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International Journal of Human Sciences ISSN:2458-9489 Volume 15 Issue 1 Year: 2018 11

Forest Fire Risk Analysis via Integration of GIS, RS and AHP: the Case of Çanakkale, Turkey Cengiz Akbulak1, Hasan Tatlı2, Gürcü Aygün3, Bülent Sağlam4 ABSTRACT Forest fire is one of the high-risk natural disasters in the north-western Anatolia section of Turkey. This paper suggests a new approach

based on Geographic Information Systems (GIS), Remote Sensing (RS) and 15

Analytical Hierarchy Process (AHP) for the development of forest fire- risk model. The proposed approach includes human factors as well as environmental factors. In this context, the 12 variables defined under anthropogenic and physical factors in the proposed model are the slope, elevation, aspect, vegetation type, crown closure, Normalized Difference Vegetation Index (NDVI),

distance to road, settlement, and agricultural areas, population density, previous fires, **and** 1

Canadian Forest Fire Weather Index (FWI). For each variable, a layer was created in the GIS database environment. GIS-layers were classified, considering the risk of potentially generating forest-fire of the relevant variables. In addition, to generate risk maps, the weights used in these GIS-layers were obtained by applying the AHP technique. One of the major results of the study shows that the rates of “extreme”, “very high”, “high”, and “moderate” risk areas are 3.87%, 63.46%, 32.13% and 0.53%, respectively. Another important result is that there are not observed the so called “no risk" and "low risk" classes in the region. The results let us to make a conclusion that the natural and human factors having significant contributions the region to be fire-prone. Yet, these results also indicate that rather than emphasizing forest-fire preparedness and mitigation, policy-makers manage forest-fires through reactive, crisis-oriented approaches. In contrast to crisis-based management plans, this study suggests that risk-based preventive plans should be developed and implemented. Keywords: Forest Fire; Risk Analysis; GIS; AHP; Remote Sensing; Turkey. 1

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Geography, Çanakkale Onsekiz Mart University, 17020 Çanakkale, Turkey. gurcuaygun@hotmail.com 4 Faculty of Forestry, Artvin Coruh University, 08100, Artvin, Turkey, bsaglam@artvin.edu.tr [Type here] 1. Introduction Forest fires are among the most critical large-scale natural disasters increasing the intensity of suppressions on forests, which are one of the richest biodiversity areas in the natural environment (Carvalho et al., 2011). Despite the advanced technology and the widespread use of this technology to prevent forest fires, as an ecological problem remains to threat the forests. Forest fires annually affect thousands of hectares of areas and cause dramatic changes in forest ecosystems (Goldammer & Mutch, 2001).

One of the most common problems of all the countries in the Mediterranean Climate Zone, e.g. Portugal, Greece, Spain, Italy, France and Turkey 1

is forest fires. Those fires in the Mediterranean Zone cause damages from 450 to 500 thousand hectares in an average of forests every year (Versini et al., 2013; Turco et al., 2014; Tonini et al., 2017). A great majority of the forests of Turkey in the Mediterranean Basin are also at risk of fire. Even though the occurrence of forest fires in Turkey exhibits a fluctuating trend, an increase in the amount of affected areas and the number of forest fires across the world over the last years in particular has been observed. This case is associated with both population growth and ever-increasing number of fire-causing factors (Ertuğrul, 2005). In Turkey, 12.76 million of 22.3 hectares of forest consists of Level 1 and 2 fire-prone areas. According to the last-10-year fire statistics, an annual average of 8903 hectares of forest has been damaged by 2330 different forest fires on average (GDF, 2017).

