

Journal of
Applied Remote Sensing

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Abstract. Fighting forest fires not only depends on the forest type, topography, and weather conditions, but is also closely related to the technical properties of fire-fighting equipment. Firefighting is an important part of fire management planning. However, because of the complex nature of forests, creating thematic layers to generate potential fire risk maps is difficult. The use of remote sensing data has become an efficient method for the discrete classification of potential fire risks. The study was located in the Central District of the Kastamonu Regional Forest Directorate, covering an area of 24,320 ha, 15,685 ha of which is forested. On the basis of stand age, crown closure, and tree species, the sizes and distributions of potential fire risk zones within the study area were determined using high-resolution GeoEye satellite imagery and geographical information system data. The status of pumper truck intervention in zones with high fire risk and the sufficiency of existing forest roads within an existing forest network were discussed based on combustible matter characteristics. Pumper truck intervention was 83% for high-risk zones, 79% for medium-risk zones, and 78% for low-risk zones. A pumper truck intervention area map along existing roads was also created. © The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: [10.1117/1.JRS.8.083598](https://doi.org/10.1117/1.JRS.8.083598)]

Keywords: forest fire management; pumper truck; remote sensing; GeoEye; geographical information system.

Paper 13482 received Nov. 28, 2013; revised manuscript received May 8, 2014; accepted for publication May 23, 2014; published online Jun. 16, 2014.

1 Introduction

Fire plays a key role as a disturbance factor in many ecosystems throughout the world. To mitigate fire problems and minimize the threat of loss from wildfires, it is crucial that forest managers conduct spatiotemporal analyses of forest fire dangers and risks¹ as well as the position and technical properties of firefighting equipment. Satellite imagery and airborne sensors have long been used to estimate, survey, and map forest fuels^{2,3} and to assess fire risks.

At the decision-making stage in fire management, fire managers need a variety of position data related to combustible matter.⁴⁻⁷ Combustible matter types,⁸ fire activity and intensity, and burned areas can be mapped using remote sensing and geographical information system (GIS) data.⁹⁻¹² The use of GIS at all stages, from the preparation of simple digital maps to the creation of complex analyses and models, is a valuable asset for decision makers. An important benefit provided by GIS is the perfect integration of attribute features and data with a graphics database. This feature has led to the creation and use of fire databases as an important technological tool in the fire hazard ratio system, as in other environmental sciences.¹³ One study¹⁴ in eastern Texas investigated modeling outputs by using fuel model maps with different accuracies. The study showed the significance of using accurate input data layers derived from LIDAR remote sensing techniques with Fire Area Simulator software for realistic predictions of fire growth.

The basic principle of creating land cover maps by remote sensing techniques is the classification of data on the image into distinct zones. Image classification is performed to generate

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topical maps from multispectral images.¹⁵ Modern remote sensing, artificial intelligence, GIS, and fire management decision support systems are widely used by most fire institutions throughout the world.¹⁶ Eva and Lambin¹⁷ examined the relationship between fires and land cover changes using remote sensing. They conducted the classification study by resampling SPOT multispectral images on two different dates and Landsat Thematic Mapper images again on two different dates to 50 m. A detailed vegetation map of Socotra Island was produced through the classification of RapidEye high-resolution satellite imagery based on classified vegetation surveys.¹⁸ This methodology allowed the user to produce a map representing the spatial distribution of plant communities on the island, identified on an ecological and phytosociological basis, by using a segmentation method.

Combustible matter distribution maps created by determining fire potential risk zones will help minimize hazards caused by fire, help determine where fires can start and in which zones they can easily spread, and help plan firefighting and prevention activities. In a study conducted by Mizuki et al.,¹⁹ a new soap-based fire-extinguishing agent was developed, drastically reducing the excessive use of precious water resources. Many forest fires occur every year in Turkey, especially during the dry season. Fire statistics from 1937 to 2013 show that Turkey has an average of 2000 forest fires annually, with a total area of 1,635,284 ha burned.²⁰ However, very few studies have addressed this topic in Turkey.

