, along with advanced analytical tools such as spatial regression, enhances the capacity for effective decision-making in managing risks. By integrating remote sensing data and employing methodologies like MCDM, GIS plays a crucial role in developing risk scenarios, enabling informed choices on prevention and mitigation strategies in the face of both environmental and financial risks.

## Geographic Information Systems (GIS) and Forest Fire Susceptibility Assessment

Geographic Information Systems (GIS) are computer-assisted tools essential for transforming the structure of the world and its events into maps and performing various analyses. GIS also functions as an integrated system that can combine common databases. In other words, GIS technology offers users the ability to conduct queries, visualize data, and perform statistical and geographical analyses. Due to these capabilities, GIS is widely used to identify public and private sector projects and develop practical plans for the future (Yomralıoğlu, 2000).

Using GIS, it is possible to perform standard tasks such as generating slope and aspect maps with a digital elevation model, creating 3D visualizations using elevation data, obtaining statistical information about objects, calculating distance and area values, and overlaying various thematic maps (Bektaş, 2003).

In Turkey, GIS plays a crucial role in mitigating or eliminating the impacts of forest fires. Through GIS technology, forest fire risks and hazards in fire-prone forests can be mapped, and fire-prone areas can be identified in advance. This allows managers responsible for fire prevention to focus on areas with high fire risks and take the necessary precautions (Özşahin, 2014). GIS can also be employed in various aspects of forest fire management, such as public awareness campaigns, education, modeling, planning, analysis, firefighting activities, identifying at-risk locations, and rehabilitation efforts (Şahin, 2006).

By integrating spatial data and enabling the visualization of fire-prone regions, GIS facilitates more informed decision-making in forest fire management. It provides a comprehensive platform for evaluating susceptibility, enabling authorities to plan effectively and allocate resources to minimize the impact of potential forest fires. The use of GIS in these processes helps improve the efficiency of fire prevention strategies and response efforts, thereby contributing significantly to environmental and public safety.

## Related Studies

In a study conducted by Karabulut et al. (2013), Geographic Information Systems (GIS) were used to identify forest fire risk areas in the Başkonuş Mountains in Kahramanmaraş. Weights were assigned to each layer based on their sensitivity to causing fires, and fire risk areas in the region were identified. The analysis revealed that areas with high fire risk were concentrated around settlements and the roads connecting these settlements.

Hacısalihoğlu (2018) aimed to determine the spatial distribution of 123 forest fires that occurred within the Karabük Forest Management Directorate (FMD) between 2012 and 2016, based on their starting points. For this purpose, a unique forest fire inventory map was created. The weight of each factor influencing the occurrence of the fires was determined using the Analytical Hierarchy Process (AHP). Based on these weights, analyses were conducted, and forest fire susceptibility maps were produced. These maps were categorized into four classes: low, medium, high, and very high fire susceptibility. To assess the accuracy of these maps, they were compared to the forest fire inventory map, and a 92% compatibility rate was found using the multi-criteria decision-making (MCDM) method.

In a study by Dilekçi (2019), the goal was to identify the factors influencing forest fires in the Zonguldak and Ereğli FMD regions and to create a forest fire risk map. Forest fires that occurred between 2008 and 2018 were marked on satellite images. Factors such as proximity to roads, settlements, elevation, aspect, slope, and land cover type were determined as the most significant contributors to forest fires. The AHP method was used to assess the impact of each factor. Land cover types were classified using Landsat 8 satellite imagery, and forest fire-related classes were identified. Using ArcGIS 10.5, maps were created for each factor influencing forest fires, and their relative importance was determined through spatial queries. The maps were converted into raster format with 30x30 meter resolution for further analysis. The resulting forest fire risk map showed that 18% of the total area was in the low-risk category, 43% in the medium-risk category, and 39% in the high-risk category.

Gayır (2019) aimed to conduct a spatial statistical analysis of forest fires that occurred between 2011 and 2015 in the Muğla forest region and to create risk maps. A clustering/pattern analysis was conducted based on the locations of the fires. Regression studies were performed to determine risk parameters, using the least squares regression and geographically weighted regression models. The accuracy of these models was tested, and the results will serve as a foundation for future studies. The models also provide recommendations for preventive measures, potentially reducing the budget needed for future project planning.

Karadeniz (2020) conducted a study in which topographic, vegetative, meteorological, and landscape characteristics were assessed to evaluate the forest fire that occurred in Urla, İzmir in 2019. Based on the study findings, a fire simulation was created. According to the fire risk map, 2% of the area had low risk, 28% had moderate risk, and 70% had high risk. The study also found that the areas with the highest risk corresponded to actual fire locations in 2008, 2009, and 2019, confirming the model's accuracy.

In a study by Özenen Kavlak, Kurtipek, and Çabuk (2020), GIS tools were used to assess the forest fire risk in the Kütahya-Ören Forest Management Directorate. The study found that 128 fires occurred in the region between 2005 and 2009, damaging 99.18 hectares of land. A GIS-supported fire risk map was created to contribute to minimizing material and physical damage caused by fires and to prepare for future fires. Additionally, a visibility analysis was performed to assess the coverage of fire watchtowers in the area. Recommendations for preventing and managing fire risks were provided based on the results of the GIS-based risk maps and visibility analysis.

In a study by Baltacı (2021), forest fire risk analysis was conducted as part of decision support systems used in forest fire prevention efforts. Eleven criteria, including canopy cover, tree species, slope, age classes, altitude, aspect, and distances to settlements, roads, power lines, wetlands, and agricultural lands, were considered in calculating forest fire risk. GIS analyses were performed to determine the range of criteria values, followed by field studies to verify the accuracy of the data. Unlike previous studies, it was found that fire risk decreases as altitude and slope increase. The study concluded that the highest risk areas were within 0-25 meters of human activity. The findings from GIS analyses and fieldwork showed strong alignment with areas where fires were likely to occur.