Forest fires in Turkey are commonly observed in the coastlines of the Aegean, Mediterranean, and Marmara Regions. Muğla, Antalya, İzmir, and Çanakkale province of this study 1

are the most fire- prone regions (SPO, 2001; Altan and Türkeş, 2011; Türkeş and Altan, 2012a,b). As the features of the Mediterranean climate, the fires in the Aegean and Mediterranean Regions in dry and hot summers cause drastic damages to forests. Forest areas between 0 and 400 m in elevation in the Mediterranean and Aegean Regions are generally listed among Level-1 fire-prone areas (GDF, 2017). Forest fires occurring in fire-prone regions affect vast forest areas and lead to serious financial damages and even losses of lives - if effective pre-fire planning has not been produced on time and the first response has not been successfully provided. Although forest fires cannot be prevented, identification of the areas with high fire potential by risk analysis offers facilitating opportunities for administrators and end-users (Karabulut et al., 2013). Pre-determination of the areas at high risk can make notable contributions to decision-making processes intended for properly conducted pre-fire plans and intensification fire-preventive measures in these areas. Therefore, a meticulous identification of fire risk levels and the conduction of studies to map them are of great importance to prevent fires. In recent studies, several fire-risk models have been produced with the effective use of Geographic Information Systems (GIS).

For example, Jaiswal **et al. (2002)** created mapped **forest fire risk** zones of **Gorna Basin in India** 1

with the aid of satellite imaging and GIS. They have found that their suggested model based on GIS for

the study area was in strong agreement with actual fire-affected sites. 12

Yin et al. (2004), by using GIS, produced forest fire risk zones on Da Hinggan Mountain, one of the most mountainous areas in China. The authors affirmed that the forest fire risk maps produced by their suggested approach are highly reliability. Forest fire risk maps were produced by Chandra (2005) in Uttaranchal of India by GIS and remote sensing (RS). This study shows that using the RS and GIS technology might be very effective

in identifying different fire risk zones based on appropriate parameters such as fuel load, slope, aspect, altitude, drainage, distan ce **from roads and settlements.** 4

Erten et al. (2005) stated that the data from the Satellite is a suitable instrument for classifying

forest places when integrating the parameter topography, vegetation type, vicinity to roads and settlements, the integration of the **satellite data into GIS** being **very useful to determine risky places** due **to** 2

the forest fires in the Gallipoli Peninsula in Turkey.

Pradhan et al. (2007) investigated forest fire sensitivity in the vicinity of Kuala Lumpur, 1

Malesia, by employing RS and GIS technology. They concluded that forest fire susceptibility mapping by RS and GIS technology is very importance for haze detection and fire prevention in the forest areas. Sağlam et al. (2008) identified forest fire risk zones and fire-prone areas in the study carried out in Korudağ Forest in Turkey. A major result of their study shows that using the

Landsat imagery provided is a valuable characterization and mapping of vegetation structure and classification with a high accuracy. 10

Assaker et al. (2012) have applied the forest fire risk analysis of Nahr Ibrahim Basin, Lebanon by using RS and GIS. The authors have a conclusion that using the satellite images made possible the coverage of a large surface and consequently facilitated field work.

Sringeswara et al. (2012) produced a forest fire risk map and a forest fire management plan for the Kudremukh National Park, India. 1

They revealed that the areas with high frequent fire occurring could not be located with the existing fire-watch towers. Güngöroğlu (2017) determined fire risk in the forest lands in Antalya, Turkey by using GIS and AHP. He underlined that the degree of different risk management might be taken into consideration in the establishment of fuzzy sets approach. The present study is intended to present a new sophisticate forest fire risk analysis for Çanakkale province, listed among the most fire-prone areas and as one of the sites of frequent forest fire occurs in

