TURKGEO
TURKISH JOURNAL OF GEOSCIENCES

ISSN: *2717-7696*
Research Article
Vol; 3, Issue; 2, pp. 58-63, 2022
DOI: 10.48053/turkgeo.1140975
Journal homepage:
https://dergipark.org.tr/en/pub/turkgeo

Analysis of the threat of forest fires to ancient cities by GIS and Remote Sensing methods

Ezgi Tükel*[1], Kaan Kalkan [2]

[1]*Eskişehir Technical University, Department of Remote Sensing and Geographic Information Systems, Eskişehir, Turkey*
[2]*TÜBITAK Space Technologies Research Institute, Ankara, Turkey*

Keywords
Forest Fires
Archaeological Site
Fire Risk
Burn Severity
Landsat-8

ABSTRACT

Forest fires have been more common in recent years and caused extensive damage. Not only settlements and natural life but also historical places and ancient cities are at risk of forest fires. This study discussed forest fires in Turkey in the summer of 2021. Forest fire risk classifications were determined using Landsat-8 images. The Normalized Burn Ratio (NBR) and Differenced Normalized Burn Ratio (dNBR) indices were used to assess the area impacted by fire and to create fire risk classes. Furthermore, the burned and unburned areas in different zones from the Amos ancient city in the Marmaris were calculated using remote sensing methods. Thus, areas that should be protected from the fire were determined in future studies for fire risk areas.

1. INTRODUCTION

Forest fires are becoming more frequent with increasing global warming worldwide (Hantson et al., 2016). Many forest fires occurred in the summer of 2021, and Turkey's total burned area reached 204, 408 hectares (EFFIS, 2021). Forest fires have a natural effect on occurrences, can rejuvenate forests, and eliminate illnesses and other dangerous risks. On the other hand, they may negatively affect settlements and natural life (Daşdemir et al., 2021; Nuthammachot and Stratoulias, 2021). Forest fires pose a threat not only to natural vegetation and settlements but also to historical and archaeological sites (Dimitrakopoulos et al., 2002).

Several studies focus on the conservation of National Park and ancient site regions. Portugal's Herdade da Contenda region is a national hunting area, and a conservation-integration plan was studied using remote sensing methods (Teodoro et al., 2015). Furthermore, to assist in the conservation plan, multi-criteria decisions and buffer zone management methods were applied to protected areas (Geneletti and Duren, 2008; Hjortsø et al., 2006). On the other hand, forest fire risk zone mapping can create to understand the fire impact on natural and cultural heritage areas (Nikhil et al., 2021).

In the literature, there are many different fire detection studies using UA and GIS techniques. Previously implemented fire detection algorithms using remote sensing are generally developed and tuned for regional, continental, and global applications (Flasse and Ceccato, 1996). "Burn severity" is a term used to describe the physical, chemical, and biological alterations for the purpose of identifying the burned area after a fire (White et al., 1996). Furthermore, several techniques are used to create fire risk maps, including weighted registration, machine learning, deep learning, and frequency ratio (Javad et al., 2014; Tien Bui et al., 2017; Stroppiana et al., 2021). On the other hand, the land surface temperature (LST) is related to burned areas based on the severity of the forest fire (Vlassova et. al., 2014).

Several remote sensing methods are used to understand the forest fire severity. Some of these are based on multi-date change detection such as differenced Normalized Burn Ratio (dNBR), the soil-adjusted vegetation index, and burned area index (Hall et al., 2008; Marino et. al., 2016; Smith et. al., 2010). Forest fire risk and hazard maps are crucial for the environmental management of forest regions

* **Corresponding Author**

*(ezgitukel@eskisehir.edu.tr) ORCID ID 0000-0002-8675-2128
(kaankalkan@gmail.com) ORCID ID 0000-0002-2732-5425

Received: 05/07/2022; Accepted: 31/08/2022

Cite this article

Tükel E., & Kalkan K. (2022). Analysis of the threat of forest fires to ancient cities by GIS and Remote Sensing methods. Turkish Journal of Geosciences 3(2), 58-63.

and for establishing long-term strategic fire prevention plans (Akay and Şahin, 2019; Eugenio et al., 2016). Remote sensing methods enable the analysis, display, and presentation of fire severity and risk classification (Boer et al., 2008; Değerliyurt and Çabuk, 2015; Sandamali and Chathuranga, 2021).