Routes comprising the shortest forest road segments between the forest fire operation center in the Bartın Forest District (Turkey) and forest fire areas in the Yenihan Forest Range District were determined using ArcGIS. Results were used to establish an optimal location for a forest fire operation center in the Yenihan region.²¹

In this study, intervention coverage in the fire potential risk zones was determined using GIS, and a GeoEye image was classified to determine fuel accumulation. The existing forest road network and effective distances for water/agent pumping trucks were also considered.

2 Study Area and Data

A 24,320-ha area of extensive Corsican pine (*Pinus nigra*) forest in the Central District of the Kastamonu Regional Forest Directorate was selected as the study area. Pure and mixed stands of predominantly high fire prone Corsican pine trees were extensively observed in the northern and northwestern regions of Turkey. The Corsican pine is one of the most ecologically and economically important species and the second most widely distributed pine species in Turkey, covering a land area of 4.2 million ha.²² The location of the study area is shown in Fig. 1.

For this study, satellite remote sensing data and official forest service stand and road network maps were combined to summarize the work in simpler terms. A GeoEye satellite image, acquired on September 3, 2011, was used regionally and spatially to determine fire potential risk regions based on fuel features within the study area. The GeoEye image was used to determine fire potential risk zones in terms of location and area based on combustible matter characteristics in that particular zone, as indicated in Table 1. ArcGIS 10 was used for positioning and evaluation of the data collected in the GIS database.

3 Methods

A workflow chart to determine the ratio of intervention by pumper truck from forest roads within zones with high fire potential was created from potential fire risk zones in the Central District of the Kastamonu Regional Forest Directorate based on combustible matter characteristics, as shown in Fig. 2.

The stand map and the forest road network plan for the Central District of the Kastamonu Regional Forest Directorate were used. In addition, a GeoEye image of the study area was classified using a maximum likelihood algorithm to create the potential fire risk map. Data export, storage, and processing; query and analysis operations; and presentation of map and attribute data were performed using ArcGIS 10. The study zone boundary was created based on the digitized stand map for the Central District of the Kastamonu Regional Forest Directorate. Individual