Turkey. 2. Material and Methods 2.1. Study Area Çanakkale is among the 16

forest-rich provinces of Turkey and incorporates two national parks, i.e. Kazdağı National Park and Troia Historical National Park. The province is located in the Southern Marmara Region in the northwest of the Anatolian Peninsula (Figure 1). The province, located on Biga and Gelibolu Peninsula, covers an area of 9,887 km2. Figure 1. Location map of the study area It is found in the Subtropical Mediterranean Climate Zone and thus it is hot and dry in summers. In Çanakkale, the annual average temperature is about 15 oC, the hottest month is July (25oC on average) and the coldest is February (6 oC on average). Annual average amount of precipitation is nearly 600 mm. While the area receives a substantial amount of precipitation during winter, the minimum amount is observed in summer. The highest and lowest amounts of mean monthly precipitation are observed in December (103 mm) and August (4 mm), respectively. The province, located in the Mediterranean Climate Zone, typically has a sub-humid climate, but a dry one in summer. Dry conditions and drying prevalent northerly winds create the favorable conditions for the breakout and spread of forest fires. One of the most important nature assets of Çanakkale, 55% of which is covered by forests is Kaz Mountains (also known as Mount Ida). The northern and western portion of the Kaz Mountains, proclaimed a national park in 1994, is located in Çanakkale province. A vast portion of ecologically rich Kaz Mountains is covered by forests. The forests from the lower to the higher elevations contain black pines, firs, beeches, and its endemic fir trees (Güngördü, 1999). In the Biga Mountains are among the most important forest areas of the province. In the Biga Mountains, one can observe Calabrian pine, Turkish oak, and black pine forests from lower to higher elevations. On the Gallipoli Peninsula, chestnuts and black pines are observed at lower elevations, while Calabrian pines prevail in and around the central zone. The peninsula's sections having been damaged by forest fires are covered by maquis shrubs. Besides the forest, plants in the areas with dunes and high salinity considerably contribute to Çanakkale's vegetation. 2.2. Datasets To produce the GIS database,

standard topographic maps at the **scale of 1:25,000 were** 2

used as basemaps. The digital topographic maps were used to produce slope, elevation, and aspect layers, digital forest stand maps for the production of vegetation type and crown closure data, Landsat (L8 OLI/TIRS) satellite images for NDVI layers (USGS, 2017), and CORINE data for the identification of agricultural areas. Meteorological data and settlement-based population data were used for the calculation of the Canadian Forest Fire Weather Index (FWI) and the production of population density, respectively. Table 1 shows an overview of all data used in the analysis. Table 1. The data used in the study Data description Source

1/25,000 scale standard **topographical maps General Command of Mapping** 5

1/25,000 scale digital elevation **maps General Command of Mapping** Meteorological data **Turkish** 5

Meteorological Service Landsat (L8 OLI/TIRS) Satellite images (18/11/2016) USGS Digital Forest Stand Map (2016) Çanakkale Regional Directorate of Forestry CORINE land cover data, Level III, (2012) Ministry of Agriculture and Forestry Population of settlement (2016) Turkish Statistical Institute (TurkStat), Address Based Population Registration System. Previous forest fire data (2007-2016) Çanakkale Regional Directorate of Forestry Variables being considered in forest fire risk analysis vary according to the size of the area where risk analysis is conducted and to the purpose of the study. For the purpose of the present study, the topographic variables "elevation", "slope", and "aspect" were chosen as sub-variables. Meteorological values were included in the analysis as a single parameter through the calculation of FWI. Primary vegetation variables include vegetation type, crown closure, and

NDVI, while human variables consist of population density, distance to settlement, road, and agricultural land. Topographic conditions are among the most influential physical factors in the emergence of forest fires and fire behaviors. Slope, aspect, and elevation are considered as the main topographic factors in several studies (Chandra, 2005; Dong et al., 2005; Pradhan et al., 2007; Adab et al., 2013; Özşahin, 2014; Thakur et al., 2014). Meteorological parameters were too considered in forest fire risk analyses. Such meteorological variables as temperature, precipitation, evaporation, wind, and relative humidity are decisive in behavior, spread, and speed of fire (Ghobadi et al., 2012; Türkeş and Altan, 2012a,b; Tatli and Türkeş, 2014). Accordingly, the FWI values included in the analysis to account the meteorological effects on the fire risk (Carvalho et al., 2008; Camia et al., 2008; Dimitrakopoulos et al., 2011). Vegetation is one of the most important factors starting forest fires and affecting their behaviors. For the purpose of the study, such vegetation-related variables as vegetation type, crown closure, and NDVI were taken into account. Since vegetation type determines fuel, it is critical for forest fires and one of the most decisive factors considered in fire risk research (Jaiswal, 2002; Chandra, 2005; Sağlam et al., 2008). Additionally, the remote sensing technique was employed to produce NDVI layer, which varies depending on water and nutrients, plant diseases, and other stress factors (Gouveia et al., 2017). Human activities pose greater risks of forest fires resulting from negligence and accidents (Jaiswal et al., 2002, Vilar et al., 2010). Thus, areas with the denser population and more complicated route networks are more prone to forest fires. Besides, forest areas in the vicinity of agricultural fields are at risk of fire too. The distance to roads and settlements listed as human factors also is tackled in a great number of studies (Jaiswall et al., 2002; Sowmya et al., 2010; Soto, 2012; Thakur et al., 2014; Biasi et al., 2015). Furthermore, it can be asserted that population density is a crucial factor influential in the breakouts of forest fires. Hence, population density together with distance to roads, distance to settlements, and distance to agricultural lands was included in the present research. The frequency of fires in a certain area is significant to hint that it might be at greater risk of fire. Starting points of the previous fires in a research area suggest that the area is potentially at risk. Therefore, the starting points of fires occurred in the research area over the last decade (2007-2016) were included in the analysis. 2.3. Methods 2.3.1.