The primary purpose of this study is to examine the impact of fire risk on the ancient city and its environment. In this study, forest fires covering the Aegean and Mediterranean regions of Turkey in 2021 were discussed. The Amos ancient city in the Marmaris district was chosen as the study area since it is one of the most damaged areas by the fire. The fire around the ancient city of Amos started on 4 August 2021 and was brought under control on 5 August 2021 with the intervention of the fire brigade (Url-1, Url-2).

In this study, dNBR, which is the most common remote sensing method, was used to determine fire severity and fire risk areas at different distances from the ancient city point were defined to assess the threat and risk of fire to the ancient city of Amos. Moreover, according to the forest fire severity map created in the study we tried to understand how much the ancient city was affected by the forest fire.

The remainder of the study is organized as follows. Section 2 presents the methodology, including the study area, the satellite data sources, and the description of the analysis indexes. Analyses are described in Section 4. Section 3 concludes the study.

2. METHODOLOGY

2.1. Study Area and Materials

Marmaris is one of the districts of Muğla province. The area of the district is 963.73 km^2; 80% is forestland, 5% is agricultural land, and a coastline of 451.72 km (Figure 1). Amos ancient city was selected as a study area (Figure 2). On the southwest side of contemporary Turunç, Marmaris, Amos is one of the Rhodian antiquities located on the Asarcık hill (Gürbüzer, 2021; Yaman, 2022).

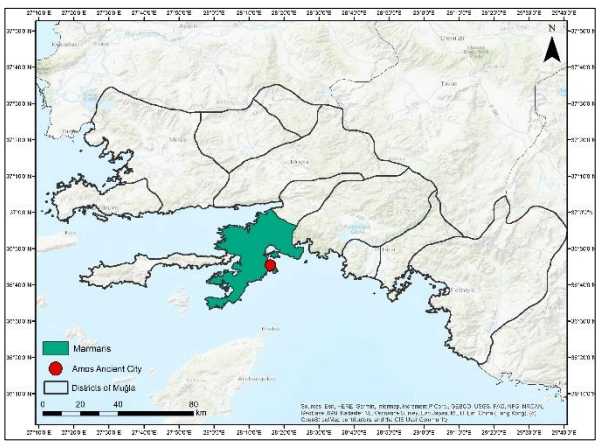

Figure 1. Study area

Landsat-8 images were used as satellite images in this study. Landsat-8 images were obtained from USGS (United States Geological Survey) websites in 2022 and has 11 bands with developed band combinations (Acharya and Yang, 2015). Two images were acquired, one from 2020 and the other from 2021 (Table 1). Moreover, ancient site point data was obtained from QGIS Open Street Map Plugin. According to Turkish news sources, the Amos ancient city was chosen for investigation since Amos was under the threat of forest fires (Url-2).

Table 1. Dates of Landsat images

Landsat Images	Date
LC08_L1TP_180034_20201224_02_T1	24.12.2020
LC08_L1TP_180034_20210821_02_T1	21.08.2021