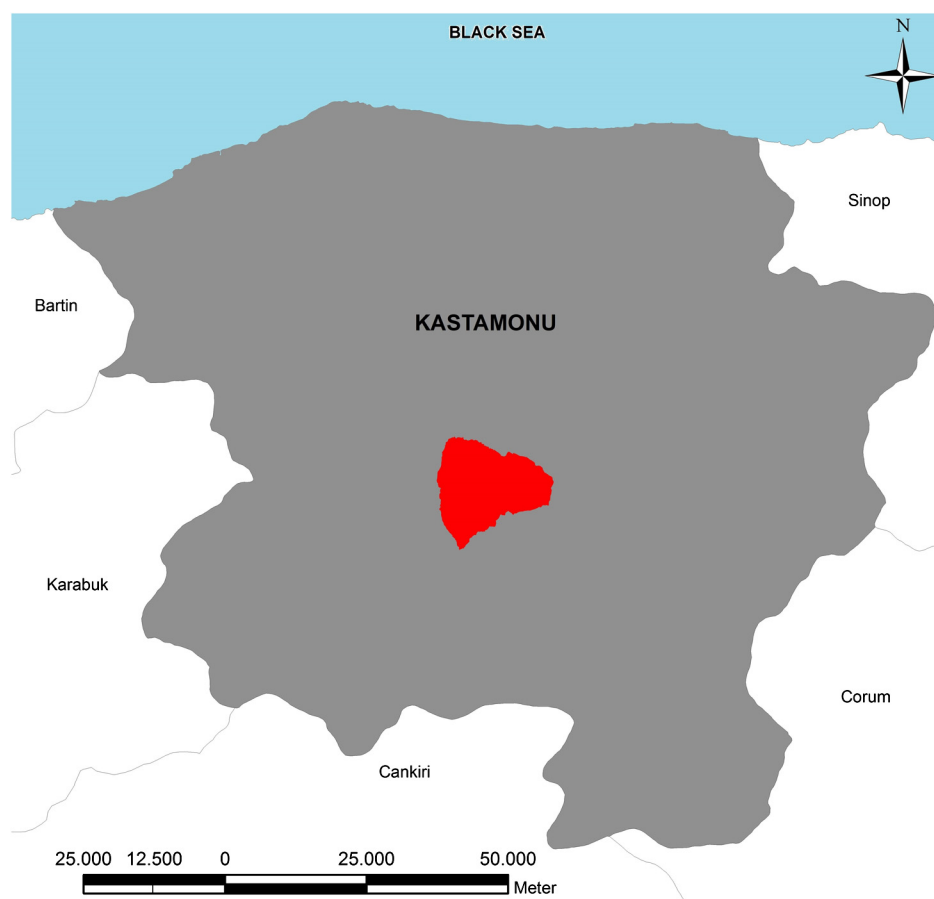


Fig. 1 Location of study area.

Table 1 Fire risk groups based on tree species, crown closure, and stand development age.

Fire risk group	Tree species ^a	Crown closure	Stand age
1	CP	3	a, ab, b
2	CP	2	a, ab, b
3	CP	0 or 1	a, ab, b
4	CP	3	bc
5	CP	2	bc
6	CP	1	bc
7	UCP	—	—
8	CP	1, 2, or 3	c, cd, d
9	Other species	—	—
10	A, FS, or R areas	—	—

^aA, agriculture; CP, Corsican pine; FS, forest soil; R, residential; UCP: unproductive Corsican pine.

layers of the GeoEye imagery, acquired as a panchromatic image, were first stacked using Erdas 9.1. The universal transverse mercator coordinate system and available quadrangle maps were used for geometric rectification.

The study zone was divided into 10 different risk groups based on tree species, crown closure, and stand development age, with group 1 indicating the highest risk. Tree species, crown

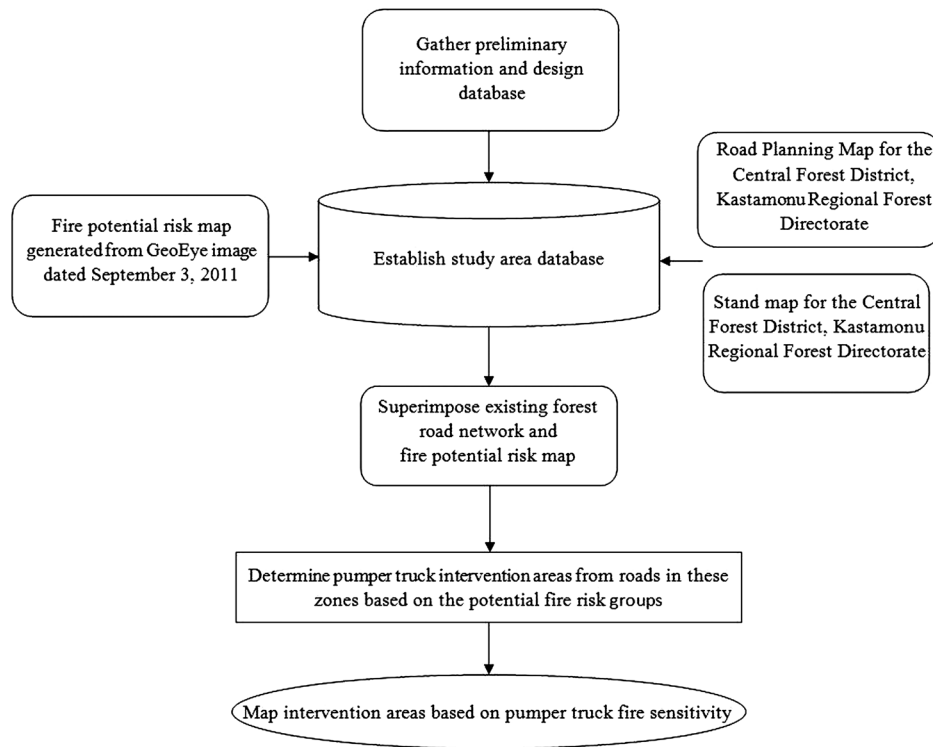


Fig. 2 Work flow of the study.

closure, and stand development age characteristics for the 10 fire risk groups created are shown in Table 1.