Forest fire weather index Forest Fire Weather Index or **fire** danger **index is** 13

a method merging fuel-related and meteorological facts and putting them in a simple numerical order and successfully employed across the world. Meteorological forest fire index system reveals fire danger in rates relying on daily meteorological measurements in relation to a fuel type (Bilgili et al., 2001; Tatli et al., 2017a; Çekmek, 2018). The primary reason for the use of this index is to express fire risk as a complicated concept in a simple number. The most common indices are Canadian

FWI system (Van Wagner, 1987) and US National Fire Danger Rating **System (Deeming et al., 1978).** 9

Besides,

Keetch-Byram Drought Index (Keetch and Byram, 1968) and Haines Forest Fire 17

Weather Index (Haines, 1988; Potter et al., 2008; Tatli and Türkeş, 2014) are quite commonly used indices created to control forest fires. Canadian FWI was used in this study because of it is widely used in the Mediterranean countries and be claimed to yield accurate results (Turner and Lawson, 1978; Vieges

et al., 1999; Carvalho et al., 2008; Camia et al., 2008; Dimitrakopoulos et al., 14

2011). This index is calculated in consideration of such meteorological variables of temperature, relative humidity, wind speed, and precipitation. The calculations were carried out by written a source code based on FORTRAN 2003. The obtained FWI values were transferred into GIS-based medium to produce the FWI layer. 2.3.2. NDVI NDVI is a simple and most commonly used approach in the related studies, such as in Bonneau et al., (1999) and Doğan et al., (2009). This index is very frequently availed of in forestry practices and particularly in forest fire risk estimations. Low NDVI value, considered indicative of vegetation flow in a specific area, is associated with higher fire risk (Gabban et al., 2006; Tatli et al, 2017b). This index is retrieved by the use of reflection values of visible and near-infrared rays (Myneni, 1997; Huete et al., 1999). It is calculated with the following formula on the basis of each pixel (Lillesand & Kiefer, 1987).

NDVI = (IR-R) / (IR+R) (1) where IR is the near-infrared band value of the pixel and R is the red 8