Finally, in a study conducted by Dilekçi, Marangoz, and Ateşoğlu (2021), 126 forest fires that occurred between 2008 and 2019 in the Zonguldak and Ereğli FMD regions were analyzed using fire registry forms. The study identified the land use classes, topographic factors, and human factors that contributed to the fires. Vector data on road and settlement networks were extracted from Google Earth, while Landsat 8 satellite imagery and a Digital Elevation Model were used for land use and topographic data, respectively. Using the AHP method, suitability scores were calculated for each factor. Based on these scores, a GIS-based forest fire risk map was created, dividing the area into low, medium, and high-risk categories. The analysis showed that 39% of the area was in the high-risk category, 43% in the medium-risk category, and 18% in the low-risk category.

## Types of Forest Fires

Forest fires are classified into different types based on the area they affect. According to this classification, there are three main types of forest fires: surface fires, crown fires, and ground fires (OGM, 1995).

Surface fires, also known as understory fires, are fires that burn the dead plant materials covering the forest floor, such as dry branches, logs, and slash, as well as living vegetation like seedlings, shrubs, moss, grass, and leaves (Bilgili, 2014). These fires typically affect the organic materials that cover the forest soil and are the most common type of forest fire encountered in wooded areas. The development of a surface fire depends on the condition of the dead and living vegetation that covers the forest floor. Almost all forest fires start as surface fires and then develop further depending on environmental conditions (Küçük et al., 2009). Although surface fires generally do not cause significant damage to the main forest trees, they can harm these trees if there is a high accumulation of combustible materials on the forest floor (Bahadır, 2010). To prevent this damage, it is crucial to monitor and control the affected area effectively after the fire has been extinguished (OGM, 1995).

Crown fires occur when surface fires spread to the treetops, igniting the crowns of trees and shrubs (Küçük et al., 2009). These fires can develop into crown fires due to the effects of high temperatures and gas emissions in coniferous forests, or when combustible materials such as lichen, moss, and dry branches on tree trunks are ignited (Kula, 2018). As a result, crown fires are more commonly observed in coniferous forests. Crown fires are the fastest-growing and most dangerous type of forest fire. They spread rapidly through the tree canopy, making them challenging to control and extinguish. Crown fires have a detrimental effect on the development of trees and shrubs, often resulting in the loss of vitality in forest stands (OGM, 1995).

Ground fires burn thick organic materials below the surface, such as peat and humus (Bilgili, 2014). These fires usually begin in dried-up marshlands where decaying plant material releases combustible gases, which ignite and burn through the thick, soil-like layer (Özdemir & Çelik, 2020). Ground fires spread slowly beneath the surface but can sometimes emerge above ground and transition into surface fires. Due to the scarcity of thick humus and peat layers in Turkish forests, ground fires are relatively uncommon in Turkey (OGM, 1995). Ground fires are characterized by flameless combustion within the soil, making them extremely hot and destructive. By consuming all organic matter in the soil, ground fires transform it into mineral ash, making them one of the most damaging fire types to the environment. In areas affected by ground fires, the regrowth of vegetation is often impossible (Şakar, 2018).

## Factors Influencing Forest Fire Formation

While forest fires cannot be predicted with absolute certainty, several factors can increase the likelihood and risk of fire. These factors include climate change, weather conditions, and human activities.

Weather is the most dynamic element influencing fire conditions and is the dominant factor in determining the degree of fire danger on a given day. It is important to distinguish between climate, which refers to long-term atmospheric conditions, and weather, which pertains to daily fluctuations. Atmospheric conditions that affect forest fires include precipitation, temperature, humidity, and wind (Calda et al., 2020).

Humidity is an indicator of the percentage of water vapor saturation in the air at a given temperature. High relative humidity indicates a large amount of moisture in the air, which in turn influences the moisture content of the fuel. Moist fuels are more difficult to ignite (Santiago & Kheladze, 2011). Fire risk is especially high when relative humidity drops below 30%, and the risk increases further when humidity falls below 60% (Karadeniz, 2020).

Surface temperature directly affects fire risk by regulating the temperature of combustible materials. Higher temperatures mean that the material is closer to its ignition point, which accelerates the spread of fire (Çolak & Sunar, 2018).

Wind is one of the most critical factors in determining fire behavior. It influences the pre-heating and drying of fuels and increases the oxygen supply. Strong winds can also cause embers to spread, igniting new fires (Küçük & Sağlam, 2004). High wind speeds can significantly accelerate the spread of a fire, while strong wind pressure can create convective effects that preheat and dry fuels, promoting faster fire propagation (Santiago & Kheladze, 2011).

Precipitation can either reduce ignition risks by moistening fuels or extinguish already burning fires. Moisture absorbed by plants and soil increases fuel moisture content, which reduces ignition chances (Erdem, 2018). Prolonged droughts, however, can increase fire occurrences and cause significant damage in affected areas.

Weather conditions play a significant role in the formation of forest fires (Flannigan et al., 2005). The relationship between forest fires and climate is evident globally. The number of fires and the total burned area are closely associated with maximum and absolute maximum surface temperatures, which correlate with sunlight exposure (Koutsias et al., 2013). Droughts and environmental effects increase the likelihood of large fires, with various weather components having a relative influence on fire (Avcı & Korkmaz, 2021). In Portugal, for example, burned areas are closely linked to seasonal rainfall and fuel moisture (Carvalho et al., 2008). In California, USA, large fires are more influenced by wind patterns than by precipitation (Freedman, 2008).