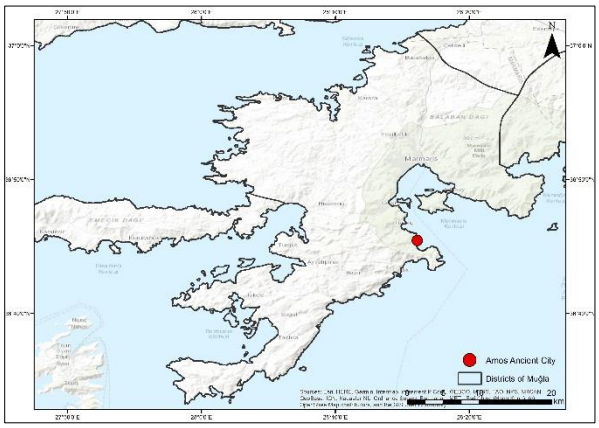

Figure 2. Location of Amos Ancient City

2.2. Method

We focused on NBR and dNBR as indices to evaluate burned areas in satellite images. First, the radiometric correction was applied to bands of Landsat-8 images. NBR analysis was performed on the image to estimate the intensity of the burn severity areas from before and after forest fire images. NBR is calculated as a ratio between the near-infrared (NIR) and shortwave infrared (SWIR) values. Furthermore, dNBR observes changes between two dates (Stankova and Nedkov, 2015).

$$NBR = (NIR - SWIR) \,/\, (NIR + SWIR) \quad (1)$$

$$dNBR = [Pre - fire\ NBR - Post - fire\ NBR) \quad (2)$$

For the Landsat 8 image, the NIR value corresponds to Band 5, while the SWIR value corresponds to Band 7 (Url-3). For Landsat 8:

$$NBR = (Band\ 5 - Band\ 7) \,/\, (Band + Band\ 7) \quad (3)$$

This study used Band 7 of Landsat-8, which detects the wavelength between 2100 and 2290 in the infrared region. On the other hand, Band 6 is at a lower wavelength and was not included in the study.

After the NBR analysis on Band 5 and Band 7 for the dates before and after the fire, dNBR analysis was applied to understand the burn severity of forests between the two dates. In a study of fire escape scenarios, the distances between the fire starting and end points were determined as 861 meters, 935 meters and 1175 meters (Castro-Basurto et al., 2021). Therefore, in this study, escape distances were determined approximately, to observe the fire threat to the Amos ancient city, 500 meters, 1 kilometer, and 2 kilometers buffer zones were applied to the point of the ancient city. In this study, the effect of fire severity in the determined buffer zones based on the area was examined. Moreover, projection systems were defined as a UTM Zone 35 in the QGIS. Figure 3 shows the methodology flow chart of the study.

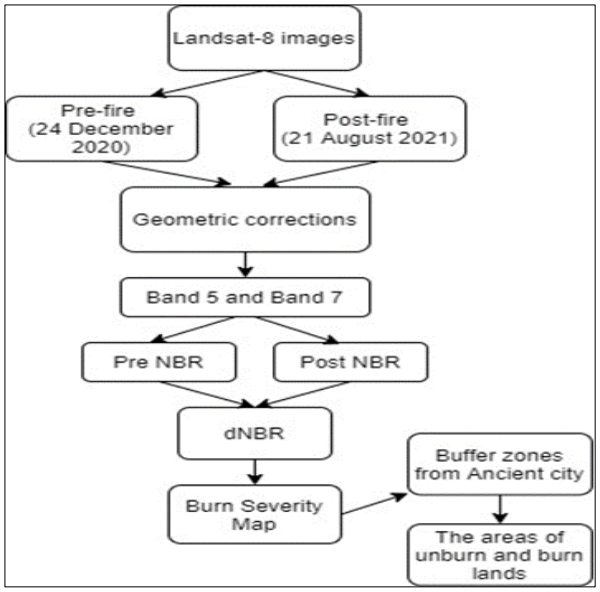

Figure 3. Methodology flow chart

3. RESULTS AND DISCUSSION

The burn severity indices values were classified as shown in Table 2. Severity indices are based on previous studies (Giddey et al., 2022; Konkathi and Shetty, 2019). The result shows the fire intensity map after applying the NBR and dNBR analyzes. Moreover, the area with high and severe burn areas are close to the Amos ancient city (Figure 4).