band value. NDVI value ranges between -1 and +1 according to surface cover properties (vegetation, water, soil, etc.). The value closer to 1 refers to lush vegetation, 0 to barren lands or sparse vegetation, and negative value to non-vegetation (Ghobadi et al., 2012). The NDVI values of the research area were obtained by processing Landsat (L8 OLI/TIRS) Satellite Images of 18 November 2016. 2.3.3. GIS layers GIS is a tool whereby spatial data are digitized, stored, manipulated, managed, analyzed to generate information (Marble et al., 1984; Clark, 1997; Esri 1999; Longley et al., 2001). GIS methodology plays an active role in spatial decision-making thanks to these properties (Tang et al., 2009). This technique has lately come to be used increasingly in forest fire research, offers significant advantages in obtaining effective and applicable results (Sharma et al., 2009; Zheng et al., 2011). GIS allows for inexpensive, fast and high-accuracy analyses in practices such as estimation, modeling, monitoring of fire emergence, organization of extinguishing efforts, determination of post-fire damage (Erten et al., 2004, 2005). Thanks to the advantages it offers, GIS has been effectively used for the purpose of this study. In this respect, layers of the variables employed in the present study were produced in GIS and then fire risk was determined by overlaying these layers in GIS environment. The elevation, slope, and aspect layers of the analysis were obtained based on digital elevation model (DEM) data by using the digitized contour lines. The raster-formatted vegetation type and crown closure layers were generated with the digital stand maps in vector format. The settlements and highways in the research area were digitized by using the topographic maps of 1:25,000-scale. The distribution of agricultural areas was determined using CORINE (Level III) land cover data and digital stand maps. The starting points of the forest fires having broken out in Çanakkale in the past decade were transferred into GIS environment to produce the layers of previous fires. The buffer analysis was applied considering the distance to settlements, roads, agricultural land and previous fire spots via GIS. The population density, another variable of the study, was calculated based on the administrative borderlines (areas) of the research area and the population size in 2016, and then the results were transferred into GIS. Consequently, each of the variables herein was converted into raster data with a spatial resolution of 100 m. 2.3.4. Risk score of the variables The variables of the fire risk analysis were classified in consideration of fire risk and a score ranging between 1 and 10 (Table 2) was assigned to each class. The variables' classes and the scores thereof were determined based on the related literature (Jaiswall

et al., 2002; Sağlam **et al.,** 2008; Ghobadi **et al.,** 2012; Malik **et al., 2013)** 6

and in view of the conditions of the research area. Table 2. Classes and ratings assigned to variables for fire risk Variable Classes Rating Variable Classes Rating Elevation (m) 0-200 201-400 401-600 601-800 801-1000 1001-1200 1201-1400 1401-1600 1600+ 10 9 8 7 6 4 3 2 1 Distance to settlement (m) 0-1000 1001-2000 2001-3000 3001-4000 4001-5000 5000+ 10 9 8 6 3 1 Slope (%) 0-5 6-10 11-15 16-20 21-25 26-30 31-35 35+ 1 2 4 5 6 7 8 10 Population density (people per km2) 0-10 11-20 21-50 51-100 101-500 501-1000 1001+ 1 2 4 6 8 9 10 Aspect Flat N NE E NW W SE S SW 5 1 2 5 2 5 7 10 8 Distance to agricultural land (m) 0-100 101-200 201-300 301-400 401-500 500+ 10 9 7 5 3 1 Vegetation type Calabrian pine, scrub Black pine Stone pine, Cyprus oak and kermes oak Juniper Cedar, hornbeam Beech Walnut, fir, cypress, abies, plane, chestnut 10 9 8 6 3 2 1 NDVI FWI ≤ 0.05 0.06- 0.1 0.11- 0.20 0.21- 0.3 0.3> 0-0.47 0.48-2.91 2.92-5.96 5.97-13.25 10 6 4 3 1 3 6 8 10 Stand crown closure (%) Bareland <11 11-40 41-70 71> 1 2 4 7 10 Distance to previous forest fires spot (m) 0-200 201-400 401-600 601-800 801-1000 1000+ 10 8 6 4 2 1 Lastly, a re-classification was conducted with the aid of "reclassify" tool in the Arc-GIS 10.0 software with respect to Table 2 in order to produce raster-formatted layers for each of the variables (Figure 2, 3 and 4). Figure 2. Risk ratings assigned to the factors of topographic and previous-fires: Elevation (a), slope (b), aspect (c), and distance to previous fire (d). Figure 3. Ratings assigned to FWI and vegetation variables for forest fire risk: FWI (a), vegetation type (b), closure (c), and NDVI (d). Figure 4. Ratings assigned to the human factors for forest fire risk:

Population density (a), **distance to settlement** (b), **distance to road** (c), and **distance to agricultural** 1

land (d). 2.3.5. Weights of the variables The impact levels, i.e. weights, of the considered variables in the forest fire risk analyses are not uniformly distributed. Therefore, it is important to determine the weight of each variable. This is a multilateral decision-making process. The weight of each variable in the study was calculated with AHP (Saaty, 1980), a Multi-Criteria Decision-Making (MCDM) technique relies on the formation of a hierarchy for the analysis of complicated multi-criteria problems. This technique determines the relative within-class superiority of elements for different layers in a view of the hierarchical structure and yields an effective solution for MCDM processes. According to Saaty (1980) a pairwise comparison matrix is created to determine the degree of significance of the criteria and sub-criteria by AHP. Decision-maker performs a value- and definition-based scoring in a way to determine the relative significances of the elements at a level and creates a pairwise comparisons matrix. As a result of the eigenvalue-eigenvector calculation this matrix, criterion weights with a total value of 1 (normalized weight coefficients) are retrieved. By a statistical test known as Consistency Ratio, the consistency of the decisions made in the pairwise comparisons in AHP technique is calculated. 12 variables were used to determine forest fire risks in the research area.

It is recommended that the number of variables should not exceed nine to calculate the 1

weights by AHP method (Saaty 1980). Therefore, 12 variables were classified into sub-groups,

so that the scores of main and sub-variables were separately calculated. The general weights of the sub-variables were obtained by 1