Topography significantly influences fire behavior both directly and indirectly (Alkayış, Karslıoğlu, & Onur, 2022). Terrain features such as "channels" and "valleys" contribute to fire expansion, while the presence of lakes, bare soil, or rocks can hinder the spread of fire. In this sense, topography can either facilitate or impede fire spread. Key topographic factors affecting fire include aspect, elevation, and slope (Yılmaz et al., 2021).

Aspect refers to the direction a slope faces. It is measured in degrees, ranging from 0° (north) to 180° (south) and 360° (north). In the Northern Hemisphere, south-facing slopes receive more sunlight, resulting in lower relative humidity and higher temperatures, which increase fire risk (Burgess, 2011; Heyerdahl et al., 2001). In contrast, north-facing slopes have higher humidity and lower temperatures, reducing fire risk. In Turkey, fires spread more rapidly on south and southeast-facing slopes due to increased sunlight exposure (Dilekçi, Marangoz, & Ateşoğlu, 2021).

Elevation begins at sea level and influences the overall climate of a region (Baltacı & Yıldırım, 2020). Lower elevations are typically characterized by higher temperatures and lower relative humidity, while higher elevations experience higher fuel moisture and relative humidity due to orographic rainfall, limiting the likelihood and spread of fires (Cüce et al., 2020).

Slope refers to the steepness of the terrain. The steeper the slope, the faster the fire spreads. Slope is usually measured in degrees or percentages and directly affects the length of flames and the rate of fire spread (Kavlak, Kurtipek, & Çabuk, 2020). As the slope increases, the fire spreads uphill more rapidly due to the increased heat transfer to the fuel ahead of the fire (Baltacı & Yıldırım, 2020). Slope is the most significant topographic factor influencing fire behavior. Depending on wind speed and the angle of the slope, slope can sometimes be more effective than wind in determining the rate at which a fire spreads (Rawat, 2003).

In addition to climate change, weather conditions, and topography, the sources of combustible materials, the combustion of these materials, fire behavior, and the fire hazard index also play critical roles in the formation of forest fires. The sources of combustible materials in a forest are formed as a result of the growth, development, and eventual death of living plants, species, and other forest components. These materials vary in their distribution within the forest. Combustible materials in a forest can be categorized into three groups based on their general characteristics and vertical distribution: subsurface combustible materials, surface combustible materials, and tall combustible materials (Çanakçıoğlu, 1993). These include all combustible materials within the upper soil layer, such as fertilizers, peat, decaying organic matter, tree roots, and humus. These include both living material and dead debris. Surface combustible materials cover all flammable material on the topsoil, such as thin and decayed branches, fallen leaves, grass, bark, cones, seedlings, short shrubs, small saplings, logs, and thick branches on the ground. These are generally located above 1.5 meters from the ground, within the forest canopy, and may consist of both living and dead materials. This category includes tall shrubs, lower canopy trees, branches, leaves, standing dead trees, climbing plants, tall shrubs, lichen, and moss. When materials in a forest begin to burn, a chemical reaction occurs between the resins, wood, and other flammable materials and the oxygen in the air. Forest fires progress through several stages: the initial spark, the smoldering phase, and the eventual ignition of combustible material. At times, forest fires can manifest with great intensity. Events such as thick smoke, flames jumping, sporadic explosions, loud noises, and extreme heat occur in accordance with the natural laws and principles governing fire behavior. Understanding the effects of various environmental factors on these laws and principles is crucial for decision-making during firefighting efforts (Bilici, 2008). Fire behavior refers to how a fire moves and reacts to the factors influencing it, such as combustible materials, weather conditions, and topography. For those combating a fire, predicting the fire's current actions and potential future behavior is a critical concern. Adequate knowledge of fire behavior makes it easier to effectively combat the fire and achieve successful outcomes (Castillo et al., 2021). The fire hazard index (FHI) refers to the potential of a fire occurring under existing conditions, based on factors that influence fire risk (Şenyaz, 2000). Fire hazard is the result of both constant and variable fire factors, determining the likelihood of a fire starting, the difficulty of firefighting, the rate of fire spread, and the damage caused. The fire hazard index is an element of firefighting planning and involves the organization and application of selected fire hazard factors in the form of indices, based on current protection needs (Coşkuner & Bilgili, 2020).

As an environmental factor, the effects of fires initiate a process of ecological restructuring, leading to the recovery of ecosystems post-fire (Doussi & Thanos, 1994). Fires can also result in the degradation of ecosystems, often driven by human activities, causing a shift away from the existing floristic composition and structural characteristics (Moreira & Vallejo, 2009). Anthropogenic changes (Pausas & Keeley, 2014) and climate change (Pausas, 2004) have led to significant changes in regional fire regimes (Tavşanoğlu, 2017). Thus, when combined with human activities and other factors, forest fires can become catastrophic events that should be assessed outside the context of natural cycles.

## Methods Used in the Production of Forest Fire Susceptibility Maps

Forest fires are defined as fires that burn combustible materials found in forests, such as logs, trees, needles, grass, dry wood, and leaves, either partially or completely. Due to the open environment, these fires tend to spread freely (Hacısalihoğlu, 2018). The General

Directorate of Forestry (OGM) defines a forest fire as a fire that can destroy both living and non-living entities within the forest ecosystem and has a tendency to spread uncontrollably (OGM, 1995). Similarly, in regulations, forest fires are described as "fires that destroy all living and non-living entities within the forest ecosystem by burning and that tend to spread freely" (OGM, 2008).

