Original scientific paper

Determining a Fire Potential Map Based on Stand Age, Stand Closure and Tree Species, Using Satellite Imagery (Kastamonu Central Forest Directorate Sample)

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Abstract

Becoming successful in fighting forest fires is not only a matter of taking the required measures into consideration and efficiently and economically using the resources, but also employing the cutting edge science and technology in every aspect of the process. Determining the potential fire prone regions within forest stands, plays an important role in the success rate of forest fire prevention and firefighting. Various techniques are used in the determination of fire potential; especially high resolution satellite imagery can provide very sensitive and detailed information regarding the conditions of regional topography and fuel material (fuel) accumulation.

Fuel material models have long been effectively used in fire management, fire behavioral estimates and determination of fire danger risks. Additionally, fuel material maps, prepared based on fuel material features, can help in the determination of fire potential. Fire potential maps include fuel material types and their distribution in the field.

In this particular study, an October, 2011 dated »GeoEye« image, encompassing 24 320 ha of Kastamonu Central Forest Directorate area, 15 685 ha of which is forested, was used. The image was classified based on fuel material features, such as tree species, mixture, crown closure, age classes, etc. Acreages and distributions of the potential fire prone areas were determined, and where these areas were concentrated, possible fire suppressing precautionary methods were discussed.

As long as the satellite image acquisition is periodically supplied, fire potential map can be updated depending on fuel material features.

Keywords: forest fire, remote sensing, GIS, Turkey

1. Introduction

Forest fires, while devouring thousands ha of productive forests every year and costing hundreds of thousands of Euros of lost resource revenues and firefighting expenditures, are jeopardizing the well-being of many assets like water management, soil reclamation, climate regulation, social well-being, nature protection, natural defense, aesthetic, recreation, science, research, etc. (Eraslan 1982, Kourtz 1984). Fuel material is defined as any type of easily ignitable fuel material or mixture, which can be found in, over and even above the soil (Robertson 1971). Determination of the amount of fuel material plays an important role when it is highly important to decide whether or not the precautionary measures are needed to lessen the possible effects of wildfires. The amount of such fuel material, which is in direct relationship with the fire behavior (Rothermel 1983), dictates the spread of the fire and the amount of energy released from it (Stinson and Wright 1969, Whelan 1995).

The spread of the fire depends on area topography and meteorological conditions. Similarly, while very intensive wildfires occur in some particular fuel types (coppice and rather young plantations, etc.), comparably less intensive ones occur in mature to old stands. When this situation is taken into consideration, it is very logical to assume that the distribution of fuel material will greatly affect the spread of the fire (Bilgili 1998).

The main principle of creating land cover maps by remote sensing techniques is the classification of data in the zone image. Image classification is a process performed to generate topical maps from multispectral images (Yomralioglu 2002).

Fuel material features such as height, crown length, crown diameter and »dbh« can be obtained both from terrestrial surveying measurements and from very detailed aerial photography or high resolution satellite imagery, and they play an important role in biomass estimations (Alemdag 1986, Ottomar and Vihnanek 1998). Especially, in young plantations, the establishment of stand and tree features (tree type, age, and crown) based on the information acquired from aerial photography or satellite imagery can simplify the biomass estimation (Oladi 1996). Remote sensing, artificial intelligence, geographic information systems and forest fire management decision support systems are widely used in any type of fire management administrations worldwide (Bilgili and Kucuk 2002).

Factors affecting the accidental fire ignition in forests are the proximity to nearby settlements, vegetation moisture, slope, aspect, distance from roads and elevation. These markers are then assigned weight values to set up the fire sensitive areas to compare with the hot spots derived from MODIS satellite imagery (Adab et al. 2013).