multiplying weight scores of sub-variables by those of primary variables (Table 3). The obtained values were used to merge the values by weighted overlay method in GIS. Table 3. Weights of main variables and sub variables. Main variable Weight of main variable Sub variable Weight of sub variable Global weight of sub variable FWI 0.117 -- -- 0.117 Previous fires 0.064 -- -- 0.064 Topography 0.169 Elevation Slope Aspect 0.493 0.196 0.311 0.083 0.033 0.053 Vegetation 0.291 Vegetation type Stand crown closure NDVI 0.540 0.297 0.163 0.157 0.086 0.047 Human factors 0.360 Distance to agricultural land Distance to settlement Distance to road Population density 0.120 0.365 0.235 0.281 0.043 0.131 0.085 0.101 2.3.6. Risk map The database produced on GIS and the variables considered in the analysis with the help of the applied model were simultaneously evaluated. Firstly, the raster layers corresponding to the variables of the risk analysis were merged by the weighted overlay method in GIS, and the risk score (Sj) of j-th pixel is calculated with the following equation. S j ? ? wi xi n (2) i ?1 where wi represents weight of the corresponding variable xi, and n is the total number of the related variables, respectively. The Sj value is calculated by using the weights of the variables given in Table 3 (the meaning of the abbreviations of the variables are seen in this table) as in the following. $\boldsymbol{Rj} = \mathbf{0.\ 003}\boldsymbol{CVI} + \mathbf{0.\ 033}\boldsymbol{PC} + \mathbf{0.\ 033}\boldsymbol{CLV} + \mathbf{0.\ 033}\boldsymbol{RL} + \mathbf{0.\ 033}\boldsymbol{ARP} + \mathbf{0.\ 033}\boldsymbol{VCR} + \mathbf{0.\ 033}\boldsymbol{RCC} + \mathbf{0.\ 033}\boldsymbol{NCVI} + \mathbf{0.\ 033}\boldsymbol{CAL} + \mathbf{0.\ 030}\boldsymbol{CR} + \mathbf{0.\ 033}\boldsymbol{CR} + \mathbf{0.\ 000}\boldsymbol{PC}$ In addition, the related Sj is rescaled as in the following. I j ? max S 5 (3) (4) The rescaled value (Ij) ranges from 1 to 5. In this expression, Smax and Ij refer to the highest value and risk-class, respectively. The map of risk-classes was produced according to those standard risk- values obtained by Equation (4). 3. Results and Discussion The results of the weighted overlay method conducted based on the evaluation of 12 different variables revealed that areas at extreme, very high, high, and moderate risk account for 3.87%, 63.46%, 32.13%, and 0.53% (Table 4). No area in the province was observed to be listed as “no risk” or “low risk” area. Table 4. The rate of fores t fires risk in Çanakkale. Risk level Area (ha) Ratio (%) Extreme 18,457 3.87 Very high 302,802 63.46 High 153,317 32.13 Moderate 2,549 0.53 Low - - Total 477,125 100 Figure 5. Forest fire risk zone map of the study area Figure 5 indicates the forests across the province are at a high risk of forest fire. The forest fires with very high risk were observed in Ezine and Bayramiç towns of Çanakkale. Furthermore, the western sectors of Kaz Mountains, the periphery of Ayvacık town, and Gökçeada were found to be under the very high risk of fire. These areas prevalently covered with such fire-prone Calabrian pine, black pine, and bushes and hosting settlements and dense route networks were observed to neighbor agricultural areas. Even though areas with extreme risk are rare, they are located where the conditions are extreme. The forests with the extreme risk are observed in the southeastern part of Gökçeada, northwestern part of Bozcaada, northwestern foot of Kaz Mountains, and the certain sections of the Gallipoli Peninsula. At-extreme-risk forests area are located at higher elevations of the Ida Mountains in the southeast of the province and Lapseki, Biga, and Çan. In these areas dominated by such plant species as firs, cedars, chestnuts, and beeches, elevation is relatively higher. Since the roads are sparsely distributed and less human activities in the Mount Ida, the fire risk is relatively lower than in the other parts of the province. The analysis of the vegetation of the research area show that a large portion of the province (68.2%) is covered by such dry plant types as Calabrian pine, black pine, scrub, Cyprus oak and kermes oak. Thus, it can be concluded that a great majority of the vegetation in Çanakkale consists of species highly prone to forest fire. The analysis of the distribution of these species by risk class showed that 5.5%, 77.7%, 16.8%, and 0.063% are located in areas at extreme, very high, high, and moderate risk of fire, respectively. This evidences that nearly 83.5% of the areas dominantly covered by these species are at a very high or extreme risk. In addition, the comparison between the analysis results and the distribution of vegetation types manifested that 99% and 85% of these areas at extreme and very high risk, respectively, are covered by the fire-prone species. The low-risk plant species, such as walnut, cypress, abies, plane, chestnut, beech, cedar, and hornbeam were typologically analyzed too. The analyses denote that 11% of forest at very high risk and 0.1% of forests at extreme risk are covered by these plant species. Another variable increasing the risk of fire is the meteorological factors in the study area. The FWI calculations in this study yielded no low-risk forest area in Çanakkale province. According to the FWI values, the areas at high and very high risk were found to account for 96.9%. The results of the analyses indicate that 99.6% of the areas at extreme risk, 97.7% at very high risk, and 90.3% at high risk are located in areas at high and very high risk as reported in FWI. Thus, it can be suggested that parallels can be drawn between FWI and the analyses results in terms of risk classes. It is known that forest fire risk is high in the densely populated areas. In these areas, the probability of fire outbreak due to the human activities, negligence, and the accident is higher than in the less populated areas. The fact that there are 602 settlements in the province and these settlements are connected to each other via a sophisticated dense road network tends to increase the risk. The comparison between the analyses results and distances to settlements showed that 97.8% of the extreme-risk areas are located in the 3-km distance to a settlement. This rate is 80.1% for areas with very high risk, 48.1% for high-risk areas, and 0.4% for moderate-risk areas. These results reveal a positive relationship between the distance to settlements and fire risk. According to the comparisons conducted to expose the relationship between the distance to roads and risk classes obtained in the present study, 91.4% of the areas at extreme risk are found in at most 1000 m away from the roads. It is 43.7%, 18.5%, and 1.8 % for the areas at very high, high, and moderate risk, respectively. Hence, it can be inferred that the risk gets higher as the distance to road gets shorter, but it will be lower if the distance is long. The forests neighboring agricultural areas are at a higher risk.