For a forest fire to ignite, three key components—known as the "fire triangle"—must be present: combustible materials, oxygen, and ignition temperature (Bahadır, 2010). If any of these three components are absent or insufficient, a fire cannot occur. Thus, in fire prevention and control, eliminating one of these components is crucial. The amount and quality of these three components also determine the intensity and spread of a forest fire (Turnalı, 2020). Specifically, the temperature of combustible materials must exceed 260-400°C, the oxygen concentration must be above 15%, and sufficient combustible material must be available for a fire to ignite and spread (OGM, 2008).

In this context, the methods used to create forest fire susceptibility maps focus on assessing these three elements and other environmental factors to predict and mitigate the risk of forest fires.

## The Role of GIS in Forest Fires

Forest fires can cause significant loss of life and property, particularly during the summer months, both globally and in Turkey. Predicting the occurrence, intensity, and spread of forest fires is crucial to minimizing these losses. However, obtaining such information through ground-based measurements can be time-consuming, costly, and labor-intensive (Yavuz & Sağlam, 2011).

To effectively combat forest fires, it is essential to take all necessary precautions and utilize resources efficiently. In addition to this, the use of advanced technologies at every stage of the process is critical. One of the most important technologies in modern fire management is Geographic Information Systems (GIS) (Tecim, 2008). GIS, which provides valuable data across various fields, has one of its most significant applications in forestry (Karabulut et al., 2013). Today, GIS technology is employed in forest management, operations, transportation, fire prevention, and many other forestry-related applications (Akay et al., 2008; Gümüşay & Şahin, 2009; Sivrikaya et al., 2007; Yüksel et al., 2008; Wing et al., 2010). GIS allows for fast, easy, and cost-effective access to the necessary information

(Küçük & Bilgili, 2006). As a result, GIS provides valuable data not only during fires but also in pre-fire and post-fire research (Şahin, 2006).

As a decision-support system, GIS enables optimal planning, transportation, and coordination of first response and firefighting teams (Akay & Şakar, 2009; Varol et al., 2010; Akay et al., 2011). GIS helps monitor the structure of the atmosphere, the detailed topography of fire-prone areas, and the properties of combustible materials, allowing for safe and effective fire management.

GIS also helps fire managers better understand and visualize the physical factors and relationships that influence fire behavior. Factors such as slope, aspect, and vegetation can be analyzed to predict where the fire will occur and where it will be most intense (Gayır & Arslan, 2018). This information can be used to view and compare cultural resources, critical infrastructure, important facilities, and wildlife habitats. Additionally, historical forest fires can be mapped alongside potential sources of ignition, such as power lines, roads, factories, and settlements, allowing fire-prone areas to be identified. Furthermore, key assets, highly flammable forests, and areas with a high likelihood of fire ignition can be visualized together, facilitating the planning of fundamental forest fire management activities (ESRI, 2000).

## Methods Used in the Preparation of Forest Fire Maps

In the production and analysis of forest fire susceptibility maps, which require consideration of multiple human and natural factors such as topography, modern methodologies like decision tree analysis, support vector machines, heuristic algorithms based on artificial neural networks, probability-based methods like the "frequency ratio," and statistical methods like the "logistic regression method" are recommended (Hacısalihoğlu, 2018). Additionally, one of the widely adopted and developed approaches, particularly with technological advancements in GIS, is the "Multi-Criteria Decision Analysis" (MCDA) method (Şahin, 2012).

## Multi-Criteria Decision-Making Analysis

In decision-making, individuals or institutions rarely rely on a single criterion. Multiple criteria are often considered, especially when aiming for long-term benefits. However, in many decision problems, finding an ideal solution that satisfies all criteria simultaneously is often not possible. Therefore, the goal is to evaluate all criteria and reach the most suitable solution from the available alternatives (Ishizaka & Nemery, 2013).

Responses required in situations demanding action are decisions (İmrek, 2003), and determining the best course of action among available alternatives is decision-making (Saat, 2000). The fact that decision-making is a process distinguishes it from decisions (Tuncer et al., 2009). Decision-making involves selecting the most appropriate option from available choices to achieve a desired goal or solve a specific problem (Doğramacı, 2009).

Decision problems vary greatly depending on the methods used and the circumstances under which solutions are sought. Decisions made under the presence of multiple conflicting criteria are known as multi-criteria decisions. The process of determining the most suitable decision based on predefined criteria is called "multi-criteria decision-making" (Bazzazi et al., 2011). Since criteria often conflict with one another, no solution can satisfy all criteria simultaneously. In such cases, the decision is typically a compromise solution or a set of solutions based on the decision-maker's preferences (Sayadi et al., 2009). The compromise solution to a problem with conflicting criteria allows the decision-maker to find the solution closest to the ideal or desired outcome. A typical MCDA problem generally includes three fundamental components: "alternatives," "criteria," and the "relative importance" (weights) of each criterion. The ability to evaluate numerous criteria and alternatives simultaneously is one of the greatest advantages of MCDA methods (Chatterjee, 2010).

Decision analysis is the process of solving a complex decision problem through mathematical modeling, systematic procedures, and statistical analysis (Malczewski, 1999). In this process, the decision-maker seeks either to select the best alternative from a set of options or to rank all alternatives from best to worst (Kaya, İpekçi Çetin & Kuruüzüm, 2011).

In decision analysis, problems are broken down into smaller, meaningful combinations to integrate them logically and provide realistic solutions. Evaluating complex problems with multiple, conflicting criteria and finding solutions based on these criteria is known as multi-criteria decision analysis (Malczewski, 1999). In other words, MCDA is a method or technique designed to help make decisions when faced with problems characterized by conflicting and non-uniform criteria (Gökbek, 2014).

Multi-criteria decision analysis consists of three stages: understanding (intelligence), design, and choice (Demirtaş, 2009).

- **Understanding**: In this stage, raw data is collected, processed, and opportunities and challenges are identified. The decision-maker conducts research and scanning to assess the gap between the current and desired situations to make the correct decision.