Fuel type maps include the conditions of fuel material in localized regions; give detailed information about the fire potential and its possible effects on other resources. Since forests are dynamically structured, fuel type maps must be periodically updated. These maps provide the forest managers the information as to where, in what amount, and in what ratio and variety these dangerous fuel materials are accumulated. Using these maps, the current potential effects of fuel material conditions on fire behavior and determination of fire damage and cost can also be determined (Kucuk 2005).

In a study conducted by Eva and Lambin (2000), remote sensing was used to investigate the relationship between forest fires and land cover change. Fuel type maps, fire activity maps, fire intensity and burned area maps can be produced, using remotely sensed data and GIS in fire and fuel material management (Schaaf 1996, Conard et al. 2001, Loveland 2001, Congaltion 2001). Due to GIS flexibility, it was suitable for making very simple and effective digital maps as well as very complex models and analyses. It could be efficiently used in every stage and hence it was an ideal tool for decision makers. The basis of this important contribution comes from the fact that GIS can excellently match the attribute values to graphic representations. Since GIS proved to be so suitable, it is widely used in making and compiling fire databases and fire danger ratios (Bilgili et al. 2001), similarly as in other environmental science disciplines.

The aim of this study is to identify the types of flammable material in the forest areas with respect to prominent features related to the combustion of flammable materials (type, closure, stand age). This will be done by means of high-resolution satellite images, by taking into account changes of positions and areas in small locations.

Fuel material distribution maps, used to determine the potential fire risk regions, will provide great help in minimizing the danger of fire, in determining where the possible fire may commence and in what regions it may spread more easily, as well as in planning fire management and suppression efforts.

2. Materials and methods

High resolution, colored, panchromatic, GeoEye satellite imagery, acquired on September 3, 2011, was used for determining, regionally and spatially, the potential fire risk regions based on the fuel features determined in the study area. ArcGIS 9.3 and Erdas 9.1 were used for establishing and evaluating the database and satellite image processing, respectively. Digital terrain model (DTM) was generated by using the elevation data obtained from the digital topographic map of the study area.

In this particular study, where potential fire risk regions are characterized by the fuel features of Kastamonu central forest directorate, the flow chart was created as shown in Fig. 1.

In gathering preliminary information and designing the database, 1/25000 quad maps containing boundaries of Kastamonu Central Forest Directorate, forest management map and GeoEye imagery, were obtained. All types of GIS functions like transferring, storing, processing, various questioning and analyses

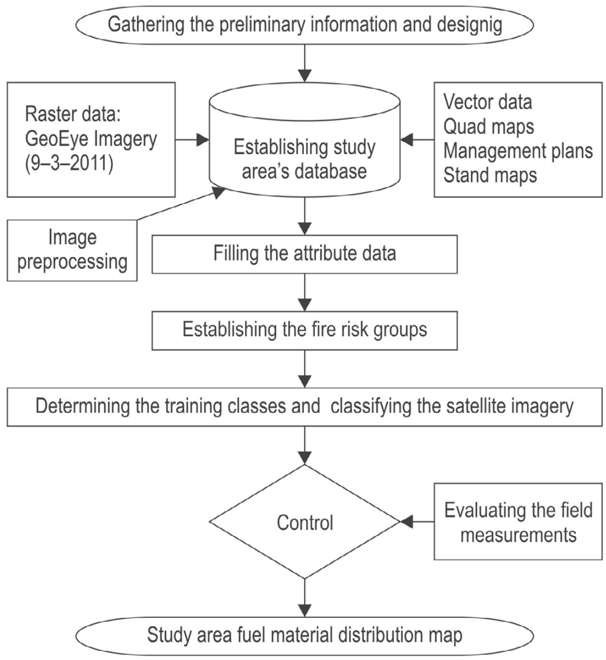

Fig. 1 Work flow of the study

of different raw data types and presenting the produced maps and attributes were performed using ArcGIS 9.3. Individual layers of the GeoEye imagery, acquired as panchromatic image, were first layer stacked in Erdas 9.1. As for geometric rectification, UTM coordinate system and available quad maps were used.