Especially the careless practices in the dry-agriculture areas and the stubble burning are among the fire-starting causes. In the present study, the effects of agricultural practices on fires were considered based on the forest distance to agricultural land. The fact that agricultural areas cover vast areas and they are interwoven into each other tends to increase forest fire risk. The high number of fires in a certain area is significant to hint that it may be at a greater risk of fire. In Çanakkale province, 272 forest fires broke out between 2007 and 2016. According to the results of the buffer analyses conducted based on the starting points of the fires to include them into the evaluation, previous fires were found to be scattered across the province and to serve as a risk- increasing factor. Besides, the comparison of at-risk areas with fire-hit sites is extremely important for the reliability of results obtained in the analyses. In this respect, the obtained risk zones were compared with the previous fire sites and starting points of the previous fires were observed to cluster in the areas at high and very high risk. Moreover, starting points were also revealed to neighbor settlements, agricultural areas, and roads. The comparison between the results of the analyses and alike studies yields similar results concerning fire risk. For example,

Karabulut et al. (2013) have determined a high **risk of fire in Başkonuş** Mountains in **Kahramanmaraş** 1

and discovered that higher fire risk is imminent especially in dry forest areas, on south-facing slopes, and in the vicinity of roads and settlements. According to the study by Erten et al. (2005), it is reported that the forests at high risk and very high risk on the Gallipoli Peninsula account for the highest percentage. Therefore, the present study has similarities with these two studies in that risk zones are high in number. In addition, this study, unlike these abovementioned studies, reports that the areas at high and very high risk have greater percentages in reality. In the current fire risk analyses, the weighted overlay method in GIS is frequently used (Jaiswal

et al., 2002; Ghobadi **et al.,** 2012; Assaker **et al.,** 2012; Malik **et al., 2013).** 6

Because no standardization of weight values of variables has been achieved in the abovementioned studies, the weight values obtained in this study are not standard, either. Unlike other studies, the weights were calculated by the AHP method. By this method, the weight values of the all variables were assigned to be “1” based on pairwise comparison matrices. The variables’ weight values as "1” allow to obtain standard values ranging between "0” and "10". This lends itself to easy classification of the standard values in view of risk levels. 4. Conclusions The results obtained in this study were reported by Akbulak et al. (2017) based on the

the Scientific and Technical Research Council of Turkey (TUBITAK) **project. The** 3

forest fires are unavoidable phenomena for Turkey just like for the Mediterranean countries and result in the destruction of thousands of hectares of forest areas. It is very difficult to estimate forest fires beforehand, but potential damages of the forest fires can be minimized with the aid of fire information systems and fire risk maps. Even if forest fires cannot be prevented thoroughly, risk analyses and pre- determination of high-risk areas facilitate fire-fighting organizations since they support the efforts to take protective and preventive measures and the decisions to be made to fight fires. In-depth identification of fire risk levels and efforts to map these risks can make substantial contributions to firefighting. The widespread coverage of areas at high and very high fire risks in Çanakkale requires protective and preservative precautions to fight forest fires. As required by protective measures, the citizens should be educated as to how to prevent forest fires and decrease outbreaks thereof. Moreover, in these areas where the fire risk is high, roadsides should be cleaned to decrease the amount of fuel, regulations should be passed in relation to the use of recreational areas, local people should be informed about the rules they are expected to observe and what to do in the case of fire in order to mitigate the risk of fire. The present

study shows that the employment **of GIS, RS, and AHP in forest fire risk** 1

analyses could provide significant results. The fact that forest fires break out in various geographical factors entails the simultaneous operationalization of a great number of datasets. Because GIS is capable of evaluating complicated datasets by the same scale, it is a very efficient tool of forest fire risk analyses. Moreover, it will be contributory in that it has a validity allowing for its use in other fire-prone areas. In consideration of up-to-date data obtained in studies like the present one, which convertible into rigid and desired formats, in decision-making processes intended to fight forest fires. Besides, the conduction of elaborate studies into forest fires and factors effective therein are of great importance for the success of forest fire management. In forest fire risk analyses conducted in view of numerous parameters, inclusion of each parameter into the analysis is likely to cause some practical problems. Therefore, the conduction of in-depth research on the relationship between forest fires and one or several of the factors affecting forest fires is believed to make great contributions to the implementation of more effective protective and preventive measures.

Acknowledgement The authors wish to thank TUBITAK (The Scientific and Technical Research Council of Turkey- Project No: 116O011) **for financial support.** 7

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