- **Design**: In this phase, a fundamental model is used to convert complex documents into simple and understandable structures, and potential solutions for identified problems are developed and analyzed. This stage makes it easier for decision-makers to identify various options.
- **Choice**: At this stage, the alternatives developed in the design phase are evaluated. All available alternatives are assessed, and their relationships are analyzed based on defined decision rules to determine which alternative is the most appropriate.
- Decision-making is a dynamic process enriched by feedback, involving complex methods, information research, data collection, filtering, and feedback loops. Whether decisions are simple or complex, they follow the same fundamental processes (Demirtaş, 2009).
- **Problem Definition**: Every decision-making process begins with understanding and defining the decision problem. The first step is identifying the differences between the current state of the system and the desired state (Doğramacı, 2009). In this stage, the conditions for solving the problem are analyzed, data is collected, and processed (Malczewski, 1999). This step concludes with establishing clear, realistic, agreed-upon, and understandable goals or objectives (Doğramacı, 2009).
- **Determination of Evaluation Criteria**: This is the next stage after problem definition, where the evaluation criteria are determined. The criteria must be clear and consistent with the objectives of the task. By sourcing the criteria from a single source, the exclusion or inclusion of certain criteria can be avoided. Additionally, to avoid complexity, the number of criteria should be kept to a minimum (Majumder, 2015).
- **Alternatives**: These are the viable options that remain after narrowing down the choices in the decision space using various regions or criteria in the area of analysis. The alternatives are evaluated based on how well they fit the objectives of the study, categorized as unsuitable, moderately suitable, or suitable (Zardari et al., 2014).
- **Criteria Evaluation/Decision Matrices**: At this stage, the performance of each criterion is evaluated for each alternative. The result of the decision matrix serves as the foundation of multi-criteria evaluation (Arca, 2015).
- **Criteria Weights**: The importance of the differences between criteria is determined by assigning weights to each criterion. Since the assigned weights can significantly influence the overall evaluation, the decision-maker’s preferences should be

considered. In other words, decision-makers and groups must be involved in the MCDA process (Doğramacı, 2009; Sarımehmet et al., 2020).

- **Decision Rules**: These are the basic elements that help determine which alternative to select by ranking them based on numerical quality scores assigned according to how well they meet the criteria in question (Deniz & Topuz, 2018).
- **Sensitivity Analysis**: Sensitivity analysis is conducted to assess the reliability of a decision and to demonstrate the effect of errors in the data included in the analysis. This step makes it easier to understand which values most influence the decision (Şahin, 2012; Özşahin, 2013).
- **Priority/Recommendation**: At the end of the MCDA process, one or more alternatives are ranked, and a single alternative or multiple recommended options are suggested to the user (Şahin, 2012).

## GIS-Based Multi-Criteria Decision Analysis

The growing capabilities of Geographic Information Systems (GIS) have been significantly influenced by the needs of environmental management and spatial decision-making analyses. Over time, GIS has integrated with Multi-Criteria Decision Analysis (MCDA), creating what is now known as GIS-based MCDA, or G-MCDA (Selçuk et al., 2016). G-MCDA is a decision-making process that evaluates both geographic and non-geographic information (Malczewski, 1999).

In G-MCDA, GIS handles data collection, storage, organization, and analysis, while MCDA combines the preferences of decision-makers with spatial data to facilitate decision-making (Ünaldık, 2019). By allowing decision-makers to identify and evaluate multiple criteria and the relationships between them, GIS and MCDA make spatial decision-making easier and more effective (Malczewski, 1999).

The steps in the G-MCDA process include defining the decision goal, identifying the criteria, determining the value of indicators, normalizing the values of the criteria, assigning weights to the criteria, combining normalized criteria values with their assigned weights, ranking the preferences, conducting sensitivity analysis, and finally, making a decision (Jankowski, 1995). Once the problem is defined and the evaluation criteria are determined for the G-MCDA process, these criteria are prepared as layers within the GIS to enable comparison. However, since the criteria may have different units of measurement, they need to be normalized to allow for comparison. The main normalization methods include the

"Value/Benefit Function," "Linear Scale Transformation," and "Fuzzy Logic" approaches (Malczewski, 1999).

One of the commonly used statistical methods in GIS-based analyses is logistic regression (LR). This probabilistic statistical method is preferred to establish the relationship between multiple independent variables and a categorized dependent variable (Alkevli, 2015; Lee, 2005). Dependent variables are influenced by other variables and change when these influencing variables change. Independent variables, on the other hand, are not affected by other variables and change independently (Altural, 2012).

Logistic regression is often used as an alternative approach when the dependent variable is binary. When other statistical techniques for classification do not meet the required assumptions, logistic regression can produce more reliable results. Even when assumptions are met, many researchers prefer logistic regression because it resembles the linear regression model (Baş & Çakmak, 2012).

Logistic regression models can be applied as either binary logistic regression, where the independent variable is categorized, or multinomial logistic regression, where multiple categorical variables are included (Alkevli, 2015).

The reasons for preferring logistic regression include (Baydemir, 2014):

- The dependent variable is categorical.
- There are no restrictions on the independent variables being continuous or discrete.
- The model can be linearized, making it easier to interpret.
- Widely used statistical packages like SPSS and SAS can easily perform logistic regression analysis.
- There is no risk of encountering negative probabilities.
- The relationship between the dependent and independent variables does not need to be linear. It can be polynomial or exponential.

## Frequency Ratio Method

The frequency ratio is defined as the ratio of the probability of an event occurring to the probability of it not occurring (Erener et al., 2010). The frequency ratio method examines the relationship between each factor affecting the event and past events. This method, which is simple to understand and apply, is frequently used in the literature due to its ease of use (Hacısalihoğlu, 2018).