Table 2. Classified Burn and Unburn Areas

Severity Level	Values
Unburn Area	<0.099
Low Burn Area	0.1-0.27
Moderate Burn Area	0.27-0.54
High Burn Area	0.54-072
Severe Burn Area	>0.72

In Marmaris, there are 67.53 km^2 of unburned land, 345.28 km^2 of low burn, 326.30 km^2 of moderate burn, 54.74 km^2 of high burn, and 38.66 km^2 of severe burn. Distance buffers of 500 meters, 1 kilometer, and 2 kilometers were applied to the unburn and burn areas of the ancient city (Figure 5).

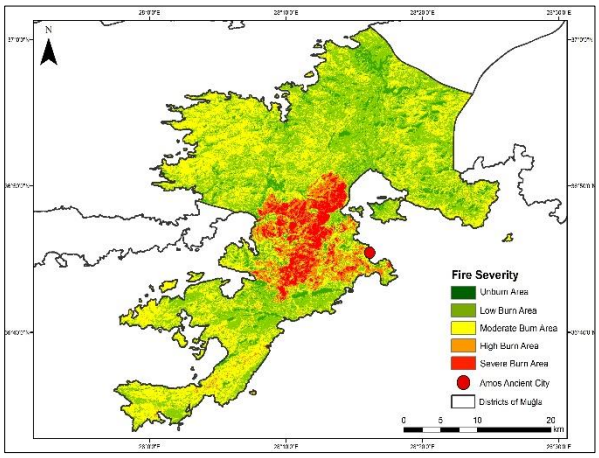

Figure 4. The dNBR results

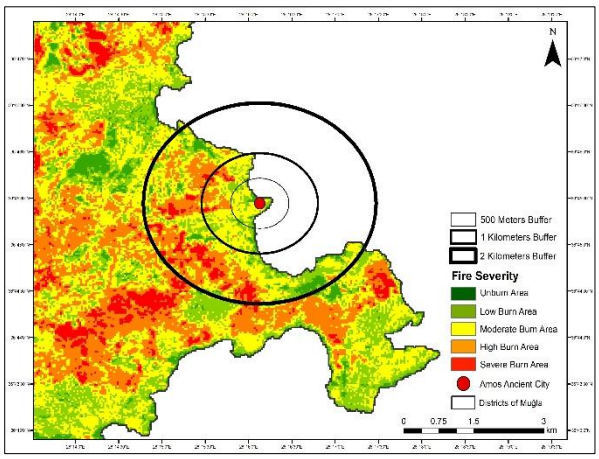

Figure 5. Buffer zones of Amos ancient city

The severe burn area of 500 meters from the Amos ancient city is 0.02 km^2, which is 0.05% of the Marmaris severe burn area. At a distance of 1 kilometer, the severe burn area is %0.18 of the district's severe burned area. Moreover, at a distance of 2 kilometers, the severe burn area is %1.26 of the Marmaris severe burned area. 2 kilometers from the Amos ancient city, the burn areas are respectively low burn area (2.3 km^2), moderate burn area (1.7 km^2), high burn area (1.04 km^2) and severe burn area (0.49 km^2). Furthermore, the Amos ancient city's unburn area is 0.6 km^2 in 2 kilometers.

According to the dNBR result, which is the difference between pre-fire and post-fire areas, there are different burn ratio classes at different distances to the Amos ancient city. While the area of the severe burn area zone of 1-kilometer distance to the ancient city is fewer, the area of the severe burn area zone of 2 kilometers distance to the ancient city is increasing. However, in the area zone of 500 meters and 1 kilometer, the moderate burn area is more than other classes (Table 3).