The GeoEye image was classified according to stand age, crown closure, and tree species. By using the digitized stand map, stand ages were categorized into four classes: a-ab-b, bc, c-cd-d, and all other areas (areas that do not belong to a stand age, e.g., forest soil, residential, agriculture, etc.). In terms of stand progress, trees with diameters ranging from 1.30 to 7.9 cm are classified as juvenile = a, those with diameters ranging from 8 to 19.9 cm are classified as pole and mast = b, those with diameters ranging from 20 to 35.9 cm are classified as thin wood = c, and those with diameters ≥ 36 cm are classified as thick wood = d. Crown closure was categorized into three groups: 0 to 1, 2, and 3. Crown closures $<10\%$ = 0; 11 to 40% = 1; 41 to 70% = 2; and 71 to 100% = 3.

Tree species were categorized into four groups: Corsican pine, degraded Corsican pine, other species, and all other areas (forest soil, residential, agriculture, etc.).

All roads in the study area were included in the database by using the road network plan for the Central District of the Kastamonu Regional Forest Directorate and the GeoEye satellite image. The pumper trucks used during fires are capable of spraying water and chemical substances at 40 bars. Water pressure drops 1 bar per 10 m vertically. Therefore, regardless of land slope severity, a pumper truck can intervene in an area with a minimum diameter of 400 m. Based on these data, a 400-m buffer zone was created to the right and left of roads using ArcGIS software. Maximum areas of intervention by pumper trucks during fires from roads were determined, the distributions of these areas based on potential risk groups were established, and the sufficiency of existing roads based on the fire potential risk distribution was discussed.

4 Results

The GeoEye satellite image of the study area was classified using a maximum likelihood algorithm with a controlled classification method based on tree species, crown closure, and

stand development age. The GeoEye satellite image classified separately was converted into vector data, and the three classes were superimposed. Using the new database obtained from the superimposition, a potential fire risk map was derived based on the separation in Table 1.

Figure 3 illustrates the potential fire risk map produced from the original GeoEye image of the Central District of the Kastamonu Regional Forest Directorate.

Queries by zone were performed on the database that was created. Distributions (area and percentage) for each fire risk group are shown in Table 2.

Ten potential fire risk groups were divided into four main categories. “Very high fire risk” included groups 1, 2, and 3; “medium fire risk” included groups 4, 5, and 6; “low fire risk” included groups 7 and 8; and “fire risk free” included groups 9 and 10. Based on distributions of the main potential fire risk groups, the Central District of the Kastamonu Regional Forest Directorate area consists of 12.09% very high fire risk, 16.21% medium fire risk, 25.75% low fire risk, and 45.90% fire risk free areas.