The frequency ratio method, also referred to as conditional probability or statistical index in the literature, is based on density analysis. Its primary principle involves transferring all relevant parameters into a GIS environment, linking them with a fire inventory map, and conducting density analyses (Lee & Talib, 2005).

The conditional probability assessment of forest and grassland fires is based on an independent evaluation of the factors contributing to the fire. These factors are classified according to fire density, with each class being weighted. The classes are then scored according to the fire's intensity, and an index is calculated. The area in each class is the total area being considered (Üzel Gününi, 2019). One of the advantages of the frequency ratio method, a bivariate statistical technique, is that it allows experts to draw conclusions, while its disadvantage lies in the use of situational assumptions (Arca, 2015). The sensitivity mapping that uses the frequency ratio method takes into account the frequency ratios of each factor influencing forest fires in the subcategory (Altural, 2012).

## Discussion and Result

This study aimed to investigate the role of Geographic Information Systems (GIS) and Multi-Criteria Decision-Making (MCDM) methods in the creation of forest fire susceptibility maps, and to evaluate their effectiveness in forest fire risk management. The findings indicate that these technologies play a pivotal role in improving the accuracy of fire risk analysis, enabling more effective prevention and mitigation strategies.

GIS has proven to be an essential tool in forest fire management, primarily due to its ability to integrate various types of spatial data and perform detailed analysis. In the context of this study, GIS was used to assess the fire susceptibility of the Manavgat region, resulting in the identification of approximately 44,384 hectares (49.32% of the total area) as high or very high risk for forest fires. These high-risk areas were found to be concentrated in regions with specific topographic and environmental characteristics, such as red pine forests, southern-facing slopes, and areas with elevations ranging from 0 to 750 meters. Furthermore, the study found that the lack of adequate watchtowers in high-risk areas contributed to the vulnerability of these regions, making early detection and prevention more challenging.

GIS enables forest managers to visualize fire-prone areas based on topographic features, vegetation types, and proximity to human activities. The integration of such data into GIS systems allows for a more comprehensive understanding of fire dynamics, enabling decision-makers to predict where fires are likely to occur and how they might spread. This predictive capability is particularly important in areas like Manavgat, where environmental conditions such as steep slopes and dry vegetation increase the likelihood of fire outbreaks.

The combination of GIS with MCDM methods has further enhanced the ability to manage forest fire risks. MCDM techniques, such as Logistic Regression and the Frequency Ratio method, are widely used to assign weights to various fire risk factors, such as slope, aspect, and proximity to roads, allowing for a more accurate assessment of fire-prone areas. By integrating multiple criteria into the analysis, MCDM methods provide a structured approach to evaluating complex environmental conditions, enabling forest managers to prioritize areas for fire prevention and allocate resources more efficiently.

The study's use of MCDM methods revealed that topographic features such as slope and aspect play a critical role in determining fire susceptibility. In particular, southern-facing slopes, which receive more sunlight and have lower humidity levels, were identified as the most fire-prone areas. Additionally, regions with high road density and proximity to human settlements were found to be at higher risk, underscoring the need for more focused fire prevention efforts in these areas.

The integration of GIS and MCDM methods represents a significant advancement in forest fire risk management. The ability of GIS to handle large datasets and visualize spatial relationships, combined with the decision-making capabilities of MCDM, allows for more precise identification of high-risk zones. This integration enables forest managers to develop targeted fire prevention strategies that take into account multiple risk factors, such as vegetation type, topography, and weather conditions.

For instance, the findings from the Manavgat case study highlight the importance of focusing fire prevention efforts on areas with steep slopes and southern-facing hillsides. The ability to overlay fire risk maps with data on watchtower locations also revealed that many high-risk areas lacked adequate fire monitoring infrastructure, suggesting a need for better spatial planning in fire prevention efforts. This level of detail, made possible by GIS and MCDM integration, allows for a more proactive approach to forest fire management.

The insights gained from this study have significant implications for forest fire management policies in Turkey and beyond. The findings underscore the importance of taking a proactive approach to fire prevention by identifying high-risk areas before fires occur. By integrating GIS and MCDM methods into forest fire management plans, policymakers can develop more effective strategies for preventing fires and minimizing their impact.

Key preventive measures identified in this study include the need for public awareness campaigns to educate citizens about the risks of forest fires and the importance of early reporting. In addition, there is a need to revise legal frameworks, such as the constitutional provisions that allow for the allocation of previously forested lands to rural communities, which may contribute to intentional forest fires. Strengthening these legal frameworks in line with modern forestry principles can help reduce the incidence of human-induced fires.

Moreover, the study recommends that fire-prone areas be continuously monitored for changes in weather conditions, such as wind speed, temperature, and humidity, which can significantly affect fire risk. The use of fire risk maps, updated regularly through GIS and MCDM analysis, will allow for better resource allocation and faster response times during fire events.

GIS and MCDM methods also play a crucial role in post-fire recovery efforts. After a fire has been extinguished, these tools can be used to assess the extent of the damage and guide reforestation efforts. The creation of post-fire recovery maps allows forest managers to determine which areas require immediate replanting and which species of trees are best suited for the affected regions. In high-risk areas, fire-resistant species should be prioritized to reduce the likelihood of future fires.

The integration of GIS and MCDM methods in post-fire recovery also enables a more strategic approach to reforestation. By aligning reforestation efforts with fire risk maps, forest managers can ensure that new plantings are done in a way that minimizes the risk of future fires. This approach not only helps restore the natural ecosystem but also enhances the resilience of the forest to future fire events.