For geometric rectification, 32 ground control points were used consisting of road intersects, bridges and houses. The nearest neighbor transformation type was used. The boundaries of the study area were set and they coincided with the map of Kastamonu central forest directorate. Then, the GeoEye imagery was delineated and cut, using the vector boundary polygon in Erdas 9.1. GeoEye imagery delineated for the study area.

The study area was categorized according to tree species, crown closure and stand age into 10 fire risk groups (Kucuk 2004), number 1, being the most fire prone group (Table 1). Supervised classification was applied to GeoEye image, employing ERDAS, based on 10 potential fire risk groups formulated according to fuel material features in Table 1. Supervised classification of all 10 potential fire risk groups was done. Maximum likelihood algorithm was applied in the classification.

Classification accuracy assessment was done, making a comparison between the classified image and a reference data set (maps or GPS measurements), whose accuracy had previously been validated. For this reason, random pixels from the classified image were compared to the corresponding pixels from a known source. Random selection of these pixels can abate the analyst's former knowledge about the region/surrounding (Musaoglu 2000). As a result of such a comparison, the possibilities of categorizing the randomly selected pixels into accurate classes can be presented in a classification error matrix and using a Kappa coefficient. In this way, statistical analyses can be made (Sunar and Musaoglu 1998).

The GeoEye image was classified according to stand age, crown closure and tree species. Using the digitized stand map, stand ages were categorized into 4 classes: »a-ab-b«, »bc«, »c-cd-d« and all other areas, which do not belong to a stand age (forest soil, residential, agriculture, etc.). In terms of the stand progress, the ones ranging from 1.30 to 7.9 cm in diameter are considered as »Juvenile and density = a«, from 8 to 19.9 cm as »Pole and mast = b«, from 20 to 35.9 cm as »Thin wood = c«, from 36 to larger diameters as »Thick wood = d«.

Crown closure was categorized into three groups; »0–1«, »2«, »3«. Crown closure of less than 10% = »0«, 11% to 40% = »1«, 41% to 70% = »2«, 71% to 100%= »3«.

Table 1 Regional type groups based on tree species, crown closure and stand development age

Fire Risk Group	Tree Species	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	DCP	–	–
8	CP	1, 2 or 3	»c«, »cd«, »d«
9	Other species	–	–
10	A, FS or R areas	–	–
CP: Corsican Pine		a: Youth and Density	
DCP: Degraded Corsican Pine		b: Pole and Mast	
FS: Forest Soil		c:Thin Wood	
A: Agriculture		d: Middle Woodland	

Tree species were categorized into four groups; »Corsican Pine«, »Degraded Corsican Pine«, »Other species« and all other areas (forest soil, residential, agriculture, etc.)

At least 200 training areas were picked from each category of each group and the images were classified. General classification accuracies and Kappa statistics were calculated. All original band pixel values in polygonal train areas were used for the classification. Boundary pixel was eliminated. The classified images were converted into vector format.

3 different vector layers obtained from the classifications were intersected in ArgGIS 9 database and a whole new layer was attained; from this new layer, through a new questioning, 10 fire risk groups were regrouped according to their features presented in Table 1. In this way, a new map was developed (Fig. 3d).

Each image, whose supervised classification had been applied, was subjected to accuracy assessment through ERDAS, and the classification accuracy of images was obtained. Besides, on the vector map of fire risk groups, prepared based on the stand groups presented in Table 1, 10 random sampling areas of »20 × 20 m« (400 m^2) were determined from each group. Control measurements were done on 100 different sampling areas (10 groups × 10 sampling areas). Through the vector map of potential fire risk groups, 100 sample areas, whose coordinates had already been established, were located, using a handheld GPS throughout the study area. Classification accuracy of each sample group found in the study area, according to the groups in Table 1, was checked. Thus, both spatial and classification accuracy of the sample areas was validated through field measurements.