Table 3. Burn and unburn areas of buffers of the Amos ancient city

Landsat Images	In 500 meters	In 1 kilometer	In 2 kilometers
Unburn area(km²)	0.01	0.15	0.6
Low burn area (km²)	0.05	0.61	2.3
Moderate burn area (km²)	0.14	0.42	1.7
High burn area (km²)	0.01	0.16	1.04
Severe burn area (km²)	0.02	0.07	0.49

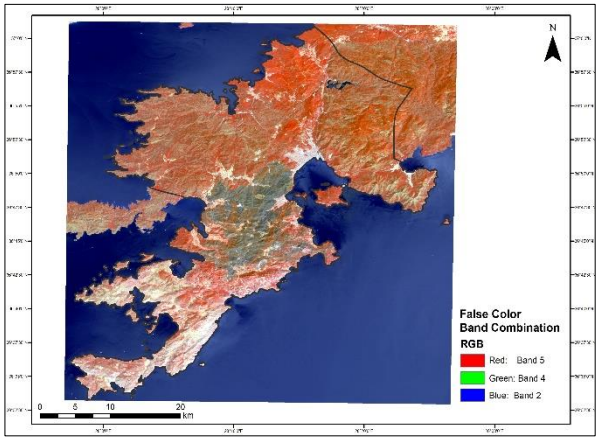

Figure 6. False color band combination

The false color band combination was applied to observe the vegetation change in the burned areas (Figure 6). Accordingly, 5-4-2 Bands were selected for Landsat 8. As a result, vegetation decreased in the severe burned forest area.

4. CONCLUSIONS

Previous studies focused on fire management in ancient cities and national parks (Humphrey et al., 2021; Roos et al., 2021). Moreover, forest fire severity and forest fire susceptibility studies were implemented for national parks using remote sensing methods (Gigović, 2019; Rozario, 2018).

However, there are no comprehensive studies in the literature that analyze the effects of forest fires on ancient cities with remote sensing methods. The study aims to determine the fire risk areas of the ancient city and its environment in Turkey in the summer of 2021 forest fires. Furthermore, forest risk areas were evaluated from Amos ancient city at different distances. According to this, severe burn areas increased by 2 kilometers from the Amos ancient city.

This study evaluated the impact using remote sensing and GIS methods. Moreover, conservation management can be created by calculating the burned areas and evaluating the situation around the ancient city.

The limitation of the study is that there is no data on the borders of Amos ancient city, so the fire risk zones were calculated by measuring the buffer from the point. On the other hand, this study can benefit future forest fire management and long-term strategic fire prevention plans.

Acknowledgement

We thank our three peer reviewers for pointing out areas where the text needed clarification.

Author Contributions

Ezgi Tükel: Methodology, Software, Validation, Formal analysis, Writing-Original Draft, Visualization. **Kaan Kalkan:** Conceptualization, Methodology, Writing- Reviewing and Editing.

Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES

Acharya, T.D., & Yang, I. (2015). Exploring Landsat 8. *International Journal of IT, Engineering and Applied Sciences Research (IJIEASR),* 4(4), 4-10.

Akay, A.E., & Şahin, H. (2019). Forest fire risk mapping using GIS techniques and AHP method: a case study in Bodrum (Turkey). *European Journal of Forest Engineering*, 5(1), 25-35.

Boer, M.M., Macfarlane, C., Norris, J., Sadler, R.J., Wallace, J., & Grierson, P.F. (2008). Mapping burned areas and burn severity patterns in SW Australian eucalypt forest using remotely-sensed changes in leaf area index. *Remote Sensing of Environment*, 112(12), 4358-4369.

Castro-Basurto, K., Jijon-Veliz, F., Medina, W., & Velasquez, W. (2021). Outside dynamic evacuation routes to escape a wildfire: A prototype app for forest firefighters. *Sustainability*, *13*(13), 7295.

Daşdemir, İ., Aydın, F., & Ertuğrul, M. (2021). Factors affecting the behavior of large forest fires in Turkey. *Environmental Management*, 67(1), 162-175.

Değerliyurt M., & Çabuk S. (2015). Defining geography with geographical information systems Eastern. *Geogr J* 20:37–48.