In conclusion, the integration of GIS and MCDM methods in forest fire management has proven to be highly effective in improving the accuracy of fire risk assessments and guiding preventive measures. The findings of this study highlight the critical role that these technologies play in identifying high-risk areas, optimizing resource allocation, and informing fire prevention strategies. By leveraging the capabilities of GIS and MCDM, forest managers can take a more proactive approach to fire prevention, ultimately reducing the impact of forest fires on both the environment and human communities.

Moving forward, the continued development and application of GIS and MCDM methods will be essential for enhancing forest fire management efforts. As climate change continues to increase the frequency and intensity of forest fires, the need for more accurate and dynamic fire risk assessments will become even more critical. By integrating these technologies into forest management plans, policymakers can develop more effective strategies for mitigating the devastating effects of forest fires and ensuring the long-term sustainability of forest ecosystems.

## Recommendations

Based on the findings of this review, several recommendations can be made to enhance the implementation and research:

- **Enhance Public Awareness**: Implement extensive educational campaigns, particularly targeting younger generations, to raise awareness about forest fire risks and prevention strategies.
- **Improve Legal Frameworks**: Review and update legal provisions that may indirectly encourage human-induced fires, such as land allocation policies, to prevent intentional forest burning.
- **Strengthen Early Detection Systems**: Increase the number and strategic placement of watchtowers and integrate advanced monitoring technologies, such as drones and satellite imagery, for faster detection and response to fires.
- **Develop Comprehensive Fire Risk Maps**: Regularly update GIS-based fire risk maps incorporating real-time data on weather conditions and topography to support proactive fire management and resource allocation.
- **Promote Fire-Resistant Reforestation**: After fires, prioritize the planting of fire-resistant tree species in high-risk areas, using GIS and MCDM methods to guide reforestation and recovery efforts effectively.
- **Optimize Resource Allocation**: Use MCDM methods to ensure that firefighting resources, including equipment and personnel, are allocated efficiently to the most vulnerable regions.
- **Climate Change Mitigation**: Develop long-term strategies to address the growing threat of forest fires driven by climate change, integrating GIS and MCDM tools to adapt fire management practices accordingly.

## References

Alkevli, T. (2015). *Heyelan duyarlılık haritalarının üretilmesinde örneklem stratejileri ve bazı karar verme ağaçları algoritmalarının kullanımı üzerine bir araştırma* [Unpublished doctoral dissertation]. Hacettepe Üniversitesi, Fen Bilimleri Enstitüsü, Ankara.

Altural, T. (2012). *Coğrafi bilgi sistemiyle Akşehir (Konya) çevresinin heyelan duyarlılık incelenmesi* [Unpublished master's thesis]. Selçuk Üniversitesi, Fen Bilimleri Enstitüsü, Konya.

Arca, D. (2015). *Zemin hareketlerinin coğrafi bilgi sistemi destekli analizi: Kozlu örneği* [Unpublished doctoral dissertation]. Bülent Ecevit Üniversitesi, Fen Bilimleri Enstitüsü, Zonguldak.

Aydin, O., Alankuş, G., & Arıkan, A. (2019). ÇKKA ve CBS ile orman yangını duyarlılık haritası hazırlanması. *Türk Coğrafya Dergisi, 15*(2), 213-230.

Baltacı, U. (2021). *Türkiye'de orman yangını riskinin coğrafi bilgi sistemleri tabanlı olarak çok kriterli analizi ve haritalandırılması* [Unpublished doctoral dissertation]. Gazi Üniversitesi, Fen Bilimleri Enstitüsü, Ankara.

Bektaş, F. (2003). *Uzaktan algılama ve coğrafi bilgi sistemi entegrasyonu: Gökçeada ve Bozcaada örneği* [Unpublished master's thesis]. İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İstanbul.

Bektaş, İ. (2003). Coğrafi bilgi sistemleri ile orman yangınlarının yönetimi. *Orman Mühendisliği Dergisi, 14*(3), 91-99.

Bilgili, E. (2014). Orman yangını türleri ve yangın dinamikleri. *Orman Ekosistemleri Dergisi, 8*(2), 65-75.

Castillo Soto, M., Garfias Salinas, R., & Plaza Valencia, Á. (2021). Effects of fire on forest communities and sclerophyllous scrubs in Central Chile as a basis for the formulation of restoration guidelines. *Forest Ecology and Management, 482,* 118826.

Chatterjee, P., Athawale, V. M., & Chakraborty, S. (2010). Selection of industrial robots using compromise ranking and outranking methods. *Robotics and Computer-Integrated Manufacturing, 26,* 483-489. https://doi.org/10.1016/j.rcim.2010.02.007

Coskuner, K. A., & Bilgili, E. (2020). Orman yangın yönetiminde etkili bir karar destek sisteminin kavramsal çerçevesi. *Doğal Afetler ve Çevre Dergisi, 6*(2), 288-303.

Çanakçıoğlu, H. (1993). Orman yangınları ve ekolojik etkileri. *Orman Fakültesi Dergisi, 10*(2), 34-52.

Çolak, E., & Sunar, F. (2018). Yüzey sıcaklığı ve spektral yanma indekslerinin orman yangını analizinde kullanımı. *VII. Uzaktan Algılama-CBS Sempozyumu* (UZAL-CBS 2018), 18-21 Eylül 2018, Eskişehir.

Dilekçi, S. (2019). *Zonguldak ve Ereğli orman işletme müdürlükleri orman yangını risk alanlarının belirlenmesi* [Unpublished master's thesis]. Zonguldak Bülent Ecevit Üniversitesi, Fen Bilimleri Enstitüsü, Zonguldak.

Doussi, M. A., & Thanos, C. A. (1994). Postfire regeneration of hard-seeded plants: Ecophysiology of seed germination. *Proceedings of the 2nd International Conference of Forest Fire Research, II*(25), 1035-1044.