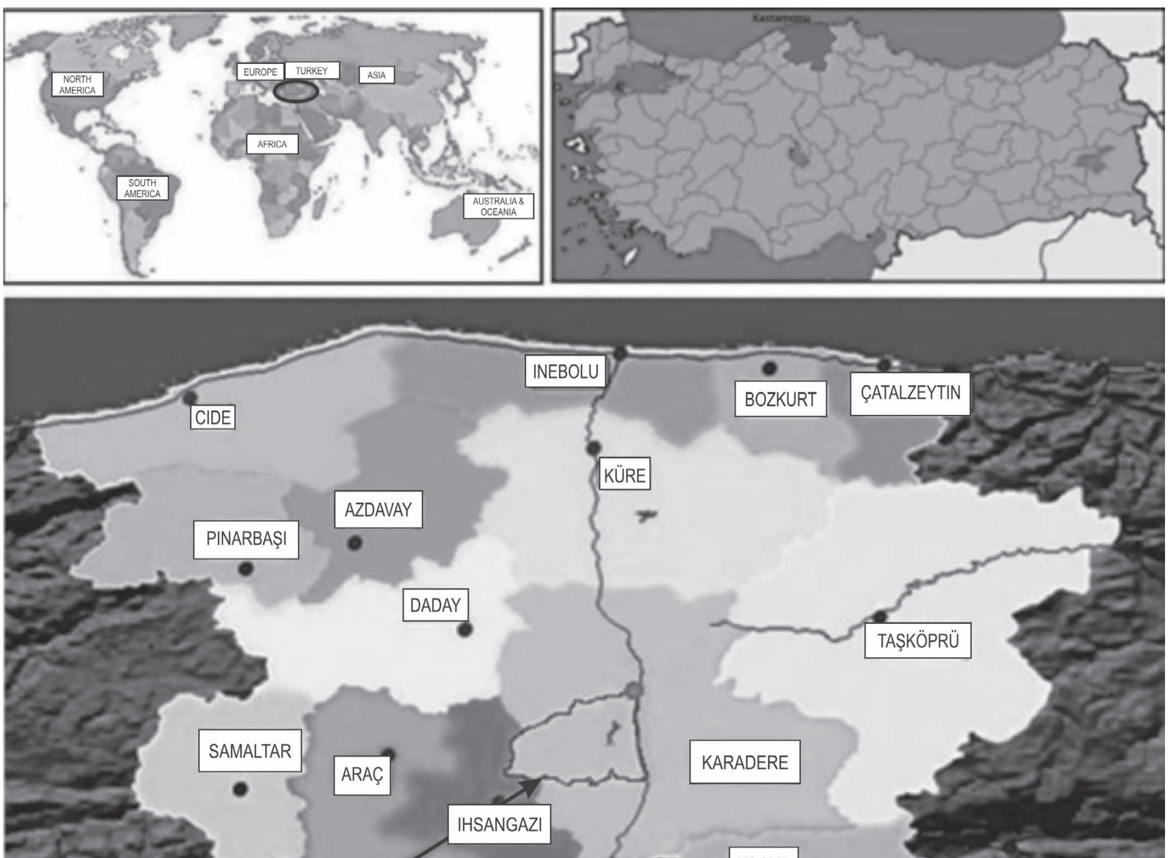

Fig. 2 The study area in Turkey

3. Area of study

Central Forest District of Kastamonu Regional Forest Directory encompassing an area of 24 320 ha of extensive Corsican Pine (*Pinus nigra*) forest, which is relatively susceptible to fire, was selected as the study area. The location of the study area positioned in the map of Kastamonu, as well in Turkey, can be viewed in Fig. 2.

Pure and mixed stands predominantly composed of high fire prone Corsican pine trees have been extensively observed in the mountainous area. Besides, other stand types consisting of Fir (*Abies bornmulleriana*), Scotch Pine (*Pinus sylvestris*) and Oak (*Quercus patreae*) can also be seen in the study area. The elevation range of themountainous study area is between 745 m and 1 510 m.