Dimitrakopoulos, A.P., Mitrakos, D., & Christoforou, V. (2002). Concepts of wildland fire protection of cultural monuments and national parks in Greece. Case study: Digital telemetry networks

at the forest of Ancient Olympia. *Fire Technology*, 38(4), 363-372.

EFFIS (European Forest Fire Information System), 2021. EFFIS Annual Country Statistics for TR – Turkey, retrieved from https://effis.jrc.ec.europa.eu/apps/effis.statistics/effisestimates, access date: 12/01/2022.

Eugenio, F.C., Dos Santos, A.R., Fiedler, N.C., Ribeiro, G.A., Da Silva, A.G., Dos Santos, Á.B., Paneto G.G., & Schettino, V.R. (2016). Applying GIS to develop a model for forest fire risk: A case study in Espírito Santo, Brazil. *Journal of environmental management*, 173, 65-71.

Flasse, S.P., & Ceccato, P. (1996). A contextual algorithm for AVHRR fire detection. *International Journal of Remote Sensing*, 17(2), 419-424.

Geneletti, D., & Van Duren, I. (2008). Protected area zoning for conservation and use: A combination of spatial multicriteria and multiobjective evaluation. *Landscape and urban planning*, *85*(2), 97-110.

Giddey, B.L., Baard, J.A., & Kraaij, T. (2022). Verification of the differenced Normalised Burn Ratio (dNBR) as an index of fire severity in Afrotemperate Forest. *South African Journal of Botany*, *146*, 348-353.

Gigović, L., Pourghasemi, H. R., Drobnjak, S., & Bai, S. (2019). Testing a new ensemble model based on SVM and random forest in forest fire susceptibility assessment and its mapping in Serbia's Tara National Park. *Forests*, *10*(5), 408.

Gürbüzer, M. (2021). Amos' ta Yeni Araştırmalar ve Bulgular. *Cedrus*, *9*, 219-249.

Hall, R. J., Freeburn, J.T., De Groot, W.J., Pritchard, J.M., Lynham, T.J., & Landry, R. (2008). Remote sensing of burn severity: experience from western Canada boreal fires. *International Journal of Wildland Fire*, *17*(4), 476-489.

Hantson, S., Pueyo, S., & Chuvieco, E. (2016). Global fire size distribution: from power law to log normal. *International journal of wildland fire*, 25(4), 403-412.

Hjortsø, C. N., Stræde, S., & Helles, F. (2006). Applying multicriteria decision-making to protected areas and buffer zone management: A case study in the Royal Chitwan National Park, Nepal. *Journal of forest economics*, *12*(2), 91-108.

Humphrey, G. J., Gillson, L., & Ziervogel, G. (2021). How changing fire management policies affect fire seasonality and livelihoods. *Ambio*, *50*(2), 475-491.

Javad, M., Baharin, A., Barat, M., & Farshid, S. (2014). Using frequency ratio method for spatial landslide prediction. *Research Journal of Applied Sciences, Engineering and Technology,* 7(15), 3174–3180.

Konkathi, P., & Shetty, A. (2019). Assessment of burn severity using different fire indices: A case study of Bandipur National Park. In *2019 IEEE Recent Advances in Geoscience and Remote Sensing: Technologies, Standards and Applications (TENGARSS)* (pp. 151-154) IEEE.

Marino, E., Guillén-Climent, M., Ranz Vega, P., & Tomé, J. (2016). Fire severity mapping in Garajonay National Park: Comparison between spectral indices. *Flamma: Madrid, Spain*, *7*, 22-28.

Nikhil, S., Danumah, J. H., Saha, S., Prasad, M. K., Rajaneesh, A., Mammen, P. C., ... & Kuriakose, S. L. (2021). Application of GIS and AHP method in forest fire risk zone mapping: a study of the Parambikulam tiger reserve, Kerala, India. *Journal of Geovisualization and Spatial Analysis*, *5*(1), 1-14.