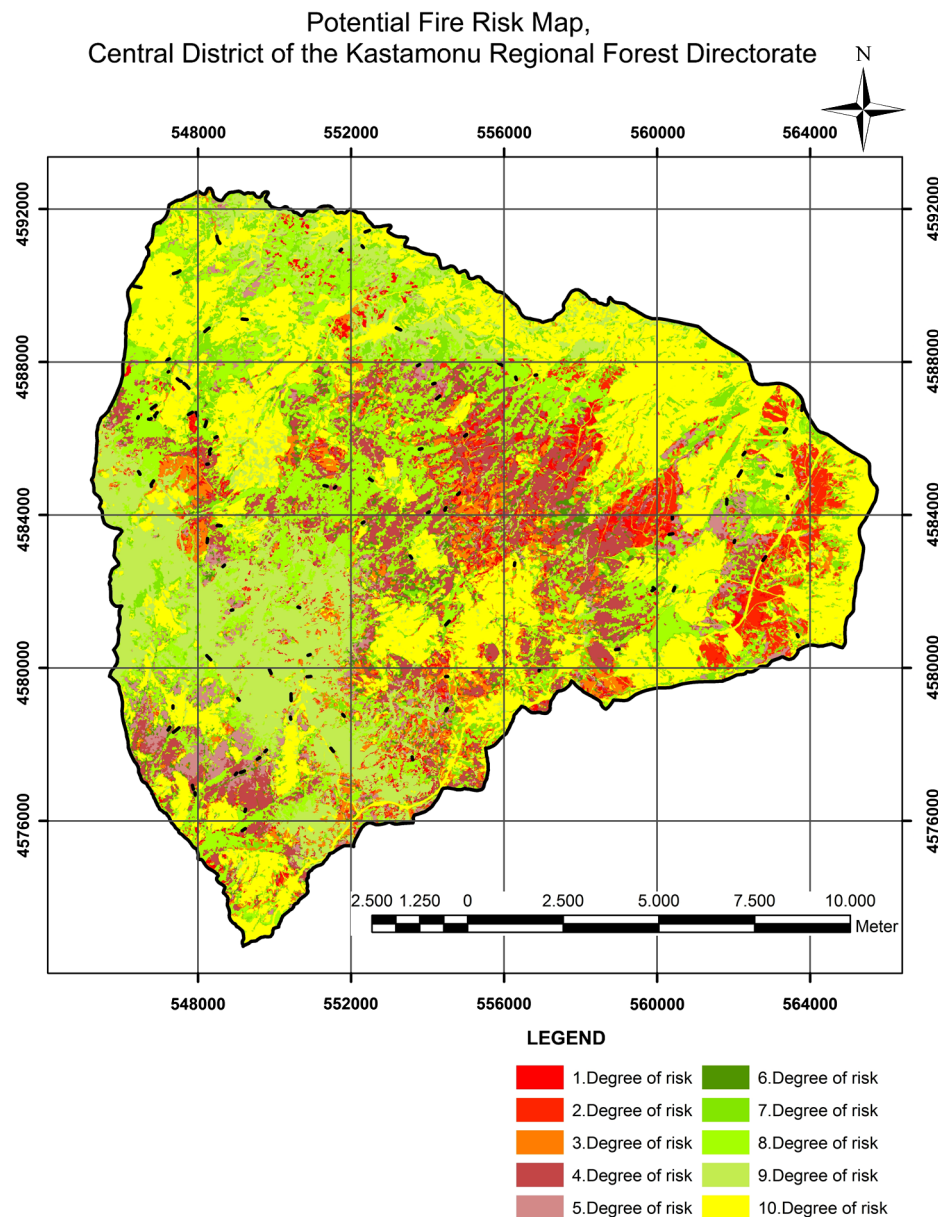


Fig. 3 Potential fire risk map from the GeoEye satellite image of the Central District of the Kastamonu Regional Forest Directorate.

Table 2 Distribution (area and percentage) of fire risk groups based on fuel material features.

Potential fire risk group	Area (ha) (%)	
1	586.5	2.41
2	821.3	3.45
3	1514.6	6.23
4	2371.2	9.75
5	1046.9	4.30
6	526.4	2.16
7	2474.4	10.14
8	3803.9	15.61
9	3867.3	15.90
10	7307.8	30.05
Total	24,320	100

Table 3 Status of intervention by pumper truck in the Central District of the Kastamonu Regional Forest Directorate.