4. Results of the study

By taking the tree species, crown closure and stand age into consideration, supervised classification was applied to the GeoEye image of the study area, using Maximum Likelihood Algorithm. Table 2 illustrates the image classification error matrix, depending on tree species. Table 3 illustrates the general image classification accuracy based on tree species.

Table 2 Classification error matrix by tree species

Classes	1. CP*	2. DCP*	3. Other Species	4. All other areas
1. CP	35	–	1	–
2. DCP	–	34	–	2
3. Other Species	–	–	35	1
4. All other areas	–	–	–	36

*CP: Corsican Pine
DCP: Degraded Corsican Pine

Table 3 Illustration of the general classification accuracy based on tree species

Classes	Reference Total	Classified Total	Number of corrects	Producer's Accuracy	User's Accuracy
1. CP*	35	36	35	100.00	97.22
2. DCP*	34	36	34	100.00	94.44
3. Other Species	36	36	35	97.22	97.22
4. All other areas	39	36	36	92.31	100.00

*CP: Corsican Pine
DCP: Degraded Corsican Pine

General classification accuracy of the GeoEye satellite image was 97.22% and Kappa statistic was 0.9630. Fig. 3a illustrates the satellite image classified based on tree species. Table 4 illustrates the classification error matrix based on stand closure, and Table 5 illustrates the overall accuracy by stand closure.

Table 4 Classification error matrix by stand closur

Classes	1. 0-I Close	2. II Close	3. III Close
1. 0-I Close	40	0	0
2. II Close	0	32	8
3. III Close	1	6	33

Table 5 General classification accuracy by stand closure

Classes	Reference Total	Classified Total	Number of Corrects	Producer's Accuracy	User's Accuracy
1. 0-I Close	41	40	40	97.56	100.00
2. II Close	38	40	32	84.21	80.00
3. III Close	41	40	33	80.49	82.50

General classification accuracy of the GeoEye satellite image was 87.5% and Kappa statistic was 0.8125. Fig. 3b illustrates the satellite image classified based on tree species stand closure. Table 6 illustrates the classification error matrix based on stand age, and Table 7 illustrates the general classification accuracy by stand age.

General classification accuracy of the GeoEye satellite image was 85% and Kappa statistic was 0.8000.

Table 6 Classification error matrix by stand age

Classes	1. a-ab-b	2. bc	3. c-cd-d	4. Out of range
1. a-ab-b	36	3	1	0
2. bc	9	25	5	1
3. c-cd-d	3	1	35	1
4. Out of range	0	0	0	40