Nuthammachot, N., & Stratoulias, D. (2021). Multicriteria decision analysis for forest fire risk assessment by coupling AHP and GIS: method and case study. *Environment, Development, and Sustainability*, 23(12), 17443-17458.

Roos, C. I., Swetnam, T.W., Ferguson, T.J., Liebmann, M. J., Loehman, R.A., Welch, J.R., ... & Kiahtipes, C.A. (2021). Native American fire management at an ancient wildland–urban interface in the Southwest United States. *Proceedings of the National Academy of Sciences*, *118*(4), e2018733118.

Rozario, P.F., Madurapperuma, B.D., & Wang, Y. (2018). Remote sensing approach to detect burn severity risk zones in Palo Verde National Park, Costa Rica. *Remote Sensing*, *10*(9), 1427.

Sandamali, K.U., & Chathuranga, K.A.M. (2021). Quantification of Burned Severity of the Forest Fire using Sentinel-2 Remote Sensing Images: A Case Study in the Ella Sri Lanka. Research and Reviews: *Journal of Environmental Sciences*, 3(3), 1-12.

Smith, A. M., Eitel, J.U., & Hudak, A.T. (2010). Spectral analysis of charcoal on soils: Implicationsfor wildland fire severity mapping methods. *International Journal of Wildland Fire*, *19*(7), 976-983.

Stankova, N., & Nedkov, R. (2015). Monitoring forest regrowth with different burn severity using aerial and Landsat data. In *2015 IEEE International Geoscience and Remote Sensing Symposium (IGARSS) IEEE*.

Stroppiana, D., Bordogna, G., Sali, M., Boschetti, M., Sona, G., & Brivio, P.A. (2021). A Fully Automatic, Interpretable and Adaptive Machine Learning Approach to Map Burned Area from Remote Sensing. *ISPRS International Journal of Geo-Information*, *10*(8), 546.

Teodoro, A., Duarte, L., Sillero, N., Gonçalves, J. A., Fonte, J., Gonçalves-Seco, L., Pinheiro da Luz, L.M., & Dos Santos Beja, N.M.R. (2015). An integrated and open source GIS environmental management system for a protected area in the south of Portugal. In *Earth Resources and Environmental Remote Sensing/GIS Applications VI* (Vol. 9644, pp. 143-154). SPIE.

Tien Bui, D., Bui, Q.T., Nguyen, Q.P., Pradhan, B., Nampak, H., & Trinh, P.T. (2017). A hybrid artificial intelligence approach using GIS-based neural-fuzzy inference system and particle swarm optimization for forest fire susceptibility modeling at a tropical area. *Agricultural and Forest Meteorology*, 233, 32-44.

Vlassova, L., Pérez-Cabello, F., Mimbrero, M.R., Llovería, R.M., & García-Martín, A. (2014). Analysis of the relationship between land surface temperature and wildfire severity in a series of landsat images. *Remote Sensing*, 6(7), 6136-6162.

White, J.D., Ryan, K.C., Key, C.C., & Running, S.W. (1996). Remote sensing of forest fire severity and vegetation recovery. *International Journal of Wildland Fire*, 6(3), 125-136.

Yaman, A. (2022). Amos arkeolojik yüzey araştırmalarında ele geçen seramikler. *Olba*, *30*, 113-127.

Url-1: https://www.haberturk.com/mugla-haberleri/89560498-tarihi-amos-antik-kenti-cevresindeki-yangina-toma-mudahelesi (last accessed 05.08.2022)

Url-2: https://www.trthaber.com/haber/turkiye/marmaristeki-yangin-amos-antik-kentine-ilerliyor-599654.html (last accessed 12 June 2022)

Url-3: https://www.usgs.gov/landsat-missions/landsat-normalized-burn-ratio (last accessed 12 June 2022)