Fire risk class	Area that cannot be intervened by pumper truck (ha) (%)		Area that can be intervened by pumper truck (ha) (%)		Total area (ha)
1	69.8	11.9	516.7	88.1	586.5
2	145.4	17.7	675.9	82.3	821.3
3	284.1	18.8	1230.5	81.2	1514.6
4	459.1	19.4	1912.2	80.6	2371.3
5	231.3	22.1	815.6	77.9	1046.9
6	119.7	22.7	406.7	77.3	526.4
7	505.3	20.4	1969.1	79.6	2474.4
8	861.1	22.6	2942.8	77.4	3803.9
9	639.3	16.5	3228.0	83.5	3867.3
10	1560.0	21.3	5747.3	78.7	7307.3
Total	4875		19,445		24,320

The 400-m buffer zone on both sides of the roads in the forest road network plan for the Central District of the Kastamonu Regional Forest Directorate was updated using the road layer classified from the satellite image. A database capable of processing combined queries on the status of intervention by pumper truck was obtained, and results from the database queries are shown in Table 3. The status of roads in the Central District of the Kastamonu Regional Forest Directorate and pumper truck intervention areas are shown in Fig. 4.

According to Table 3, of the 24,320-ha area of the Central District of the Kastamonu Regional Forest Directorate, 19,445 ha can be intervened by pumper truck from the existing roads.