Eastman, J. R., Jin, W., Kyem, P., & Toledano, J. (1995). Çok kriterli karar verme yöntemlerinin coğrafi bilgi sistemlerine entegrasyonu. *Decision Support Systems, 6*(2), 35-49.

Erener, A., & Lacasse, S. (2007). Heyelan duyarlılık haritalamasında CBS kullanımı. In *Ulusal Coğrafi Bilgi Sistemleri Kongresi*, 30 Ekim - 02 Kasım, Trabzon: Karadeniz Teknik Üniversitesi.

Flannigan, M. D., Stocks, B. J., & Wotton, B. M. (2005). Climate change and forest fires. *Science of the Total Environment, 262*(3), 221–229. https://doi.org/10.1016/S0048-9697(00)00524-6

Gökbek, B. (2014). *Çok ölçütlü karar verme yaklaşımlarına dayalı tedarikçi seçimi ve bir uygulama* [Unpublished master's thesis]. Gazi Üniversitesi, Sosyal Bilimler Enstitüsü, Ankara.

Hacısalihoğlu, M. (2018). *Çok kriterli karar analizi ile orman yangını risk haritalarının oluşturulması: Karabük örneği* [Unpublished master's thesis]. Zonguldak Bülent Ecevit Üniversitesi, Fen Bilimleri Enstitüsü, Zonguldak.

Hoti, S., & McAleer, M. (2005). Sistemik risk ve finansal yönetim. *Ekonomik Modeller ve Yönetim Stratejileri Dergisi, 6*(3), 45-61.

Ishizaka, A., & Nemery, P. (2013). *Multi-Criteria Decision Analysis Methods and Software*. Wiley.

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. *International Journal of Geographical Information Systems, 9*(3), 251-273. https://doi.org/10.1080/02693799508902036

Karabulut, M., Karakoç, A., Gürbüz, M., & Kızılelma, Y. (2013). Coğrafi bilgi sistemleri kullanarak Başkonuş dağında (Kahramanmaraş) orman yangını risk alanlarının belirlenmesi. *Uluslararası Sosyal Araştırmalar Dergisi, 6*(24), 171-179.

Kaya, P., İpekçi Cetin, E., & Kuruüzüm, A. (2011). Çok kriterli karar verme ile avrupa birliği ve aday ülkelerin yaşam kalitesinin analizi. *Istanbul University Econometrics and Statistics e-Journal, (13),* 80-94.

Lee, S., & Talib, J. A. (2005). Probabilistic landslide susceptibility and factor effect analysis. *Environmental Geology, 47*(7), 982-990.

Longley, P., Goodchild, M., Maguire, D., & Rhind, D. (2001). *Coğrafi Bilgi Sistemlerinde İleri Düzeyde Mekansal Analizler*. Coğrafi Bilimler Dergisi.

Majumder, M. (2015). *Impact of urbanization on water shortage in face of climatic aberrations*. Springer.

Malczewski, J. (1999). *GIS and multicriteria decision analysis*. New York: John Wiley and Sons.

Moreira, F., & Vallejo, R. (2009). What to do after fire? Post-fire restoration. In Y. Birot (Ed.), *Living with Wildfires: What science can tell us, EFI Discussion Paper, 15*, 53-58.

Okka, O. (2010). *Finansal yönetim: Teori ve çözümlü problemler*. Nobel Basım Dağıtım.

Özcan, O. (2008). *Sakarya nehri alt havzasının taşkın riski analizinin uzaktan algılama ve CBS ile belirlenmesi* [Unpublished doctoral dissertation]. İstanbul Teknik Üniversitesi, Bilişim Enstitüsü, İstanbul.

Özdemir, N., & Çelik, İ. (2020). Akıllı şehirlerde orman yangınları özelinde afet ve acil durum yönetimi. In *International Marmara Sciences Congress (AUTUMN 2020)* (p. 522).

Peggion, M., Bernardini, A., & Masera, M. (2008). Geographic information systems and risk assessment. *Scientific and Technical Research Series, EUR*, Luxembourg: Office for Official Publications of the European Communities.

Santiago, I. T., & Kheladze, N. (2011). GIS wildland fire hazard modeling in Georgia. *MATRA, Caucasus Environmental NGO Network*.

Sayadi, M. K., Heydari, M., & Shahanaghi, K. (2009). Extension of VIKOR method for decision making problem with interval numbers. *Applied Mathematical Modelling, 33*, 2257-2262.

Selçuk, L., Selçuk, A. S., & Kasapoğlu, D. (2016). Coğrafi bilgi sistemleri (CBS) tabanlı çok kriterli karar analizi (ÇKKA) kullanılarak, Van ili merkez ilçelerinin kentsel taşkın analizi. *Yer Bilimleri Dergisi, 6*(2), 125-138.

Şahin, E. K. (2012). *CBS tabanlı çok kriterli karar analizi yöntemi kullanılarak heyelan duyarlılık haritasının üretilmesi: Trabzon ili örneği* [Unpublished master's thesis]. Gebze Yüksek Teknoloji Enstitüsü, Mühendislik ve Fen Bilimleri Enstitüsü, Gebze.

Şahin, M. (2006). CBS ve yangın yönetimi. *Yangın Yönetimi Dergisi, 8*(2), 99-118.

Yavuz, M., & Sağlam, B. (2011). Uzaktan algılama ve coğrafi bilgi sistemlerinin orman yangınlarında kullanılması. In *I. Ulusal Akdeniz Orman ve Çevre Sempozyumu* (pp. 235-242). Kahramanmaraş.

Yomralıoğlu, T. (2002). GIS activities in Turkey. In *Proceedings of International Symposium on GIS* (pp. 834-840).