a: Youth and Density
b: Pole and Mast
c:Thin Wood
d: Middle Woodland

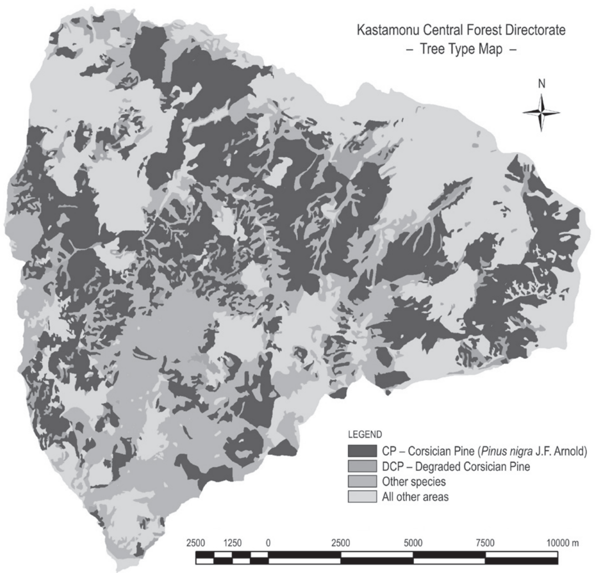

Fig. 3a Classified satellite map, based on tree species

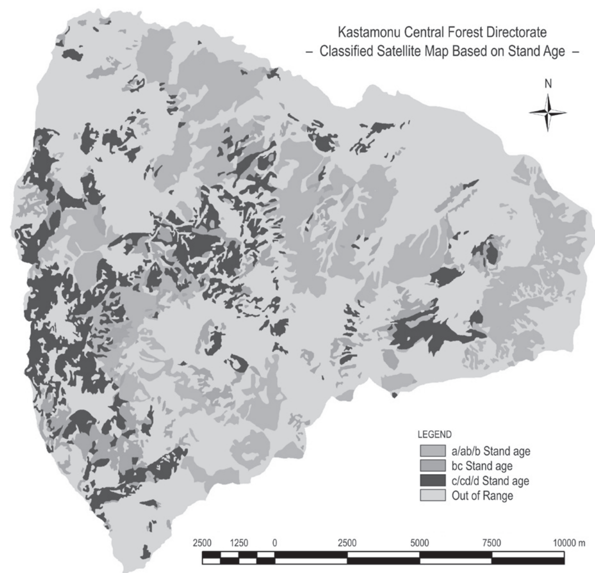

Fig. 3c Classified satellite map, based on stand age

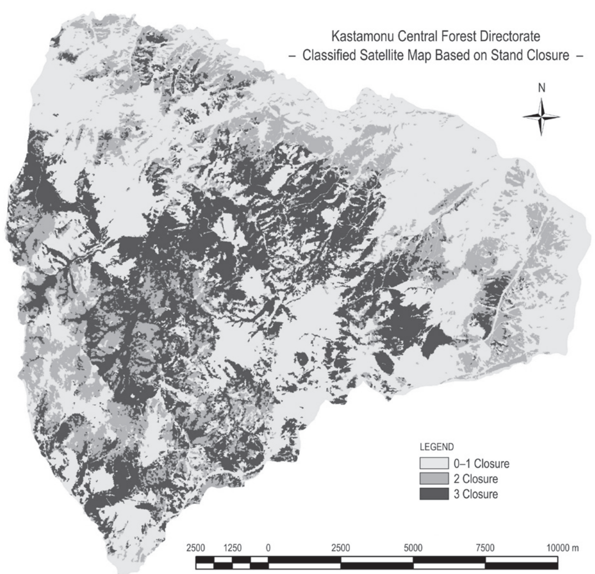

Fig. 3b Classified satellite map, based on stand closure

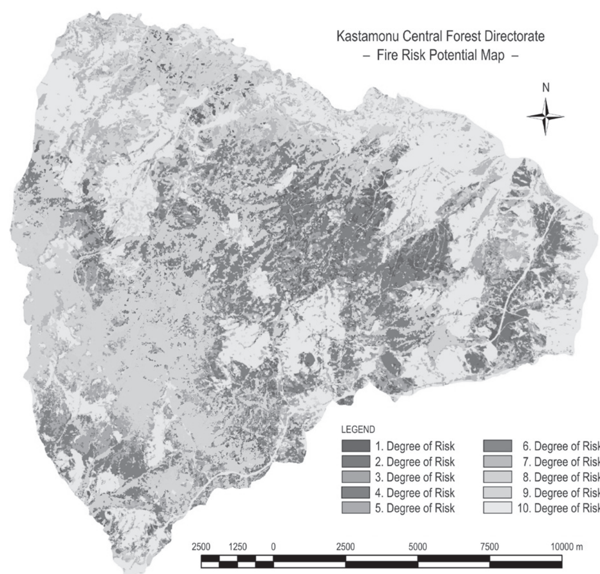

Fig. 3d Fire risk potential map from the GeoEye satellite image of the Kastamonu Central Forest Directorate

Table 7 General classification accuracy by stand age

Classes	Reference Total	Classified Total	Number of corrects	Producer's Accuracy	User's Accuracy
1. a-ab-b	48	40	36	75.00	90.00
2. bc	29	40	25	86.21	62.50
3. c-cd-d	41	40	35	85.37	87.50
4. Out of range	42	40	40	95.24	100.00

a: Youth and Density c: Thin Wood
b: Pole and Mast d: Middle Woodland

Fig. 3c illustrates the satellite image classified based on tree species stand age.