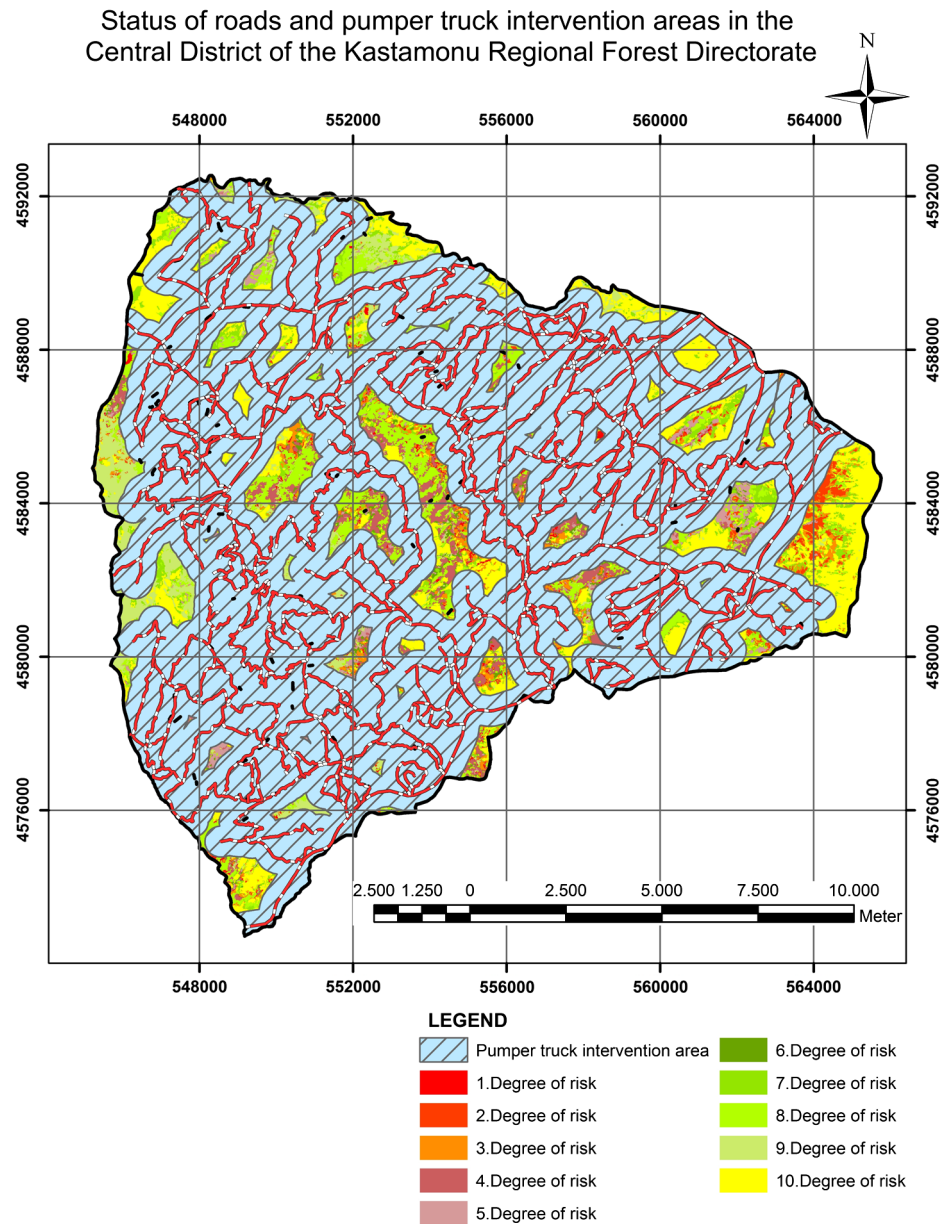


Fig. 4 Status of roads and pumper truck intervention areas in the Central District of the Kastamonu Regional Forest Directorate.

5 Conclusions

In this study, a fire potential risk map was produced using a GeoEye satellite image and fuel material features, such as tree species, stand closure, and stand age, within the Central District of the Kastamonu Regional Forest Directorate (Fig. 3).

On the basis of the satellite data, the distributions of fire potential risk within the Central District of the Kastamonu Regional Forest Directorate are as follows: 12.09% very high fire risk (Table 1, groups 1, 2, and 3); 16.21% medium risk (Table 1, groups 4, 5, and 6); 25.75% low risk (Table 1, groups 7 and 8); and 45.90% fire risk free (Table 1, groups 9 and 10).

According to the road network plan for the Central District of the Kastamonu Regional Forest Directorate, during fires, the ratios of intervention by pumper truck from existing roads is 83% for high-risk zones, 79% for medium-risk zones, and 78% for low-risk zones.

The Central District of the Kastamonu Regional Forest Directorate covers 6867 ha in terms of fire potential. Accordingly, the road network within this district is deemed sufficient for intervention by pumper truck in a possible fire. These areas are shown in Fig. 4.

Some of the existing roads are not accessible by pumper truck intervention (Fig. 4), and other fire-extinguishing equipment, such as helicopters and hydrant systems, could be accessed. In addition, vehicle tracking systems and the forest road network map for this study could be used to direct pumper trucks to fire and water-loading areas as quickly and as efficiently as possible.

The use of high-resolution satellite imagery to determine fire potential in forest lands based on combustible matter characteristics is both time- and cost-efficient and provides highly accurate and up-to-date data. Thus, concentrations of zones with high fire potential should be determined using the method established in this study and should be updated frequently during fire seasons using fire watch systems.

When fire potential is high because of large fuel accumulations, fires will likely spread quickly and be very intense. Forest fire roads and breaks must be planned efficiently and effectively, and fire extinguishers and hydrants must be strategically placed in areas with high fire risk. In such situations, the construction of water reservoirs could benefit fire trucks and helicopters by limiting unnecessary travel distances.

Satellite images of forest lands with high fire potential should be acquired regularly, and changes in zones with high fire potential based on combustible matter characteristics should be monitored in forests with a dynamic structure.

Acknowledgments

This study (project no. 111O033) was fully supported by the Scientific Technological Research Council of Turkey (TUBITAK) Short Term R&D Funding Program (1002).

References

1. B. Saglam et al., "Spatio-temporal analysis of forest fire risk and danger using LANDSAT imagery," *Sensors* **8**(6), 3970–3987 (2008).
2. G. J. Jia et al., "Assessing spatial patterns of forest fuel using AVIRIS data," *Remote Sens. Environ.* **102**(3–4), 318–327 (2006).
3. R. Lasaponara and A. Lanorte, "Remotely sensed characterization of forest fuel types by using satellite ASTER data," *Int. J. Appl. Earth Obs.* **9**(3), 225–234 (2007).
4. W. W. Convington et al., "Historical and anticipated changes in forest ecosystems of the inland west of the United States," *J. Sustainable For.* **2**(1/2), 13–63 (1994).
5. G. W. Ferry et al., "Altered fire regimes within fire-adapted ecosystems," in *Our Living Resources: A Report to the Nation on the Distribution, Abundance and Health of U.S. Plants, Animals, and Ecosystems*, E. T. LaRoe, Ed., pp. 222–224, Government Printing Office, Washington, DC (1995).
6. B. Leenhouts, "Assessment of biomass burning in the conterminous United States," *Conserv. Biol.* **2**(1), 1–24 (1998).
7. R. W. Mutch et al., "Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystem," Gen. Tech. Rep. PNW-GTR-310. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 14 p. (Quigley, T.M., ec. Forest health in the Blue Mountains: science perspectives), <http://www.treeseearch.fs.fed.us/pubs/9056> (1993).
8. O. Kucuk, "Yanici Madde Ozellikleri ve Yangin Davranisina Bagli Yangin Potansiyelinin Belirlenmesi ve Haritalanmasi (Fuel material properties and determination of fire risk potential related with fire behavior)," PhD Thesis (KTU Fen Bilimleri Enstitüsü (Karadeniz Technical University, Graduate School of Natural and Applied Sciences), 2004).
9. S. G. Conard et al., "Changing fuel management strategies—the challenge of meeting new information and analysis needs," *Int. J. Wildland Fire* **10**(4), 267–275 (2001).
10. R. G. Congalton, "Accuracy assessment and validation of remotely sensed and other spatial information," *Int. J. Wildland Fire* **10**(4), 321–328 (2001).
11. T. R. Loveland, "Toward a national mapping strategy: lessons from selected mapping programs," *Int. J. Wildland Fire* **10**(4), 289–299 (2001).

12. M. D. Schaaf, "Development of fire emission trade off model (FEMT) and application to the Grande Ronde River Basin, Oregon," Final Report, Contract 53-82FT-03-2, USDA Forest Service, Pacific Northwest Region, Portland, Oregon (1996).
13. E. Bilgili, B. Saglam, and E. Z. Baskent, "Yangin Amenajmanı Planlamalarında Yangin Tehlike Oranları ve Coğrafi Bilgi Sistemleri," *KSU Fen ve Mühendislik Dergisi* **4**(2), 288–297 (2001).
14. M. Mutlu, S. C. Popescu, and Z. Kaiguang, "Sensitivity analysis of fire behavior modeling with LIDAR-derived surface fuel maps," *For. Ecol. Manage.* **256**(3), 289–294 (2008).
15. T. Yomralioglu, *Cografî Bilgi Sistemleri Temel Kavramlar ve Uygulamalar* (Geographic Information Systems Basic Concepts and Applications), Karadeniz Technical University, Trabzon (2002).
16. E. Bilgili and O. Kucuk, "Remote sensing in detecting forest fire," in *Proc. Fourth GAP Engineering Cong.*, pp. 1631–1637, Harran University (2010).
17. H. Eva and F. E. Lambin, "Fires and land-cover changes in the tropics: a remote sensing analysis at the landscape scale," *J. Biogeogr.* **27**(3), 765–776 (2000).
18. L. Malatesta et al., "Vegetation mapping from high-resolution satellite images in the heterogeneous arid environments of Socotra Island (Yemen)," *J. Appl. Remote Sens.* **7**(1), 073527 (2013).
19. H. Mizuki et al., "Novel environmental friendly soap-based fire-fighting agent," *J. Environ. Eng. Manage.* **17**(6), 403–408 (2007).
20. Anonymous, "2013 Fire Action Plan," 2013, <http://web.ogm.gov.tr/diger/yanginhareket/dokumanlar> (6 June 2014).
21. T. Varol, H. B. Ozel, and K. Macaroglu, "The use facilities of network analysis in the forest fires (Yenihan Forest Range District case study)," in *Proc. Third National Blacksea Forestry Cong.*, pp. 1262–1269, Artvin Coruh University (2010).
22. O. Kucuk, E. Bilgili, and B. Saglam, "Estimating crown fuel loading for Calabrian pine and Anatolian black pine," *Int. J. Wildland Fire* **17**(1), 147–154 (2008).

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