The results of three separate classifications, by tree species, stand closure and stand age, were then converted to vector format and intersected; the newly created database allowed us to produce the fire risk potential map.

Wise questioning was carried out through the created database. Table 8 illustrates the areas of the fire risk groups.

Table 8 Areas of fire risk groups distributed based on fuel material features

Potential Fire Risk Groups	Area, ha	Area, %
1	586.5	2.41
2	821.3	3.45
3	1 514.6	6.23
4	2 371.2	9.75
5	1 046.9	4.30
6	526.4	2.16
7	2 474.4	10.14
8	3 803.9	15.61
9	3 867.3	15.90
10	7 307.8	30.05
TOTAL	24 320	100

100 different sampling points, obtained by taking 10 random sampling points from each group in the map of potential fire risk groups, were cross-checked through land surveying and observations of random sampling areas. The final accuracy matrix, obtained based on these data, is given in Table 9. According to Table 9, producers' accuracy of very high fire risk groups (Group 1, 2, 3) is approximately 80%.

Table 9 Error matrix produced according to the results of potential fire risk groups

Potential Fire Risk Groups	1	2	3	4	5	6	7	8	9	10
1	7	2	1	–	–	–	–	–	–	–
2	1	8	1	–	–	–	–	–	–	–
3	–	2	8	–	–	–	–	–	–	–
4	–	–	–	6	2	2	–	–	–	–
5	–	–	–	1	5	4	–	–	–	–
6	–	–	–	2	1	7	–	–	–	–
7	–	–	–	–	–	–	9	–	1	–
8	–	–	–	–	1	1	–	8	–	–
9	–	–	–	–	–	2	–	–	8	–
10	–	–	–	–	–	–	–	–	–	10

5. Discussions and Conclusions

Forest fires are one of the major causes of ecological disturbance and environmental concerns in forests of Turkey. The degree of forest fire risk is changeable from year to year and it is different for each kind of stand structure. In this particular study, the fire risk potential map was produced by GeoEye satellite image according to fuel material features, such as tree species, stand closure and stand age gathered in Kastamonu central forest directorate (Fig. 3d).

The distribution of potential fire risk in the map created using the satellite data acquired in September, 2011 in the region of Kastamonu central forest directorate is as follows:

⇒ 12.09% very high fire risk (Table 1, Group 1, 2, 3),
⇒ 16.21% medium risk (Table 1, Group 4, 5, 6),
⇒ 25.75% low risk (Table 1, Group 7, 8),
⇒ 45.90% fire risk free (Table 1, Group 9, 10).

The fire risk potential map will change from year to year depending on the forest growing features. For this reason, the satellite images were taken periodically for creating the fire risk potential map.

Using high resolution spatial satellite imagery to determine the fire potential according to fuel material features in forest lands is both time and cost efficient and provides highly accurate, up-to-date information. This is especially true for mountainous forests, where the road network is less extensive than in the other parts of the country. In such forests, due to ecological and economical constraints, forest fire probability is much higher. The implementation of the proposed method will increase the possibility of suppression of forest fires. By this method, according to the established fuel material features, forest fires could be monitored through fire surveillance systems, after determining the regions with increased fire risk potential.

Especially in Mediterranean and Aegean regions, where the forest fire risk is rather high in most of the year, the acquisition of periodic satellite imagery will help the decision makers to effectively monitor the ever changing dynamic structure of forests.

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